1. What is SBAS?
A Satellite Based Augmentation System (SBAS) is a primary air navigation system that provides augmented accuracy and integrity to a Global Navigation Satellite Systems (GNSS) navigation signal such as used by the U.S. Global Positioning System (GPS). GNSS alone is considered a supplemental air-navigation system. An SBAS provides improved service availability over a wide area and is a more reliable navigation service than GNSS alone.

The internationally cooperative standards for SBAS were published as the Standards and Recommended Practices (SARPs) Annex 10 by the International Civil Aviation Organization (ICAO), a specialized agency of the United Nations. The ICAO is chartered to provide globally interoperable SBAS aviation standards that describe the principles and practices of international air navigation.

The ICAO SARPs foster the planning and development of international air transport systems that support SBAS interoperability and SBAS avionics technology interchangeability. The SARPs establish that the introduction of new GNSS navigation elements should include evaluation of the navigation systems with respect to four essential criteria:

- Accuracy
- Integrity (including time-to-alert)
- Service continuity
- Availability

These specific criteria define the standards for Approach with Vertical guidance (APV), the ICAO term for an SBAS approach classification that allows the use of stabilized descent using vertical guidance.

The Interoperability Working Group (IWG), made up of SBAS providers around the world, provides the forum to allow the coordinated development of interoperable SBAS systems and common aircraft avionics receiver technology that enable aircraft to easily transition from one SBAS system to the next.

As technology evolves both groups provide guidance and planning objectives to maintain seamless global operations as systems expand, are enhanced, or as new SBAS systems are implemented.

2. Where are SBAS networks in operation or under development?
There are three SBAS networks in operation today, the European Geostationary Navigation Overlay Service (EGNOS), the Multifunctional Transport Satellite (MTSAT) Satellite Augmentation System (MSAS) and the United States (US) Wide Area Augmentation System (WAAS), providing coverage geographically to most of Europe, Asia-Pacific and North America. Both India’s GPS Aided Geo Augmented Navigation (GAGAN) and the Russian System of Differential Correction and Monitoring (SDCM) are in development that will provide coverage to Indo-Asia and Euro-Asia. Completion of all five systems will provide near total coverage of the northern hemisphere for approach operations and near worldwide coverage for enroute, terminal and non-precision approach operations.

**WAAS** - The U.S. WAAS supports over 5461 ends of runways and hundreds of heliport/helipads in the U.S. National Airspace System (NAS).

As of May 30, 2013, the WAAS supports:
- 3,123 Localizer Performance with Vertical guidance (LPV) procedures.
- 5,663 Lateral Navigation (LNAV) procedures.
- 3,003 LNAV / Vertical Navigation (VNAV) procedures published.
- 2,046 LPVs published to non-ILS runways.
- 421 Localizer Performance (LP) procedures.
There are now more than twice the numbers of WAAS-enabled LPV procedures as there are Category I ILS approaches.

The FAA is currently in Phase III of a four-phase WAAS program life cycle. WAAS has completed the operational integration of a new Geostationary Earth Orbit (GEO) satellite (Inmarsat 4F3-PRN 133). Future Phase III improvements underway include technology refresh and algorithmic improvements to increase service availability.

The U.S. SBAS expansion into Canada and Mexico was achieved with the integration of nine international wide-area reference stations (WRS) into the WAAS network. As of May 2013 Canada has published 147 LPVs serving 81 Airports with plans for more to follow. Mexico has announced plans to publish LPV procedures in the near future.

**EGNOS** - The first pan-European satellite navigation system. EGNOS Open Service was declared on October 1st 2009, supporting multimodal applications in non-aviation domains. Later on March 2nd 2011, EGNOS Safety of Life (SoL) service was declared operational, enabling the publication of LPV procedures over Europe. As of May 2013, there are 137 procedures based on EGNOS across Europe, supporting LPV and APV Baro approach operations. Nowadays, the publication of LPV procedures is very active, increasing the number continuously. Implementation of LPV-200 Service Level is planned for 2015. Up-to-date information is available [http://www.essp-sas.eu/](http://www.essp-sas.eu/).

**MSAS** – Japan’s Satellite Based Augmentation System using their MTSAT satellites. MSAS was declared operational in 2007 and provide horizontal guidance within the MSAS service volume. MSAS supports En Route, Terminal and Non-Precision Approach operations.

**GAGAN** – Is being implemented in three phases by the Airport Authority of India with the help of the Indian Space Research Organization’s (ISRO) technology and space support. GAGAN plans to deliver RNP 0.1 as the first deployment milestone. The second milestone is Approach with Vertical Guidance (APV) 1.0 over 90% of the Indian landmass. The timeline for completion and certification of APV 1.0 is slated for June of 2013. It is applicable to safety-of-life operations, and meets the performance requirements of international civil aviation regulatory bodies.

