April 24, 2014

Ms. Margaret Gilligan
Associate Administrator for Aviation Safety
Federal Aviation Administration
800 Independence Avenue, SW
Washington, DC 20591

Dear Peggy:

The Performance-based operations Aviation Rulemaking Committee (PARC) is pleased to submit the attached report and recommendations for implementing GPS Ground-Based Augmentation System (GBAS) capability at key airports in the National Airspace System (NAS). This activity was initiated at the request of FAA's NextGen Office (ANG) and led to the formation of the GBAS Action Team. The request was for a recommended GBAS implementation plan identifying the level of GBAS capability needed (how much, where, and by when) to support NextGen performance goals (throughput, efficiency, reliability) supported by a high level business case, aircraft equipage forecast, funding options, and future research and development requirements.

The GBAS Action Team was formed with representatives from A4A, ACI, Airbus, ALPA, Boeing, Honeywell, MITRE, NBAA, the Port Authority of NY/NJ, Rockwell Collins, Southwest Airlines, United Airlines and the FAA. FAA participants were drawn from Aircraft Certification, Airports, Flight Standards, NextGen and the Technical Center.

The team concluded that an overall positive business case for GBAS capability in the NAS could be established and recommends that the FAA restart their investment decision process for GBAS acquisition. This should be pursued with some urgency since a significant number of new aircraft will be entering the U.S. airline fleet in the coming years and an accelerated FAA investment decision on GBAS will stimulate airline investment decisions to equip these new aircraft with matching GPS Landing System (GLS) capability. A full set of recommendations and supporting information is included in the attached report.

The transformation towards a modernized airspace infrastructure must include a detailed deployment strategy for all applicable technology, of which GBAS is one, identified in the NextGen Implementation Plan as well as the 2009 Task Force 5 report.

The PARC appreciates your continued support of its activities and invites you to discuss any aspects of these recommendations at your earliest convenience. The PARC respectfully requests the FAA to provide the PARC with a formal response.

Sincerely,

Mark Bradley
Chairman, PARC

Ground-Based Augmentation System (GBAS) Action Team Report

1. Executive Summary

The GPS Ground-Based Augmentation System (GBAS) is included as an enabler in the FAA's NextGen Implementation Plan and ICAO's Aviation System Block Upgrade Program. Aircraft OEMs (Boeing/Airbus) are currently delivering aircraft with GBAS and GPS Landing System (GLS) capability. Category I GBAS facilities are operational or underway in the U.S. (EWR, IAH, …) and globally (Germany, Australia, Brazil, India, South Korea, Switzerland, …). FAA & industry are investing in category II/III capability. However, despite all this GBAS development and deployment activity, there is neither a plan, nor funding for implementing GBAS capability in the NAS.

In 2012, the FAA asked the PARC to develop a recommended GBAS implementation plan. The PARC formed a GBAS Action Team to address this request. The Action Team includes representatives from a range of GBAS stakeholders – airports, aircraft operators, labor, manufacturers, and several FAA lines of business. The team explored the costs and benefits of GBAS relative to other precision landing alternatives, with a focus on locations where a positive business case supporting FAA objectives exists.

Considering the limited resources available to the Action Team, maximum use was made of prior studies and existing data. Additional analysis was performed where needed and justified. The goal was not to develop a comprehensive assessment of ALL potential GBAS/GLS applications and benefits but rather to determine the likelihood that a business case could be made to justify FAA deployment of a minimum GBAS network and if so, where and when that minimum network would best be deployed.

The Action Team reviewed prior GBAS (LAAS) Benefits Studies sponsored by FAA for results that remained valid and applicable to this review. Following that, we considered a number of benefits offered by GBAS/GLS capability, focusing on those most uniquely and efficiently provided by GBAS, applicable to a broad number of airports, and supported by existing data. Based on those criteria, we selected the flexible approach capability of GBAS/GLS (variable glideslopes and touchdown zones) as a good candidate for demonstrating a viable cost-benefit analysis.

The ability to provide multiple precision final approach paths to a single runway creates the potential to mitigate wake turbulence risks and reduce aircraft separation on approach, increasing airport capacity and reducing delays. The analysis and underlying assumptions are outlined in Section 4.1 and Appendix A. While some issues must be resolved before these benefits can be realized, the resulting business case was sufficiently strong to conclude that an overall positive business case for GBAS deployment could be established. A number of other benefits were reviewed but determined to be more difficult to quantify with the limited resources available to the

Action Team. These benefits are described in Section 3.2 and viewed as additive to the business case.

In support of the Action Team's efforts to understand aircraft GLS capability, MITRE undertook a study to forecast the level of GLS capability in the U.S. commercial fleet through 2030. The study showed that by 2030, GLS-capable aircraft would range from 11% if no actions were taken by airlines (standard fit only) to 65% if all GLS options were taken and retrofits completed on all aircraft where modifications or service bulletins are currently available. Further adoption is possible if GLS retrofit solutions are developed for additional aircraft types or vintages.

The results of the aircraft separation reduction analysis were coupled with results from earlier GBAS studies on the benefits of additional precision landing capability and the MITRE forecasts for new aircraft that could be delivered with GLS capability to establish a recommended set of airports and associated timeline for GBAS implementation.

2013	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**
EWR	ATL	DFW	JFK	CLT	BOS	DEN	IAD	MIA	DCA	DAL	CLE	MCO
IAH	ORD	SFO	LAX	SEA	DTW	LGA	MSP	PHL	FLL	PHX	SAN	MEM
		MDW		BWI		HOU						

Based solely on benefits attributable to separation reduction associated with variable glideslopes and touchdown zones at the airports included in the proposed deployment schedule, our analysis resulted in a payback period for FAA and airline investment in GBAS/GLS of roughly five years.

Year	2013	2014	2015	2016	2017	2018	2019	2020
ROI ($M)	$ (14.45)	$ (23.23)	$ (29.53)	$ (20.40)	$ (3.57)	$ 27.16	$ 67.55	$ 124.75

Finally, the Action Team reviewed an earlier GBAS study on ILS decommissioning options. While there are clearly opportunities to reduce FAA's costs for ILS infrastructure as GBAS capability is deployed, the parameters for decommissioning decisions were deemed too complex to include in the Action Team's recommendation. The study forecasted cost savings of between $139M and $294M over 25 years depending on the scenario for retaining ILS capability. The PARC supports the eventual draw down of ILS capability at GBAS equipped airports and recommends that the FAA stand up an activity involving industry stakeholder input, similar to that used for the VOR Minimum Operational Network (MON), to develop plans to achieve ILS cost savings while avoiding any negative operational impacts.

The benefits of GBAS to FAA could be significant, both in terms of meeting NAS performance objectives (system capacity, productivity, efficiency and on-time operations) and infrastructure cost reduction. The ability to achieve these benefits is closely linked with aircraft equipage. Decisions by airlines and other aircraft operators to invest in GLS capability are strongly influenced by the availability of GBAS ground facilities and GLS procedures. It is especially important for these services to be routinely and consistently available at the most frequently used airports. As such, a GBAS acquisition program led by the FAA rather than resulting from random decisions of independent airport authorities is the recommended approach.

GBAS implementation is recommended for 29 of the NAS major airports as indicated in the proposed deployment schedule (two systems are already deployed and operational at IAH and EWR). The acquisition strategy could include an initial commercial off the shelf (COTS) acquisition of 4-12 GBAS Cat I systems for implementation from 2015 to 2017. The existing Cat I non-Fed systems are in compliance with the FAA non-Fed GBAS specification and approved for operations in the NAS. This could be followed by the acquisition and deployment of the remaining 15-23 GBAS Cat III systems starting in 2018 (after FAA standards, requirements, specification, development are completed). The initial Cat I systems could then be upgraded to Cat III systems in parallel with the Cat III deployment.

2. Baseline Operational Capability

2.1. Instrument Landing System (ILS)

The ILS has been the mainstay of landing navigation aids for well over 50 years. The modernized versions used by the FAA provide aircraft with precision vertical and horizontal navigation guidance information during approach and landing. The attractiveness of ILS lies in the economy of its avionics costs and its wide international acceptance. Technology advances over the years have yielded improvements in accuracy, dependability, and maintainability, along with additional flexibility using Required Navigation Performance (RNP) transitions to ILS final segments.

At the same time, ILS technology suffers from several limitations. These include:

- A complete installation only supports one approach path to a single runway end
- Interference from other aircraft or obstructions can impact stable approach guidance
- Antenna locations are vulnerable to accidents or weather impacts
- Routine flight inspections lead to high annual maintenance costs
- Position accuracy decreases with distance from runway threshold

In the FAA's Proposed Provision of Navigation Services for the Next Generation Air Transportation System (NextGen) Transition to Performance-Based Navigation (PBN) published in the Federal Register on 15 Dec 2011, the FAA proposes that "the FAA plans to satisfy any new requirements for Category I instrument operations with WAAS localizer performance with vertical guidance (LPV) procedures. A network of existing [ILS] would be sustained to provide alternative approach and landing capabilities to continue recovery and dispatch of aircraft during GPS outages." The FAA also proposes that "the FAA no longer intends to establish new Category I ILSs using Facilities and Equipment (F&E) funding" and "FAA is also evaluating the use of the Ground-Based Augmentation System (GBAS) in addition to ILS to provide Category II/III approach services." A final policy has not yet been published.

A more complete description of ILS is included in Appendix C.

2.2. Performance-Based Navigation (PBN) Approaches with Vertical Guidance

<u>RNP Approach [RNAV (GPS)] to LNAV/VNAV minima</u>

Lateral Navigation/Vertical Navigation (LNAV/VNAV) is an Area Navigation (RNAV) function that computes, displays, and provides both horizontal and approved vertical approach navigation. Both Wide Area Augmentation System (WAAS) vertical guidance and baro-VNAV support approaches to LNAV/VNAV lines of minima. Procedures with approved vertical approach navigation have minimums as low as 250-400 foot ceiling and 3/4 mile visibility. Limitations for these procedures include lateral and vertical performance, temperature restrictions associated with baro-VNAV, and the application of curved transitions.

RNP Approach [RNAV (GPS)] to LPV minima

Localizer Performance with Vertical Guidance (LPV) is an RNAV function requiring WAAS (or other regional Space-Based Augmentation System, e.g., EU's EGNOS, or comparable performance from an enhanced Satnav constellation, e.g., multi-frequency), using a final approach segment (FAS) data block, which computes, displays and provides both horizontal and approved vertical approach navigation to minimums as low as 200 foot ceiling and ½ mile visibility. LPV minima primarily support general aviation users. As of September 2013, there are 1519 airports with LPV procedures including 803 LPV procedures at non-ILS airports. Overall, there are 3030 LPV procedures including 781 with minimums less than 250 feet (760 LPVs with minimums of 200 feet). LPV capability is currently only supported in the U.S. and Europe.

RNP AR Approach [RNAV (RNP)]

Required Navigation Performance (RNP) Authorization Required (AR) approaches provide an unprecedented level of flexibility in construction of approach procedures. These operations are RNAV procedures with a specified level of performance and capability. RNP AR approaches include unique capabilities that require special aircraft and aircrew authorization similar to Category II/III ILS operations. All RNP AR approaches have reduced lateral obstacle evaluation areas and vertical obstacle clearance surfaces aligned with their RNP levels (0.3-0.1).

RNP AR approaches primarily support transport category aircraft. As of September 2013, there are 114 airports with RNP AR procedures and 10 RNP AR procedures at non-ILS airports. Overall, there are 345 RNP AR procedures and 19 RNP AR procedures with minimums of 250 feet.

A more complete description of PBN approaches is included in Appendix D.

2.3. GNSS Modernization & Expansion

GPS continues to be the primary Global Navigation Satellite System used for aviation applications globally. Over the coming decade, as the constellation is updated with Block IIF and Block III satellites, an additional civil signal designed for aviation and other safety-of-life applications, L5, will be coming online. L5 is expected to be available on 24 satellites by 2021[1]. At that point, it is expected that airborne GPS receivers will be deployed that leverage the two

[1] http://www.gps.gov/systems/gps/modernization/civilsignals/

signals (L1 & L5) to increase system performance, primarily accuracy and availability, although the magnitude of the potential performance improvement is not known at this time.

Russia's GLONASS is fully operational today, however will be refreshed over the coming decade with newly-designed GLONASS-K satellites broadcasting two civil signals consistent with other international GNSS (based on CDMA). While there are some GLONASS receivers used for aviation today, it is expected that more widespread use of the system (outside of Russia) will not occur until after the availability of the new signals.

EU's Galileo & China's Beidou are in initial implementation phase. Both constellations are targeted for full GNSS service by the end of the decade[2].

GNSS performance will continue to improve over the coming years and decades through upgrades to existing constellations and the introduction of new constellations however there's currently no expectation that these improvements will obviate the need for additional augmentation to support Cat III landing operations.

2.4. Aircraft equipage

2.4.1. Commercial

The vast majority, if not all, commercial aircraft are equipped with ILS capability to support precision landing operations – Cat I at a minimum and Cat II and/or III as needed.

Almost 90% of the commercial passenger and cargo fleet are equipped with GPS - ~85% of narrow and wide-body aircraft and ~95% of regional aircraft[3]. For RNP-0.3 approach capability[4], over 85% of the commercial fleet is equipped – ~82% of narrow and wide-bodies and ~95% of regionals. For RNP-AR approach capability[5], almost 60% of the commercial fleet are equipped – ~80% of the narrow and wide-bodies and ~15% of regionals.[6]

[2] http://www.esa.int/Our_Activities/Navigation/The_future_-_Galileo/Next_steps; http://www.beidou.gov.cn/

[3] Regional aircraft are defined as commercial jets or turboprop aircraft with 90 seats or less

[4] RNP-0.3 Approach Capability is defined as equipped with GPS navigator with approach capability or RNP able FMC integrated with multi-scan DME/DME and GPS sensors

[5] RNP-AR approach capability is defined as equipped with dual RNP-capable Flight Management Computers integrated with multi-scan DME/DME, dual GPS, single Inertial Reference Unit, and an RNP alerting function

[6] Source: MITRE Report F084-B14-04 titled "Avionics Evolution for the NextGen Transition: Expanded Data Set NGIP Capability Report", December 2013

Availability of LPV capability on the commercial fleet remains very limited. A small percentage of regional aircraft are capable and the majority of new regional aircraft deliveries are expected to be equipped. There are no plans for LPV solutions (forward fit or retrofit) for the vast majority of the major or cargo airline (Airbus & Boeing) fleet. One exception is the A350 which will include a Satellite Landing System (SLS) option providing LPV-equivalent performance. This option will only be available in combination with GLS (GBAS) capability.

