Benefits of RNP and GLS for Noise and Capacity

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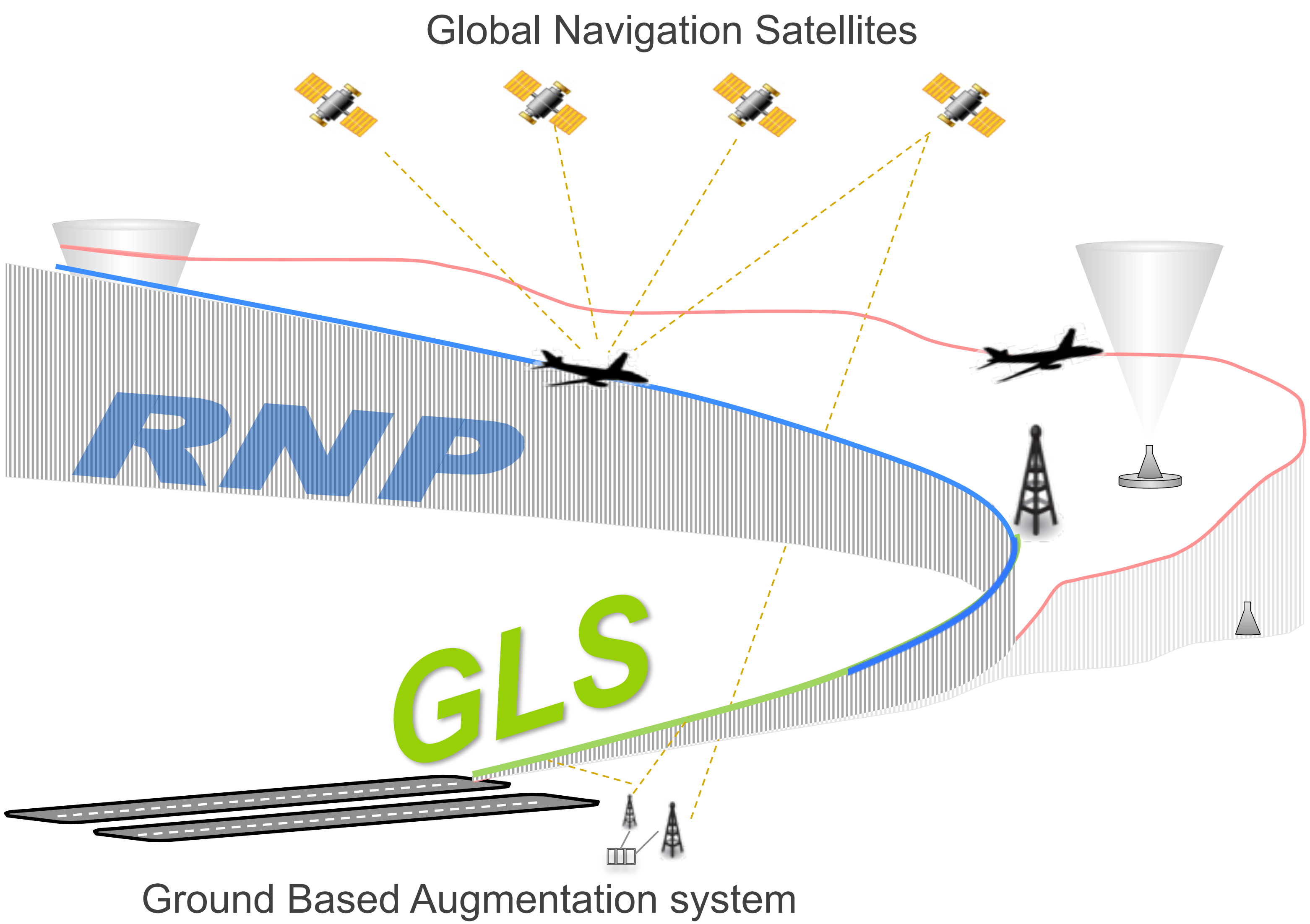
Nov 2017

Overview

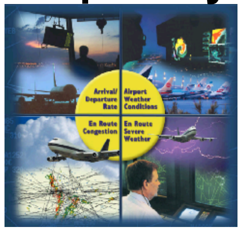
- PBN (RNP) and GLS
- Current GBAS Status
- Benefits of GBAS/GLS
- Examples of projects/programs that have validated GNSS benefits mechanisms
- Next Steps for GBAS
- Summary

Refresher on RNP and GLS



All Components Must be in Place to Realize the Full Value Potential of RNP & GLS Operations

Regulatory Capability



- Procedure criteria
- Operations requirements
- Approval process

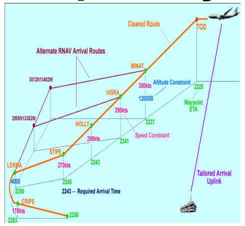
X

Airport & Facility Capability

- GPS availability
- Airport Data

X

Air Traffic Capability



- Flight procedures
- ATC procedures
- Controller training

X

Airline Capability

- Crew ops procedure
- Airline Dispatch procedures
- Initial Pilot Training
- Application package

X

Airplane Capability

- Certified capability
- System integrity/ alert
- Operation continuity

=

Value for Operators

- **Environment benefits**
- **Save time & money**
- **Schedule Reliability**
- **Improve competitive position**
- **Improve safety**

GBAS Deployment Status as of 2017

- *Approximately 140 GBAS stations are certified and transmitting SARPS compliant signals,*
  - *71 of which have published procedures for GLS Category I operations.*
  - *2 GBAS stations support published RNAV procedures via the GBAS Positioning Service*
- *Additionally*
  - *20 Special Category I GBAS stations are in commercial operation.*
  - *There are 18 prototype stations providing signals for test and evaluation, 7 of which were used for validation of GBAS approach service types to support Category II/III operations.*
- *Over 100 airlines currently have GBAS equipage, totaling over 2,000 airplanes.*
- *GBAS is currently used in daily revenue service having accrued more than 10,000 GLS operations in seven states, including many automatic landings.*
- *GBAS avionics are available for large airline and business aircraft, helicopters as well as small general aviation aircraft.*

Current Installations from FLYGLS.net

Note: this site is somewhat out of date now

- Projects
- Other Research Installations
- Operational (non-published)
- GBAS CATI Ops (published)
- Investigations

CAT III prototypes

- FAA TC Atlantic City
- Oslo
- Frankfurt-(EDDF) CAT III
- New Ishigaki Airport
- Ramenskoye (UUBW)
- Toulouse (LFBO)
- Barcelona–El Prat Airport

