GPS at 50: Results for Transportation and New Threats

Aviation Perspective

To: 103rd Transportation Research Board

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Chair ICAO Navigation Systems Panel

Co-Chair National PNT Engineering Forum

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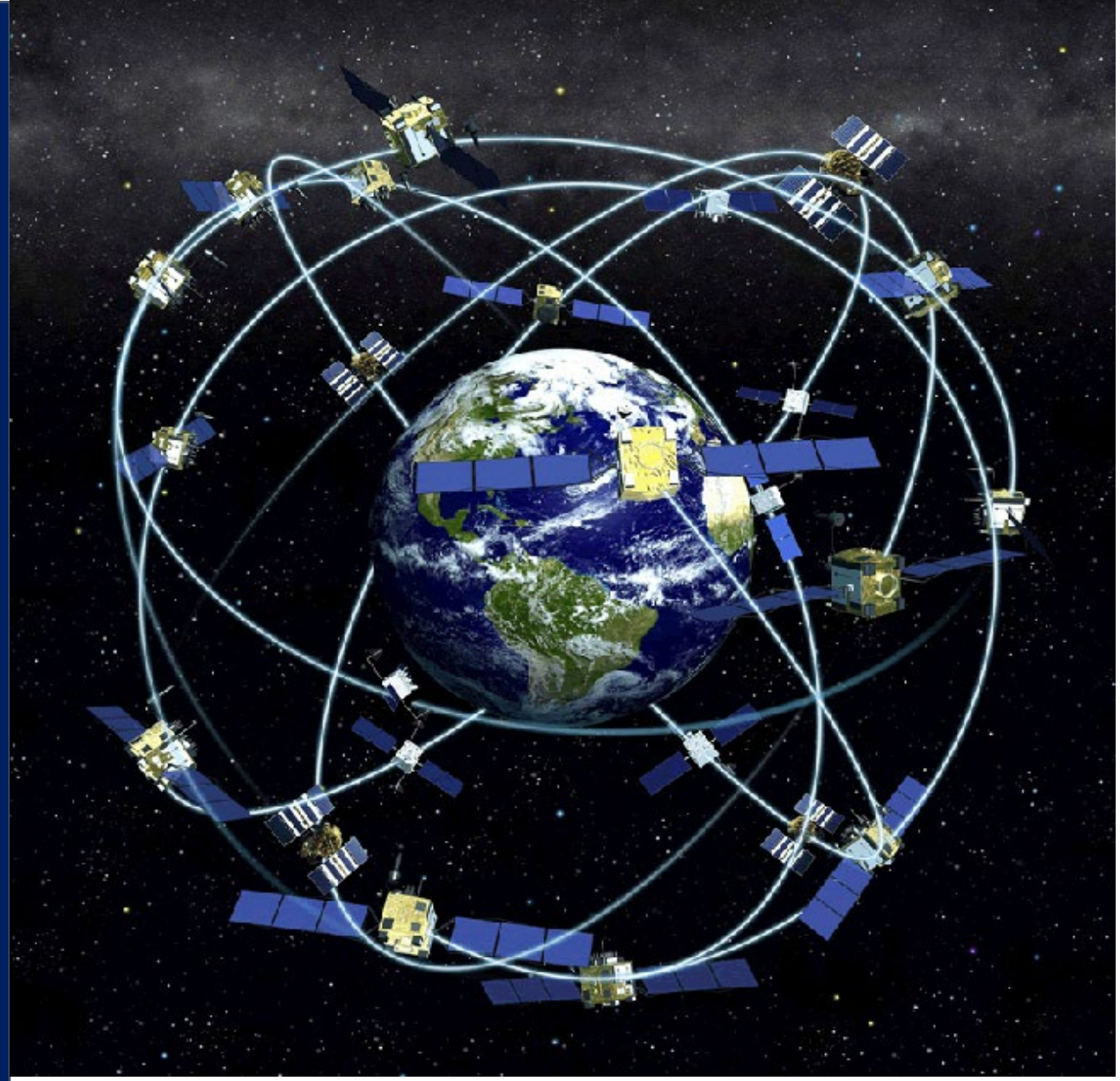