2.4.2. Business & General Aviation

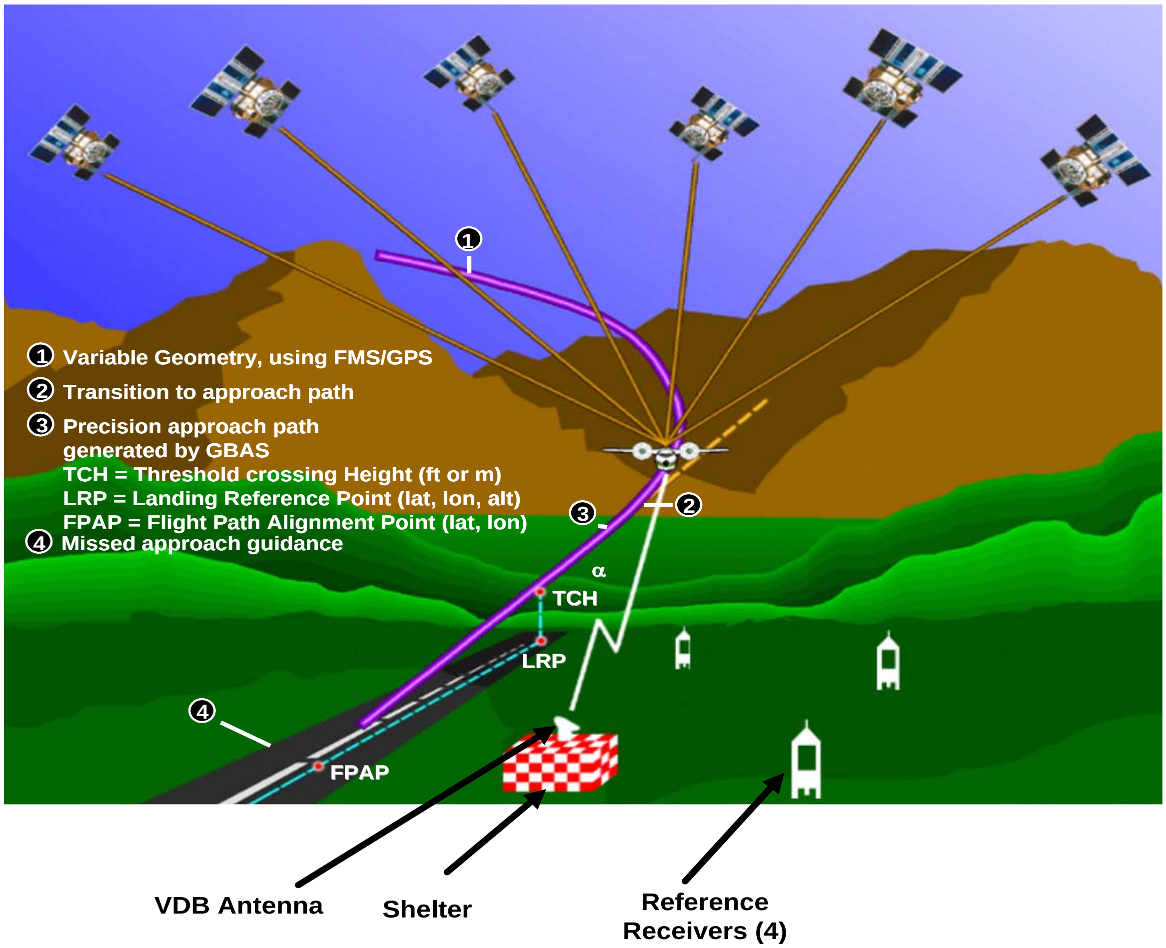
A high percentage of the business aviation fleet are equipped with ILS and GPS, with RNP capability growing in the high end aircraft in the fleet and LPV capability expanding throughout the fleet.

In the GA fleet, GPS and LPV are widely available and aircraft are equipped with ILS where needed.

3. GBAS

The GBAS provides guidance to pilots of properly equipped aircraft to assist them in landing safely under reduced visibility conditions. The use of a GBAS aids the service to airports under all weather conditions. GBAS is based on the concept known as Differential Global Positioning System (DGPS). In addition to application of basic DGPS concepts, the GBAS utilizes hardware and software to ensure accuracy, integrity, continuity, and availability to support precision approaches. GBAS is currently approved for category I operations. Category II and III capability is in development and expected to be available in 2017.

3.1. System Description



The purpose of a Ground Based Augmentation System (GBAS) is to provide the aircraft with corrections to its GPS position, integrity parameters to bound the position uncertainty, and selectable trajectory based flight paths.

The GPS corrections are accomplished by utilizing four GPS receivers located at specifically surveyed points on the airport. The GBAS system knows the exact location of each GPS receiver, so it is able to detect differences or errors for each satellite in view. This information is sent to a central processing computer housed in a shelter located on the airfield where differential corrections to the GPS signal measurements along with parameters to bound the uncertainty are computed. The corrections improve the accuracy from meters to centimeters enabling the aircraft to fly a very precise approach. These differences or corrections are broadcast to the aircraft via a VHF datalink. The aircraft then applies these corrections to its GPS data to determine a more precise navigation position.

The trajectory based flight paths for each airport are defined and coded into individual Final Approach Segment (FAS) blocks. These FAS data blocks are loaded into the GBAS system. This data is broadcast to the aircraft via the same VHF datalink transmission as the GPS corrections as a separate message.

The pilot selects the desired GBAS procedure via a Mode Select Unit or the Flight Management System. This selection is provided to the avionics where the aircraft's corrected navigation position is compared to the selected path. Lateral and vertical deviations to the selected path are provided to the cockpit displays and auto-pilot system. This allows the pilot to fly the selected precision approach to the runway.

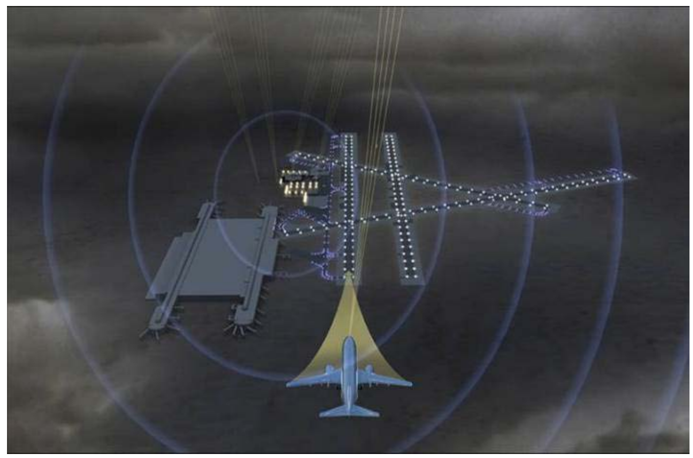
A more complete description of GBAS is included in Appendix B.

3.2. Benefit Overview

3.2.1. Value to FAA and Airports

Infrastructure and Maintenance

GBAS system significantly reduces ground infrastructure requirements over traditional ILS installations. GBAS serves all approach ends to multiple runways within a 6 KM radius of the existing approach decision heights unlike ILS which only provides precision approach capability to one runway end.



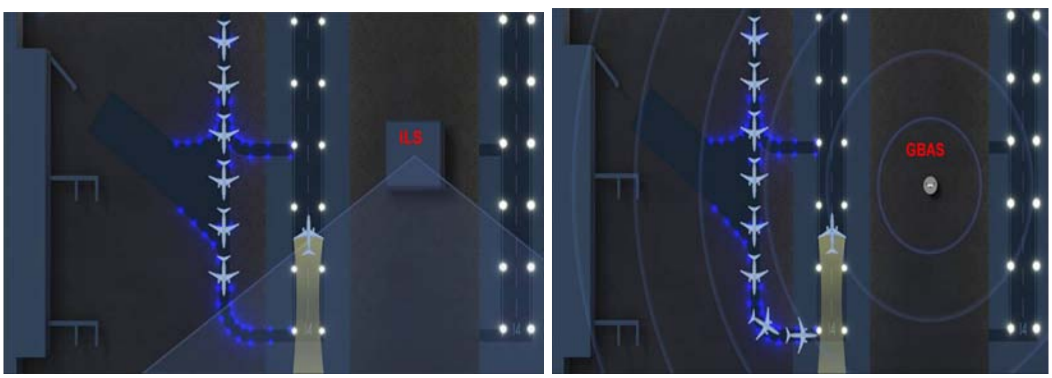
The approach information integrity in GBAS is digital and unchanging, unlike the analog signal from ILS which can change over time with component aging, and changes in the local environment through urbanization and construction. ILS requires regular flight inspection to ensure the approach path is repeatable and accurate. Once a GLS approach is defined and verified, its position does not change. Therefore, the flight inspection requirement (and cost) is reduced to approximately 50% of the ILS flight time requirement. For GLS, the requirement is 2.5 hours per station, 1.5 hours per approach (IAH example – 6 approaches with 11.5 hours total), ILS requires 10 hours per approach (equating to 60 hours for the IAH example). Annual maintenance/operations cost of GBAS for all runways is estimated at $75,000 whereas ILS operations cost per runway is over $90,000 (based on a 2010 GBAS program office assessment). For an airport like Houston with 6 ILS systems this amounts to $540,000 for ILS ops cost versus $75,000 for GBAS.

With ILS, two systems (glideslope, localizer) are needed for each runway end. ILS creates a single approach to that singular runway end which cannot be changed after installation.

GBAS Frees up ILS footprint of 200m X 400m per installation

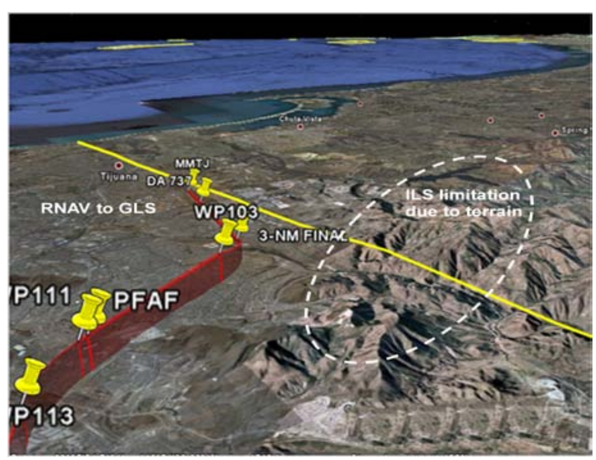
ILS critical zones

GBAS unlocks airport real estate that is otherwise tied to ILS critical zones to ensure safety as ILS signal is prone to distortions. GBAS eliminates hold-short zones for greater tarmac capacity. This improves capacity and efficiency by moving departing aircraft closer to the runway enabling decreased separation between arriving aircraft.



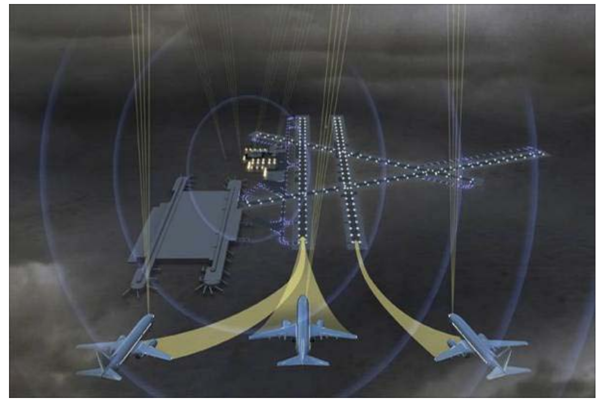
ILS site limitations

GBAS can be sited in areas where ILS cannot due to terrain, airspace or other restrictions. Therefore GBAS can provide precision approach capabilities to airports and runways which are unable to be served by traditional ILS. The figure shows an RNAV to GBAS approach in a region where ILS is restricted due to terrain.



Increasing Capacity

GBAS enables flexible approaches. GBAS defines the final approach segments through a digital data link to the aircraft. If additional approaches are needed (offsets, displaced thresholds, steeper glide path), it is a simple matter of loading software after the procedure has been designed and validated. Multiple glide paths and/or displaced thresholds can be used to manage wake turbulence and improve capacity. GBAS also enables closely spaced parallel operations and/or multiple operations to different runways. Additionally, GBAS can be used for precision departures.

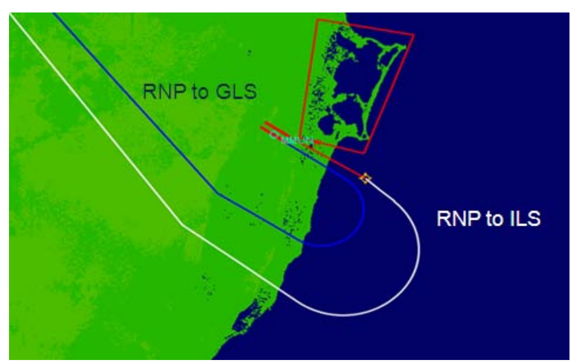


3.2.2.Value to Airlines and Other Operators

<u>Improve schedule integrity and reduce operational cost</u>

GBAS (and aircraft enabled with GBAS Landing System, GLS) expands operators access to airports in degraded meteorological conditions. This results in fewer cancellations and delays. This also enables better aircraft utilization, lower fuel costs, and increased on-time performance. This affects the operator's costs by not incurring additional cost due to missed approach, re-routing or cancellations. Even in visual meteorological conditions (VMC), utilizing GLS finals allows airlines to repeatedly execute stabilized approaches, increasing safety and decreasing pilot workload. With modifications to the aircraft's flight control system to take advantage of the increased accuracy and stability of GBAS (versus ILS), the final segment distance can be reduced and the aircraft can be configured each and every time for reliable performance. Additionally, operators can efficiently manage fuel uplift due to increased availability of precision approach. GBAS reduces the safety risk associated with ILS signal loss or distortion and resulting go-around operations at airports with very large aircraft.

GBAS improves terminal operational efficiency by reducing short final from 8-10 nm to 4-5 nm for RNAV/RNP to GLS approaches. RNAV/RNP can curve the final approach to begin on the downwind leg and provide lateral and vertical guidance to a GLS intercept. A GNSS approach with a 4nm final would save ~10.6nm or 2.9 minutes per flight, a savings of ~180lbs of fuel (27.5 gallons)



As an example, Qantas has evaluated fully automated RNP transitions to GLS final segments using B737 aircraft at Sydney Airport. They have calculated savings of 308 lbs of fuel and 968 lbs of CO_2 for each approach leading to estimated annual savings of 3.1 million lbs of fuel and 9.7 million lbs of CO_2 for their B737 fleet alone. GBAS can also reduce taxi time and fuel by eliminating the ILS critical areas around runway ends.

3.3. GBAS Ground Station Costs

The cost of procuring the Honeywell SmartPath (SLS-4000) GBAS ground station hardware and software is catalog priced at $1,679,000. The SLS-4000 currently complies with ICAO GBAS GAST C (Cat I) requirements and is designed to be upgradable to comply with ICAO GBAS GAST D (Cat III) requirements. The system includes a standard 12 month warranty which begins upon completion of system installation. In addition the customer can procure a set of recommended spares for a catalog price of $197,292. The complete system price including the recommended spares package is $1,876,292.

The cost of installation is broken down into the following phases: site selection and survey process, required civil works construction and actual system installation.

The first phase is a study phase designed to determine the optimum GBAS installation site. This is done via an analysis comprised of surveying potential installation candidate sites, assessing airport needs and GBAS installation requirements. The down selection of the recommended installation site is made by reviewing of the candidate sites with the airport and ANSP customer. This phase culminates in the publishing of a Site Survey report in which the potential sites are ranked and a recommendation is made to the customer. This process is priced at $261,000.

The construction or civil works phase utilizes the Site Survey report and installation requirements in addition to any local codes and regulations governing the installation. The civil works is normally contracted by the customer and/or the airport. The nominal civil works cost includes constructing the five antenna pads, the equipment shelter and the trenching and cabling to interconnect the GBAS sub-system components. Civil works cost varies from location to location. These costs are dependent on any existing infrastructure which may be re-used, material, labor rates and other factors. Typically, civil works cost falls within the range of $250,000-750,000.

System installation, i.e., installing the SmartPath equipment and the work required to get the station up and running, is priced at $268,000.