**SDCM** – Russia’s SBAS styled overlay for either GLONASS or GPS. SDCM plans to provide both horizontal and vertical guidance.

Although SBAS providers guarantee adequate service provision only in their nominal service volumes, SBAS broadcast signals will be available anywhere in their respective GEO footprints. This fact, together with the fact that EGNOS/GAGAN/MSAS/WAAS intermediate regions are not covered by any other SBAS system, has fostered debate about the possibility of providing a minimum service level in the intermediate region by means of SBAS interoperability.

Figure 1 shows the ionospheric coverage for several of the SBAS constellations. For WAAS, EGNOS and MSAS, the grids shown are actual grids with no extrapolation. The grid shown for GAGAN was recorded by an SXBlue II GPS during the Final Acceptance Test phase and is not an official grid from the Indian authorities.

### 3. What are the benefits of SBAS?

SBAS is designed to enable users to rely on GNSS navigation data for all phases of flight, from en route through category I approach for all qualified airports within an SBAS coverage area.

SBAS provides a capability to conduct vertically guided approaches to non instrumented runways, providing significant improvement to operational safety that was previously un-available.

SBAS is not sensitive to temperature fluctuations and has no
barometric / temperature limitations. When using Barometric Vertical Navigation (Baro VNAV) a minimum temperature limitation is published for each procedure for which Baro-VNAV minimums are published. This temperature represents the airport temperature below which the use of Baro-VNAV is not authorized to the LNAV/VNAV DA. The pronounced effect of cold temperatures on Baro-VNAV operations means that the approach may not be flown at all using Baro-VNAV when the temperature is below -20° Celsius.

SBAS is an enabler for FAA Next Generation Transportation System (NEXTGEN) and European Single European Sky Air Traffic Management Research (SESAR).

SBAS provides benefits beyond aviation to all modes of transportation, including maritime, highways, and railroads.

Other benefits of an SBAS are:

**En Route Capability**

SBAS operational criteria include integrity assurance and eliminate the need for GNSS avionics Receiver Autonomous Integrity Monitoring (RAIM) checks. This feature means that SBAS is considered a primary Navigation system. GNSS navigation alone requires RAIM checks and is considered a supplementary navigation system.

The very high resolution point-in-space of SBAS supports flexibility to design more efficient airspace and instrument procedures SBAS technology provides the opportunity to cover very large areas of airspace and areas formerly un-served by navigation aids and is an enabler of ICAO Performance Based Navigation (PBN). The ICAO PBN manual provides initiative for development of en route navigation guidance. Two key components of PBN are Area Navigation (RNAV) and RNP. Each includes lateral navigation standards for performance, functionality and capability.

These standards allow the flexibility to design more efficient airspace and instrument procedures that collectively improve safety, access, capacity and efficiency. Direct routes minimize track dispersion and environmental impacts by reducing fuel use and pollution.

By eliminating the need for airways to be tied to ground-based navigation aids, SBAS-equipped aircraft gain the flexibility and benefit of point-to-point operations. SBAS satisfies PBN based equipment requirements for the new, more direct en route flight options of ‘T’ and ‘Q’ routes.

- **T-Route:** an RNAV route used in low-altitude airspace operating below 18,000 feet.
- **Q-Route:** an RNAV route used in high-altitude airspace (18,000 feet – 45,000 feet).

Immediate, tangible benefits have been noted. Controller/pilot transmissions are reduced by over 30%. There is a significant reduction in track dispersion and the more efficient procedure designs reduce flight distances resulting in fuel savings for the operators. Learn more about T-routes, Q-routes, and LPVs at http://www.faa.gov/nextgen/flashmap/

**Approach Capability**

SBAS provides the vertical guidance necessary for Localizer Precision Vertical Guidance (LPV) defined approaches. SBAS LPV-200 approaches are equivalent to Category I Instrument Landing System (ILS) approaches for runway ends qualified for Category I ILS. For non-qualifying runway ends, SBAS supports a Localizer Precision (LP) non-precision approach. These SBAS supported approaches do not require the installation and maintenance of any landing system navigation aids.

LPVs are operationally equivalent to a Category I Instrument Landing System (ILS), but are more economical. LPV specifications are developed within the definition of ICAO APV’s and add increased capability, flexibility, and in many cases, more cost-effective navigation options than legacy ground-based navigation aids. SBAS use will become increasingly more vital as older legacy equipment (such as NDB, VOR, or ILS) is decommissioned and taken out of service.