Federal Aviation Administration

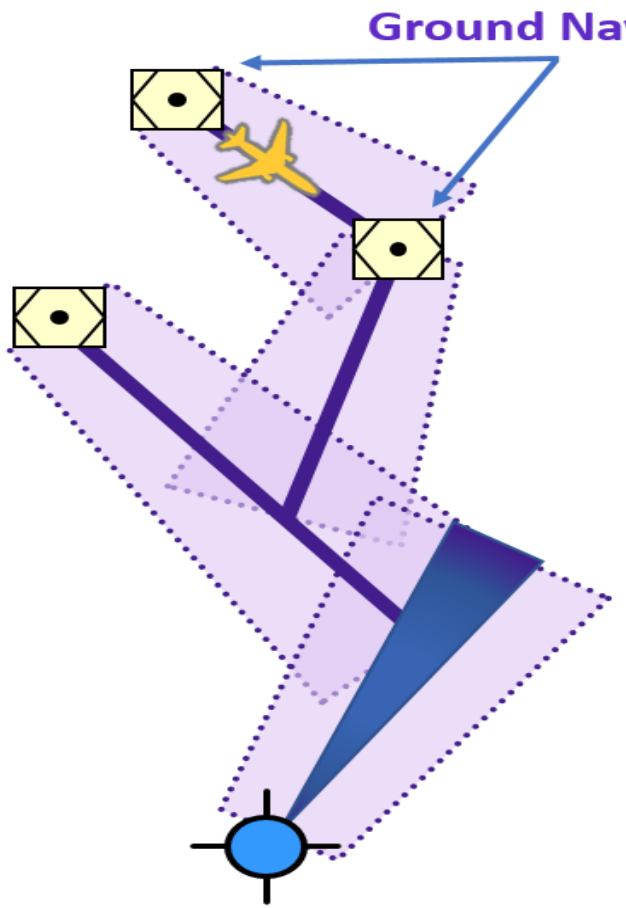
STEP SENIOR TECHNICAL EXPERTS PROGRAM

ADVANCING SAFETY THROUGH SCIENCE


DOT
FAA
DOD
DHS
DOC
NASA
OSTP
NGATS Institute
State/Local Government
Industry & Community
Air Navigation Operations and Support
Flight Operations and Support
ICAO
GPS is the Foundation for Global Aviation Operations
Super Density Operations
Policy & Regulations
Equivalent Visual Operations
Airport Operations and Support
Flight Planning
Flight Data
Aeronautical Information
Enterprise Services
Geospatial Information
Communication
Performance Metrics
Environment
Layered Adaptive Security
Surveillance
Position, Navigation, and Timing
Safety
Weather
Net Centric Infrastructure Services
Network-Enabled Information Acess

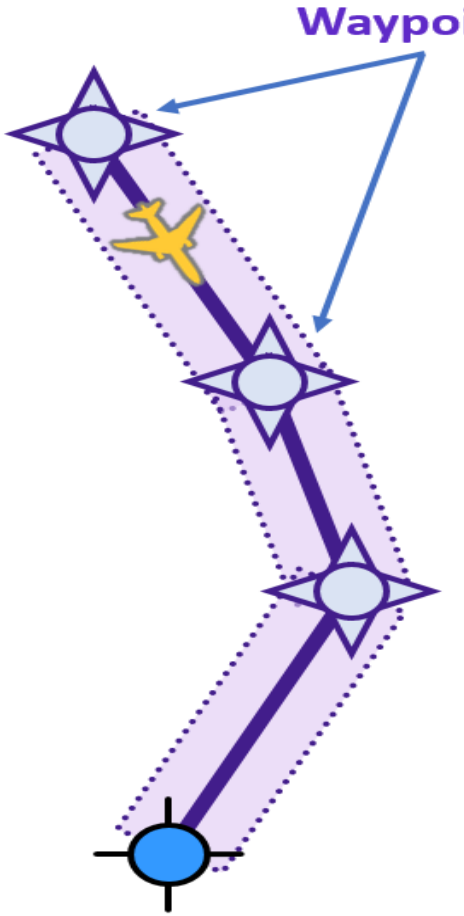
GPS Enables Performance Based Navigation (RNAV and RNP)