Once the station is on line and providing approach path guidance and corrections, the station and the GLS approach procedures must be flight inspected and the station approved by the regulating authority for operational use. Flight Inspection cost (example Houston with 6 approaches) are approximately $50,000 based on commercial rate for Lear ($4204.86/per flight hour) and 2.5 hours for system flight check and 1.5 hours per approach.

3.4. Aircraft equipage

3.4.1.Commercial

Current

There are currently less than 100 aircraft with active GLS capability in the U.S. commercial fleet however new GLS-capable aircraft are being delivered every month. Globally, there are over 800 GLS-capable aircraft in operation.

Although GLS has been available as an option on 737NG aircraft for over ten years, airlines have been slow to activate the capability due to the lack of certified and operational ground stations. Following the installation of a certified GBAS facility at EWR by the Port Authority of New York and New Jersey, United Airlines began taking delivery of 737 NG aircraft with operational GLS. This led to a second GBAS installation at Houston Intercontinental Airport, another United hub, by the Houston Airport System.

New Production

GLS is currently offered either as a standard feature or optional selection on most new production Airbus and Boeing aircraft as follows:

- A320 Family – Option
- A380 – Option
- B737NG – Option
- B747-8 – Standard
- B787 – Standard

GLS is expected to be made available as an option for new production A330 aircraft by early 2014. GLS is forecast to be available for new production B777 aircraft and Embraer E-Jets (170/190 family) in 2017.

Retrofits

Service bulletins are available for retrofitting GLS capability on in-service A320 family and B737NG aircraft. Retrofit solutions for in-service A330 and A340 aircraft are expected by the end of 2013. Cost for these retrofits vary significantly depending on the age of the aircraft (how close it is to current production standards) and the existing avionics (e.g., MMR).

Retrofit solutions for in-service regional aircraft (CRJ, ERJ, turboprops), B777, and other out-of-production aircraft are not available at this time.

<u>Forecast</u>

The MITRE Corporation provided a forecast of GLS capability for the U.S. commercial fleet NAS-wide and at the Core 30 airports through 2030. Key assumptions for this forecast:

- FY12 ETMS operations data for Core 30 airports
- Operations grown via TAF growth rates through 2030
- Fleet growth based on an adjusted FY11 FAA Fleet Forecast
- Tail-by-tail equipage assessments based on operator and airframe manufacturer feedback
- The equipage data is high confidence data due to source, e.g. operators, manufacturers
- The forecasted operations data is medium confidence due to
  - Assumption that fleet mix today dictates fleet mix of tomorrow
  - Equipage of fleet at airports assumed to mirror equipage of NAS operations as a whole
- Equipage Availability
  - Standard/Equipped on all Boeing 747-8 and 787, Boeing 777 (starting in 2017), and the 70 currently equipped Boeing 737
  - Option Forward Fit on new delivery Airbus, Boeing 737-NG, and Embraer Jets (beginning in 2017)
  - Option Retrofit on existing Boeing 737-NG
  - Not available on
    - Existing Airbus
    - All other Boeing models not listed above
    - All regional jet/turboprop aircraft not listed above

The MITRE forecast shows that if no GLS equipage actions are taken – new production, standard-fit GLS aircraft only –just over 11 percent of commercial aircraft in the NAS would be GLS capable by 2030. If GLS options were selected on all new production aircraft, over 55% of commercial aircraft would be GLS capable by 2030. If GLS capability were retrofitted on all aircraft where retrofit solutions are currently available, close to 65% of commercial aircraft would be GLS capable by 2030.

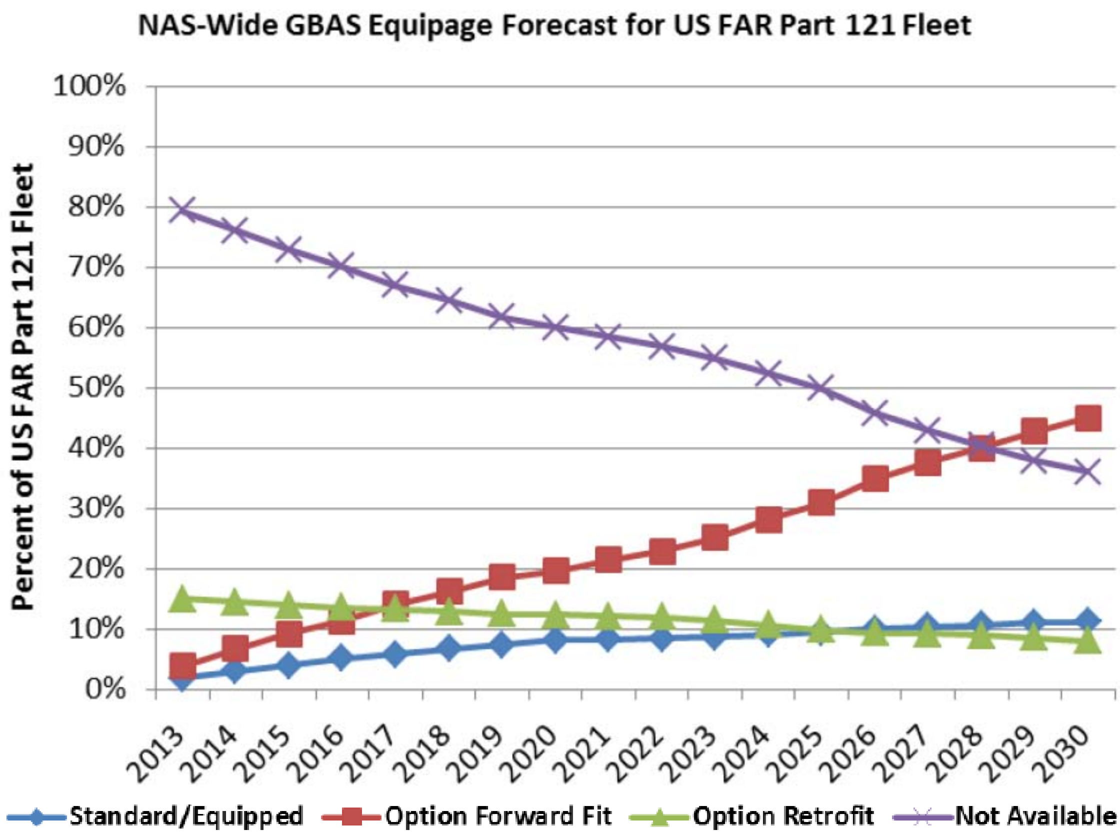


Figure 1 – MITRE NAS-wide GLS Equipage Forecast

3.4.2. Business and General Aviation

There are currently no business or general aviation aircraft equipped with GLS capability and no specific plans for offering this capability. It is expected that once GBAS ground stations are more widely installed, GLS capability will be developed and offered, particularly in the larger and longer range business aviation aircraft.

4. GBAS/GLS Benefit Assessment

The Action Team reviewed prior GBAS (LAAS) Benefits Studies sponsored by FAA for results that remained valid and applicable to this review. Following that, we considered a number of benefits offered by GBAS/GLS capability, focusing on those most uniquely and efficiently provided by GBAS, applicable to a broad number of airports, and supported by existing data. Based on those criteria, we selected the flexible approach capability of GBAS/GLS (variable glideslopes and touchdown zones) as a good candidate for demonstrating a viable cost-benefit analysis. Other benefits (Section 3.2) are more difficult to quantify with the limited resources available to the Action Team but are viewed as additive to the business case.

4.1. Variable glideslopes & touchdown zones

A single GBAS installation at an airport provides up to 26 unique GLS approach procedures. These procedures can be to different runway ends, different touchdown points on the same runway, and with a range of glideslope angles. This capability supports more flexible procedure design addressing numerous objectives including noise reduction, wake mitigation and avoidance of temporary obstacles (e.g., cranes).

For wake mitigation, it is possible to use a steeper approach to a touchdown zone farther down the runway to keep trailing aircraft out of lead aircraft wake zones. This solution can be applied to parallel runway operations as well as single runway operations.

Preliminary information from FAA's Wake Office suggests that sufficient separation could be achieved using as little as 0.2° variation in glideslope angle and shifting the touchdown zone by 2X the wingspan of the lead aircraft (for single runway operations).

A more detailed summary of the analysis is included in Appendix A.

4.1.1. Operational benefit

At busy airports with significant numbers of large, "wake generating" aircraft[7], additional spacing is provided between aircraft, reducing capacity and increasing delays, particularly as demand nears airport capacity. By implementing GLS procedures that enable trailing aircraft to safely remain out of lead aircraft wake zones, aircraft separations can be minimized resulting in increased aircraft capacity and reduced delays.

These benefits are realized by multiple stakeholders:

- FAA – Supports NAS performance objectives for capacity, delay, and safety
- Airports – Increases productivity (operations) with existing infrastructure
- Airlines – Lower costs, increased ability to meet customer demand, and greater schedule reliability
- Passengers – Minimize travel times (passenger value of time, PVT)

4.1.2. Required enablers

Criteria must be established to define the minimum amount of separation needed between procedures at single runways and parallel runways. Initially, these criteria could

[7] B757, Heavy, Super

be based on conservative estimates and further research could be used to refine and minimize the separation between procedures over time.

Requirements for runway lighting, marking, and crew training must be analyzed and solutions developed and implemented to support alternate glideslopes and touchdown zones.

U.S. Terminal Instrument Procedures (TERPS) design criteria currently requires a waiver for glideslope angles greater than 3.1° for Category D aircraft[8]. Effective use of this GLS capability would require this TERPS limitation be revised to better align with ICAO Procedures for Air Navigation Services (PANS-OPS) criteria where the Category D limitation is 3.5°.

Controllers will need sufficient information (e.g., GLS capability) on arriving aircraft and supporting tools (automation) to strategically sequence and space aircraft for the optimum procedures.

Most current production Airbus and Boeing aircraft are approved for autoland operations with maximum glideslopes of at least 3.25°. Gaining approval to 3.25° for the remaining aircraft is possible without aircraft modification but would require investment by the OEM and aircraft operators. Further increase of these limits to at least 3.5° should be considered to provide greater flexibility in leveraging this GLS capability.

4.1.3. Where – high potential sites

The benefit analysis was performed for 16 airports where current FAA Annual Service Volume studies existed. These airports are in the top 26 busiest and top 27 most delayed airports in the NAS. One notable absence from the list is ORD. The ASV for ORD has not been updated to reflect the new runways however based on configuration and fleet mix, it is very likely that ORD would be high in the list of cumulative benefit.

GLS capability was assumed to be only available on new production aircraft where GLS is offered as a standard or optional feature. No GLS retrofits were included.

[8] Aircraft with landing speeds between 141 and 165 knots (1.3 times the stall speed with the aircraft in landing configuration at maximum certificated landing weight)

Airport	Cumulative Benefit (M)
SFO	$ 362
DFW	$ 360
ATL	$ 352
JFK	$ 260
LAX	$ 166
EWR	$ 132
SEA	$ 79
IAH	$ 49
CLT	$ 49
BOS	$ 42
DTW	$ 14
DEN	$ 14
LGA	$ 14
IAD	$ 5
PHX	$ 5
BWI	$ 2

Table 1 – Cumulative Benefits Through 2030 of Wake Mitigation using GLS Variable Glideslopes and Touchdown Zones

4.1.4. Other alternatives

Recategorization of wake turbulence separation distance is currently being implemented across the NAS. An attempt was made to reflect the benefits of this initiative in the core ASV data and calculate GLS benefits from that baseline.

It is possible to use varying ILS glideslopes to minimize wake impacts on parallel runways. This solution is not practical for single runway operations, limits flexibility for mixed traffic, and could introduce noise concerns in certain environments (lower than standard glideslopes).

RNAV(RNP) and RNAV(GPS) with barometric vertical navigation (VNAV) could also provide variable glideslopes however might require greater path separations (higher angles or touchdown zone shifts) due to reduced VNAV performance and would be limited to higher minimums (above Cat I).

4.2. Additional Precision Landing Capability

In 2004, the FAA contracted with IBM Business Consulting Services to provide an independent analysis[9] that estimates the benefits attributable to LAAS [Local Area Augmentation System, aka GBAS] beyond those provided by existing and planned navigation services. The benefits were estimated over a 20 year period (2009-2028) at 121 selected airports.

One of the benefits this study looked at was the value of additional precision landing capability. The study considered two cases: where 100% of aircraft were WAAS/LPV capable and where 0% of aircraft were WAAS/LPV capable. The first case essentially provides the benefits associated with Cat II and III capability (where any additional Cat I capability is provided by WAAS/LPV) and the second case looks at Cat I, II and III capability (all additional precision landing capability provided by GBAS). The aircraft equipage assumptions for GLS used for this IBM analysis differ from the assumptions used in the PARC analysis and are documented in the referenced report.

Cat I benefits and the Cat II/III benefits were broken out separately for 29 airports considered most relevant to the GBAS Action Team and are shown in the following table (computed benefits are in 2004 dollars).

	Cat I Only			Cat II/III Only		
Airport	**Total Benefit**	**Ops Cost**	**Pax Value of Time**	**Total Benefit**	**Ops Cost**	**PAX Value of Time**
DTW	$29,411,000	$12,494,000	$16,917,000	$25,073,000	$10,815,000	$14,258,000
ORD	$0	$0	$0	$53,109,000	$23,039,000	$30,070,000
CLE	$38,120,000	$16,266,000	$21,854,000	$11,680,000	$4,949,000	$6,731,000
DFW	$0	$0	$0	$37,224,000	$16,127,000	$21,097,000
DEN	$0	$0	$0	$34,161,000	$14,829,000	$19,332,000
MDW	$61,000	$52,000	$9,000	$31,798,000	$13,714,000	$18,084,000
LGA	$0	$0	$0	$28,897,000	$12,296,000	$16,601,000
CLT	$0	$0	$0	$26,059,000	$11,320,000	$14,739,000
BOS	$0	$0	$0	$24,537,000	$10,484,000	$14,053,000
IAH	$0	$0	$0	$22,885,000	$9,879,000	$13,006,000
ATL	$0	$0	$0	$22,619,000	$9,826,000	$12,793,000
EWR	$0	$0	$0	$21,801,000	$9,749,000	$12,052,000
SEA	$0	$0	$0	$16,840,000	$7,304,000	$9,536,000
IAD	$0	$0	$0	$16,811,000	$7,093,000	$9,718,000
LAX	$0	$0	$0	$15,445,000	$6,752,000	$8,693,000
MSP	$0	$0	$0	$13,968,000	$6,041,000	$7,927,000
MEM	$0	$0	$0	$11,776,000	$6,331,000	$5,445,000
PHL	$0	$0	$0	$11,597,000	$5,145,000	$6,452,000
BWI	$0	$0	$0	$11,576,000	$5,106,000	$6,470,000

[9] LAAS Benefits Analysis – LAAS Efficiency, Safety, and Societal Benefits, IBM Business Consulting Services, 31 Oct 2004

HOU	$701,000	$304,000	$397,000	$10,457,000	$4,688,000	$5,769,000
MIA	$4,145,000	$1,903,000	$2,242,000	$6,760,000	$3,082,000	$3,678,000
JFK	$0	$0	$0	$9,518,000	$4,268,000	$5,250,000
MCO	$3,925,000	$1,657,000	$2,268,000	$5,315,000	$2,318,000	$2,997,000
SFO	$0	$0	$0	$5,088,000	$2,225,000	$2,863,000
FLL	$427,000	$183,000	$244,000	$4,623,000	$2,013,000	$2,610,000
DCA	$453,000	$178,000	$275,000	$4,089,000	$1,749,000	$2,340,000
DAL	$0	$0	$0	$3,193,000	$1,496,000	$1,697,000
PHX	$0	$0	$0	$3,162,000	$1,375,000	$1,787,000
SAN	$0	$0	$0	$0	$0	$0
Total	**$76,790,000**	**$32,859,000**	**$43,931,000**	**$479,617,000**	**$209,393,000**	**$270,224,000**

Table 2 – Benefits of Additional Precision Approach Capability (2009-2028)

4.3. ILS decommissioning

In 2006, FAA contracted with Tetra Tech to perform a study of the cost savings to the FAA that can be achieved by implementing LAAS [GBAS] at 118 airports that currently use ILS (same airports as the 2004 IBM study excluding 3 airports not equipped with ILS), looking at various LAAS [GBAS] implementation and ILS divestment scenarios.