SBAS also provides for immunity to improper setting of QNH on the aircraft. Additionally, SBAS provides vertical guidance via GNSS constellation augmentation, SBAS supported. Finally, SBAS provides for positive guidance (RNP 0.3) across the SBAS service volume.

**Terminal**

SBAS supports Trajectory Based Operations (TBO) Continuous Descent Approach (CDA) supporting significant fuel savings for operators.

SBAS Terminal operations offer a significant reduction in track dispersions.

**4. What is SBAS interoperability?**

Although all SBAS are regional systems, the need to establish adequate co-operation/coordination among SBAS providers is commonly recognized so that their implementation becomes more effective and part of a seamless world-wide navigation system. ICAO SARPs Annex 10 and Aviation Standards support interoperability among SBAS service providers by:

- **Seamless transition between SBAS Service Areas.**
  - Evaluating transitions between SBAS and RAIM along with transitions between two SBAS and between SBAS and GBAS.
- **Common interpretation of Standards amongst SBAS Developers.**
  - Established a work plan for development of a definition document to support a dual-frequency, multi-constellation user.
- **Currently Limited Global Coverage.**
  - Global coverage to be expanded with addition of GAGAN and SDCM.
  - Availability of worldwide LPV-200 service expected with addition of a second frequency, extended networks and additional GNSS constellations.
- **Continued support to legacy single frequency users by ensuring backwards compatibility.**
SBAS IWG objectives established to support technical interoperability and cooperation:

Objective 1: Harmonize SBAS modernization plans.
Objective 2: Forum for discussion on SBAS standards.
Objective 3: Harmonize technical improvements for operation and user feedback.
Objective 4: Research and development cooperation on key SBAS technologies.
Objective 5: Support joint SBAS promotion.

5. **Will SBAS provide a performance comparable to ILS?**

Yes. An SBAS LPV approach is designed to provide performance comparable to a Category 1 Instrument Landing System (ILS) approach. In fact, efforts undertaken by the FAA have demonstrated that an SBAS is capable of supporting Height Above Touchdown (HAT) heights down to 200 ft. The level of service provided by an SBAS is contingent on a number of factors:

- Environmental conditions based on geographic location.
- The number and density of ground monitoring stations.
- The approach for monitoring and correcting system errors.

6. **Can an SBAS avionics receiver be used to fly RNAV approaches?**

An approved SBAS avionics receiver is certified for all of the lines of minima on the RNAV (GPS) approaches (LPV, LP, LNAV/VNAV, and LNAV).

7. **What are the differences between GPS/SBAS LPV, LP, LNAV/VNAV and LNAV approaches?**

LPV is the most desired APV approach. It is similar to LNAV/ VNAV except it is much more precise (40m lateral limit), enables descent as low as 200-250 feet above the runway and can only be flown with an approved SBAS Avionics receiver. LPV approaches are operationally equivalent to the legacy instrument landing systems (ILS), but are more economical because no navigation infrastructure is required at the runway. There are over 2,327 LPV approaches in use today and the FAA is publishing over 500 new LPV approaches per year.

Localizer Performance (LP) is a recent non-precision approach (NPA) procedure that uses SBAS precision of LPV for lateral guidance and barometric altimeter for minimum descent altitude (MDA) guidance. These approaches are needed at runways where, due to obstacles or other infrastructure limitations, a vertically guided approach (LPV or LNAV/VNAV) cannot be published. LP approaches can only be flown by aircraft equipped with SBAS Avionics receivers. The MDA for the LP approach is expected to be nominally 300 to 400 feet above the runway.

LNAV / VNAV approaches use lateral guidance (556m lateral limit) from GPS and/or SBAS and vertical guidance provided by either the barometric altimeter or SBAS. Aircraft that don’t use SBAS for the vertical guidance portion must have a Baro-VNAV system, which are typically part of a flight management system (FMS). When the pilot flies an LNAV / VNAV approach, lateral and vertical guidance is provided to fly a controlled descent and a safer maneuver to the runway. The decision altitudes on these approaches are usually 350 feet above the runway.

GPS NPA (LNAV) refers to a Non-Precision Approach (NPA) procedure which uses GPS and/or SBAS for Lateral Navigation (LNAV). On an LNAV approach, the pilot flies the final approach lateral course, but does not receive vertical guidance for a controlled descent to the runway. Instead, when the aircraft reaches the final approach fix, the pilot descends to a minimum descent altitude using the barometric altimeter. LNAV approaches are less precise (556m lateral limit) and therefore usually do not allow the pilot to descend to as low an altitude above the runway. Typically, LNAV procedures achieve a minimum descent altitude (MDA) of 400 feet height above the runway.

