

G. Curt Keedy  
Federal Aviation Administration  
Flight Inspection Policy and Standards  
Mike Monroney Aeronautical Center  
Oklahoma City, Oklahoma  
United States of America



## FLIGHT INSPECTION SYSTEMS FOR THE FUTURE: The 21<sup>st</sup> Century Change, Challenge, and Opportunity

### ABSTRACT

The Twenty-first Century will present a dynamic environment for the global aviation community. Transition from terrestrial-based communication, navigation, and surveillance systems to space-based technology has already begun. The challenge for flight inspection organizations is to be prepared for these new changes. Advanced technologies and the associated flight procedure capabilities present opportunities for new flight inspection methodologies and analysis systems. This paper will address the currently planned changes, the challenges they present, and the opportunities they provide for the flight inspection community.

### CHANGE

The most obvious change in navigation technology has been and will continue to be the development and operation of satellite-based navigation systems. Although they have been operational for many years, civil use of the systems is relatively new, especially for the international aviation community.

**Global Positioning System (GPS).** The changes began almost 30 years ago when the U.S. Department of Defense (DoD) developed the concept and general configuration for the Global Positioning System in the early 1970s. DoD established the U.S. Air Force Space and Missile Systems Organization as the executive agent to manage and implement the system. The GPS Joint Program Office (JPO) was formed for this purpose. The JPO successfully launched 10 GPS Block I developmental spacecraft from 1978 to 1985. This demonstration verified the system's capabilities and DoD subsequently approved the implementation of an operational system, with the first operational spacecraft deployed in 1985. GPS was declared fully operational in April 1995. Total cost of the initial operational constellation was \$1.5 billion. [1]

GPS has matured since then, to an operational navigation system of 27 spacecraft serving millions of users worldwide. More than one million GPS receivers have been produced each year since 1997. The rapidly expanding market – including equipment and applications – is estimated to reach \$8.5 billion this year and exceed \$50 billion in ten years.

A Presidential Decision Directive on GPS issued in 1996 directed that selective availability (SA) be terminated by 2006. In May 2000, the President ordered SA be set to zero. The accuracy of the predictable civil GPS signal has now improved from 50-100 meters to 10 meters. [2]

### **Global Navigation Satellite System (GLONASS).**

The former Union of Soviet Socialist Republics' Defense Ministry began the development and deployment of the GLONASS system virtually in parallel with the GPS development. The first GLONASS spacecraft was in orbit in December of 1982. The full constellation consists of 24 spacecraft. Political and economic changes and the establishment of the Russian Federation have slowed development of an operational system. Currently the system contains ten spacecraft, with eight operational. However, the government of the Russian Federation has approved measures to provide GLONASS operations (both military and civil), system improvements, and full international cooperation. [3]

**Galileo.** The European Union member states have agreed to build and operate a civilian controlled global satellite navigation system called Galileo. The program is in the definition phase at this time. Candidate architectures include a Medium Earth Orbit (MEO) constellation or a MEO constellation with Geostationary (GEO) spacecraft included. The definition phase will conclude at the end of this year, followed by technology development and design. Deployment of the spacecraft is planned to begin in 2006 with full operational capability in 2008. [4]

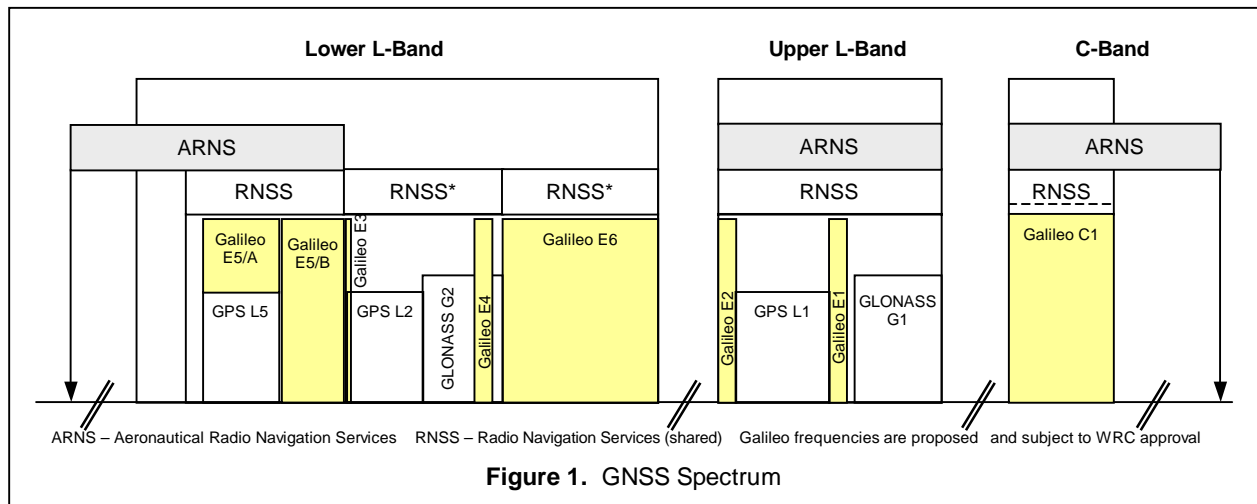
**Global Systems.** In 1991 the International Civil Aviation Organization (ICAO) adopted the Communications, Navigation, and Surveillance/Air Traffic Management (CNS/ATM) concept as a major part of a long-term modernization program for upgraded infrastructures to deal with the ever increasing air traffic demands. The combination of GPS and GLONASS, along with their augmentations, make up the infrastructure of the first generation Global Navigation Satellite System, GNSS-1. The addition of Galileo and other regional augmentation systems will evolve into GNSS-2.