While ILS divestment is a complex and uncertain undertaking, the study provides a good assessment of the relative costs and ranges of possible savings. A general conclusion of the study was that **net life-cycle cost savings begin to accrue when two ILSs are divested for every one LAAS station installed**. A summary of the results for the most likely cost scenario is included in the following table. In scenario 1, ILSs were assumed to be decommissioned at the time of LAAS [GBAS] installation. For all other scenarios, ILSs were assumed to be decommissioned at the end of their lifecycle.

LAAS Implementation Scenarios	Total Cost ($M)	Total Cost Savings ($M) (vs. Baseline)	End-State Annual Cost Savings ($M)	Remaining # of ILSs
ILS BASELINE	1,582	N/A	N/A	448
1. Divest 100% ILSs at LAAS Installation	645	937	40	0
2. Divest 75% of ALL ILSs (Keep at least 1 ILS per airport)	1,288	294	21	151

3. Divest All ILSs if Airport Operates 2 or Fewer*, Keep 2 Elsewhere	1,283	299	20	149
4. Keep 50% of ILSs at OEPs, Keep 1 Elsewhere	1,407	175	15	197
5. Divest Two ILSs per airport*	1,443	139	15	225

* OEPs keep at least 1 ILS

Table 3 – Most Likely Comparative Costs of Removing ILSs

5. Options for Acquisition and Operation

5.1. Non-Federal Option

The current Cat I GBAS ground station (installed at EWR and IAH) is approved by FAA as a non-Fed system. In this configuration, systems must be procured, installed, operated, and maintained by entities other than the FAA (e.g., airports). FAA continues to be responsible for safety oversight including system, facility and procedure approval.

FAA's support of non-Fed navaids and other ATC Facilities and Equipment is covered in FAA Order 6700.20A. This order was last updated in 1992 and would need a revision to address FAA support for a network of non-Fed GBAS installations.

While not currently eligible for Airport Improvement Program (AIP) funding, GBAS is included in a draft update to the AIP Handbook (FAA Order 5100.38D). As drafted, this order would authorize the use of AIP funding for the procurement and installation of a GBAS ground station.

5.2. Federal Option

If a positive business case can be established via the FAA's investment analysis process, a federal acquisition program could be undertaken in two phases.

GBAS implementation is recommended for 29 of the major NAS airports as indicated in the proposed deployment schedule (two systems are already deployed and operational at IAH and EWR). The first phase of the acquisition strategy could include an initial commercial off the shelf (COTS) acquisition of 8 GBAS CAT I systems with a contractor maintenance option for implementation from 2015 to 2017. The existing CAT I non-Fed systems are in compliance with the FAA non-Fed GBAS specification and approved for operations in the NAS.

Presently the CAT III system design approval is based on the ICAO SARPS. To upgrade existing CAT I systems to CAT III and develop a CAT III system under an FAA acquisition program, an FAA

Cat III GBAS specification could be developed. This specification would require minor modifications from the Cat I specification, primarily to address ICAO GAST D requirements and FAA logistics and maintenance requirements. This effort could be accomplished without significant impact to the current GBAS development ensuring the initial Cat III GBAS approval meets FAA Fed requirements.

The second phase of the acquisition strategy could include the acquisition and deployment of 19 GBAS CAT III systems starting in 2018 (after FAA standards, requirements, specification, development are completed). The initial ten CAT I systems could then be upgraded to CAT III systems in parallel with the CAT III deployment.

The development of a Fed-approved GBAS adds marginal incremental cost and could yield significant longer-term benefits. Federal (FAA) acquisition of a minimum network of GBAS ground facilities would ensure an organized and prioritized roll-out of GBAS capability in the NAS leading to consistent availability of GLS service where it is needed most to enhance NAS performance. It also would enhance the safety and efficiency of providing this GBAS capability by establishing clear FAA authority for operational support (e.g., system availability monitoring) and maintenance services.

6. R&D Requirements and Plans

GBAS is a component of the FAA plan to transition from a ground-based navigation and landing system to a satellite-based navigation system. The strategy to achieve this capability is to initially develop and approve a single-frequency GBAS to provide Category I service and then enhance the threat mitigation to provide Category II/III service.

GBAS System Design Approval (SDA) for Category I use in the NAS was completed in 2009. An incremental update was made to enhance availability, improve maintenance and implement a modification to the design to increase operational availability by minimizing outages caused by illegal broadband jammer interference on GPS for the Newark installation. This modification and subsequent SDA was completed in 2012. GBAS Category I is being implemented as a non-Federal system on a per-airport request basis. **GBAS Category I was operationally approved at Newark International Airport in September 2012 and Houston Intercontinental Airport in April 2013.**

The first operational systems at Newark and Houston Intercontinental are just scratching the surface of GBAS capabilities by performing ILS “look alike” procedures. A GLS approach to Newark runway 29 has been proposed that would provide precision approach to a runway that is not able to site an ILS. Another potential operational enhancement is the ability to perform a Special Cat II using the existing Cat I approved GBAS per order 8400.13D.

The Category I system design is an essential baseline for GBAS Category III and serves as an incremental step toward the development of a Category III system. Operational experience with the existing GBAS installations is feeding work with industry committees, ANSPs and regulatory bodies to address updates and modifications, maturing and optimizing the GBAS performance. This supports high performance, safe and robust systems for current users while reducing the risks with implementation of Category III systems. The Honeywell SLS-4000 GBAS system is designed to be upgradable to satisfy the ICAO GBAS GAST D requirements for serving Category III operations.

6.1. Needs

The FAA approach for Satellite Navigation (SATNAV) for precision approach has always been a combination of space-based and ground-based augmentations of GPS. The Wide Area Augmentation System (WAAS) is a Space Based Augmentation System (SBAS) that was designed to provide Category I precision approach over the Continental United States and Alaska, while GBAS was designed to augment the CAT I Precision Approach service provided by WAAS, and provide CAT II/CAT III where required. WAAS now provides LPV and LPV 200, an approach service with performance approaching CAT I performance but with varying approach minima depending on the location.

A SATNAV solution for more stringent approach services is still desired worldwide, and led to the development of ICAO standards for GBAS Approach Service Type D (GAST-D), equivalent to Category III Precision Approach, which have been published and are in the validation phase. The RTCA has also developed and published the accompanying update to DO-253 MOPS to provide compatible avionics requirements for operation with GAST-D SARPS requirements. The FAA has current funded plans in place to progress and complete the validation of the ground and avionics requirements by September 2014.

Development work must also demonstrate that GLS can provide the same or better performance and CAT II/III landing minima as the existing ILS infrastructure. To that end, under MOU to the FAA, Boeing is cooperating with the FAA to demonstrate this capability by exercising the anticipated airworthiness criteria to be applied for aircraft using GAST-D to support CAT III operations. This work is expected to be complete by first quarter 2015. These validation activities are intended to provide the risk reduction desired for applicants to apply for GLS airworthiness and operational approvals. "Final validation" may not be considered "closed" until an aircraft project has been through the complete certification and operational approval process and a ground facility has completed its system design approval and commissioning at a site.

6.2. Investment requirements

Since 2008, FAA's NextGen office has invested more than $27M in GBAS technologies. The bulk of the funding was used to award prototype contracts that leverage approved Category I GBAS equipment, both ground systems and avionics, to validate the ICAO and RTCA Category III equipment requirements. **These contracts have been structured such that a feasible GBAS CAT III prototype will be available by mid-2014.**

The validation of the ICAO and RTCA Category III equipment requirements under the FAA Category III DTFACT-10-R-00010, have been shown to be feasible with no known issues identified to date. Nearly all of the threats have been analyzed and shown to be addressable. Seven of eight scheduled software prototype builds for the CAT III ground station have been delivered and four of four airborne software prototype builds for the CAT III airborne Multi Mode Receiver (MMR) have been delivered. The prototype software has been successful integrated into the FAA Technical Center's SLS-4000 and MMRs by the Federal Aviation Administration Engineering Development Services Navigation Team (AJP-652) and tested. Testing has included multiple flight test demonstrations showing compatibility and interoperability between the airborne and ground sub-systems. Eighty percent of the FAA DTFACT-10-R-00010 contract work is complete with the remaining work to complete in 2013 on plan. Significant progress has been made in establishing the creditability and feasibility of the ICAO and RTCA CAT III equipment requirements. Additionally, it is being shown that the approved and installed SLS-4000 CAT I GBAS can be updated to incorporate the CAT III functionality.

In order to complete the FAA's System Design Approval (SDA) work, FAA funding is being used to maintain the set of GBAS Key Technical Advisors (KTAs). These KTAs, comprised of government, university, and contractor personnel are subject matter experts required to evaluate system-safety analysis, threat mitigation and validation, and system test and analysis artifacts, all critical to issuing an FAA System Design Approval.

Investment is required to define how the requirements in 8400.13D apply to GBAS which will allow airlines the ability to achieve operational benefits from properly equipped aircraft. This is critical to ensure the requirements of 8400.13D are addressed for GLS approaches.

6.3. Timing

FAA investments in GBAS are currently focused on validation of ICAO GAST D (Cat III) requirements. This validation work is expected to be completed by July 2014, with System Design Approval targeted for late-2017.

7. Recommendation

The review and analysis performed by the PARC GBAS Action Team resulted in a business case that was sufficiently strong to conclude that an overall **positive business case for GBAS capability in the NAS could be established.** We expect this would apply to Cat I performance initially and independently as well as for Cat II and III capability in the future.

The Action Team analysis supports the deployment of a minimum NAS GBAS infrastructure per the following schedule:

2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
EWR	ATL	DFW	JFK	CLT	BOS	DEN	IAD	MIA	DCA	DAL	CLE	MCO
IAH	ORD	SFO	LAX	SEA	DTW	LGA	MSP	PHL	FLL	PHX	SAN	MEM
		MDW		BWI		HOU						

Table 4 – Proposed GBAS Deployment Schedule

The following were key considerations in developing the proposed GBAS deployment plan:

- **Pace the deployment** consistent with anticipated growth in aircraft GLS capability
- **Priority to airports where early operational benefits are possible** (e.g., wake separation reduction, additional precision landing capability)
- **Priority to airports where GLS availability could help accelerate airline adoption** (e.g., hubs for airlines with pending new aircraft deliveries)
- **Ensure a sufficient number of early stations** to gain operational experience and evaluate new operational concepts and procedures

Acknowledging the Congressional direction included in the 2012 FAA reauthorization bill requesting a plan for deploying GBAS at the 35 Operational Evolution Plan (OEP) airports, seven of the 35 OEP airports (CVG, HNL, LAS, PDX, PIT, STL, TPA) are not included in the proposed deployment schedule. This is either due to lack of justification for the installation or lack of sufficient data to assess the justification. Further analysis could support their inclusion.

As GBAS capability and GLS capable aircraft are added to the NAS, the FAA has the opportunity for significant cost reductions from the decommissioning of unneeded ILS equipment. **The PARC supports the eventual draw down of ILS capability at GBAS equipped airports and recommends that the FAA stand up an activity involving industry stakeholder input, similar to that used for the VOR Minimum Operational Network (MON), to develop plans to achieve ILS cost savings while avoiding any negative operational impacts.**

The benefits of GBAS to FAA could be significant, both in terms of meeting NAS performance objectives (system capacity, productivity, efficiency and on-time operations) and infrastructure cost reduction. The ability to achieve these benefits is closely linked with aircraft equipage. Decisions by airlines and other aircraft operators to invest in GLS capability are strongly influenced by the availability of GBAS ground facilities and GLS procedures. It is especially important for these services to be routinely and consistently available at the most frequently used airports. As such, **a GBAS acquisition program led by the FAA** rather than resulting from random decisions of independent airport authorities **is the recommended approach**.

To act on this recommendation, the FAA must follow the processes of their Acquisition Management System. This includes the development of a robust business case capable of supporting an FAA investment decision. **The Action Team recommends that the investment decision process,**

currently in an indefinite holding pattern, be restarted with target completion dates for an Initial Investment Decision by 31 Dec 2014 and Final Investment Decision by 30 Jun 2016.

As demonstrated by the Action Team analysis, the flexible approach capability of GBAS/GLS could enable significant operational benefits by mitigating wake turbulence risks leading to reduced aircraft separation on approach. Realizing this benefit is dependent on successful completion of the supporting wake research and the development of operational solutions and criteria supporting variable geometry approach operations. **The Action Team recommends that the necessary wake research be accelerated and development of operational solutions and criteria for variable geometry approaches be initiated immediately.**

CAT I GBAS ground stations are currently operating at EWR and IAH. **The Action Team recommends that the FAA initiate NextGen projects in partnership with industry to validate anticipated GBAS/GLS benefits leveraging these ground stations, any additional ground stations installed in the near-term, and the growing fleet of GLS capable aircraft operating at these airports.**

Until a Cat III ground station is available, **on-going installations should be accomplished using an FAA-approved non-Fed Cat I ground station**. Requirements should be established and efforts undertaken to **develop the Cat III system as a Fed GBAS ground station**.

GBAS implementation is recommended for 29 of the major NAS airports (including the two systems already deployed and operational at IAH and EWR).

The recommended acquisition strategy includes **two phases**:

2015-2017: Initial commercial off the shelf (COTS) acquisition of 4 to 12 GBAS Cat I systems and development of a contractor maintenance program. These initial systems would be used to develop and demonstrate operational benefits of new GLS criteria, gain experience in GLS operations, and stimulate GLS aircraft equipage.

2018+: Acquisition development program for the remainder of the 15 to 23 GBAS Cat III systems (including FAA standards, requirements, specification development) for system deployment 2018 to 2025. This second phase could also include an upgrade program for the existing Cat I systems. The Cat III upgrade program could start in 2018 for 2 airports per year until all of the initial Cat I systems are upgraded.

Appendix A
Variable Glideslopes and Touchdown Zones

1. Methodology

The Action Team explored the potential to use the flexibility inherent in GBAS/GLS procedures to provide additional precision approach procedures with higher glideslopes and extended touchdown zones to mitigate wake turbulence risks, thereby reducing the required aircraft spacing. This analysis uses FAA's airport terminal area Annual Service Volume (ASV) reports and MITRE's GLS aircraft equipage forecasts to quantify resulting delay reductions and the corresponding savings in airline operational costs and passenger value of time.

The analysis was performed for 16 of the NAS Core 30 airports for which the FAA was able to provide current ASV reports. DFW will be used as an example to explain the methodology.