Boeing GLS Program

737NG-7/8/9

GLS CAT I
Option

89
Airlines Selected Option

1300
Airplanes with GLS activated

20%
In-Service Fleet with GLS

747-8

GLS CAT I/II
Standard

14
Airlines

110
Airplanes & Counting

100%
In-Service Fleet

787-8/9/10

GLS CAT I/II
Standard

63
Airlines

530
Airplanes & Counting

100%
In-Service Fleet

737MAX-7/8/9

GLS CAT I*
Option

83
Airlines Ordering 737MAX

3162
Airplanes on Order

*** GLS CAT II/II Study for 2020**

777X-8/9

GLS CAT I/II/III

CAT I/II Standard, CAT III Option

7

Airlines Ordering 777X

340

Airplanes on Order

GNSS Enhances Safety, Improves Airspace Capacity and Efficiency

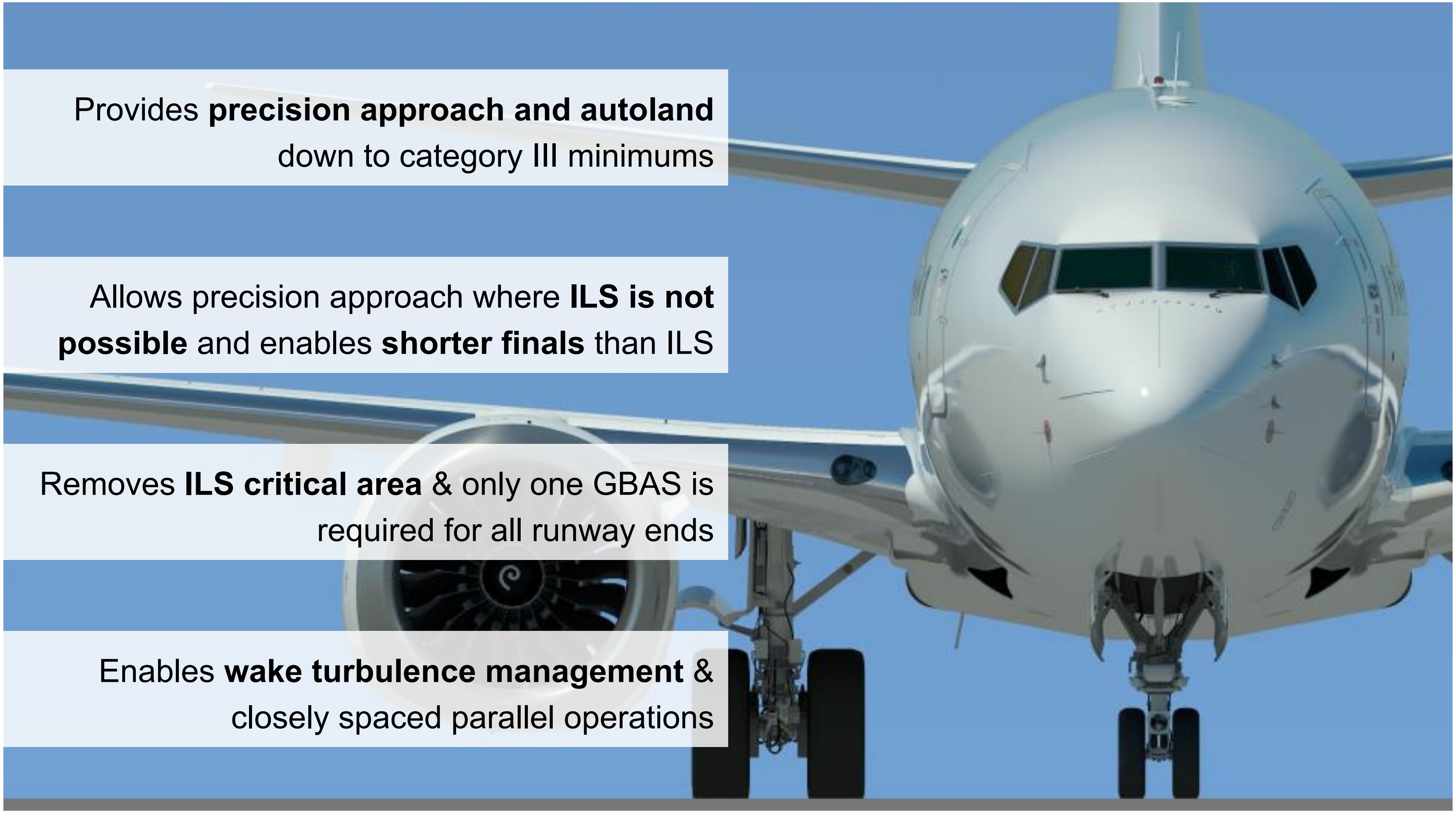
Supports more efficient operations through Performance Based Navigation

Improves safety by enabling approach with vertical guidance where none existed before

Provides improved surveillance capabilities through ADS-B and ADS-C

Has saved many lives through incorporation in Enhanced Ground Proximity Warning Systems

GLS (with PBN) Enhances Safety, Improves Airport Capacity and Efficiency



Provides **precision approach and autoland** down to category III minimums

Allows precision approach where **ILS is not possible** and enables **shorter finals** than ILS

Removes **ILS critical area** & only one GBAS is required for all runway ends

Enables **wake turbulence management** & closely spaced parallel operations

Why GLS?
Airline Perspective – Site Specific

Improved Performance

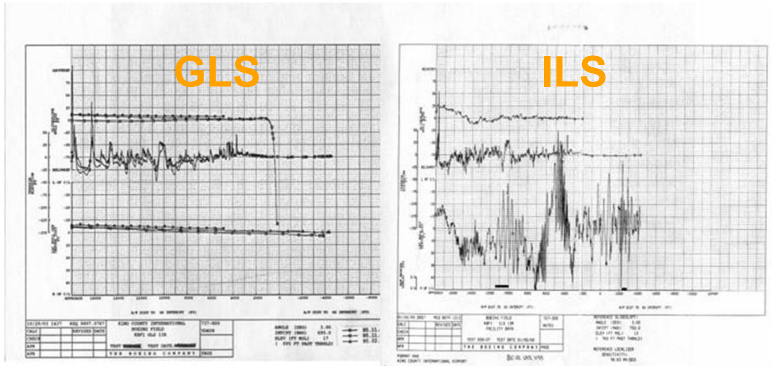
- Less susceptible to interference from buildings, vehicles, terrain
- Eliminates need for “critical areas” required for ILS beam protection

Increased Capability Through **Flexibility**

- Multiple glide-paths, displaced thresholds, staggered touch-downs &, offset localizer paths
- Steeper, lower noise profile glide-paths could increase night operations
- Increased efficiency from reduced separation as a result of wake vortex mitigation
- Low RNP capability in terminal area and for surface operations
- Precision guidance for departures

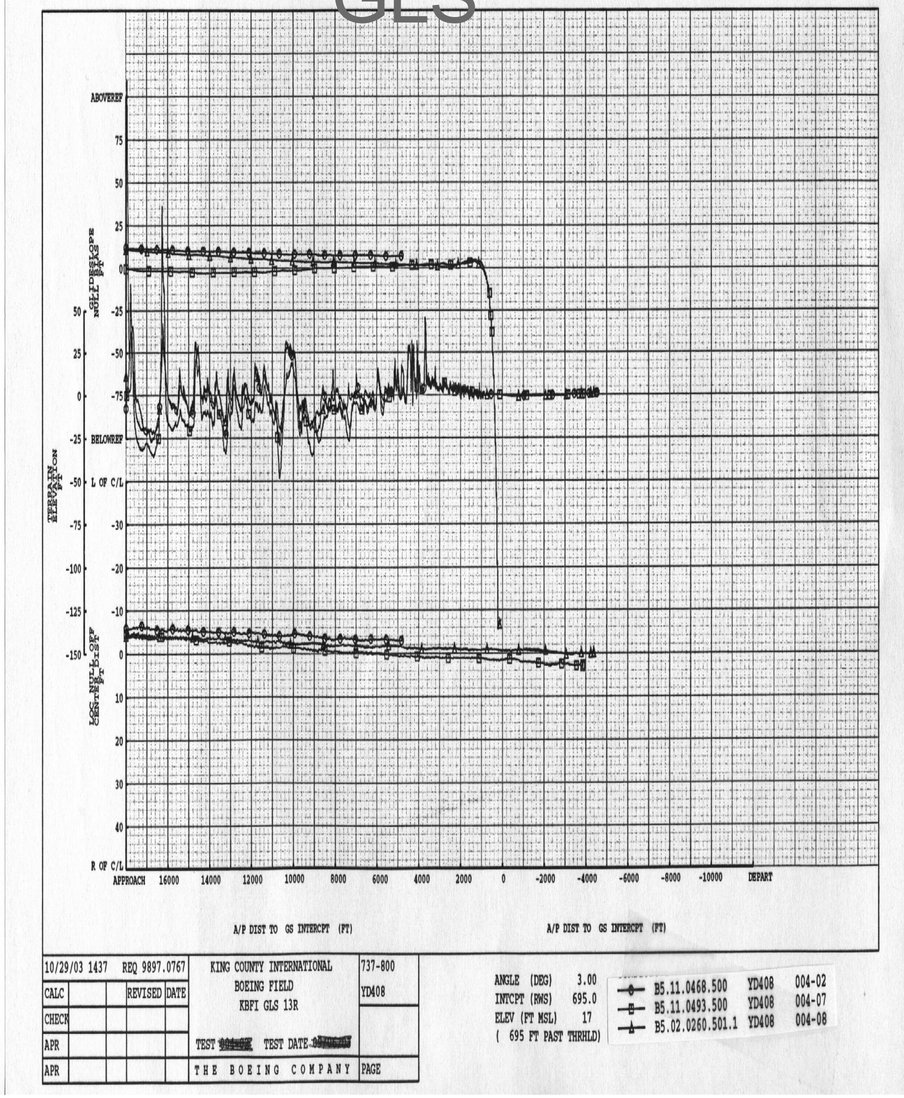
Cost Avoidance

- Fewer diversions
- Reduced fuel reserves from improved access to ETOPS and destination alternates
- Reduced landing fees. (Some airports are expected to pass savings to airlines.)
- Reduced flight inspection
- Improved Safety
- Provide precise ILS-like guidance in places where ILS is not feasible