Conventional Routes



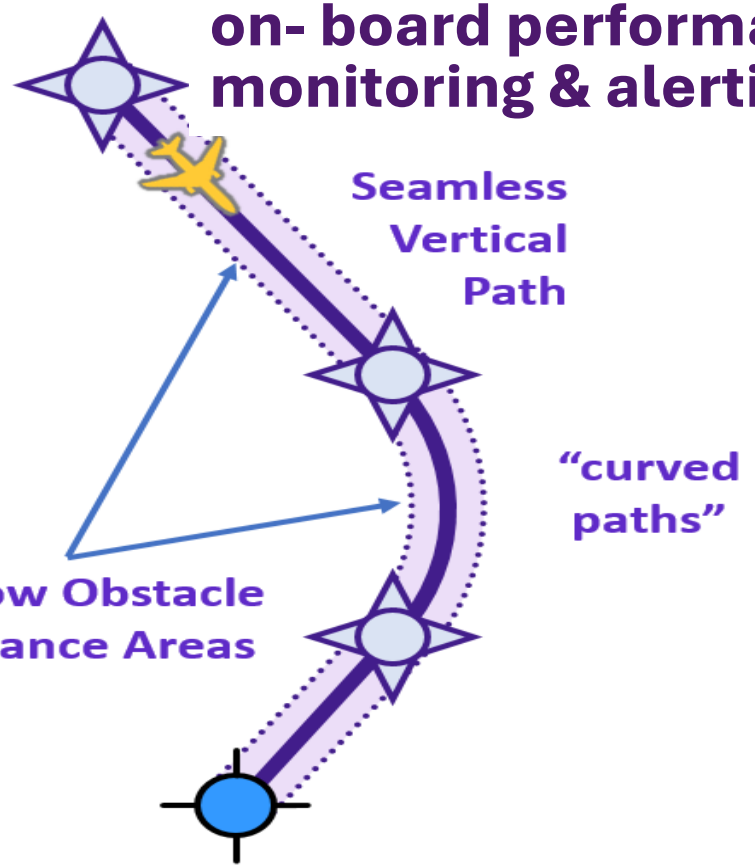
Limited Design Flexibility

RNAV (Area Navigation



Increased Airspace Efficiency

RNP (Required Navigation Performance – includes on- board performance monitoring & alerting)



Highly Optimized Use of Airspace

Trajectory Based Operations (TBO)

TBO is a collection of systems, capabilities, processes, and people working together to achieve operational objectives

Time-Based Flow Management (TBM)

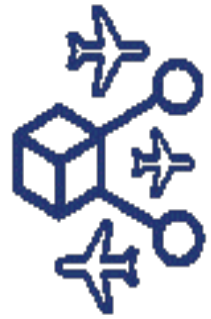
Arrival Metering
Surface Metering
Terminal Metering
Departure Scheduling
- - - and more

Helps Manage Trajectories by Scheduling and Metering Aircraft through Constraint Points

Performance Based Navigation (PBN)

Area Navigation (RNAV)
Required Navigation Performance (RNP)
Flight Management Systems (FMS)
STARS, SIDs, IAP, Routes
. . . And more