1.1. Aircraft Operations Forecast

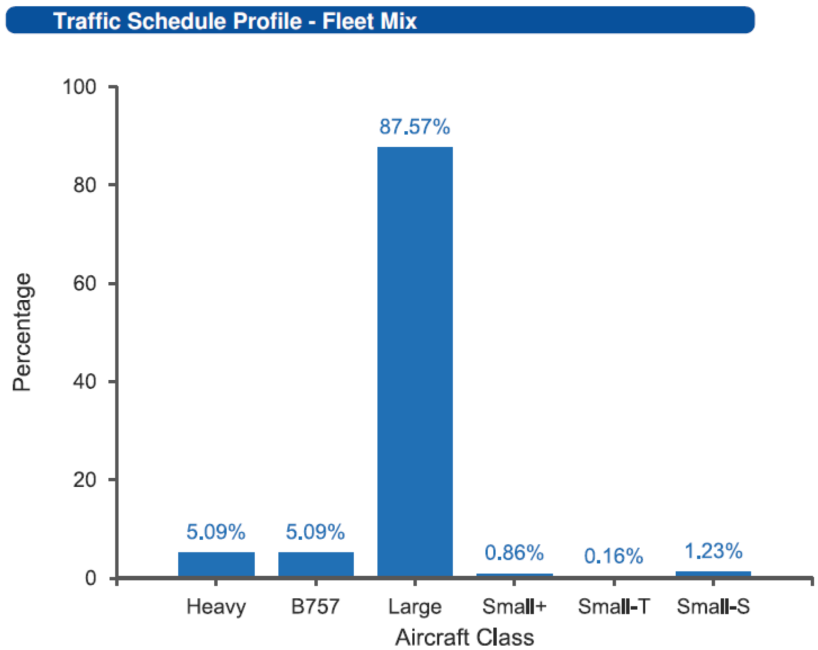
MITRE provided a forecast for GLS capability at each airport. Aircraft operations were forecast using FAA's FY12 Enhanced Traffic Management System (ETMS) data, Terminal Area Forecast (TAF) and FY11 Fleet Forecast. Fleet mix at each airport was assumed to stay constant but grow based on new aircraft entering the fleet. GLS capability was assumed to be only available on new production aircraft where GLS is offered as a standard or optional feature. The business case for retrofit of GLS capability on in-service aircraft varies significantly by aircraft type, vintage and carrier. As a result, to maintain a conservative approach to the analysis, no GLS retrofits were assumed.

Year	Standard/ Equipped	Option Forward Fit	Option Retrofit	Not Available	Total	Total Daily Ops	Equivalent Annual Days
2013	11598	26462	108171	491270	637502	1926	331
2014	17965	45159	103975	476968	644068	1946	
2015	24159	63164	100715	466819	654857	1978	
2016	30468	77699	98478	459376	666021	2012	
2017	33612	96809	95989	450392	676803	2045	
2018	37899	110775	92628	443383	684686	2069	
2019	41859	127113	89541	434320	692831	2093	
2020	46179	134906	89569	430589	701243	2119	
2021	46325	148908	88995	425697	709925	2145	
2022	47006	161964	89012	420897	718879	2172	
2023	47981	182078	87228	410821	728108	2200	
2024	49462	208811	82733	396612	737618	2228	
2025	50992	234793	79053	382574	747412	2258	
2026	53736	272959	77589	353210	757494	2289	
2027	55040	301005	77744	334079	767867	2320	
2028	56086	327968	76978	317504	778536	2352	
2029	57069	358296	74361	299779	789505	2385	
2030	58014	385721	72395	284648	800778	2419	

Year	Standard/ Equipped	Option Forward Fit	Option Retrofit	Not Available	Total Fwd Fit - Std & Opt	Total with Retrofit
2013	1.80%	4.20%	17.00%	77.10%	6.00%	23.00%
2014	2.80%	7.00%	16.10%	74.10%	9.80%	25.90%
2015	3.70%	9.60%	15.40%	71.30%	13.30%	28.70%
2016	4.60%	11.70%	14.80%	69.00%	16.30%	31.10%
2017	5.00%	14.30%	14.20%	66.50%	19.30%	33.50%
2018	5.50%	16.20%	13.50%	64.80%	21.70%	35.20%
2019	6.00%	18.30%	12.90%	62.70%	24.30%	37.20%
2020	6.60%	19.20%	12.80%	61.40%	25.80%	38.60%
2021	6.50%	21.00%	12.50%	60.00%	27.50%	40.00%
2022	6.50%	22.50%	12.40%	58.50%	29.00%	41.40%
2023	6.60%	25.00%	12.00%	56.40%	31.60%	43.60%
2024	6.70%	28.30%	11.20%	53.80%	35.00%	46.20%
2025	6.80%	31.40%	10.60%	51.20%	38.20%	48.80%
2026	7.10%	36.00%	10.20%	46.60%	43.10%	53.30%
2027	7.20%	39.20%	10.10%	43.50%	46.40%	56.50%
2028	7.20%	42.10%	9.90%	40.80%	49.30%	59.20%
2029	7.20%	45.40%	9.40%	38.00%	52.60%	62.00%
2030	7.20%	48.20%	9.00%	35.50%	55.40%	64.40%

1.2. IFR Spacing Reduction Using GLS

Average VFR spacing is computed using the fleet mix for the airport and the spacing rules for varying aircraft types. The fleet mix is used to estimate the percentage of operations that occur between various aircraft classes. These percentages are then applied to the spacing (NM) used during these operations to compute the average spacing for the airport during VFR conditions.



VFR Arrivals			Trail Aircraft (per class)					
			Heavy	B757	Large	Small+	Small-T	Small-S
		Frequency	5%	5%	88%	1%	0%	1%
Lead Aircraft (per class)	Heavy	5%	0.26%	0.26%	4.46%	0.04%	0.01%	0.06%
	B757	5%	0.26%	0.26%	4.46%	0.04%	0.01%	0.06%
	Large	88%	4.46%	4.46%	76.69%	0.75%	0.14%	1.08%
	Small+	1%	0.04%	0.04%	0.75%	0.01%	0.00%	0.01%
	Small-T	0%	0.01%	0.01%	0.14%	0.00%	0.00%	0.00%
	Small-S	1%	0.06%	0.06%	1.08%	0.01%	0.00%	0.02%

VFR Arrivals		Trail Aircraft (per class)					
		Heavy	B757	Large	Small+	Small-T	Small-S
Lead Aircraft (per class)	Heavy	3.76	4.58	4.58	5.48	5.41	5.26
	B757	3.76	3.68	3.68	4.58	4.51	4.36
	Large	2.96	2.88	2.88	3.68	3.61	3.46
	Small+	2.96	2.88	2.88	2.88	3.61	3.46
	Small-T	2.96	2.88	2.88	2.88	2.81	2.66
	Small-S	2.96	2.88	2.88	2.88	2.81	2.66

VFR Arrivals		Trail Aircraft (per class)					
		Heavy	B757	Large	Small+	Small-T	Small-S
Lead Aircraft (per class)	Heavy	0.0097	0.0119	0.2041	0.0024	0.0004	0.0033
	B757	0.0097	0.0095	0.1640	0.0020	0.0004	0.0027
	Large	0.1319	0.1284	2.2085	0.0277	0.0051	0.0373
	Small+	0.0013	0.0013	0.0217	0.0002	0.0000	0.0004
	Small-T	0.0002	0.0002	0.0040	0.0000	0.0000	0.0001
	Small-S	0.0019	0.0018	0.0310	0.0003	0.0001	0.0004
						Ave VFR Spacing	3.0241

The same percentages are then applied to the spacing used for IFR operations (NM) to compute the average spacing for the airport during IFR conditions.

IFR Arrivals		Trail Aircraft (per class)					
		Heavy	B757	Large	Small+	Small-T	Small-S
Lead Aircraft (per class)	Heavy	5.06	5.98	5.98	6.98	6.91	6.76
	B757	5.06	4.98	4.98	5.98	5.91	5.76
	Large	4.06	3.98	3.98	4.98	4.91	4.76
	Small+	4.06	3.98	3.98	3.98	4.91	4.76
	Small-T	4.06	3.98	3.98	3.98	3.91	3.76
	Small-S	4.06	3.98	3.98	3.98	3.91	3.76

IFR Arrivals		Trail Aircraft (per class)					
		Heavy	B757	Large	Small+	Small-T	Small-S
Lead Aircraft (per class)	Heavy	0.0131	0.0155	0.2665	0.0031	0.0006	0.0042
	B757	0.0131	0.0129	0.2220	0.0026	0.0005	0.0036
	Large	0.1810	0.1774	3.0521	0.0375	0.0069	0.0513
	Small+	0.0018	0.0017	0.0300	0.0003	0.0001	0.0005
	Small-T	0.0003	0.0003	0.0056	0.0001	0.0000	0.0001
	Small-S	0.0025	0.0025	0.0429	0.0004	0.0001	0.0006
				Ave IFR Spacing			4.1535

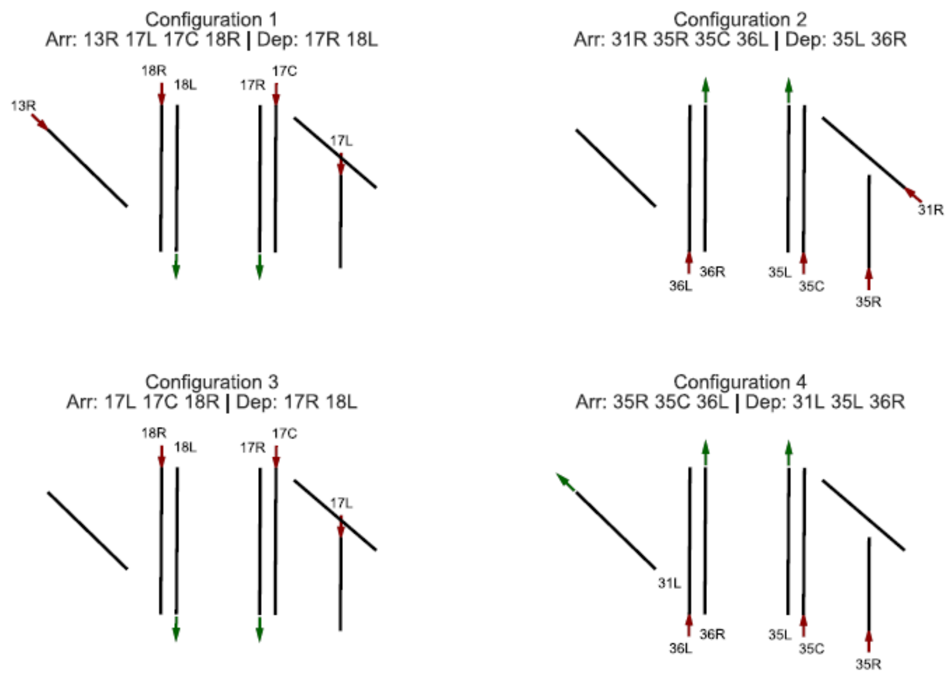
IFR spacing rules are adjusted to eliminate extra wake separation for those aircraft with GLS capability available or expected to be available in the future (e.g., Airbus, Boeing, E-Jet) and revised average IFR spacing is computed. Then, the percent reduction in spacing due to GLS relative to the nominal VFR to IFR spacing difference is calculated.

IFR Arrivals with GLS		Trail Aircraft (per class)					
		Heavy	B757	Large	Small+	Small-T	Small-S
Lead Aircraft (per class)	Heavy	4.06	3.98	3.98	6.98	6.91	6.76
	B757	4.06	3.98	3.98	5.98	5.91	5.76
	Large	4.06	3.98	3.98	4.98	4.91	4.76
	Small+	4.06	3.98	3.98	3.98	4.91	4.76
	Small-T	4.06	3.98	3.98	3.98	3.91	3.76
	Small-S	4.06	3.98	3.98	3.98	3.91	3.76

IFR Arrivals with GLS		Trail Aircraft (per class)					
		Heavy	B757	Large	Small+	Small-T	Small-S
Lead Aircraft (per class)	Heavy	0.0105	0.0103	0.1774	0.0031	0.0006	0.0042
	B757	0.0105	0.0103	0.1774	0.0026	0.0005	0.0036
	Large	0.1810	0.1774	3.0521	0.0375	0.0069	0.0513
	Small+	0.0018	0.0017	0.0300	0.0003	0.0001	0.0005
	Small-T	0.0003	0.0003	0.0056	0.0001	0.0000	0.0001
	Small-S	0.0025	0.0025	0.0429	0.0004	0.0001	0.0006
				Ave IFR Spacing with GLS			4.0068
				% Reduction vs VFR			12.99%

1.3. Annual Delay Reduction Using GLS

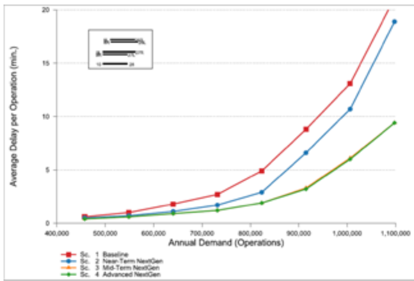
The delay forecast for the primary VFR and IFR arrival configurations at the airport is provided by the ASV report.



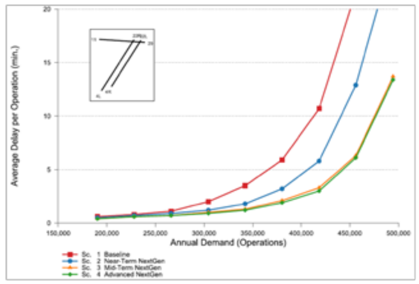
Delay Forecast based on Current Capability

Daily Demand	Config 1 VFR Arrival Delay (min/day)	Config 2 VFR Arrival Delay (min/day)	Config 3 IFR Arrival Delay (min/day)	Config 4 IFR Arrival Delay (min/day)
1,868	602	659	57,545	2,084
2,055	809	869	94,175	4,071
2,242	1,117	1,228	137,333	8,581
2,429	1,547	1,791	187,794	24,773
2,615	2,140	2,683	237,737	48,500
2,803	3,121	4,058	293,827	75,860
2,989	6,112	8,212	368,072	117,435
3,176	15,865	24,438	452,898	162,968
3,362	28,043	45,080	540,619	214,383
3,550	45,552	69,447	642,264	272,117
3,736	65,820	100,005	746,836	333,579

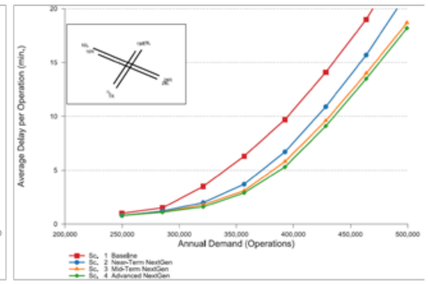
The ASVs for ATL, EWR, and SFO included an additional analysis considering the introduction of NextGen capabilities over time. NextGen capabilities include RNP/RNAV, Traffic Management Advisor (TMA), Fanned Departures, and Wake Re-catagorization. Since these capabilities were not modeled in all ASVs, to ensure GLS benefits were not overestimated, the average improvement for full NextGen deployment at ATL, EWR and SFO was factored into all other airport delay forecasts.