8. **What comprises a typical SBAS infrastructure?**

A network of precisely surveyed ground reference stations is strategically positioned across a geographic coverage region to collect Global Navigation Satellite Systems (GNSS) navigation data. Using this information, a System User Message is generated to either correct GNSS signal errors or provide notice to users of potential signal errors. These correction messages are then broadcast through specialized Navigation Transponders on GEO satellites via GNSS-like signals to an SBAS avionics receiver onboard service user aircraft.

9. **Can SBAS information be trusted?**

SBAS Integrity is outlined by ICAO SARPs Appendix 10 and refers to the level of trust of the satellite navigation information received and the computed position. Integrity of a navigation system includes the ability to provide timely warnings if the information broadcast or that is computed could potentially create hazards. The ICAO SARPS specification for SBAS requires the system to detect errors in the GNSS or GEO network and notify users within a very small time constraint. Certifying that SBAS is safe for instrument flight rules (IFR) requires proving there is only an extremely small probability that an error exceeding the requirements for accuracy will go undetected. Specifically, the probability is less than $1 \times 10^{-7}$, and is equal to no more than 3 seconds of bad data per year.

For safety reasons, within the specified time constraint, SBAS can do one of two actions:

I. Provide a correction to the information that is detected as misleading. If SBAS is able to correct misleading information within the time constraint, there is no lapse in system integrity.

II. Notify the user not to use the information.

10. **Can an alternative be used with an SBAS approach?**

With approved SBAS avionics installed; a pilot may plan to use any instrument approach authorized for use with SBAS avionics that meets ICAO aviation requirements as an alternative. The LNAV minima line must be used for planning purposes in case vertical guidance is not available. SBAS removes the Receiver Autonomous Integrity Monitor (RAIM) and fault detection and
exclusion (FDE) prediction scenarios.

RAIM is a form of integrity monitoring performed within the avionics themselves. It ensures available GNSS satellite signals meet the integrity requirements for a given phase of flight. By comparing the pseudorange measurements of a number of GNSS satellites, the RAIM function can identify a GNSS satellite failure and issue an alert to the pilot. A minimum of five GNSS satellites is required to detect a bad satellite; at least six GNSS satellites are required to detect and exclude a bad satellite from the navigation solution if the SBAS Avionics receiver has an FDE RAIM algorithm. RAIM checks are a requirement for use of non SBAS avionics.

11. Are there SBAS plans for technology evolution and performance enhancements?
Algorithmic improvements will increase service availability with improved modeling of ionospheric signal distortion.

Because of the availability impacts due to ionospheric storms, SBAS providers are making plans to implement dual-frequency in order to increase SBAS availability and performance by direct mitigation of ionospheric signal delay using two civil frequencies. Dual frequency extends coverage outside reference networks & allows LPV operation in equatorial areas because of its superior properties to mitigate ionospheric interference. Expanding SBAS networks into Southern Hemisphere would allow global coverage of land masses. A further benefit is improved robustness against unintentional interference.

Phase IV of WAAS will introduce Dual Frequency operation by 2018, taking advantage of new GPS satellites broadcasting the current L1 signal (1575.42 MHz) along with the new, civilian, L5 Safety of Life signal (1176.45 MHz). EGNOS version 3 will introduce Dual Frequency operation by 2020 and other SBAS systems are also planning its implementation.

With the use of L5, a dual-frequency SBAS avionics receiver could use the SBAS corrections message or generate its own ionospheric delay corrections by comparing the L1 and L5 signals. Dual-frequency SBAS avionics receivers promise to provide greater accuracy and increased service availability.

Under the concept of Interoperability, methods for seamless transitions between SBAS service regions are being developed. This includes analysis for transitions between SBAS and RAIM, two SBAS regions and between SBAS and GBAS service areas.

There are also options being considered regarding inclusion of additional GNSS constellations in SBAS such as GLONASS, Galileo and BeiDou (COMPASS). Multiple constellations will allow SBAS avionics receiver manufacturers to develop Interchangeability. With interchangeability a given SBAS avionics receiver can select all satellites in view from any constellation and use the four best suited for an optimal navigational solution. Additional constellations allow even greater coverage with fewer stations.

SBAS operators are committed to deploy and maintain a sufficient number of GEO satellites to ensure availability requirements are met across each SBAS service volume.

SBAS deployments will continue to support legacy single frequency users by ensuring backward compatibility.

Every major avionics manufacturer is incorporating multi-constellation capable SBAS avionics products as flight-certified navigation solutions.

LPV-200 service is expected to be available world-wide with the development of dual frequency operation, extended network service areas and additional GNSS constellations.

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