Each of these systems provides a central point for three-dimensional position, navigation, timing, and synchronization for civil safety, security, science, engineer-

ing and related applications. In addition, each of these systems will also provide compatibility. The journey toward GNSS-2 will end with an unprecedented open, seamless, continuous service global resource.

The most significant benefit from multiple constellations of satellite systems will be sole-means positioning and navigation. Each system is independent – mitigating common-mode failures. In addition, future improve-

ments in the systems will offer additional benefits. Frequency diversity and additional civil frequencies within each system will reduce the interference susceptibility and separate the interdependency of military and civil signals (Figure 1). Multiple signal transmission will also improve atmospheric errors. Each system will also provide regional and local augmentation, improving integrity, availability, continuity, and accuracy.



**Aircraft-based Augmentation System (ABAS).** ABAS integrates the information obtained from the GNSS with information available on board the aircraft. The ABAS function combined with one or more of the GNSS elements must include a fault-free GNSS receiver and aircraft systems to meet the requirements for accuracy, integrity, continuity, and availability.

ABAS includes processing schemes which provide integrity monitoring for the position solution using redundant information such as multiple range measurements. The monitoring scheme generally consists of two functions: fault detection and fault exclusion (FDE). The goal of fault detection is to detect the presence of a positioning failure. Upon detection, proper fault exclusion determines and excludes the source of the failure (without necessarily identifying the individual source), thereby allowing GNSS navigation to continue without interruption. There are two general classes of integrity monitoring: Receiver Autonomous Integrity Monitoring (RAIM), which uses GNSS information exclusively, and Aircraft Autonomous Integrity Monitoring (AAIM), which uses information from additional onboard sensors such as barometric altimeter, clock and inertial navigation system (INS); continuity aiding for the position solution using information of alternative sources like INS, barometric altimetry, and external clocks; availability aiding for the position solution and accuracy aiding through estimation of remaining errors in determined ranges.

Augmentation information may be combined with GNSS information by integration within the GNSS solution algorithm – modeling altimetry data like an additional satellite measurement or external to the basic GNSS position calculation – comparison of the altimeter data with the vertical GNSS solution. Each processing scheme has specific advantages and disadvantages. It is not possible to present a generic description of all potential integration options, including the situation in which several GNSS elements are combined, such as GPS and GLONASS.

**Space Based Augmentation Systems (SBAS).** SBAS is a wide-coverage augmentation system from which the user receives augmentation information from a satellite-based transmitter. SBAS is made up of three distinct elements: the ground infrastructure, SBAS satellites, and the aircraft receiver.

The ground infrastructure includes monitoring and processing stations that receive data from the navigation satellites and compute integrity, corrections, and ranging data to form the SBAS signal-in-space (SIS). The SBAS satellites relay the data from the ground infrastructure to the airborne receivers, which determine position and time information from GNSS and SBAS satellites. The airborne receivers acquire the ranging and correction data and apply these data to determine the integrity and improve the accuracy of the derived position.

The SBAS ground system measures the pseudorange between the ranging source and SBAS reference receivers at the known locations and provides separate corrections for ranging source ephemeris, clock, and ionospheric errors. The user applies a tropospheric delay model. The ranging source ephemeris and slow moving clock errors are the primary basis for the long-term correction. The ranging source clock error is adjusted for the long-term correction and tropospheric error and is the primary basis for the fast correction. The ionospheric errors among many ranging sources are combined into vertical ionospheric errors at predetermined ionospheric grid points.