Enables Aircraft to Accurately Navigate along their Trajectories

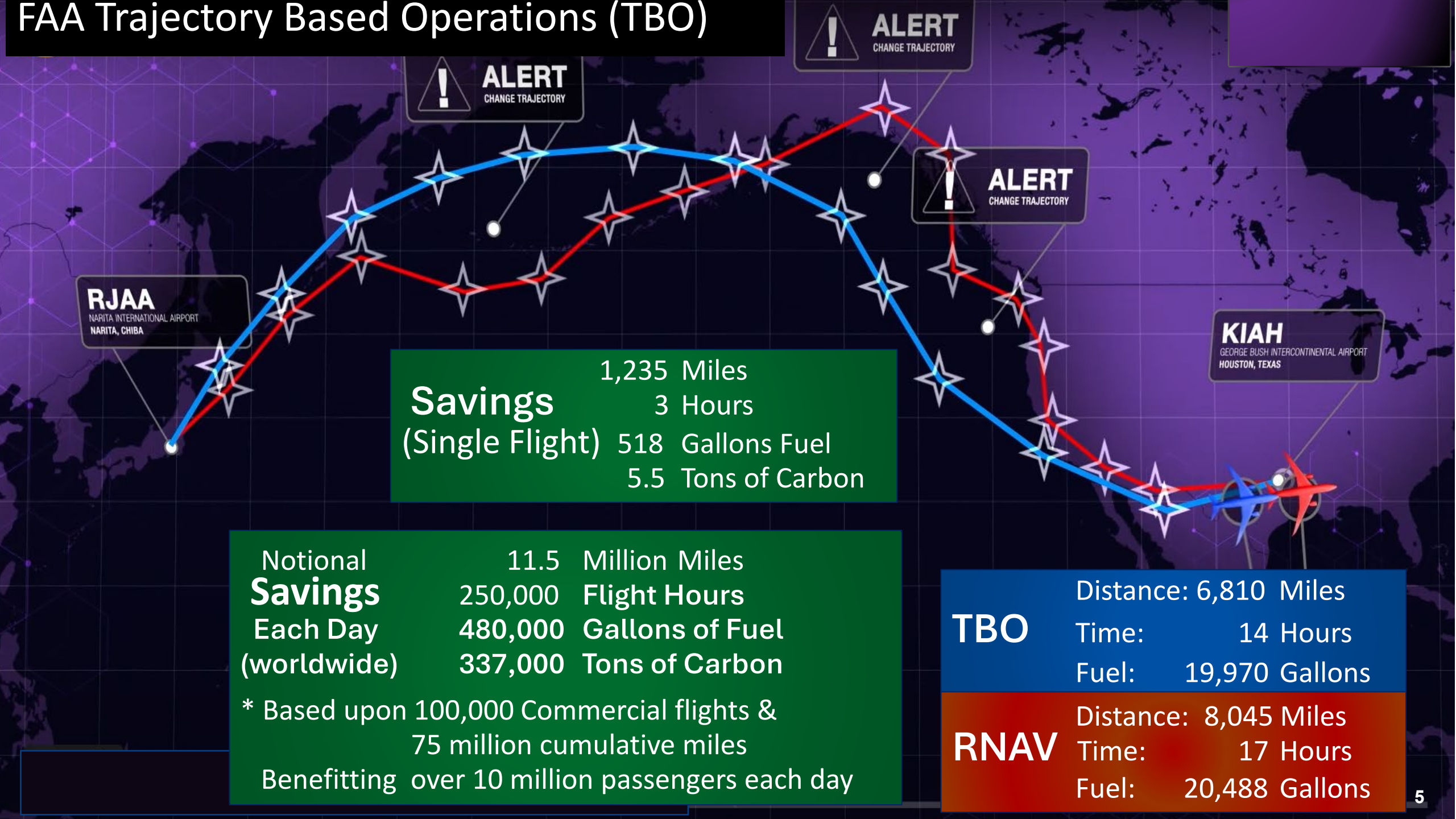


Info centric Enablers

DataComm
System-Wide Information Management
Enhanced Data Exchange
Advanced Weather Products
Airborne Rerouting
. . . And more

Expand and Automates Sharing or Common Information About Aircraft Trajectories

FAA Trajectory Based Operations (TBO)



Savings (Single Flight)

1,235	Miles
3	Hours
518	Gallons Fuel
5.5	Tons of Carbon

Notional Savings Each Day (worldwide)

11.5	Million Miles
250,000	Flight Hours
480,000	Gallons of Fuel
337,000	Tons of Carbon

* Based upon 100,000 Commercial flights & 75 million cumulative miles Benefitting over 10 million passengers each day

TBO

Distance: 6,810 Miles
Time: 14 Hours
Fuel: 19,970 Gallons

RNAV

Distance: 8,045 Miles
Time: 17 Hours
Fuel: 20,488 Gallons

FAA Next Generation Air Transportation System (NextGen)

Between 2010 and 2022 implemented capabilities generated $9.5 Billion in benefits. *(in 2022 dollars)*

Safety Benefits

encompass

$0.5 Billion

5%

Fuel Savings

amount to

$1.6 Billion

17%

Aircraft Operating Cost Savings

come to

$1.9 Billion

21%

Passenger Travel Time Savings*

make up

$5.5 Billion

57%

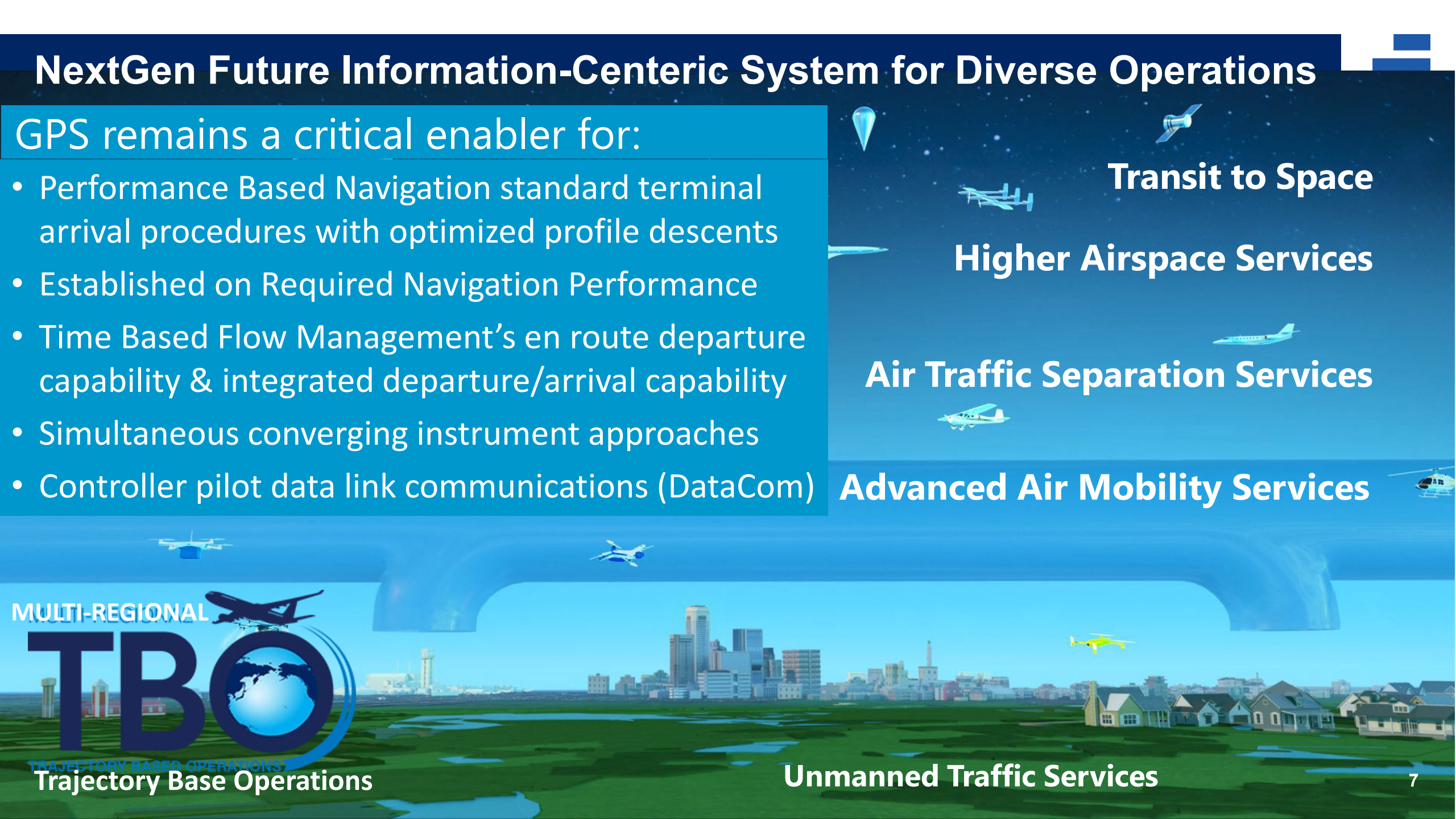
GPS is an essential FAA NextGen enabling capability