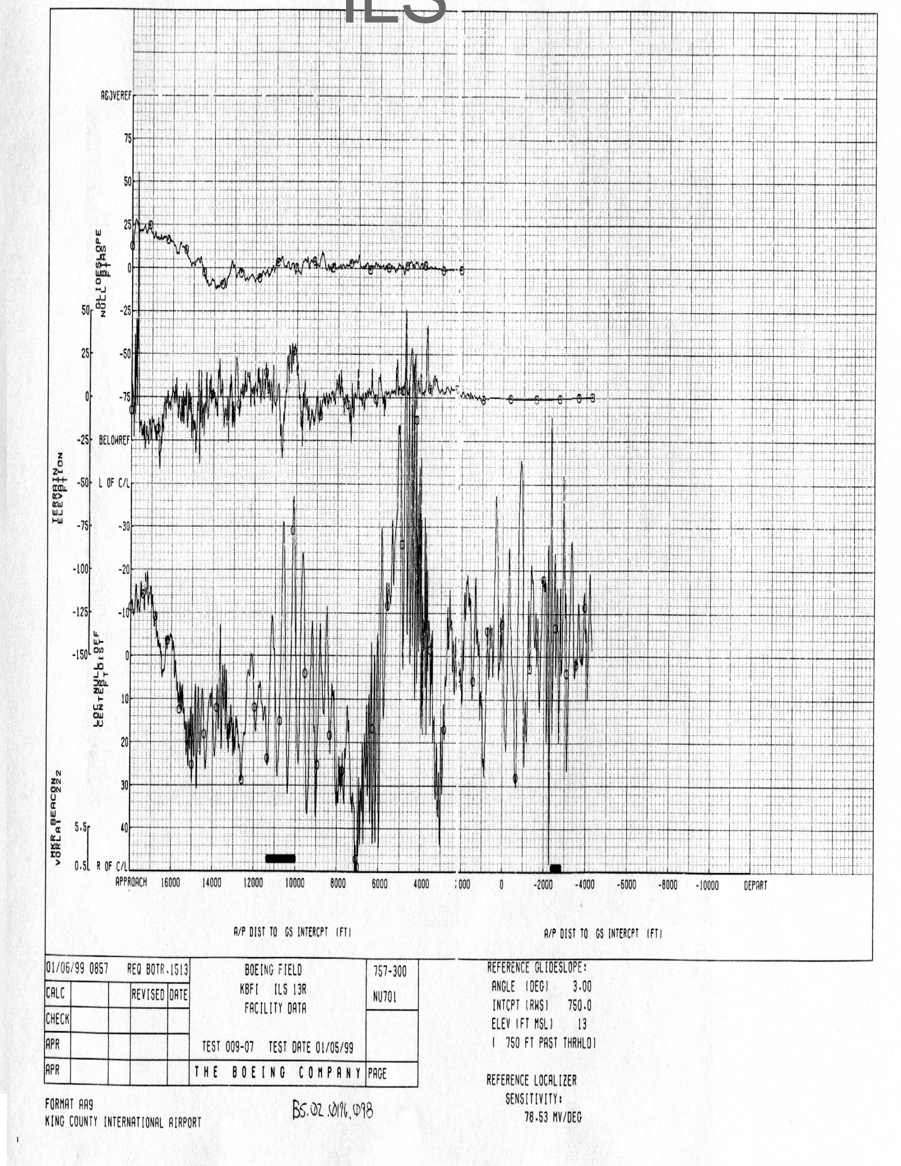


KBFI 13R

GLS



ILS



Why GLS?
Air Navigation Service Provider's Perspective

Lower Infrastructure Costs Compared to ILS

- Single GBAS serves all runway ends and potentially multiple airports
- Reduced flight inspection costs

Improved Performance

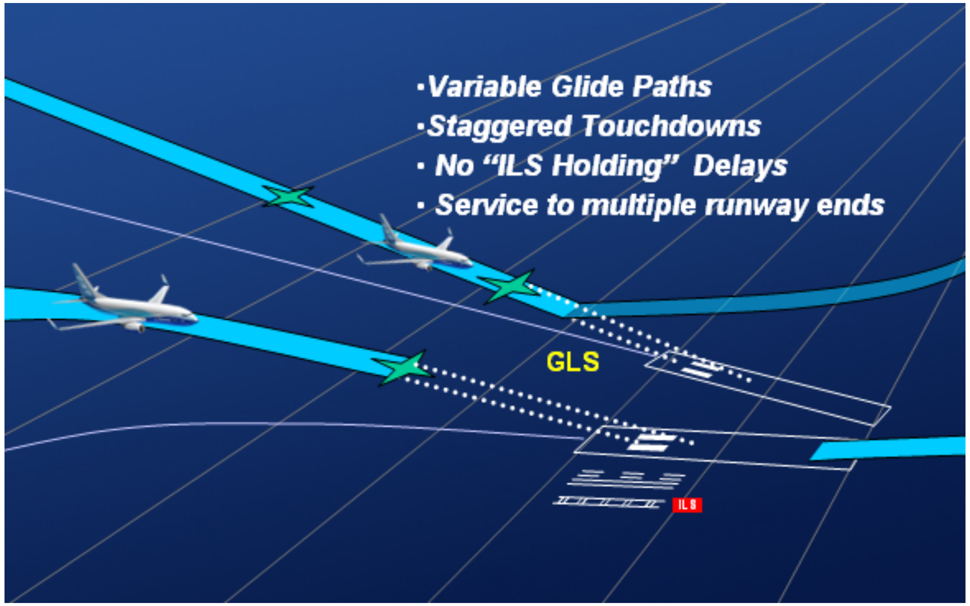
- Not susceptible to interference from buildings, vehicles, terrain, overflight
- Eliminates need for "critical areas" required for ILS beam protection

Increased Capability

- Potential for multiple glide paths

Environmental Considerations

- Community noise abatement
- Reduced emissions



Qantas Airways - RNP to GLS Transitions

First RNP to GLS operation in revenue service involving 737NG in May 2009

- Extremely smooth transition
- Radar & ADS-B data confirm track conformance
- Fuel saving of 140 kg (168 litres) per flight over conventional radar vectoring to ILS
- Emission reduction of 440 kg CO2
- Noise reductions

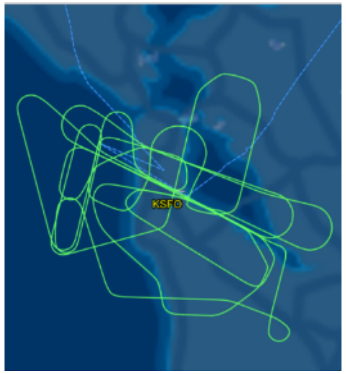
San Francisco RNP to GLS Demonstration Project

Communicate benefits of RNP to GLS procedures with a demonstration flight

Accelerate GLS operations and GBAS implementation

Early airport and ATC stakeholder buy in – collaboratively designed procedures

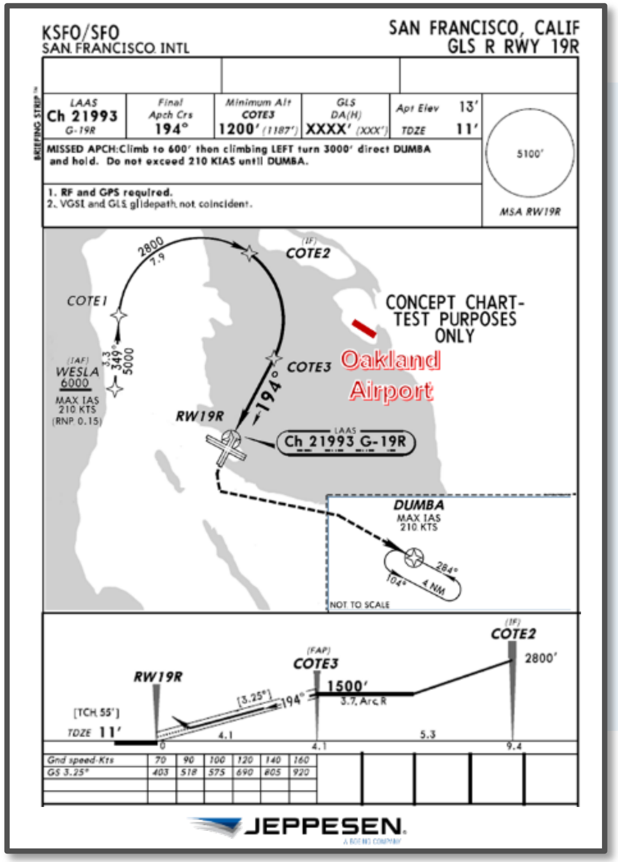
DELTA UNITED BOEING SFO San Francisco International Airport



Using RNP and GLS Procedures to Solve Operational Constraints at SFO

Noise and Emissions Benefits for 19R

Efficient Procedure Design by Jeppesen



DESIGN OBJECTIVES

- First precision approach to 19R
- De-conflict approach with Oakland airspace
- Continuous descent reduces noise and emissions instead of a long, straight-in final