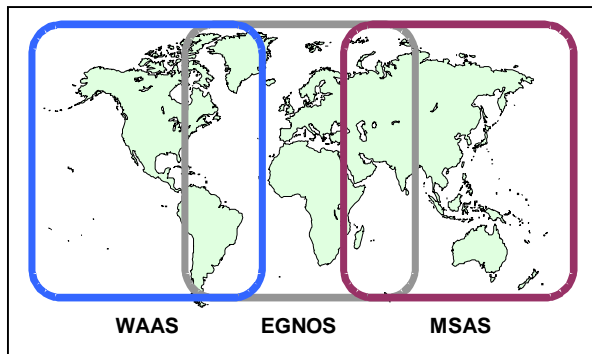


Figure 2. SBAS Systems

SBAS systems currently under development include the U.S. Wide-Area Augmentation System (WAAS), Japan's Multi-transport Satellite-based Augmentation System (MSAS), and the European Geostationary Navigation Overlay Service (EGNOS) planned for interface with Galileo (Figure 2). [5]

#### **Ground-Based Augmentation Systems (GBAS).**

GBAS is an augmentation system in which the user receives augmentation information directly from a ground-based transmitter. GBAS consists of ground and aircraft elements. One ground sub-system will support all the aircraft within its area of coverage. GBAS will provide the capability for precision landing minima to the Category III level.

The ground sub-system provides the aircraft with approach data, corrections, and integrity information for in-view GNSS satellites utilizing VHF data broadcast (VDB). The VDB transmits with either horizontal or elliptical polarization (GBAS/H or /E), which allows the service provider to tailor the broadcast to their operational requirements and user community. The majority of aircraft will be equipped with a horizontally polarized VDB receiving antenna, which can be used to receive VDB from both GBAS/H and /E equipment. Aircraft equipped with only a vertically polarized antenna are limited to operations supported by GBAS/E only.

The U.S. Local Area Augmentation System (LAAS) is an example of a GBAS. Other systems are under con-

sideration for development to include GLONASS and Galileo augmentation. The Russian Federation is developing and three part differential system as part of the United (State) Differential System (UDS). The plan includes Wide Area Differential (WADS), Regional Area Differential (RADs), and Local area Differential (LADS) systems, with each system providing an increased level of accuracy.

**Eurofix.** Eurofix is an integrated navigation system that combines Loran-C and differential GNSS (GPS, GLONASS, or future Galileo). Corrections are provided to users by additional modulation of the pulsed Loran-C signal. GNSS reference stations will be located at each Loran-C transmitter facility. Loran-C continues to remain an independent component of the navigation system, operating even if GNSS signals are not available in a particular area. Discussions are ongoing concerning adding this feature to the U.S. Coast Guard chains, Russian Federation Chayka stations and the Northwest European Loran-C System (NELS).

The fully integrated system will provide users with differential corrections for GNSS with an availability of approximately 99.99% and a 2-distance root mean square accuracy of 2-5 meters. Integration with WAAS and EGNOS is under discussion. The system will also provide GNSS integrity messages, emergency messages for the covered area, and coordinated Universal Time (UTC). [6]

**Surveillance.** Aircraft surveillance for air traffic control and air-to-air situational awareness is rapidly becoming a reality. The use of satellite-based position, velocity and time (PVT) information is under development and testing in the U.S. and other states. The PVT information is being evaluated for oceanic, enroute, and terminal traffic control; collision avoidance; and closely spaced parallel approaches. Results have shown the information more accurate than primary and secondary radar. Autonomous Dependent Surveillance (ADS) will replace ground-based surveillance systems and allow precise air traffic control in the oceanic environment.

**The Non-change.** Satellite navigation, PVT, augmentations...etc. aside, the flight inspection community must continue to support the traditional systems. The transition to sole-means GNSS navigation is 10 to 15 years in the future. Instrument landing systems (ILS), microwave landing systems (MLS), VHF omnirange (VOR), distance measuring equipment (DME), primary and secondary radar...etc. will be operational for years to come. Advances in ground-based hardware and software have provided more stable signals and great improvements in system reliability.

Avionics advances have caused a redefinition of instrument procedures capabilities. Flight Management Systems (FMS) aided by inertial reference units (IRU), barometric altimetry, rho-theta/rho-rho positioning, and the Required Navigation Performance (RNP) program provide new flight procedure possibilities.