*** Per DOT guidance, the FAA values include benefits using not only aircraft operating cost savings, but also passenger travel time savings**

NextGen Future Information-Centeric System for Diverse Operations

GPS remains a critical enabler for:

- Performance Based Navigation standard terminal arrival procedures with optimized profile descents
- Established on Required Navigation Performance
- Time Based Flow Management's en route departure capability & integrated departure/arrival capability
- Simultaneous converging instrument approaches
- Controller pilot data link communications (DataCom)

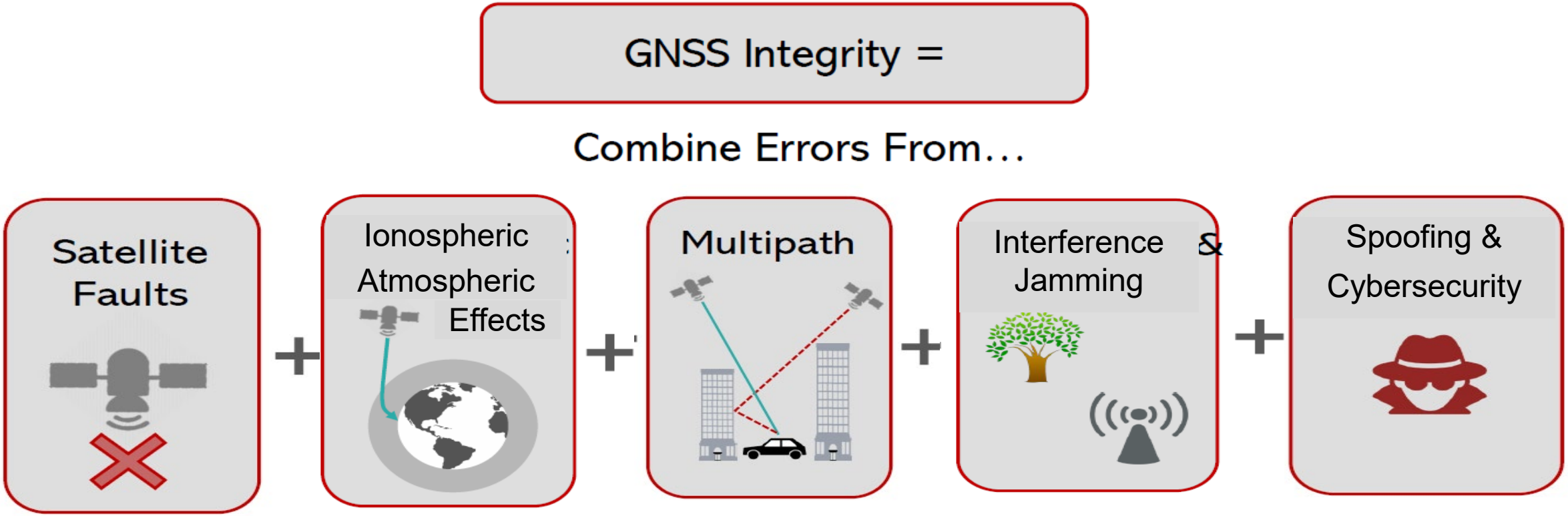


Why is civil GPS & other GNSS use vulnerable?