POTENTIAL BENEFIT

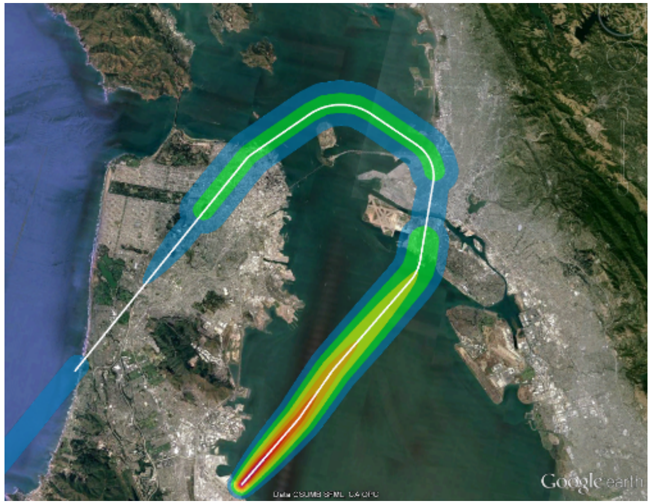
- Continuous descent reduces noise and emissions instead of a long, straight-in final

Noise and Emissions Benefits for 19R

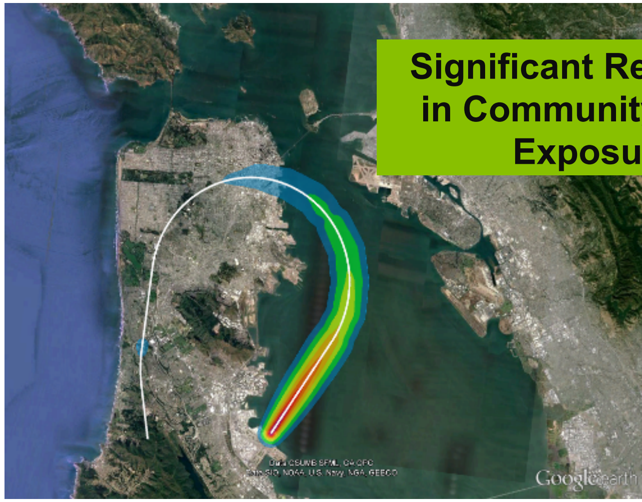
RNP Route Shortens the Ground Track and Moves Noise Away from Densely Populated Suburbs

Noise Level (dBA)
55
60
65
70
75
80
85

Typical Short Vector Route
Estimated Population: 329,600 to 55dBA



SFO GLS R RWY 19R
Estimated Population: 47,300 to 55dBA



Significant Reduction in Community Noise Exposure

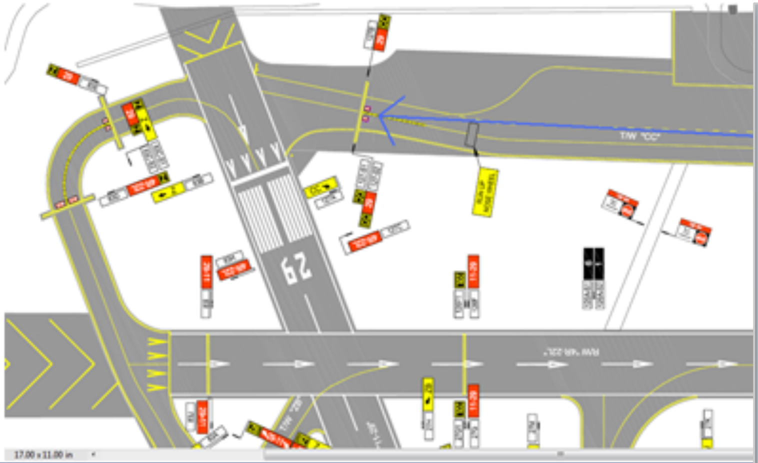
	Typical Short Vector Route	SFO GLS R RWY 19R
FLIGHT TRACK	36.3 nm	20.5 nm
FUEL BURN	792 lb / 360 kg	424 lb / 193 kg
CARBON EMISSIONS	2499 lb / 1136 kg	1338 lb / 608 kg

↓46% Reduction in Fuel Burn & Emissions

Reduce ground movement delay due to no ILS critical area (Newark)

Protecting ILS CA's

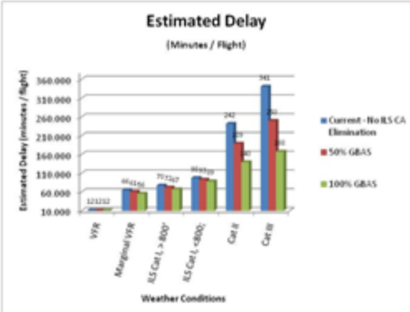
– CA's are protected by requiring aircraft to hold short at some distance from the runway before crossing the runway, and/or taxiing into position for takeoff.
  - Ex: ILS Hold Lines at EWR:



GBAS Critical Area Benefits
7 July 2010

Time-Savings

– The amount of time-savings depends on the operating condition, estimated peak-hour operations and projected demand.
  - Example: EWR 2010, 50% GBAS Equipage:



Condition	Freq.	Est. Delay		Time Savings (minutes / flight)	Weighted Contribution to Total Time Savings (minutes / flight)
		Base	50% GBAS		
VFR	78.29%	11.596	11.596	0.000	0.000
Marginal VFR	8.70%	65.533	60.527	5.006	0.436
ILS Cat I, > 800'	12.11%	77.547	72.356	5.191	0.629
ILS Cat I, <800;	0.53%	97.652	93.016	4.636	0.025
Cat II	0.13%	241.962	189.125	52.837	0.069
Cat III	0.24%	341.151	249.796	91.355	0.219
				TOTAL	1.377

- Estimated delays increase significantly as weather deteriorates.
- Time-savings are greater in worse weather.
- Total average time-savings is estimated to be 1.377 minutes / flight.

GBAS Critical Area Benefits
7 July 2010
Federal Aviation Administration
25

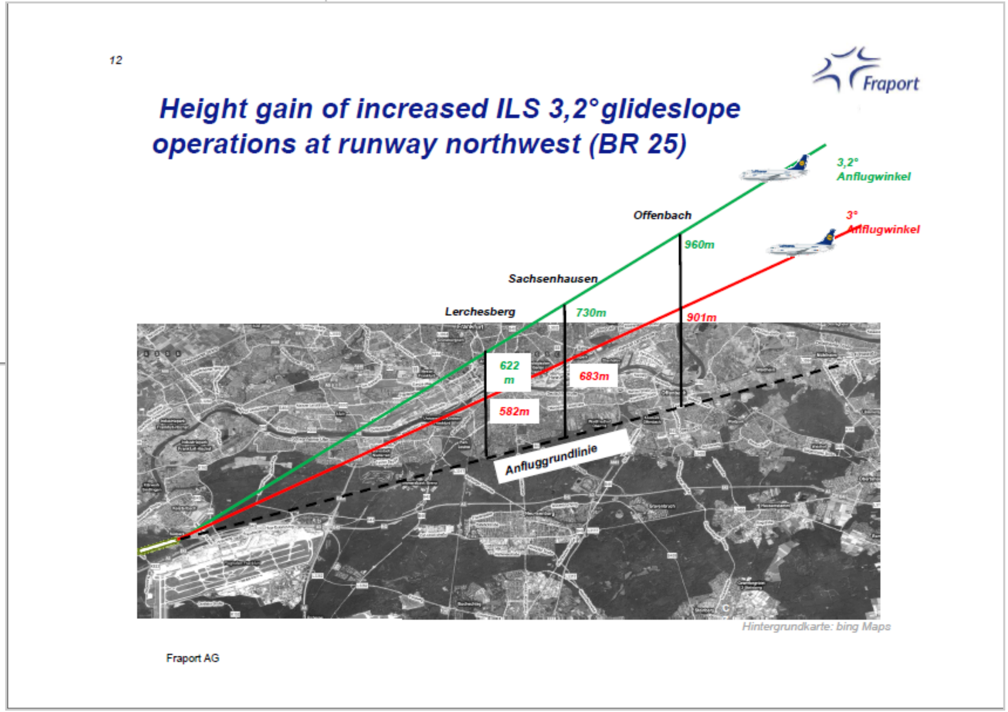
Enable alternative noise abatement procedures during night hours due to multiple glide paths (Frankfurt, Europe)

airberlin group

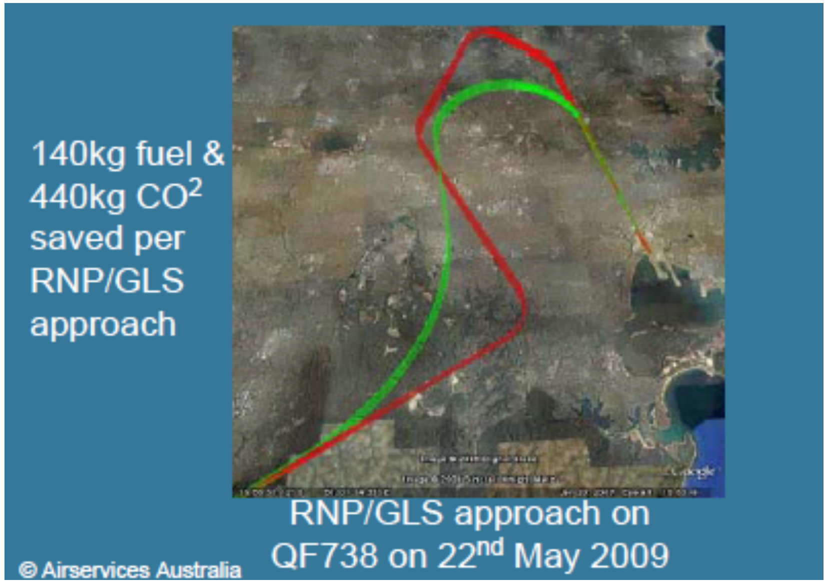
C. Why GBAS?