ATL



EWR



SFO

Delay Forecast based on Current Capability

Daily Demand	Config 1 VFR Arrival Delay (min/day)	Config 2 VFR Arrival Delay (min/day)	Config 3 IFR Arrival Delay (min/day)	Config 4 IFR Arrival Delay (min/day)
1,868	602	659	57,545	2,084
2,055	809	869	94,175	4,071
2,242	1,117	1,228	137,333	8,581
2,429	1,547	1,791	187,794	24,773
2,615	2,140	2,683	237,737	48,500
2,803	3,121	4,058	293,827	75,860
2,989	6,112	8,212	368,072	117,435
3,176	15,865	24,438	452,898	162,968
3,362	28,043	45,080	540,619	214,383
3,550	45,552	69,447	642,264	272,117
3,736	65,820	100,005	746,836	333,579

Eliminate impact of other NextGen benefits

Delay Forecast based on Advanced NextGen Capability

NextGen Delay Impact	Daily Demand	Config 1 VFR Arrival Delay (min/day)	Config 2 VFR Arrival Delay (min/day)	Config 3 IFR Arrival Delay (min/day)	Config 4 IFR Arrival Delay (min/day)
29%	1,868	428	469	40921	1482
31%	2,055	562	603	65399	2827
47%	2,242	593	652	72947	4558
55%	2,429	699	809	84805	11187
55%	2,615	963	1207	106982	21825
55%	2,803	1404	1826	132222	34137
55%	2,989	2750	3695	165632	52846
55%	3,176	7139	10997	203804	73336
55%	3,362	12619	20286	243279	96472
55%	3,550	20498	31251	289019	122453
55%	3,736	29619	45002	336076	150111

The daily operations for each airport from the MITRE forecast are used to compute the average delay (minutes per day and per operation) for each runway configuration.

Per Day

Year	2013	2014	2015	2016	2017	2018
Daily Ops	1926	1946	1978	2012	2045	2069
1 VFR Delay	470	484	507	531	554	564
2 VFR Delay	510	525	548	573	596	607
3 IFR Delay	48512	51108	55375	59790	64054	65946
4 IFR Delay	1899	2042	2276	2519	2753	2952

Per Arrival

Year	2013	2014	2015	2016	2017	2018
Daily Arrivals	963	973	989	1006	1022	1034
1 VFR Delay	0.49	0.50	0.51	0.53	0.54	0.55
2 VFR Delay	0.53	0.54	0.55	0.57	0.58	0.59
3 IFR Delay	50.38	52.53	55.98	59.43	62.65	63.76
4 IFR Delay	1.97	2.10	2.30	2.50	2.69	2.85

The delay reduction using GLS procedures is computed by factoring the delay increase between the comparable IFR and VFR configurations by the computed GLS IFR spacing reduction. It is then factored again by the percent of GLS equipped aircraft from the MITRE forecast. Finally, it is converted to annual delay reduction (minutes) based on the frequency of use for each IFR configuration.

Config 3 IFR Delay Reduction	6.48	6.76	7.20	7.65	8.07	8.21
Config 4 IFR Delay Reduction	0.19	0.20	0.23	0.25	0.27	0.29

	6.00%	9.80%	13.30%	16.30%	19.30%	21.70%
Config 3 IFR Delay Reduction (% equipped)	0.39	0.66	0.96	1.25	1.56	1.78
Config 4 IFR Delay Reduction (% equipped)	0.01	0.02	0.03	0.04	0.05	0.06

Config 3 IFR Annual Delay Reduction	11772	20260	29801	39446	50048	57940
Config 4 IFR Annual Delay Reduction	161	288	445	614	805	985

Runway Configuration and Weather (Procedures)	Daily Demand	Configuration Use
Configuration 1 VFR	3,176	56.00%
Configuration 2 VFR	3,176	30.00%
Configuration 3 IFR	3,176	9.50%
Configuration 4 IFR	3,176	4.50%

1.4. Cost Savings Due to GLS Procedures

Operational cost savings are computed using FAA data for airline block hour costs.

FY13$	**Variable Cost[1]				Fixed Cost[2] per Block Hour	Total Per Block Hour
	Per Airborne Hour	Per Ground Hour	Per Gate Hour	Per Block Hour		
Air Carrier - Passenger	$ 4,246	$ 2,092	$ 1,447	$ 3,916	$ 859	$ 4,776
Air Carrier - Cargo	$ 8,195	$ 4,042	$ 2,806	$ 7,673	$ 1,969	$ 9,642
Air Carrier - TAF	$ 4,516	$ 2,225	$ 1,540	$ 4,173	$ 935	$ 5,108
Air Taxi - TAF	$ 1,214	$ 597	$ 411	$ 1,099	$ 618	$ 1,718
General Aviation[3]	$ 694	$ 341	$ 235	$ 629	$ 910	$ 1,539
Military[4]	$ 8,041	$ 3,966	$ 2,753	$ 7,529	$ 1,932	$ 9,461

Config 3 IFR Ops Cost Savings ($M)	$ 0.94	$ 1.61	$ 2.37	$ 3.14	$ 3.98	$ 4.61	$ 5.24	$ 5.65
Config 4 IFR Ops Cost Savings ($M)	$ 0.01	$ 0.02	$ 0.04	$ 0.05	$ 0.06	$ 0.08	$ 0.10	$ 0.11

Passenger Value of Time (PVT) savings are computed using FAA data for PVT cost. Then the total GLS cost savings is calculated as the sum of operational savings and PVT savings.

PVT ($/hour)	$45.20	$45.92	$46.65	$47.40	$48.16	$48.93	$49.71	$50.51
Config 3 IFR PVT Cost Savings ($M)	$ 1.33	$ 2.33	$ 3.48	$ 4.67	$ 6.03	$ 7.09	$ 8.19	$ 8.97
Config 4 IFR PVT Cost Savings ($M)	$ 0.02	$ 0.03	$ 0.05	$ 0.07	$ 0.10	$ 0.12	$ 0.15	$ 0.18

Year	2013	2014	2015	2016	2017	2018	2019	2020
Total GLS Cost Savings ($M)	$ 2.30	$ 3.99	$ 5.93	$ 7.94	$ 10.17	$ 11.90	$ 13.67	$ 14.91

2. GBAS/GLS Cost Estimate

GBAS ground station costs for acquisition, installation, and operation are estimated in the following table.

GBAS Ground System Acquisition and Installation	
Hardware & Spares	$1.900
Site Preparation	$0.250
Civil Works	$0.625
Installation	$0.250
Operational Approval	$0.500
Procedures & Flight Inspection	$0.500
Total ($M)	**$4.025**
GBAS Annual Maintenance ($M)	**$0.050**

Using the Action Team's recommended deployment schedule, the costs for ground station deployment and operation are shown in the following table.

Year	Recommended Installation Date	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
EWR	2013	$ 4.03	$ 0.05	$ 0.05	$ 0.05	$ 0.05	$ 0.05	$ 0.05	$ 0.05	$ 0.05	$ 0.05	$ 0.05	$ 0.05	$ 0.05	$ 0.05	$ 0.05	$ 0.05	$ 0.05	$ 0.05
IAH	2013	$ 4.03	$ 0.05	$ 0.05	$ 0.05	$ 0.05	$ 0.05	$ 0.05	$ 0.05	$ 0.05	$ 0.05	$ 0.05	$ 0.05	$ 0.05	$ 0.05	$ 0.05	$ 0.05	$ 0.05	$ 0.05
ATL	2014	$ -	$ 4.03	$ 0.05	$ 0.05	$ 0.05	$ 0.05	$ 0.05	$ 0.05	$ 0.05	$ 0.05	$ 0.05	$ 0.05	$ 0.05	$ 0.05	$ 0.05	$ 0.05	$ 0.05	$ 0.05
DFW	2015	$ -	$ -	$ 4.03	$ 0.05	$ 0.05	$ 0.05	$ 0.05	$ 0.05	$ 0.05	$ 0.05	$ 0.05	$ 0.05	$ 0.05	$ 0.05	$ 0.05	$ 0.05	$ 0.05	$ 0.05
SFO	2015	$ -	$ -	$ 4.03	$ 0.05	$ 0.05	$ 0.05	$ 0.05	$ 0.05	$ 0.05	$ 0.05	$ 0.05	$ 0.05	$ 0.05	$ 0.05	$ 0.05	$ 0.05	$ 0.05	$ 0.05
JFK	2016	$ -	$ -	$ -	$ 4.03	$ 0.05	$ 0.05	$ 0.05	$ 0.05	$ 0.05	$ 0.05	$ 0.05	$ 0.05	$ 0.05	$ 0.05	$ 0.05	$ 0.05	$ 0.05	$ 0.05
LAX	2016	$ -	$ -	$ -	$ 4.03	$ 0.05	$ 0.05	$ 0.05	$ 0.05	$ 0.05	$ 0.05	$ 0.05	$ 0.05	$ 0.05	$ 0.05	$ 0.05	$ 0.05	$ 0.05	$ 0.05
BWI	2017	$ -	$ -	$ -	$ -	$ 4.03	$ 0.05	$ 0.05	$ 0.05	$ 0.05	$ 0.05	$ 0.05	$ 0.05	$ 0.05	$ 0.05	$ 0.05	$ 0.05	$ 0.05	$ 0.05
CLT	2017	$ -	$ -	$ -	$ -	$ 4.03	$ 0.05	$ 0.05	$ 0.05	$ 0.05	$ 0.05	$ 0.05	$ 0.05	$ 0.05	$ 0.05	$ 0.05	$ 0.05	$ 0.05	$ 0.05
SEA	2017	$ -	$ -	$ -	$ -	$ 4.03	$ 0.05	$ 0.05	$ 0.05	$ 0.05	$ 0.05	$ 0.05	$ 0.05	$ 0.05	$ 0.05	$ 0.05	$ 0.05	$ 0.05	$ 0.05
BOS	2018	$ -	$ -	$ -	$ -	$ -	$ 4.03	$ 0.05	$ 0.05	$ 0.05	$ 0.05	$ 0.05	$ 0.05	$ 0.05	$ 0.05	$ 0.05	$ 0.05	$ 0.05	$ 0.05
DTW	2018	$ -	$ -	$ -	$ -	$ -	$ 4.03	$ 0.05	$ 0.05	$ 0.05	$ 0.05	$ 0.05	$ 0.05	$ 0.05	$ 0.05	$ 0.05	$ 0.05	$ 0.05	$ 0.05
DEN	2019	$ -	$ -	$ -	$ -	$ -	$ -	$ 4.03	$ 0.05	$ 0.05	$ 0.05	$ 0.05	$ 0.05	$ 0.05	$ 0.05	$ 0.05	$ 0.05	$ 0.05	$ 0.05
LGA	2019	$ -	$ -	$ -	$ -	$ -	$ -	$ 4.03	$ 0.05	$ 0.05	$ 0.05	$ 0.05	$ 0.05	$ 0.05	$ 0.05	$ 0.05	$ 0.05	$ 0.05	$ 0.05
IAD	2020	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 4.03	$ 0.05	$ 0.05	$ 0.05	$ 0.05	$ 0.05	$ 0.05	$ 0.05	$ 0.05	$ 0.05	$ 0.05
PHX	2023	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 4.03	$ 0.05	$ 0.05	$ 0.05	$ 0.05	$ 0.05	$ 0.05	$ 0.05
Total Costs (Annual)		$ 8.05	$ 4.13	$ 8.20	$ 8.30	$ 12.43	$ 8.55	$ 8.65	$ 4.73	$ 0.75	$ 0.75	$ 4.78	$ 0.80	$ 0.80	$ 0.80	$ 0.80	$ 0.80	$ 0.80	$ 0.80
Total Costs (Cumulative)		$ 8.05	$ 12.18	$ 20.38	$ 28.68	$ 41.10	$ 49.65	$ 58.30	$ 63.03	$ 63.78	$ 64.53	$ 69.30	$ 70.10	$ 70.90	$ 71.70	$ 72.50	$ 73.30	$ 74.10	$ 74.90

Using the MITRE equipage forecast and assuming $25,000 average cost to select the GLS option on a newly delivered aircraft, the airline GLS equipage costs are shown in the following table. Note that these costs do not include flight crew training or related costs (simulator upgrades).

Year	2013	2014	2015	2016	2017	2018	2019	2020
GLS Options Annually	256	207	204	175	232	197	244	104
GLS Options Cumulative	256	463	667	842	1074	1271	1515	1619
Cost ($M Cumulative)	$ 6.4	$ 11.6	$ 16.7	$ 21.1	$ 26.9	$ 31.8	$ 37.9	$ 40.5

2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
175	153	213	279	270	302	252	249	267	287
1794	1947	2160	2439	2709	3011	3263	3512	3779	4066
$ 44.9	$ 48.7	$ 54.0	$ 61.0	$ 67.7	$ 75.3	$ 81.6	$ 87.8	$ 94.5	$ 101.7

Using the Action Team's recommended deployment schedule and the computed GLS benefits for each airport, the total GLS benefit is shown in the following table.

Year	Recommended Installation Date	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
EWR	2013	$ -	$ 0.42	$ 0.71	$ 0.98	$ 1.33	$ 1.63	$ 2.18	$ 2.71	$ 3.38	$ 4.17	$ 5.23	$ 6.66	$ 8.31	$ 10.80	$ 14.22	$ 18.14	$ 22.81	$ 27.89
IAH	2013	$ -	$ 0.09	$ 0.14	$ 0.18	$ 0.23	$ 0.28	$ 0.39	$ 0.52	$ 0.68	$ 0.86	$ 1.11	$ 1.78	$ 2.75	$ 4.09	$ 5.59	$ 7.59	$ 10.17	$ 13.00
ATL	2014	$ -	$ -	$ 6.16	$ 7.34	$ 9.54	$ 11.77	$ 14.44	$ 16.53	$ 18.63	$ 19.76	$ 21.54	$ 23.99	$ 26.20	$ 29.68	$ 31.88	$ 34.04	$ 36.35	$ 38.41
DFW	2015	$ -	$ -	$ -	$ 7.94	$ 10.17	$ 11.90	$ 13.67	$ 14.91	$ 16.32	$ 17.67	$ 19.79	$ 22.53	$ 25.47	$ 29.95	$ 33.61	$ 37.22	$ 41.39	$ 45.44
SFO	2015	$ -	$ -	$ -	$ 5.36	$ 7.55	$ 9.30	$ 11.43	$ 13.11	$ 15.11	$ 17.18	$ 19.91	$ 23.44	$ 27.22	$ 32.40	$ 36.50	$ 40.67	$ 45.43	$ 50.37
JFK	2016	$ -	$ -	$ -	$ -	$ 4.16	$ 5.13	$ 6.30	$ 7.42	$ 8.69	$ 10.06	$ 12.00	$ 14.81	$ 18.01	$ 22.14	$ 27.05	$ 32.40	$ 38.64	$ 45.29
LAX	2016	$ -	$ -	$ -	$ -	$ 2.08	$ 2.63	$ 3.29	$ 3.89	$ 4.94	$ 6.15	$ 7.64	$ 9.62	$ 11.78	$ 14.93	$ 18.19	$ 21.72	$ 25.73	$ 29.99
BWI	2017	$ -	$ -	$ -	$ -	$ -	$ 0.04	$ 0.05	$ 0.06	$ 0.07	$ 0.09	$ 0.10	$ 0.12	$ 0.15	$ 0.18	$ 0.20	$ 0.24	$ 0.30	$ 0.37
CLT	2017	$ -	$ -	$ -	$ -	$ -	$ 0.55	$ 0.70	$ 0.96	$ 1.26	$ 1.63	$ 2.11	$ 2.77	$ 3.49	$ 4.54	$ 5.60	$ 6.80	$ 8.20	$ 9.60
SEA	2017	$ -	$ -	$ -	$ -	$ -	$ 0.98	$ 1.34	$ 1.68	$ 2.04	$ 2.52	$ 3.33	$ 4.34	$ 5.44	$ 6.92	$ 8.41	$ 10.81	$ 13.45	$ 16.33
BOS	2018	$ -	$ -	$ -	$ -	$ -	$ -	$ 0.94	$ 1.17	$ 1.44	$ 1.74	$ 2.13	$ 2.63	$ 3.18	$ 3.96	$ 4.67	$ 5.40	$ 6.26	$ 7.12
DTW	2018	$ -	$ -	$ -	$ -	$ -	$ -	$ 0.39	$ 0.44	$ 0.50	$ 0.58	$ 0.68	$ 0.82	$ 0.96	$ 1.17	$ 1.37	$ 1.60	$ 1.85	$ 2.08
DEN	2019	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 0.58	$ 0.64	$ 0.70	$ 0.79	$ 0.90	$ 1.01	$ 1.18	$ 1.29	$ 1.38	$ 1.48	$ 1.58
LGA	2019	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 0.55	$ 0.61	$ 0.66	$ 0.74	$ 0.84	$ 0.95	$ 1.11	$ 1.23	$ 1.36	$ 1.50	$ 1.62
IAD	2020	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 0.14	$ 0.17	$ 0.23	$ 0.29	$ 0.37	$ 0.48	$ 0.59	$ 0.71	$ 0.86	$ 1.01
PHX	2023	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 0.24	$ 0.31	$ 0.40	$ 0.53	$ 0.68	$ 0.85	$ 1.05
Total Benefit (Annual)		$ -	$ 0.52	$ 7.01	$ 21.80	$ 35.05	$ 44.21	$ 55.13	$ 64.53	$ 74.45	$ 83.95	$ 97.33	$ 115.76	$ 135.60	$ 163.93	$ 190.93	$ 220.76	$ 255.28	$ 291.15
Total Benefit (Cumulative		$ -	$ 0.52	$ 7.52	$ 29.33	$ 64.38	$ 108.59	$ 163.72	$ 228.25	$ 302.70	$ 386.65	$ 483.98	$ 599.74	$ 735.34	$ 899.28	$ 1,090.2	$ 1,311.0	$ 1,566.2	$ 1,857.4