## THE CHALLENGE

What will be the role of flight inspection for GNSS? How do we manage the planned changes to the existing GNSS infrastructure? How can we manage sustainment of the ground-based systems while transitioning the new? The challenges we face in the new millennium are many. A thorough understanding of satellite navigation and the associated flight procedures is the necessary first step. What we analyze and how we determine the safety of flight operations will become more apparent with this knowledge.

**GNSS Flight Inspection.** In 1995, the Federal Aviation Administration (FAA) established a goal to develop a GNSS approach procedure for every qualified runway. We have commissioned approximately 500 procedures per year since that time and are rapidly approaching the goal of over 4,000 GNSS procedures. In addition, we commissioned three Special Category I Differential GPS (SCAT-I) systems and conducted the required periodic evaluations. These systems were early LAAS designs. We began flight validation of the WAAS two years ago utilizing the National Satellite Test Bed and eventually the WAAS during authorized test periods. This involved numerous flight evaluations of WAAS aided approach procedures to Category I minimums. We have also commissioned several special GPS-based airways/routes, departure, arrival, and special helicopter procedures for emergency medical services, law enforcement, and offshore oil platforms.

We have learned much about the flight inspection role in GNSS procedure evaluation. As with any new endeavor, we began by measuring every possible parameter we could recover through the flight inspection system (FIS), even if we had no idea what to do with the data. Time and knowledge have caused us to refine these requirements. We believe our methodologies are sound and allow us to deliver a safe flight procedure to both the public and special needs users.

These challenges were not met easily. We have struggled through volumes of documents and flight inspection data. Our aircraft are now equipped with avionics and FIS improvements that allow us to evaluate non-precision stand-alone GPS, WAAS and LAAS procedures. As is normally the case, certified receivers are not available early in a new program. We have worked with other organizations within the FAA and DoD to utilize prototype receivers. These will be replaced with certified equipment when available.

**ICAO Performance Parameters.** The International Civil Aviation Organization has developed draft Standards and Recommended Practices (SARPs) for GNSS operations. Table 1 is a reprint of the performance requirements for various phases of flight and the associated notes. These requirements represent the total system and include the signal-in-space (SIS), aircraft and non-aircraft equipment, and the ability of the aircraft to fly the desired path. In other words, these are Total

System Error (TSE) requirements, which include Navigation System Error (NSE) and Flight Technical Error (FTE). [7]

It is important to understand the terminology used. The associated error budget and error allocations are critical to the development of flight inspection standards.

The *control* and *user segments* provide a SIS and subsequent navigation solution that meets the NSE for the phase of flight operations. The receiver calculations account for satellite geometry (DOP); signal-to-noise and/or carrier-to-noise-ratios; and fault detection and/or exclusion (FDE). Horizontal and vertical protection levels/limits establish the integrity of the navigation solution and will cause a "flag" if the performance requirement is not being met, corresponding to "fail-safe" operations.

Augmentation systems have little effect on the error allocation; rather they provide improvements in accuracy and integrity. The SBAS *ground infrastructure* uses multiple reference stations to receive the data from the GPS satellites. The monitoring and processing stations then compute integrity, corrections, and ranging data for uplink to the GEO satellites using forward error checking techniques. The GEO satellites rebroadcast the WAAS augmentation data and GPS-like ranging signals to the aircraft receiver (*user segment*), which acquires and applies the data to determine the integrity and improve the accuracy of the derived position. The uplinked corrections and augmented navigation data is received from the GEOs by the ground monitoring and processing stations and cross-checked with the data originally sent, forming a closed monitoring loop. Accuracy and integrity are improved but the error allocation remains the same.

GBAS operates in the same basic manner on a more localized scale. LAAS services include a *ground infrastructure* comprised of multiple reference stations, a monitoring and processing station, and the VDB. The nominal service area for a LAAS installation will be omnidirectional to a distance of 22 NM. Since the service area is small (compared to SBAS), the augmentation data improves accuracy and integrity to a high precision level – meeting Category III requirements. The correction data and final approach segment data are uplinked to the aircraft receiver using forward error correction on VOR frequencies. Again, the error allocation remains the same.

Performance monitoring and data history is recommended in the GNSS SARPs. This data will aid in incident/accident investigations and anomaly analysis. Regions utilizing GNSS services provided by another state are encouraged to implement a monitor and data archive function. The parameters to be recorded are dependent on the type of operation, augmentation system, and core elements used (GPS, GLONASS, EG-NOS, etc.).