- Airberlin operates in noise sensitive areas
  - Possibility to reduce noise polution
- Future procedure design to decrease number of diversions (e.g. critical airports SPC, INN)
- Future ILS CAT II/III substitute
- ILS identical procedures – easy to fly

airberlin - GBAS - IGWG 2012

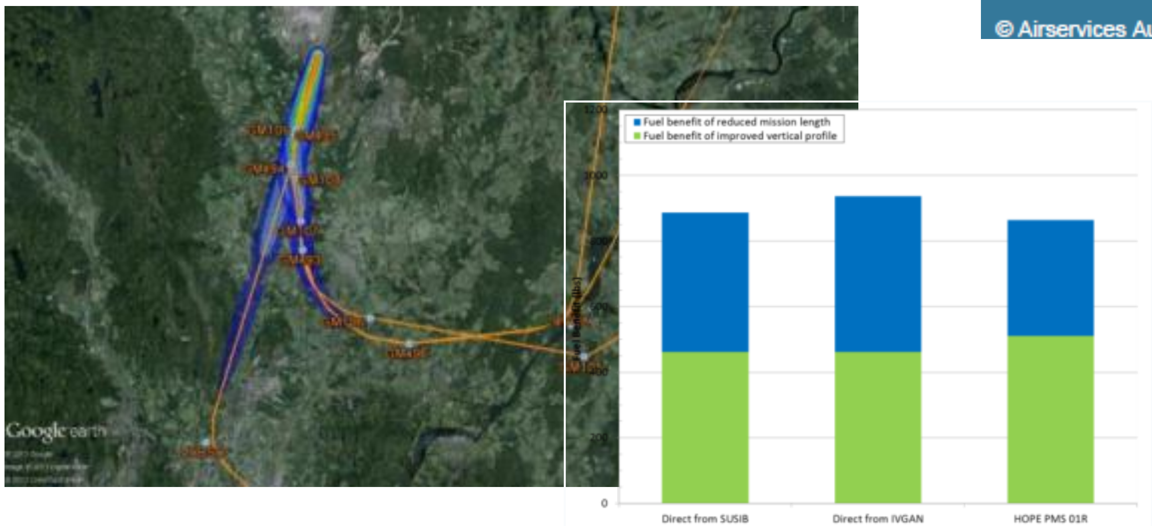


Improve terminal operational efficiency by reducing short final from 8-10 nm to 4-5 nm for RNAV/RNP approaches (Oslo, Sydney)



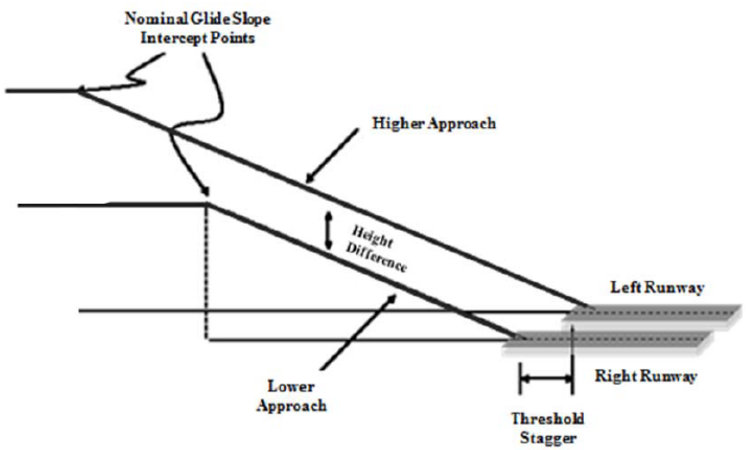
737-800 RNAV Visuals

- 250 flights weekly
- Savings up to 12M lbs. of fuel per year
- Savings up to 38M lbs. of CO2 per year

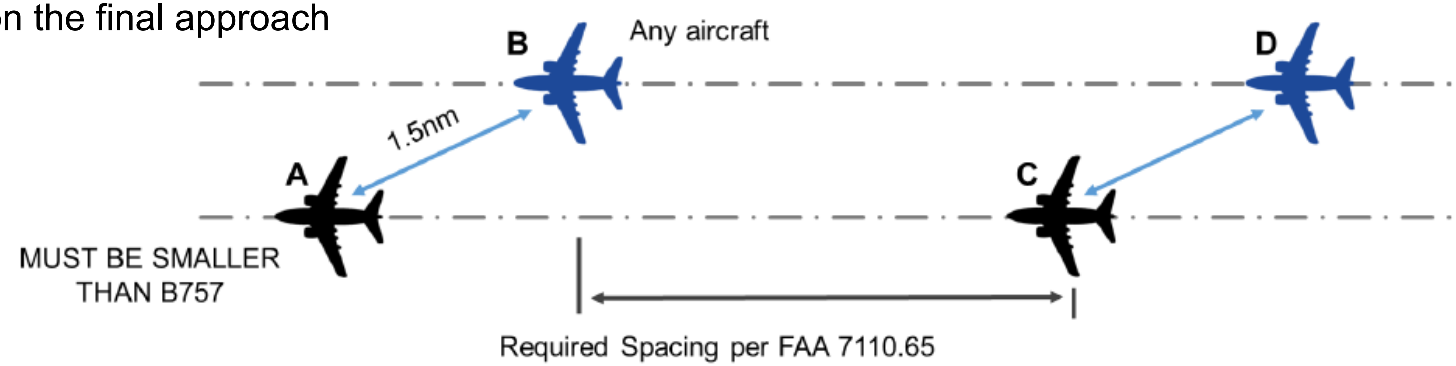


Concept for Wake Vortex Mitigation

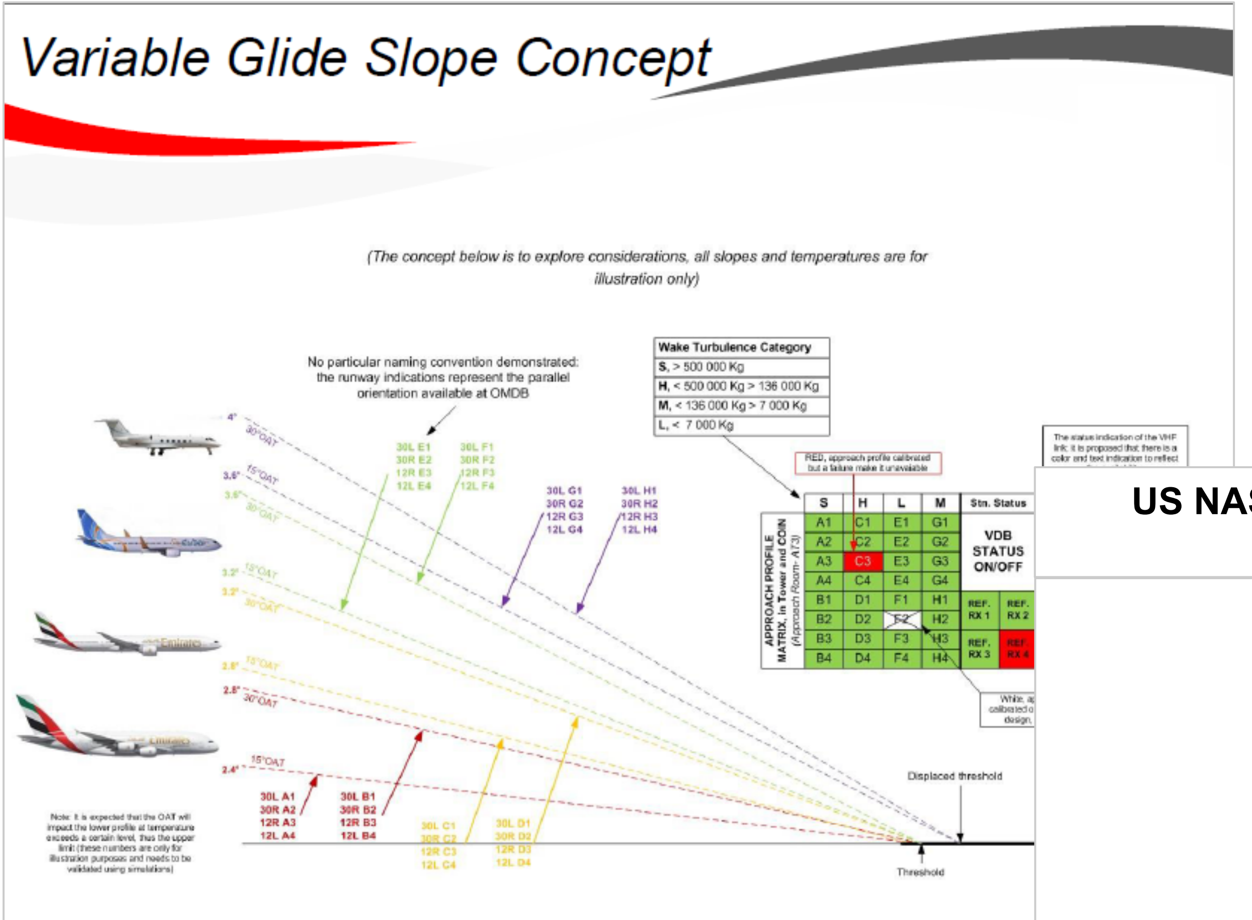
- Simultaneous Dependent Approaches to Closely-Spaced Parallel Runways (CSPO).
  - FAA Order 7110.308A
- 1.5-Nautical Mile Dependent Approaches to Parallel Runways Spaced Less Than 2500 Feet Apart
- At SFO this operation can increase the arrival rate by 4 to 7 movements per hour above that of CAT I and allows the airport to continue to land on both runways.
- Mandatory a 1.5 nm stagger between the aircraft landing on the parallel runways is in effect which translates to a larger spacing between departures.
- Approach for leading aircraft has a lower GPA
- Provides safe vertical separation behind the wakes of the paired aircraft.
- 1000 ft vertical separation until both are established on the final approach