3. GBAS/GLS Return on Investment

   Using the Action Team's recommended GBAS deployment schedule and solely benefits attributable to separation reduction associated with variable glideslopes and touchdown zones, the payback period for FAA and airline investment in GBAS/GLS is roughly five years.

Year	2013	2014	2015	2016	2017	2018	2019	2020
ROI ($M)	$ (14.45)	$ (23.23)	$ (29.53)	$ (20.40)	$ (3.57)	$ 27.16	$ 67.55	$ 124.75

Appendix B
Ground-Based Augmentation System – GBAS

Brief system description

The existing GBAS CAT-I Ground station, is a design developed to satisfy the FAA's Non-Federal Specification, FAA-E-AJW44-2937A, for Category I GBAS Ground Facility, dated October 2005.

A description of GBAS components is provided in this section. At this time, the only FAA certified GBAS is Honeywell's SmartPath system and therefore it is being used as the basis for the system description. The overall GBAS system architecture is shown in Figure 1. The components include GPS Receivers and antennas, the SmartPath cabinet, Air Traffic Status Unit (ATSU)/Maintenance Data Terminal (MDT) and VHF Broadcast antenna. The SmartPath system is designed so that it meets the RTCA DO-254 (hardware) and RTCA DO-178B/DO-278 (software) design assurance levels necessary for a low-visibility landing system in accordance with FAA standards and industry best practices.

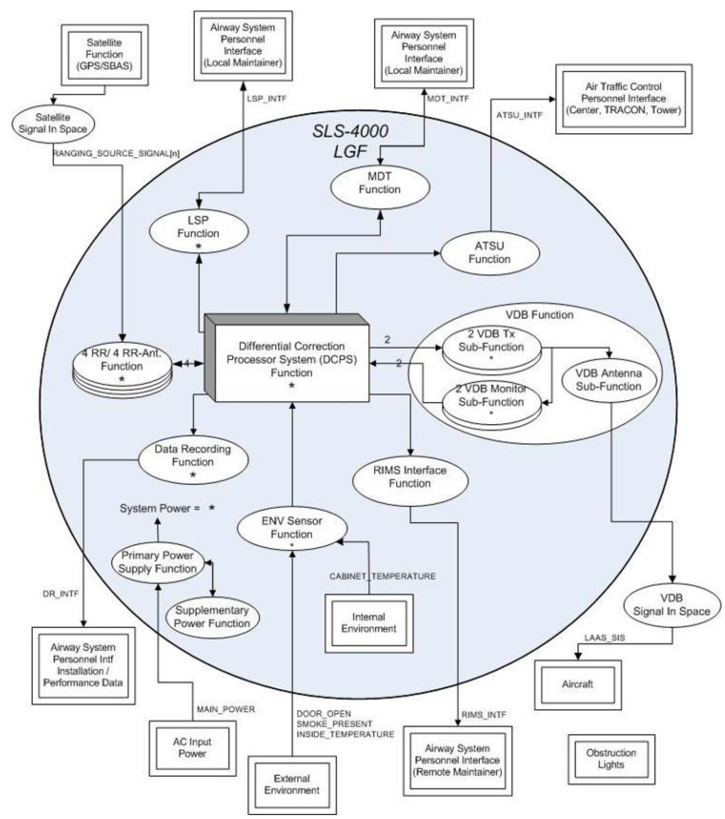


Figure 2 – Overall GBAS system architecture

GPS Antennas and Receivers

The critical function of the GBAS system is to track GPS satellites, and monitor their signals. The system includes four GPS receivers and antennas.

Each antenna consists of a high-performance, multipath-limiting antenna and requires a Low-Noise Amplifier (LNA) to improve the system's ability to track the GPS satellites. Each antenna is connected to a 24-channel, GPS single-frequency (L1), coarse-acquisition (C/A) receiver. Each receiver is housed in a weather-proof enclosure and collectively referred to as the Remote Satellite Measurement Unit (RSMU). The four RSMUs are installed in a pattern providing at least 100 meters of separation between units. This configuration of GPS receivers enables enhanced GPS satellite constellation monitoring and robust system performance by placing each receiver in a slightly different environment and view angle to the satellite.

Figure 3 - Remote Satellite Measurement Unit (RSMU)

GBAS Cabinet (Elements in Shelter)

The data signals and power to/from the GPS receivers are routed through a surge suppression enclosure in the shelter. The cabinet includes a status panel, redundant processors with operational software and integrity monitors, redundant VHF transmitters and receivers, redundant power supplies, redundant Ethernet switches for intersystem communications, environmental sensors, data recorder, and maintenance terminal.

Figure 4 – GBAS Cabinet

Air Traffic Status Unit (ATSU) / Maintenance Data Terminal (MDT)

The primary purpose of the ATSU or MDT is to communicate the current status of the GBAS equipment (Normal, Not Available, or Test mode).

The secondary purpose is to alert Air Traffic personnel of the current status of the GPS Constellation. SmartPath monitors and predicts the geometry of the GPS constellation. If less than four GPS satellites are tracked, monitored, and corrected, it will alert the Air Traffic personnel to a Constellation Alert, if predicted to occur within the next 30 minutes and if expected to last for more than 15 minutes.

Figure 5 – Maintenance Data Terminal

VHF Broadcast Antenna

A three-bay, horizontally polarized (HPOL) antenna is used to broadcast SmartPath digital information to nearby aircraft during approach and landing. It is typically installed within 100 feet of the VDB transmitter.

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Figure 6 – VHF Data Broadcast (VDB) Antenna

Appendix C
Instrument Landing System - ILS

Brief system description

The ILS has been the mainstay of landing navigation aids for well over 50 years. The modernized versions used by the FAA provide aircraft with precision vertical and horizontal navigation guidance information during approach and landing. Associated Marker Beacons and/or Low Power Distance Measuring Equipment (LPDME) identify distance to the runway. The attractiveness of ILS lies in the economy of its avionics costs and its wide international acceptance. Technology advances over the years have yielded great improvement in accuracy, dependability, and maintainability.

The FAA supports ground-based ILS systems in the National Airspace System (NAS) and will continue procuring and deploying new/replacement ILS for the foreseeable future. It is anticipated that some amount of ILS capability will eventually be replaced with GPS-based systems in the future (e.g., WAAS and GBAS). Presently the FAA has a contract with Thales Air Traffic Management (TATM) corporation to procure the existing NAS-deployable Mark 20A ILS system on a requirements contract. A new TATM FAA ILS 420 system has been developed and is currently undergoing Operational Test. The FAA ILS 420 will be procured after rendering of the In-Service Decision in 2013.

Current capability – coverage and supporting hardware

The ILS provides precision approach guidance for aircraft. The elements of the ILS are the glide slope, localizer, and marker beacons. Other components may be required such as Runway Visual Range (RVR) and Marker Beacons or LPDME. Note that the more precise the approach is (lower weather minimums/visibility) the more ancillary components may be required. On board aircraft, pilots navigate the approach using the Course Deviation Indicator (CDI) and glide slope indicator.

The lateral guidance on the flight path is given through a localizer antenna array, while vertical guidance is provided through a glide path antenna array. The localizers are in most cases aligned with runway direction and are located beyond the opposite landing threshold. The glide path antennas are located on the left or right side of the runway, in the vicinity of the landing threshold.
The localizer provides course guidance throughout the descent path to the runway threshold from a distance of 18 NM from the antenna between an altitude of 1,000 feet above the highest terrain along the course line and 4,500 feet above the elevation of the antenna site. Proper off-course indications are provided throughout the following angular areas of the operational service volume, to 10 degrees either side of the course along a radius of 18 NM from the antenna; and from 10 to 35 degrees either side of the course along a radius of 10 NM. Unreliable signals may be received outside these areas. The glide slope is normally usable to a distance of 10 NM. However, at some locations, the glide slope has been certified for an extended service volume which exceeds 10 NM.

All pilots should be aware that disturbances to ILS localizer and glide slope courses may occur when surface vehicles or aircraft are operated near the localizer or glide slope antennas. Most ILS installations are subject to signal interference by surface vehicles and aircraft. ILS Critical Areas are established near each localizer and glide slope antenna. The critical areas are protected when instrument approaches are being conducted with ceilings less than or equal to 800 feet or visibility is less than or equal to 2 miles.

Pilots must be alert when approaching the glidepath interception. False courses and reverse sensing will occur at angles considerably greater than the published path. Disruption of the ILS signal can lead to problems, such as misalignment of the course, disengaging of the arriving aircraft's autopilot, or oscillatory error causing the plane to S-turn.

The quality of the signal affects the way sensors process data and produce Navigation Sensor Error (NSE). Some examples are:

- False glide path
- ILS signal distortions outside the Final Approach Fix (FAF) which can cause the aircraft to wander around the centerline but appear to the pilot that the aircraft remains on the approach path and within the Normal Operating Zone (NOZ).
- Multi-path effects or signal distortions from other aircraft

- *Due to the complexity of ILS localizer and glide slope systems, there are some limitations*
- Interference by Frequency Modulation (FM) broadcast
- Beam distortions due to construction at the airport
- Spectrum availability/ Number of channels
- One fixed glide slope
- No selectable thresholds
- False courses inherent in the signal
- Requires two big antenna arrays per approach/runway end
- Channel pairing with Distance Measuring Equipment (DME) complicates spectrum allocation
- Very short final segments not be feasible due to ILS deviations capture performance dependent on the distance from the threshold;
- Positional accuracy decreases further from the runway threshold

Costs of operating and maintaining current capability

ILS cost are based on equipment and spares based on MK 20A & ILS-420 Data, with FAA performing site preparation, installation, and check-out. Costs include factors for Provisioning, Factory Acceptance, Freight, F & E Training and Depot, and Contractor Support.
Average cost estimates for CAT I-III ILS (MK 20) are:

EQUIPMENT COST	$601,034
AVERAGE REGIONAL SUSTAIN INSTALLATION COST	$275,000
AVERAGE REGIONAL ESTABLISH INSTALLATION COST	$1,090,000
AVERAGE TOTAL SUSTAIN CAT I - III ILLS COST	$876,034
AVERAGE TOTAL ESTABLISH CAT I - III ILLS COST	$1,691,034

Cost of flight inspection, procedure development, and publication are additional.

Advanced Capabilities (RNP transitions)

FAA Order 8260.58, *United States Standard for Performance Based Navigation (PBN) Instrument Procedure Design* provides guidance for the development of area navigation (RNAV) transitions to Instrument Landing System (ILS), Localizer Performance with Vertical guidance (LPV) and Ground Based Augmentation System (GBAS) Landing System (GLS) instrument approach procedures (IAP).

ILS procedures may incorporate RNAV segments. Procedure designers try to avoid using RF legs since they require specific aircraft equipment. The requirements are outlined in Appendix 5 of FAA Advisory Circular 90-105, *Approval Guidance for RNP Operations and Barometric Vertical Navigation in the U.S. National Airspace System* and primarily include autopilot or flight director with roll-steering, and an electronic moving map. [10] However, RF leg is a valuable option for locations where obstacles prevent the use of a flyby or flyover turn.[11]An RF leg terminating at an ILS final has been very helpful in Ketchikan, Alaska (reference Fig 1).

There are limitations to the use of RF legs outside of required navigation performance (RNP) approach procedures with authorization required (AR). In terms of procedure design, RF legs may not be used in the final approach segment or in section 1 of the missed approach. Additionally, if an RF leg is utilized in the intermediate segment, it must terminate at least 2 nautical miles prior to the Precision Final Approach Fix (PFAF).[12]

There are limitations and rules for using a straight RNAV segment to an ILS, LPV or GLS final. When incorporating an RNAV transition to an ILS final, there cannot be a course change at the PFAF.[13] As the procedure designer reviews the obstacle evaluation area (OEA), LPV criteria must be used to evaluate the final and missed approach section 1 for RNAV transitions to an ILS or GLS final.[14] Finally, in terms of

[10] AC 90-105, *Approval Guidance for RNP Operations and Barometric Vertical Navigation in the U.S. National Airspace System.* Appendix 5.
[11] Order 8260.58, *United States Standard for Performance Based Navigation (PBN) Instrument Procedure Design,* volume 6, chapter 1, section 1, paragraph 1.3.3.
[12] Order 8260.58, volume 6, chapter 1, section 1, paragraph 1.3.3, note.
[13] Order 8260.58, volume 6, chapter 1, section 2, paragraph 1.9.1.
[14] Order 8260.58, volume 6, chapter 4, paragraph 4.0.

final segment OEA, designers need to be mindful that ILS continues to splay while LPV and GLS are linear outside 50200 feet.[15]

There are six examples of GLS procedures incorporating RNAV segments. Order 8260.58 advises procedure designers to design final track intercept within 20 nm of the airport using performance based navigation or conventional routing for GLS procedures due to the current service volume limitations of GBAS.[16] At George Bush Intercontinental Airport (IAH) in Houston, Texas, the GLS procedures were designed with an RNAV segment prior to the GLS final to support airspace efficiency (reference Fig 2). At this large airport, air traffic control (ATC) has been using ILS with extended service volume, RNAV (GPS) and RNAV (RNP) IAPs simultaneously to provide the most expeditious arrivals to IAH. When GLS IAPs were designed for the Airport, procedure designers incorporated an RNAV extension to the GLS final to provide a published approach that could be used beginning at distances outside of the GBAS service volume without reliance on ATC vectors. This design will allow air traffic controllers to maintain efficiency and provide flexibility to aircrews by supporting simultaneous approaches based on any combination of ILS, RNAV (GPS), RNAV (RNP) or GLS.