**Table 1. ICAO GNSS Performance Requirements**

Typical operation(s)	Accuracy horizontal 95% (1)(3)	Accuracy vertical 95% (1)(3)	Integrity (2)	Time to alert (3)	Continuity (4)	Availability (5)	Associated RNP type(s)
En-route	3.7 km (2.0 NM) (6)	N/A	1-10 <sup>-7</sup> /h	5 min	1-10 <sup>-4</sup> to 1-10 <sup>-8</sup> /h	0.99 to 0.99999	20 to 10
En-route, Terminal	0.74 km (0.4 NM)	N/A	1-10 <sup>-7</sup> /h	15 s	1-10 <sup>-4</sup> to 1-10 <sup>-8</sup> /h	0.999 to 0.99999	5 to 1
Initial approach, Intermediate approach, Non-precision approach (NPA), Departure	220 m (720 ft)	N/A	1-10 <sup>-7</sup> /h	10 s	1-10 <sup>-4</sup> to 1-10 <sup>-8</sup> /h	0.99 to 0.99999	0.5 to 0.3
Non-precision approach with vertical guidance (NPV-I)	220 m (720 ft)	20 m (66 ft)	1-2x10 <sup>-7</sup> per approach	10 s	1-8x10 <sup>-6</sup> in any 15 s	0.99 to 0.99999	0.3/125
Non-precision approach with vertical guidance (NPV-II)	16.0 m (52 ft)	8.0 m (26 ft)	1-2x10 <sup>-7</sup> per approach	6 s	1-8x10 <sup>-6</sup> in any 15 s	0.99 to 0.99999	0.03/50
Category I precision approach (8)	16.0 m (52 ft)	6.0 to 4.0 m (7) (20 to 13 ft)	1-2x10 <sup>-7</sup> per approach	6 s	1-8x10 <sup>-6</sup> in any 15 s	0.99 to 0.99999	0.02/40

Notes:

1. The 95 percentile values for GNSS position errors are those required for the intended operation at the lowest height above threshold (HAT).
2. The definition of the integrity requirement includes an alert limit against which the requirement can be assessed. These alert limits are:

Typical operation	Horizontal alert limit	Vertical alert limit	Associated RNP type(s)
En-route	7.4 km (4 NM)	N/A	20 to 10
En-route	3.7 km (2 NM)	N/A	2 to 5
En-route, Terminal	1.85 km (1 NM)	N/A	1
NPA	556 m (0.3 NM)	N/A	0.5 to 0.3
NPV-I	556 m (0.3 NM)	50 m (164 ft)	0.3/125
NPV-II	40.0 m (130 ft)	20.0 m (66 ft)	0.03/50
Category I precision approach	40.0 m (130 ft)	15.0 m to 10.0 m (50 ft to 33 ft)	0.02/40

(A range of vertical limits for Category I precision approach relates to the range of vertical accuracy requirements.)

3. The accuracy and time-to-alert requirements include the nominal performance of a fault-free receiver.
4. Ranges of values are given for the continuity requirement for en-route, terminal, initial approach, NPA and departure operations, as this requirement is dependent upon several factors including the intended operation, traffic density, complexity of airspace and availability of alternative navigation aids. The lower value given is the minimum requirement for areas with low traffic density and airspace complexity. The higher value given is appropriate for areas with high traffic density and airspace complexity.
5. A range of values is given for the availability requirements as these requirements are dependent upon the operational need which is based upon several factors including the frequency of operations, weather environments, the size and duration of the outages, availability of alternate navigation aids, radar coverage, traffic density and reversionary operational procedures. The lower values given are the minimum availabilities for which a system is considered to be practical but are not adequate to replace non-GNSS navigation aids. For en-route navigation, the higher values given are

are not adequate to replace non-GNSS navigation aids. For en-route navigation, the higher values given are adequate for GNSS to be the only navigation aid provided in an area. For approach and departure, the higher values given are based upon the availability requirements at airports with a large amount of traffic assuming that operations to or from multiple runways are affected but reversionary operational procedures ensure the safety of the operation.

6. This requirement is more stringent than the accuracy needed for the associated RNP types but it is well within the accuracy performance achievable by GNSS.
7. A range of values is specified for Category I precision approach. The 4.0 m (13 ft) requirement is based upon ILS specifications and represents a conservative derivation from these specifications.
8. GNSS performance requirements for Category II and III precision approach operations are under review and will be included at a later date.