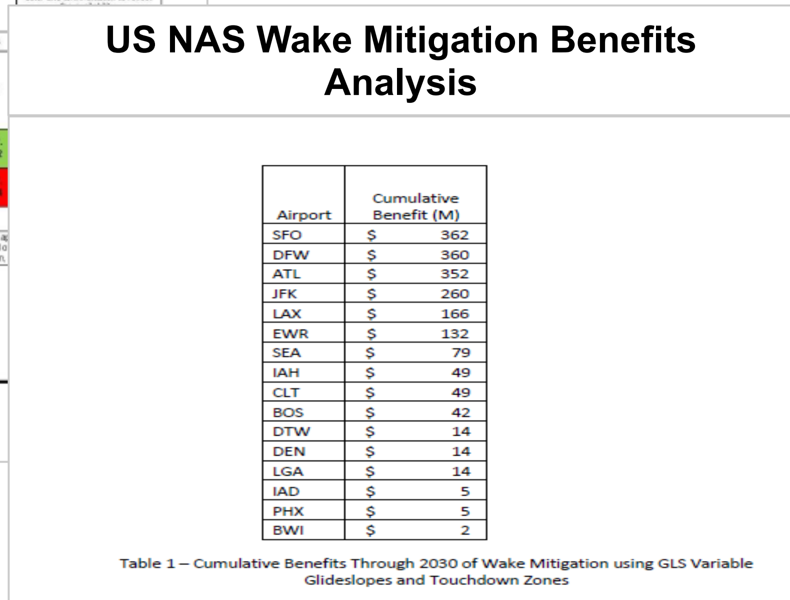


Glide slope height differences are achieved by using a common reference point from the lead aircraft runway threshold, threshold stagger, or small glide slope angle differences, thus yielding a higher and lower approach.



Improved capacity through management of wake turbulence with multiple glide paths and/or displaced thresholds (Dubai)





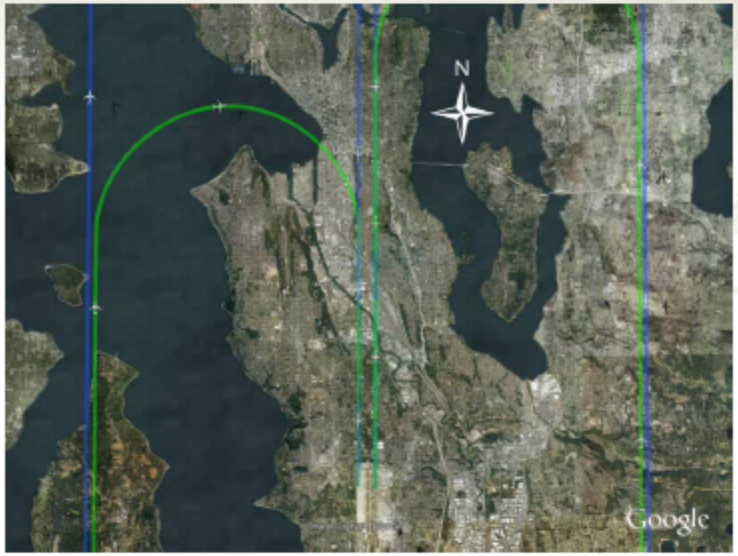
US NAS Wake Mitigation Benefits Analysis

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

Improved capacity through enabling closely spaced parallel independent operations from navigation, multiple glide paths and/or displaced thresholds (Seattle)

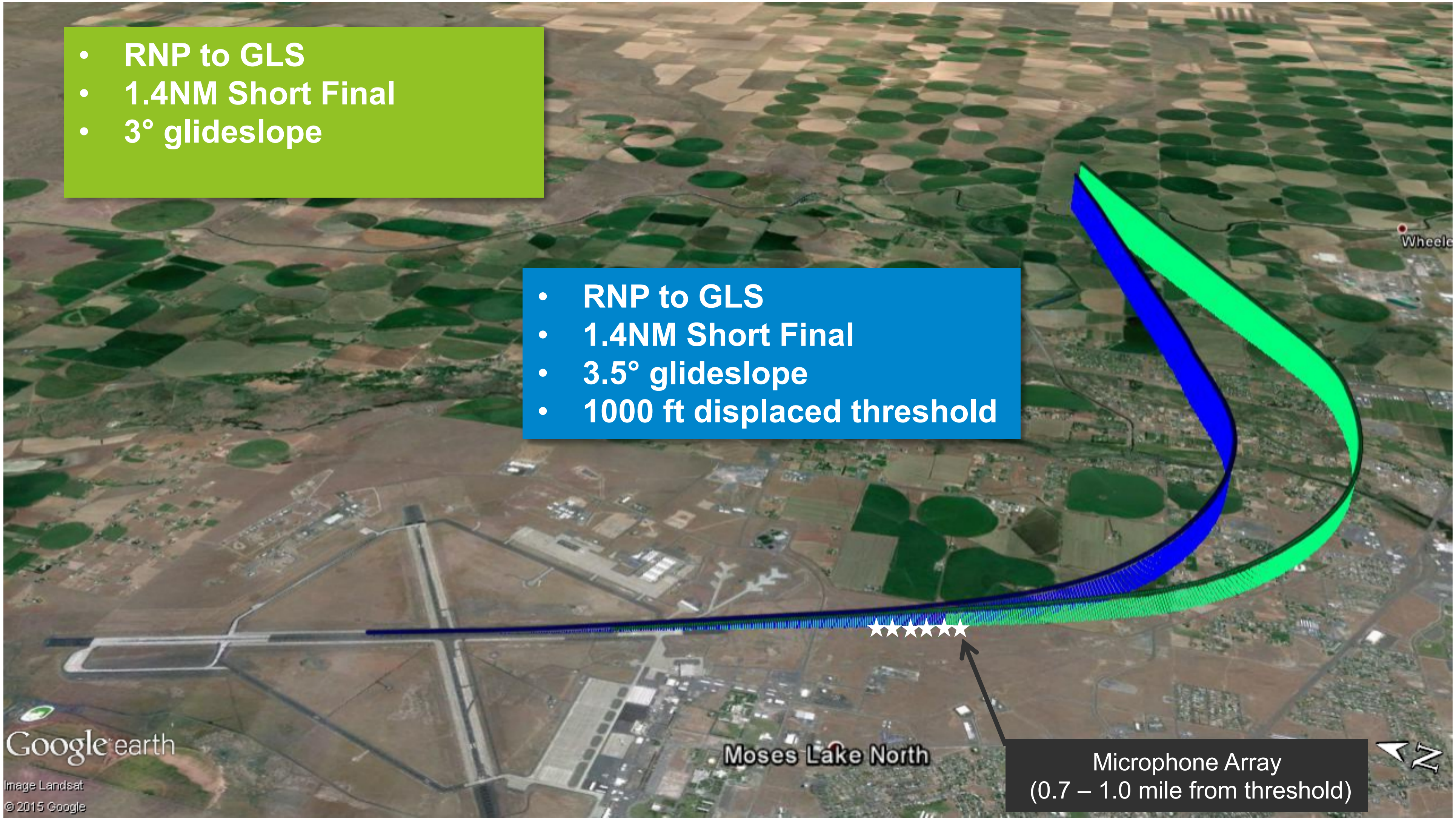
Annual Benefits



Time	4800 Hours	$20.4M
Fuel Burn	2.9 M Gallons	$7.3M
CO2 Emissions	30,500 Metric Tons	Removing 5600 cars