[15] Order 8260.58, volume 6, chapter 4, paragraph 4.1

[16] Order 8260.58, volume 6, chapter 4, paragraph 4.0.

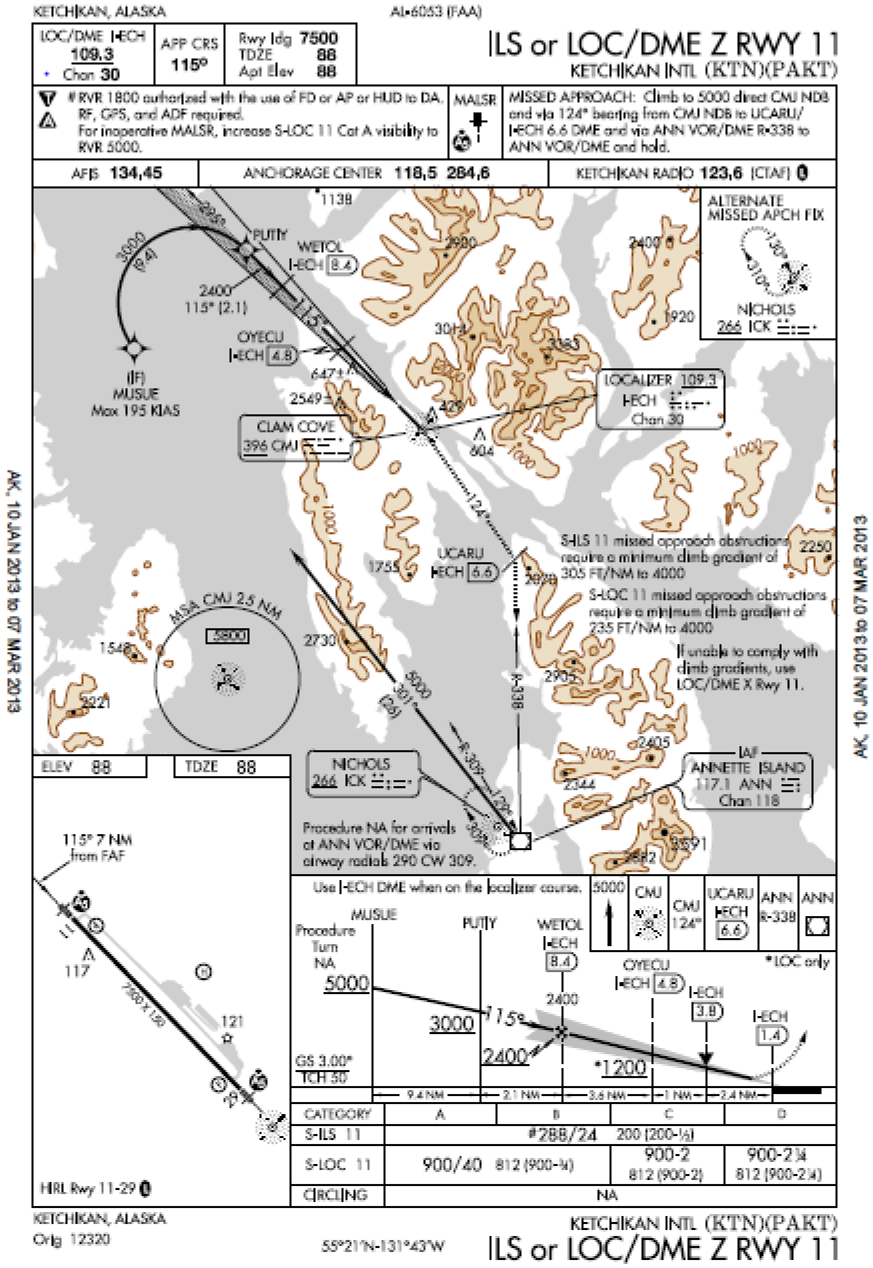

Figure 7 – RF Leg to ILS Final

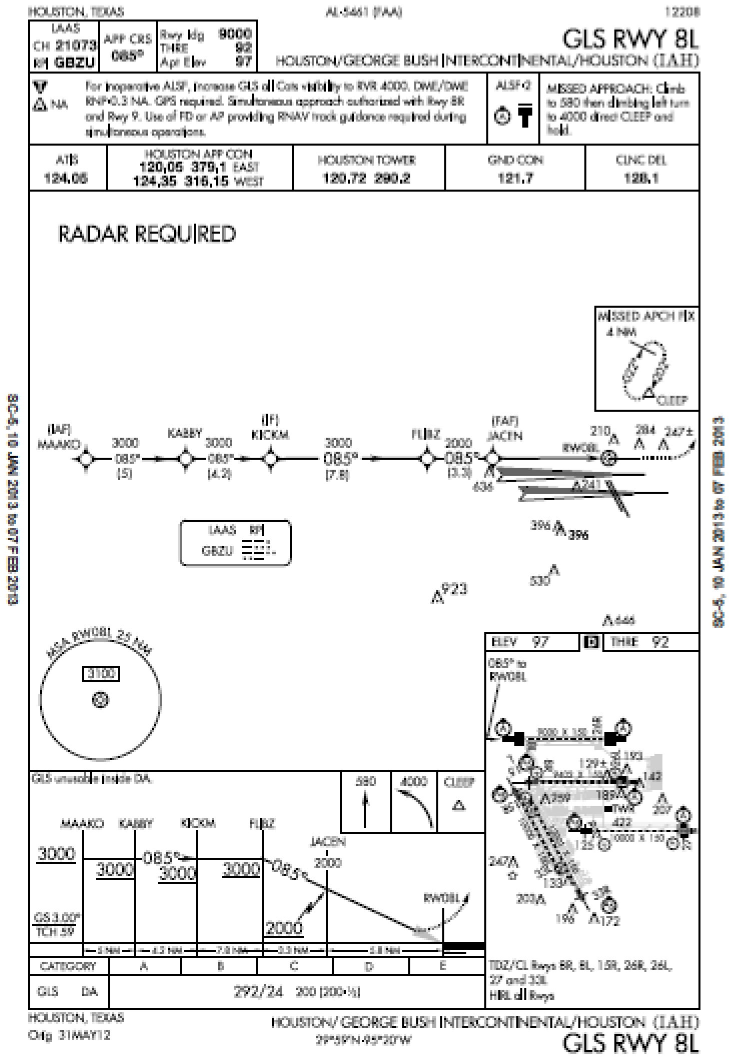

Figure 8 – RNAV to GLS Final

Appendix D
PBN Approaches with Vertical Guidance

1. RNP Approach [RNAV (GPS)] to LNAV/VNAV minima

Brief system description

Lateral Navigation/Vertical Navigation (LNAV/VNAV) is an Area Navigation (RNAV) function that computes, displays, and provides both horizontal and approved vertical approach navigation. Both Wide Area Augmentation System (WAAS) vertical guidance and baro-VNAV support approaches to LNAV/VNAV lines of minima. Procedures with approved vertical approach navigation have minimums as low as 300-400 foot ceiling and 3/4 mile visibility. GLS may have lower minima than LNAV/VNAV because designers are instructed to use Localizer Performance with Vertical (LPV) guidance criteria to evaluate the final and missed approach section 1 for an RNAV transition to an ILS or GLS final. [17] Additionally, GLS approaches do not have the temperature restrictions associated with baro-VNAV use for LNAV/VNAV minima.[18]

Current capability – coverage and supporting hardware

The LNAV/VNAV minima primarily support transport category aircraft. There are 1423 airports with LNAV/VNAV with 1217 LNAV/VNAV procedures at non-ILS airport. Additionally, there are 2914 LNAV/VNAV procedures with 128 LNAV/VNAV procedures to 250 foot height above touchdown (HAT). Procedure designers cannot develop a curved path in the final to this line of minima. A radius-to-fix (RF) leg must terminate 2 nautical miles (nm) prior to the precision final approach fix (PFAF). However, pilots are eligible to fly simultaneous approaches to this line of minima.

Note: Radius-to-Fix (RF) legs may be added in the future where potential benefits are warranted.

GPS and WAAS integration information to support flying to the LNAV/VNAV line of minima is found in the following Technical Standard Orders (TSO):

-TSO-C129, *Airborne Supplemental Navigation Equipment Using the Global Positioning System (GPS);*

-TSO-C196*, Airborne Supplemental Navigation Sensors for Global Positioning System Equipment Using Aircraft-Based Augmentation*;

-TSO-C145, *Airborne Navigation Sensors Using the Global Positioning System Augmented by the Satellite Based Augmentation System; and*

[17] Order 8260.58, United States Standard for Performance Based Navigation (PBN) Instrument Procedure Design volume 6, chapter 4, paragraph 4.0.

[18] AC 20-138C, *Airworthiness Approval of Positioning and Navigation System,* chapter 7-1.d.

-TSO-C146, *Stand-Alone Airborne Navigation Equipment Using the Global Positioning System Augmented by the Satellite Based Augmentation System.*

Airworthiness and Operational Guidance information are found in:

-AC 20-138C, *Airworthiness Approval of Positioning and Navigation Systems* (formerly AC 20-129, *Airworthiness Approval of Vertical Navigation (VNAV) Systems for use in the U.S. National Airspace System (NAS) and Alaska*.) ; and

-AC 90-105, *Approval Guidance for RNP Operations and Barometric Vertical Navigation in the U.S. National Airspace System.*

Procedure development including missed approach criteria is found in Order 8260.58, *United States Standard for Performance Based Navigation (PBN) Instrument Procedure Design* (formerly Order 8260.54A).

2. RNP Approach [RNAV (GPS)] to LPV minima

Brief system description

Localizer Performance with Vertical Guidance (LPV) is an RNAV function requiring WAAS, using a final approach segment (FAS) data block, which computes, displays and provides both horizontal and approved vertical approach navigation to minimums as low as 200 foot ceiling and ½ mile visibility.

RNAV (GPS) approaches to LPV lines of minima take advantage of the improved accuracy of WAAS lateral and vertical guidance to provide an approach that is very similar to a Category I (CAT I) ILS. Just as with an ILS, LPV has vertical guidance and is flown to a decision altitude (DA). The design of the LPV approach incorporates angular guidance with increasing sensitivity as an aircraft gets closer to the runway (or point in space (PinS) type approaches for helicopters). The sensitivities are nearly identical to those of the ILS at similar distances. This was done intentionally to allow the skills required to proficiently fly an ILS to readily transfer to flying RNAV (GPS) approaches to the LPV line of minima.

Current capability – coverage and supporting hardware

LPV minima primarily support general aviation users. There are 1519 airports with LPVs with 803 LPVs at non-ILS airports. Additionally, there are 3030 LPV procedures and 781 LPVs with less than 250'HAT (760 LPVs to 200' HAT). Procedure designers cannot develop a curved path in the final to this line of minima. A radius-to-fix (RF) leg must terminate 2 nautical miles (nm) prior to the precision final approach fix (PFAF). However, pilots are eligible to fly simultaneous approaches to this line of minima.

Note: RF legs may be added in the future where potential benefits are warranted.

WAAS integration information to support flying to the LPV line of minima is found in the following Technical Standard Orders (TSO):

-TSO-C145, *Airborne Navigation Sensors Using the Global Positioning System Augmented by the Satellite Based Augmentation System*

-TSO-C146, *Stand-Alone Airborne Navigation Equipment Using the Global Positioning System Augmented by the Satellite Based Augmentation System*

Airworthiness and Operational Guidance information are found in:

-AC 20-138C, *Airworthiness Approval of Positioning and Navigation Systems*

-AC 90-105, *Approval Guidance for RNP Operations and Barometric Vertical Navigation in the U.S. National Airspace System*

-AC 90-107, *Guidance for Localizer Performance with Vertical Guidance and Localizer Performance without Vertical Guidance Approach Operations in the U.S. National Airspace System*

Procedure development including missed approach criteria is found in Order 8260.58, *United States Standard for Performance Based Navigation (PBN) Instrument Procedure Design* (formerly Order 8260.54A).

3. RNP AR Approach [RNAV (RNP)]

<u>Brief system description</u>

Required Navigation Performance (RNP) Authorization Required (AR) approaches provide an unprecedented level of flexibility in construction of approach procedures. These operations are RNAV procedures with a specified level of performance and capability. RNP AR approach procedures build upon the performance-based National Airspace System (NAS) concept. When RNP AR approaches replace visual or Non-precision Approaches (NPA) safety is enhanced and efficiency improves through more repeatable and optimum flight paths. Predefined aircraft capability and navigation systems are the basis for conventional obstacle evaluation areas for ground-based NAVAIDs. The RNP AR criteria design is flexible in order to adapt to unique operational requirements, which can include avoiding terrain or obstacles, de-conflicting airspace, or resolving environmental constraints. Terrain challenged airfields and locations which need a shorter final approach segment can benefit from the implementation of RNP AR.

RNP AR approaches include unique capabilities that require special aircraft and aircrew authorization similar to Category (CAT) II/III instrument landing system (ILS) operations. All RNP AR approaches have reduced lateral obstacle evaluation areas and vertical obstacle clearance surfaces predicated on the aircraft and aircrew performance requirements of AC 90-101A, *Approval Guidance for RNP Procedures with AR*. Some procedures may require the capability to fly an RF leg and/or a missed approach, which requires RNP less than 1.0. SBAS and GBAS sensors can be approved on FMS-equipped aircraft without baro-VNAV to provide vertical path guidance for RNP 0.3 operations and RNP AR operations as low as RNP 0.1 with no change to existing RNP criteria, SBAS or GBAS performance standards.[19]

[19] AC 20-138C, *Airworthiness Approval of Positioning and Navigation System,* chapter 7-1.c.

Current capability – coverage and supporting hardware

RNP AR approaches primarily support transport category aircraft. There are 114 airports with RNP AR procedures and 10 RNP AR procedures at non-ILS airports. Additionally, there are 345 RNP AR procedures and 19 RNP AR procedures with 250' HAT. Procedure designers may develop a curved path in the final. Pilots are eligible to fly simultaneous approaches with these procedures.

RNP AR integration information is found in the following Technical Standard Orders (TSO):

-TSO C129, *Airborne Supplemental Navigation Equipment Using the Global Positioning System (GPS);*

-TSO-C196*, Airborne Supplemental Navigation Sensors for Global Positioning System Equipment Using Aircraft-Based Augmentation*;

-TSO-C145, *Airborne Navigation Sensors Using the Global Positioning System Augmented by the Satellite Based Augmentation System;*

-TSO-C146, *Stand-Alone Airborne Navigation Equipment Using the Global Positioning System Augmented by the Satellite Based Augmentation System.*

Airworthiness and Operational Guidance information are found in:

-AC 20-138C, *Airworthiness Approval of Positioning and Navigation Systems*

-AC 90-101A, *Approval Guidance for RNP Procedures with AR*

Procedure development including missed approach criteria is found in Order 8260.58, *United States Standard for Performance Based Navigation (PBN) Instrument Procedure Design* (formerly Order 8260.52).