---

**Flight Inspection Role.** The error allocation and navigation processing schemes utilized in GNSS flight operations limits the requirements for flight inspection validations. If we compare GNSS with a typical ILS, we find that standard methodologies no longer apply. ILS signals are generated in the ground transmitter and radiated through elaborate phasing and antenna circuits. Monitoring is accomplished at the ground site utilizing integral and near-field antennas. Guidance is generated from the recovered modulation relationships applied to the carrier by a passive receiver.

GNSS guidance is generated within the aircraft avionics using data received from the satellites, procedure databases and augmentation services. The receivers use algorithms designed and certified to meet the safety-of-life requirements of RTCA DO-178B, Software Considerations in Airborne Systems and Equipment Certification. These algorithms determine position, guidance, guidance scaling, distance information, real-time integrity monitoring, and fault detection and exclusion. All of these processes are certified by a comprehensive set of test programs to meet the TSO requirements.

The role of flight inspection now becomes that of flight procedure design validation and anomaly identification. The only signal-in-space analysis required is for the GBAS VDB signal strength/coverage. This has not been an easy transition within the FAA flight inspection program. Flight inspectors are, by nature and training, accustomed to analyzing microamps, ddm, microvolts, structure...etc. Replacing this with procedure design validation and the occasional interference situation is not unlike a trip to the dentist! Value-added analysis, experience, and education help smooth the road.

**Flight Procedures.** Navigation accuracy of flight procedures is solely dependent on the geographic coordinates used in the design process. International standards for these data is published in ICAO Doc 9674, Airport Survey Accuracy (WGS-84 Manual) and RCA DO-201, Standards for Aeronautical Information. Survey system accuracy is required in millimeters and airport coordinates at 1 meter or less.

The coordinates for runway centerline – threshold and stop-end – provide the basis for the approach procedure design. Certified survey data for ground reference

stations is another critical element. Reference antenna phase-centers are located to centimeter accuracies.

Flight inspection of the procedure includes design validation, obstacle validation, and flyability. Design validation is performed by entering the procedure waypoints into the FMS or GNSS receiver and comparing the bearing and distance between each with the design package. The validation should be done utilizing true bearing. Use of magnetic bearing can cause confusion. GNSS receivers and FMS use different methods to apply magnetic variation – some use look-up tables and others provide real-time calculations. Procedure design is based on the airport magnetic variation, which does not provide accuracy comparable with the receiver technology.

Certified receivers will not operate in the approach mode when waypoints are manually entered, however, the guidance scale-factor can be manually selected. Many FMS manufacturers provide software that allows waypoints and leg-types to be developed in a special data file and downloaded into the FMS database. This allows the system to function in the full approach mode.

**Multiple Approach Minima.** GNSS and SBAS approach procedures are being published in the U.S. as Area Navigation (RNAV) approach charts. These charts contain multiple landing minima to accommodate various aircraft/avionics capabilities. Separate minima lines are provided for GLS PA (SBAS Category I precision approach), LNAV/VNAV (lateral and barometric vertical guidance), VNAV, and circling when applicable. In addition, RNP requirements are included for certified aircraft. GBAS approach charts will be published separately.

LNAV guidance may be provided by GNSS or ground-based facilities (DME/DME). This requires flight inspection validation of DME coverage throughout the final segment of the approach at the designed altitudes. DME coverage models are used to generate a listing of probable facilities that may support the procedure.

These procedures require validation to the Decision Altitude (DA) for precision and VNAV approaches and to the Minimum Descent Altitude (MDA) for nonprecision. Obstacle evaluation is based on standard trapezoidal surfaces for all cases except RNP, which utilizes

linear surfaces. The approach procedure is flown from initial waypoints through the missed approach segment.

Pilot analysis of flyability must include knowledge of performance capabilities for all categories of aircraft anticipated to operate at the location. This is especially true for arrival and departure procedures to ensure deceleration legs and heading/altitude changes are manageable. Future enhancements such as curved and segmented approach procedures will require careful human factors consideration.

As you can see, validation of the flight procedure can be complicated and will keep the flight crew very busy. But what of the flight inspection engineer/technician? In addition to the DME coverage and GBAS VDB analysis mentioned above, the FIS is continuously monitoring GNSS parameters. Any loss of guidance will require these data be analyzed to identify the cause. This includes interference, geometry, or receiver failure.