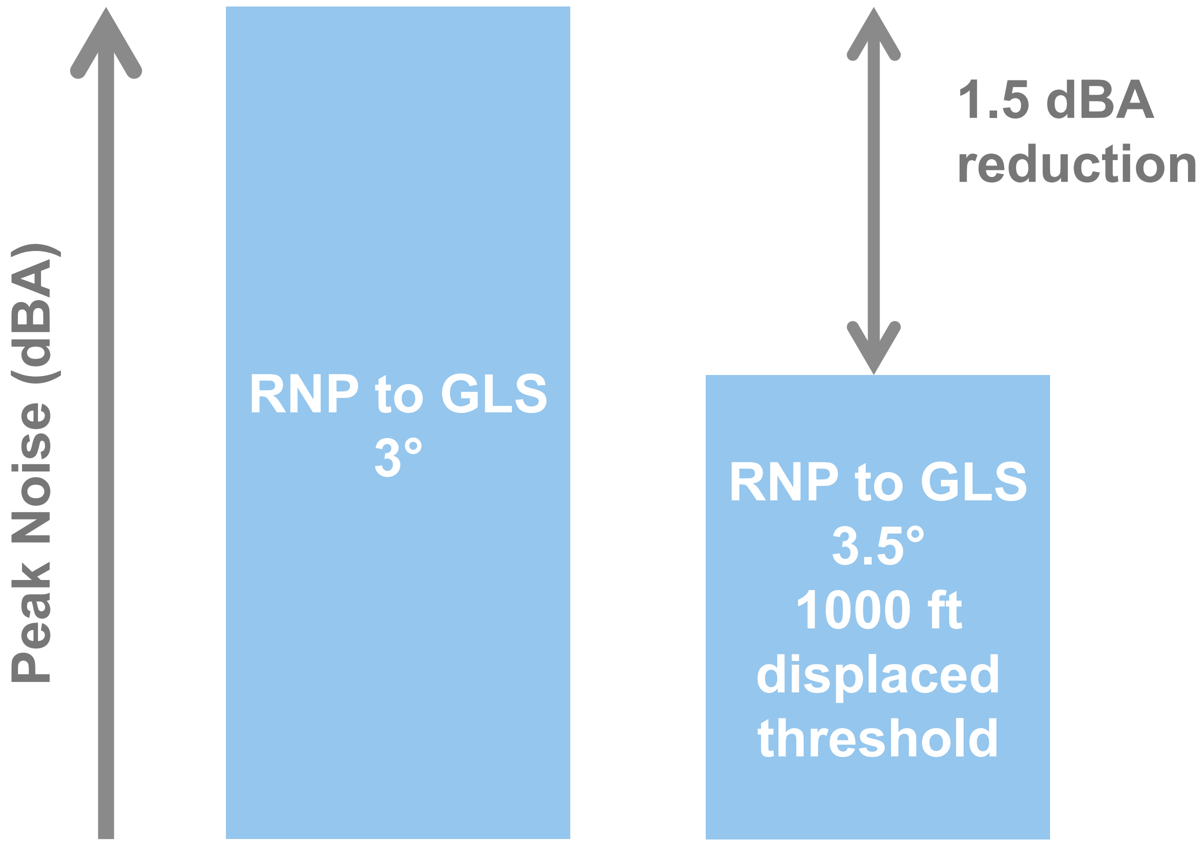
787 Operational Efficiency

Curved Approaches



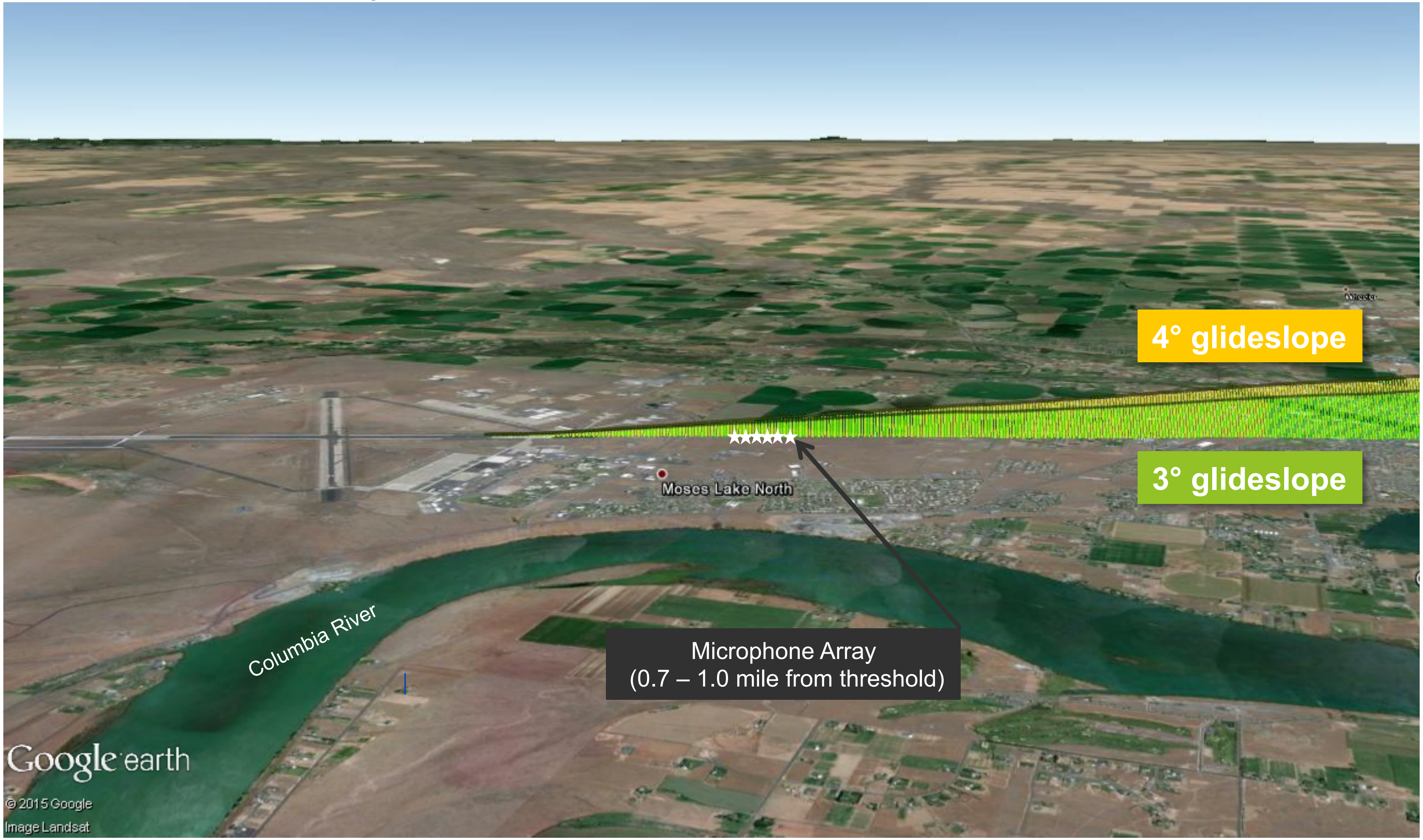
787 Operational Efficiency

Curved Approaches Noise Savings



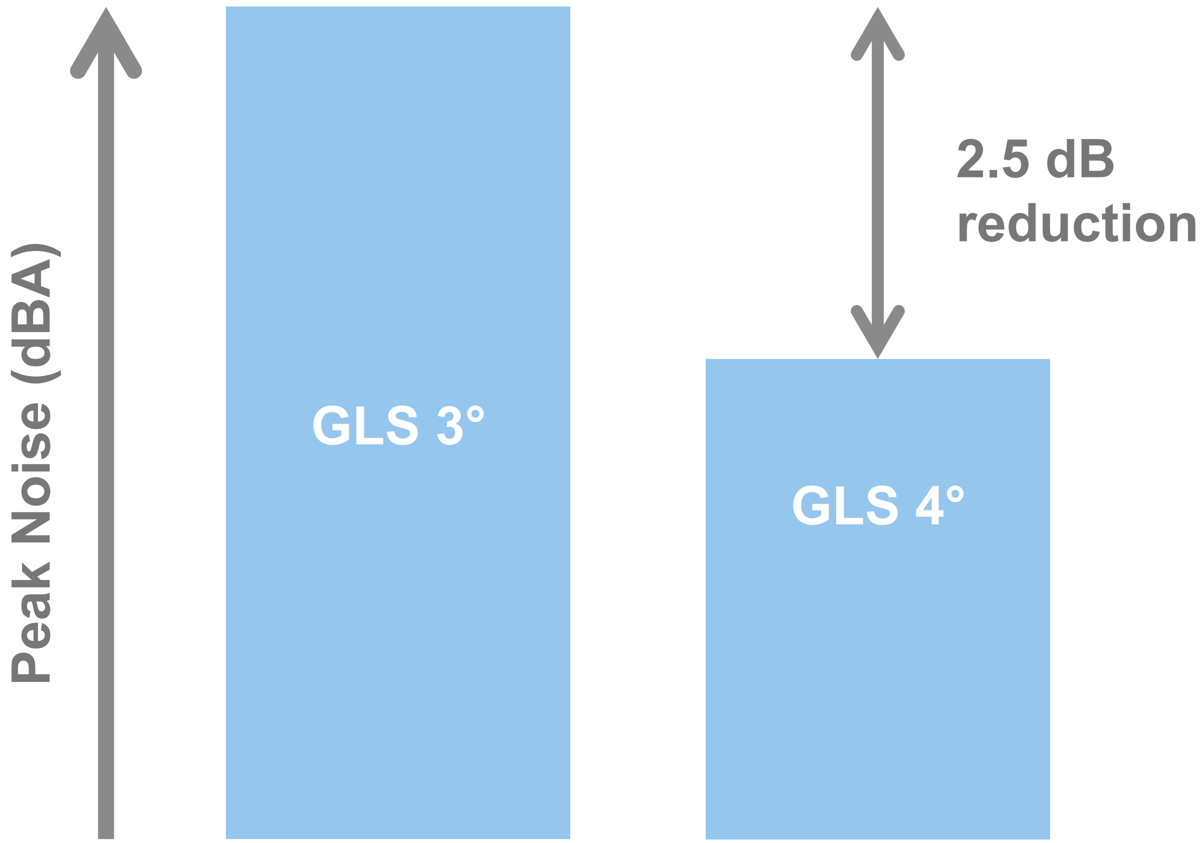
787 Operational Efficiency

Variable Glideslopes



787 Operational Efficiency

Variable Glideslopes Noise Reduction



Conclusions from 787 ecoD Program

eco Demonstrator PROGRAM

Demonstrated GLS procedures designed to reduce fuel and noise including

- Curved approaches
- Variable glideslopes
- Displaced thresholds
- Combinations of the above

15
tons less fuel per year per airplane

2
dB noise reduction per operation

Allows airlines and airports to realize the full potential of airplane capabilities

What is next for GBAS?

Wider deployment of GAST C to support CAT I operations

Authorization of CAT II operations using GAST C

Implementation of CAT III via GAST D

Evolution to Dual Frequency/Multi-Constellation GBAS (2025 timeframe and beyond)

GLS CAT II on CAT I GBAS

- GLS CAT II GBAS Approach Service Type C (GAST C)
  - No current CAT II operational approval
  - United Airlines, Delta Airlines, Honeywell, Boeing and FAA Project in-work to determine how to gain CAT II authorization
    - First approval projected at Newark Airport by mid 2018
  - Based on SARPS Compliant GAST C equivalence to II/D/2 ILS
    - Boeing completed analysis that shows autoland performance meets time to alert requirements
    - Requires mitigation for ionospheric anomalies: Honeywell GBAS with Satellite Based Augmentation System (SBAS)
    - GLS using autoland or head up guidance system
  - 787 and 747-8 - Boeing provided AFM (Airplane Flight Manual) Statement on GLS CAT II
    - 787 & 747-8 certified for GLS autoland
  - 737 - Develop flight deck procedures that would enable pilots to mitigate guidance signal failures in the visual segment

Summary

GNSS is a fundamental cornerstone for future Air Traffic Management

- RNP and GLS are important tools necessary to realize the potential of GNSS

Current GNSS already delivers capabilities that are not fully exploited

- Need greater focus on developing procedures and using the technology we already have developed in smarter ways to deliver benefits
- All the elements need to be in place before benefits are enabled

GBAS/GLS and RNP are complementary Technologies that can Enable Environmentally Beneficial Operational Improvements in Many Ways

GLS / GBAS Implementation

Which comes first?

or

BOEING

Safety by enabling precision approach where ILS is not possible or additional safety buffer desired (Guam)

Simplicity of pilot training (United Airlines)

Pilot Training

✈ Training via AFM Training Bulletin

737-07-XX July XX, 2007

GLOBAL POSITIONING LANDING SYSTEM (GLS) PROCEDURES

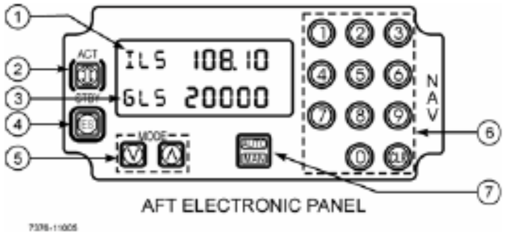
This bulletin describes aircraft systems and procedures for GLS approaches.

The initial aircraft to obtain this system will be the Continental Micronesia 737-800's. Installation will commence at the end of June, with flight procedures to begin in the fall timeframe.

The aircraft will have the following physical differences on the flight deck:

1. Multi-Mode Navigation Control Panel. This is visually identical to the panel currently installed in the 500's. The difference is the ability to select GLS frequencies.