- Signals are extremely weak and easily overpowered (1/10th of one Millionth of one Billionth of a Watt)
- Public GPS/GNSS signals are unencrypted, unauthenticated digital data messages without security protocols
- Open public standards enable entities to easily imitate real signals
- GPS/GNSS devices are essentially networked computers with a wireless access point & antenna comparable to an internet connection or unsecured USB port
- Spoofing, tactics & techniques are available on the internet
- GPS test/maintenance equipment (e.g., simulators & re-radiators) & low-cost Software Defined Radios (SDR) can have large area effects (radio line of sight)

Can you trust GPS—Yes!
But how do you know the information you are using is coming from the GPS Satellites?

GNSS Vulnerability and Integrity



- Interference, Jamming & Spoofing can be unintentional, collateral or deliberately harmful
- Spoofing effects can include: false position and/or time, data manipulation and “zero-day” exploitation of latent uncorrected receiver software faults

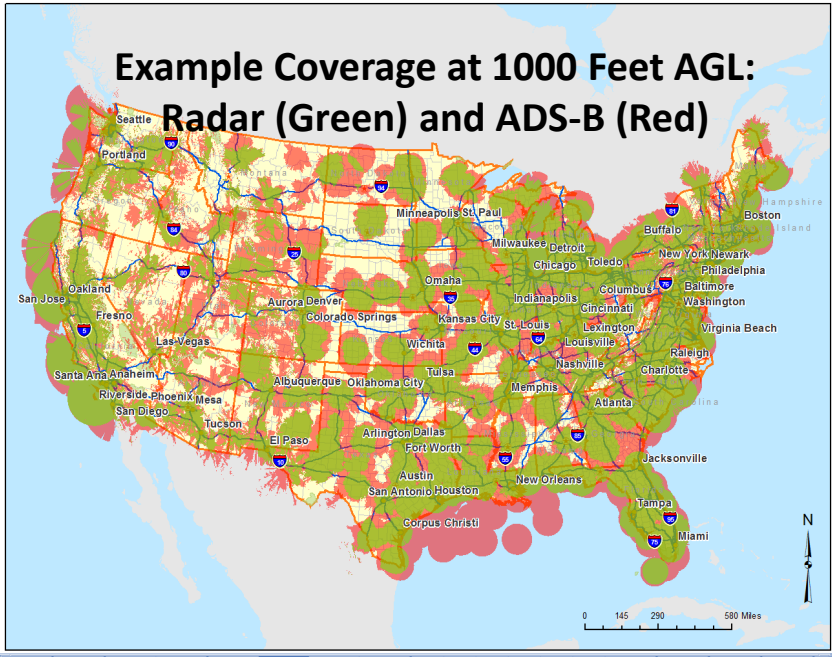
ADS-B Vulnerabilities and Mitigations

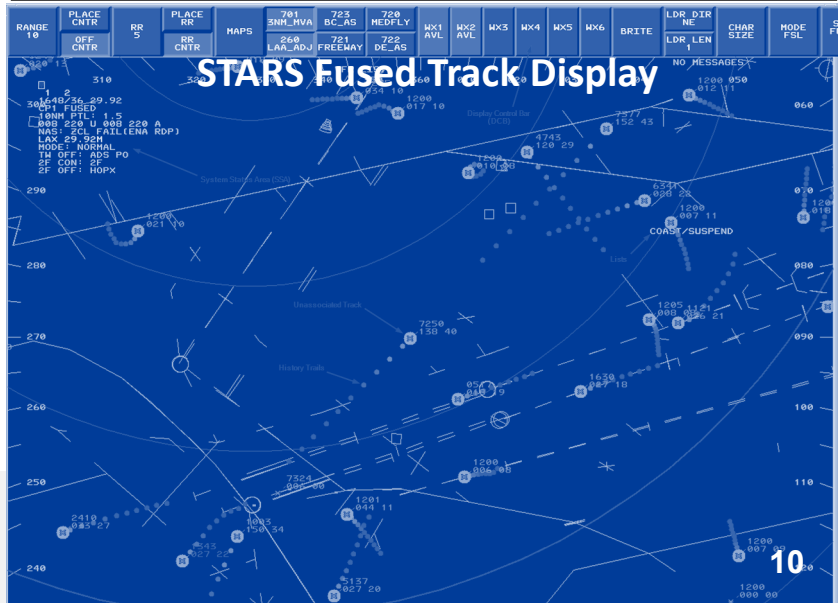
Mitigations for GPS Interference or Jamming:

- Layered capabilities ensure continued ATC surveillance operations:
  - **Automatic Dependent Surveillance Broadcast (ADS-B),**
  - **Secondary Surveillance Radar,**
  - **Wide Area Multi-lateration (WAM), and**
  - **Primary Surveillance Radar**
- Fusion processing enables continuous aircraft tracking
- GPS & ADS-B monitoring enables RF interference detection
- Aircraft performance monitoring detects ADS-B aircraft avionics anomalies for corrective action

Mitigations for GPS Spoofing

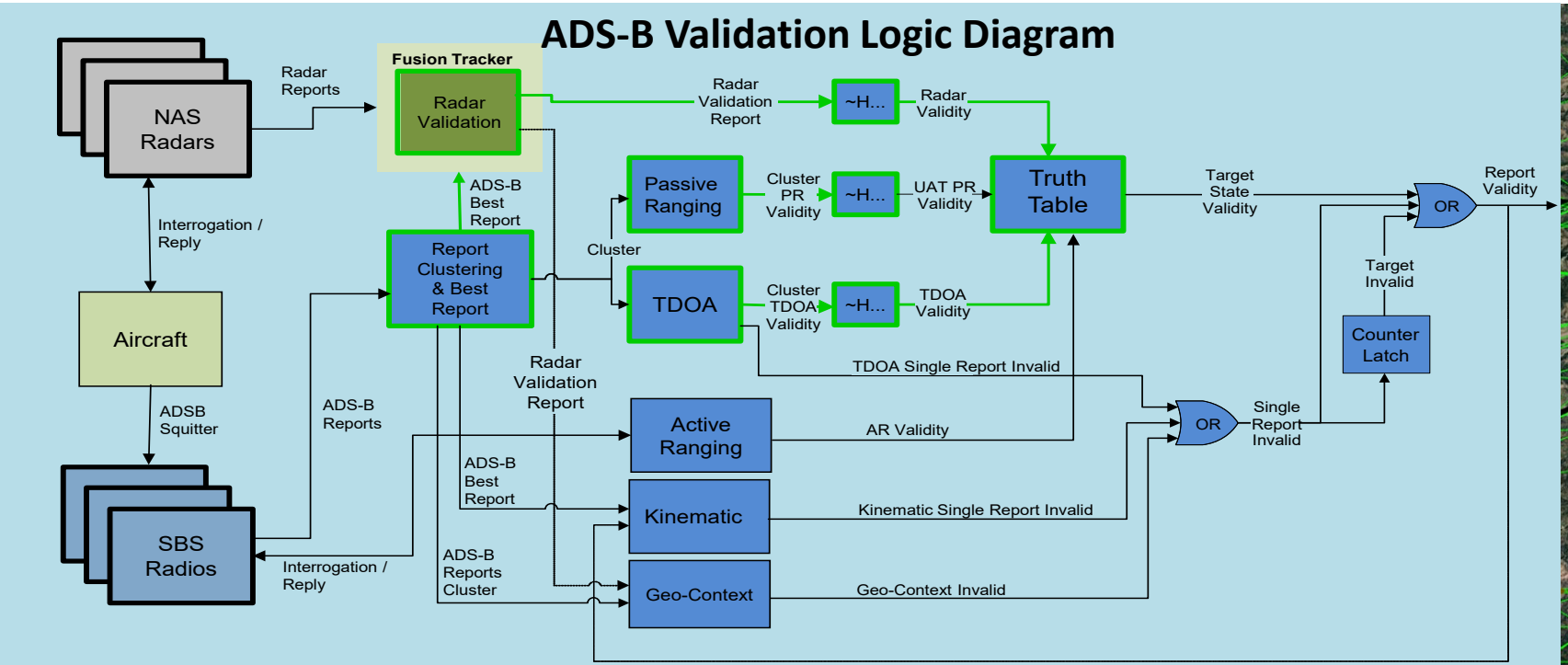
- Layered capabilities ensure position validation and continued surveillance system integrity
- Aircraft movements/spacing validated using TCAS or other means
- Aircraft detected by performance monitor as “Noncompliant” are placed on a “No Services List” & filtered from future ATC services