FAA flight inspection systems are being equipped with GNSS passive monitoring capabilities. This system begins archiving specific GNSS parameters at wheels-up. If any of these parameters exceed predetermined levels during the flight, the FIS retains the last five minutes of good data, the data during the anomaly, and five minutes of good data after. The crew is alerted and may decide to re-fly the route or procedure. If interference is suspected, they may fly across and/or around the initial flight path to determine the area affected. Parameters that are monitored are listed in Table 2. If interference is continuously present, a spectrum analysis and interference location aircraft will be dispatched to the location for further investigation.

**Table 2.** Passive Monitoring Parameters

GPS Sensor (GNSSU)	FIS
UTC	A/C Heading
GPS Altitude (MSL)	A/C Baro Altitude
HDOP	A/C Pitch
VDOP	A/C Roll
RAIM	A/C Ground Speed
Signal-to-Noise Ratio	A/C Latitude
GPS Latitude	A/C Longitude
GPS Longitude	System Time
GPS Ground Speed	System Date
GPS Date	
GNSSU Status	
Measurement Status	
Autonomous Horizontal Integrity Limit	
Autonomous Vertical Integrity Limit	

**Interference Detection and Localization.** As reliance on GNSS increases, the FAA is taking several steps to mitigate the effects of interference incidents. The program consists of the establishment of an agency-wide coordinated program, fielding of interference localization equipment, and development of traffic management procedures. Performance goals for this program phase

are to detect and localize an interference source near a major hub in real time and to eliminate the source in near real time. [8]

A spectrum manager has been established at the Air Traffic Control System Command Center (ATCSCC) to coordinate tactical efforts addressing interference to GNSS signals; collaborate with ATC managers responsible for re-routing flights when necessary, personnel who issue NOTAMs, and flight inspection aircraft utilized in localizing the interference source.

The FAA is deploying GPS interference detection and localization systems for use on five platforms: aircraft, portable (temporary vehicle installation), handheld, fixed (ground-based installation), and transportable (permanent vehicle installation). The five systems have complementary features (range, accuracy, and mobility) and, used in concert provide an integrated interference detection and localization capability.

Normally, the first reports of GPS interference will be from aircraft carrying out normal operations. The airborne component of the interference detection/localization system will be quickly dispatched to establish the source position to an accuracy of approximately 1 nautical mile.

The airborne system is based on a direction finding (DF) antenna. DF systems can provide both improved localization time and increased accuracy by enabling direct homing to and fly-over of the source. The airborne system is deployed on FAA flight inspection aircraft.

Once the interference source is localized to within a small area, portable and/or handheld systems will be used to find the precise source position. These units are easily installed in a passenger vehicle, and are more efficient than handheld units for interference source localization. Handheld localization systems are best suited to conditions that preclude using portable systems – e.g., wooded areas or building interiors.

Fixed-installation multi-band interference detection and localization systems along with the associated transportable units will be deployed at critical high-traffic airports and surrounding terminal areas. The first operational systems have been installed at Los Angeles International and Chicago O'Hare airports. These systems will protect the aeronautical frequency bands used for current ground-based communications, navigation and surveillance systems, as well as the GPS bands.

A fixed system installation has three or more remote towers, equipped with a DF antenna and electronics unit. Outputs from the remote sites are linked to a base station on the airport, which provides a source location estimate by triangulation and a recording capability. Recent operational incidents involving interference to VHF communications located the source in less than 15 minutes.

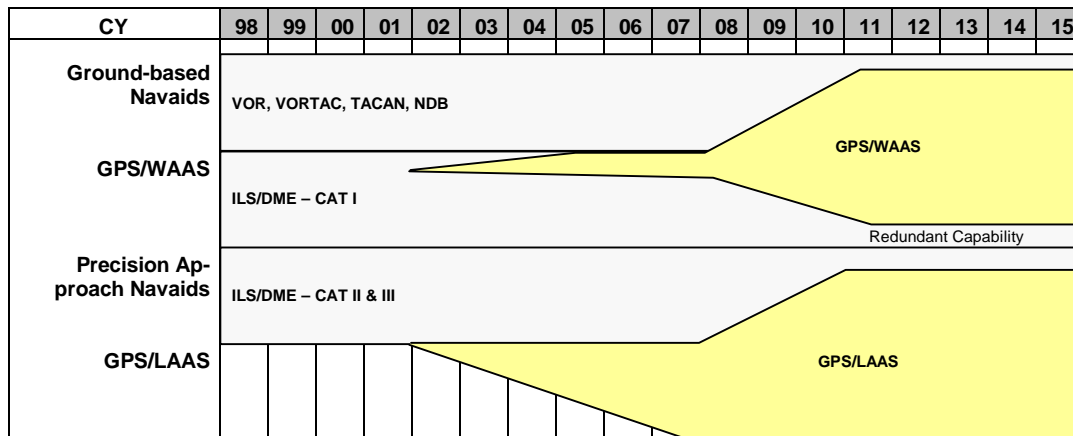


Figure 3. Transition Timeline for the U.S.