Multi – Mode Navigation Control (If Installed)



AFT ELECTRONIC PANEL

- Active (ACT) Mode and Frequency Indicator

  Indicates the active mode and frequency.

- Transfer Switch

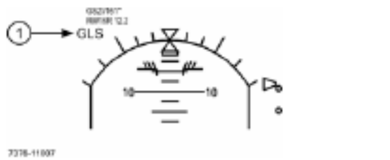
This system uses the GPS position of the aircraft in conjunction with a ground based augmentation system (LAAS) to provide look-a-like ILS guidance.

The flight crew will:

1. Select the GLS approach from the database.
2. Enter GLS channel in NAV panels.
3. Enter inbound courses on MCP.
4. Set DA minimums on barometric altimeter.
5. Set RA minimums as backup.
6. Arm APPROACH MODE when:
   - The approach is tuned and verified.
   - The aircraft is on an inbound intercept heading.
   - Both lateral and vertical pointers appear on the attitude display in the proper position.
   - Clearance for the approach has been received.

ADI will display GLS information including LOC and GS indices.

Attitude Indicator – GLS Source Annunciation Indication (If Installed)



- GLS Source Annunciation

  Displays the selected GLS identifier, channel, selected course and source annunciation.

4

Next Generation GNSS

GNSS continually evolving

- GPS & GLONASS Modernization
- New GNSS constellations (Galileo and Beidou)
- More augmentation systems and updates to existing augmentation systems

Trend towards Multi-Constellation/Dual Frequency GNSS

- More satellites and signals will improve the robustness of GNSS
  - Availability problems associated with the number of satellites in view will be a thing of the past
- New capabilities will be enabled by dual frequency GNSS
  - Vertical positioning with integrity straight from the constellation without an overlay augmentation system
  - Enhanced performances with both local and wide area augmentations

Transition to MC/DF will take a very long time

- Development of standards are underway… but will not be mature until early next decade
- Equipage rates in the fleet will be low unless driven by real economic drivers

MC/DF alone does not by itself address all the robustness issues with GNSS

- Robustness to RF interference and GNSS backup capabilities are unsolved issues…
- Cyber security is the next frontier

Evolution of GNSS

Fragmentation of Navigation Services not a good thing for Aviation

- Original vision for satellite navigation was as a ***seamless*** global resource
  - Looks like we are determined to put some seams in …
- GNSS receivers for aviation are expensive to develop – too much fragmentation raises the costs of development
- Fragmentation means development costs are spread over smaller installation bases
- When variations in performance of regional/national systems start to impact cockpit operations, risk is introduced and crew training costs rise

Regional mandates for specific technologies and services are counter productive

- Mandates based on political motivations that don't have a clear operational advantage over other technologies and services that provide adequate performance should be avoided
- The aviation industry has enough real problems to solve and limited resources to address them
- Requirements should be kept performance based to maximum extent possible
  - Allows flexible technology implementations which allows the best solutions to be applied as they are developed
  - Over specification stifles innovation and slows development and deployment of new receivers