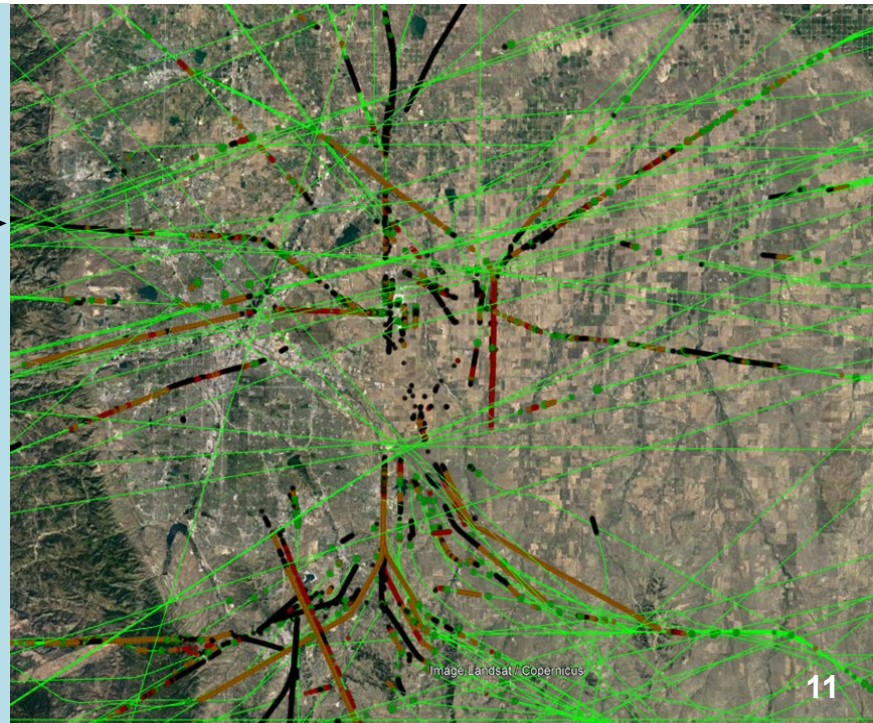




ADS-B Validation Processes

- **Time-Difference-of-Arrival (TDOA):** compares estimated position computed from multi-radio observation of ADS-B signals with ADS-B reported position
- **Radar:** compares radar track position (secondary and primary) with aircraft ADS-B reported position
- **Passive Ranging:** compares range from ground-based transceiver (GBT) with ADS-B precise time broadcast
- **Kinematics:** compares estimated position based on velocity extrapolation of track with ADS-B position
- **Geo-Context:** filters targets not detected by a required minimum number of GBTs in a defined airspace
- **Active Ranging:** compares target range from radar interrogation / reply sequence with ADS-B position





16-19 Oct 2022 FAA Cancelled Use of GPS in Greater Texas Area

- GPS interference impacted Greater Texas area
- Complex airport with 7 runways and 120 departures/hour
  - Many aircraft were unable to revert to conventional (non-GPS) for arrival, departure, and approach operations
  - Runway 35R ILS approach was out of service
  - Air Traffic Control reverted to “hands on” radar vectors
- More than 30% reduced traffic flow and six fold increase in flight delays
- Onset increased ATC and Pilot workload
  - Airport weather was good; impacts would have increased if weather degraded
- Despite extensive efforts to locate the interference source remains unknown

Executive Order 13010, *Critical Infrastructure Protection*, 15 July 1996

- Established President's Commission on Critical Infrastructure (CI) Protection to *assess scope and nature of vulnerabilities of, and threats to, CI*
- Found no evidence of an impending cyber attack that could have debilitating effects on the nation's critical infrastructure but highlighted that is not a basis for complacency
- Identified widespread capability to exploit critical infrastructure vulnerabilities
- The most significant vulnerability identified was National Airspace System (NAS) modernization plans to adopt Global Positioning System (GPS) as the sole basis for radionavigation in the U.S. by 2010
- Plan for "sole means" was abandoned; however, leveraging GPS benefits without over dependence continues to be a challenge

Executive Order 13905 *Strengthening National Resilience Through Responsible Use of Positioning, Navigation, & Timing Services*

- Acknowledges increased and growing critical infrastructure and commercial dependence on GPS/GNSS Positioning, Navigation, and Timing (PNT)
- Acknowledges PNT disruption or manipulation can adversely affect national and economic security
- Provides direction to strengthen national resilience and foster responsible use of PNT services by critical infrastructure owners and operators

"Responsible use of PNT services" means the deliberate, risk-informed use of PNT services, including their acquisition, integration, and deployment, such that disruption or manipulation of PNT services minimally affects national security, the economy, public health, and critical functions

Space Policy Directive 7 (SPD-7)

- Focus on protecting GPS and its augmentations
- Incorporates E.O. 13905 Principles for Responsible Use of GPS
- U.S. DOT direction includes:
  - Address GPS cybersecurity protections to Increase resilience against disruption and/or manipulation of GPS signals
  - Ensure earliest availability of modernized civil signals
  - Implement Federal, State, local and commercial capabilities to monitor, identify, locate, and attribute space-based PNT service disruption and manipulations within the U.S.
  - Develop international signal monitoring standards
  - Provides caution on use of some foreign GNSS (not guaranteed by USG and not protected from interference)
  - Directs pursuit of GPS and Space based augmentation system authentication (FAA's WAAS)

GPS Resiliency and the National Space Based PNT Advisory Board

National PNT Advisory Board's three-legged strategic framework known as "PTA"

We must protect, toughen & augment GPS to ensure that it continues to provide economic and societal benefits to the nation.