The mobile unit consists of a van carrying a top-mounted telescoping tower, a DF antenna, and associated electronics. The van is linked via radio to the airport base station and serves as a real-time deployable sensor. By dispatching the van to a location near an initial estimate of the source location, a stronger interference signal and better DF geometry are obtained, resulting in an improved estimate of the source location.

### OPPORTUNITIES

The new requirements for flight inspection of GNSS and the overlap with traditional navigation and landing aids offers many opportunities for methodology and technology advancements in the flight inspection arena.

**Traditional Facilities Inspection.** The future implementation of GNSS services and the phase-out of the ground-based infrastructure are depicted in Figure 3. The transition period will increase flight inspection workload dramatically. This situation calls for more efficient flight inspection aircraft and analysis tools.

The increasing use of FMS – utilizing both GNSS and ground-based facilities – coupled with inertial units will expand potential flight operations into new areas. Curved approaches with continual vertical guidance will require validation. Today's flight inspection airframe should include dual FMS and IRU avionics that will facilitate these operations. FMS controlled navigation utilizing the RNP concept provides an additional tool. These systems announce the RNP value for the phase of flight and the Actual Navigation Performance (ANP) achieved in real-time. These two values – with proper calibration – provide an in-flight validation of many procedures without external equipment.

**Flight Inspection System Advances.** There is also an opportunity in incorporate new technologies into the flight inspection system. Reducing the size, weight and

power requirements would enhance the selection of available airframes and associated environmental systems to support the flight inspection mission. The incorporation of computer controlled sampling receivers with digital signal processing (DSP) would provide improved performance, higher reliability and lower cost. The entire ground-based navigation spectrum could be analyzed utilizing two receivers of this type – one covering 10 kHz to 30 MHz and the second 30 to 1200 MHz. These receivers can be programmed to scan or sweep one hundred channels per second. They provide data bus interface for ease of integration with ARINC data modules, 32-bit computers, and storage devices.

DSP data provides a direct source for signal analysis algorithms -- digital in and digital out – also supporting data archiving and report generation. Analysis software modules can provide results in graphic and/or tabular formats, in near real-time, to the flight inspection engineer/technician. In addition, the data would easily input to desktop analysis tools currently available for multi-path analysis and other modeling programs.

This system would be the size of a standard desktop computer, weigh less than 100 pounds, and present an electrical load of 100 watts.

### SUMMARY

*We have met the enemy, and we are them* (or is it *they are us?*). The changes are upon us and will continue at a rapid pace. Conversely, the traditional systems will be in parallel operation for many years to come. The challenges are many; be prepared for and accept the new, sustain the traditional, and meet the increased demand for flight inspection during the transition. Opportunities abound for new equipment and analysis tools to meet these challenges. It is an exciting time for flight inspection.

## REFERENCES

1. Opportunity Knocks – Will GPS Modernization Open Doors?, K. McDonald, GPS World, September 1999.
2. Leadership in Satellite Navigation and Timing, J. McNeff, GPS World, October 1999.
3. Russian Federation Ministry of Defense, Coordination Scientific Information Center, Declaration of the Government of the Russian Federation, 29 March 1999.
4. Galileo Signals for Civil Aviation, Dr. M. Ruete, Directorate General for Energy and Transport, European Commission, Galileo Presentation to ICAO Air Navigation Council, Montreal, March 2000.
5. EGNOS, A First Step for Europe, C. Allemand, CNES Magazine, August 1999.
6. Loran-C/Eurofix, A European Approach for an Integrated System, U. Klinge, Galileo's World, Winter 2000.
7. Proposal for the Amendment to ICAO Annex 10, Volume I concerning the inclusion of Standards and Recommended Practices (SARPs) and guidance material relating to the global navigation satellite system (GNSS), 3 September, 1999.
8. FAA GPS RFI Mitigation Program, M. Geyer, Institute of Navigation 1999 Proceedings, Nashville, Tennessee, September 1999.