Backup Strategies for Navigation and Surveillance

Gary Church

Mike Harrison

Bob Lilley

International Loran Association
Mystic Marriott, Groton, CT
October 25, 2006

Backup to GPS? Why?

- Task - Independent look at backup strategies and define a transition
- Paid for by Loran's Modernization and Evaluation Program (FAA)
- Independence meant freedom to say what we feel
- Prior history with navigation and ADS-B helps
- Full report available at www.avmgt.com Click on Publications

Process Flow

Assume Backup Needed

Characterize GPS Interference

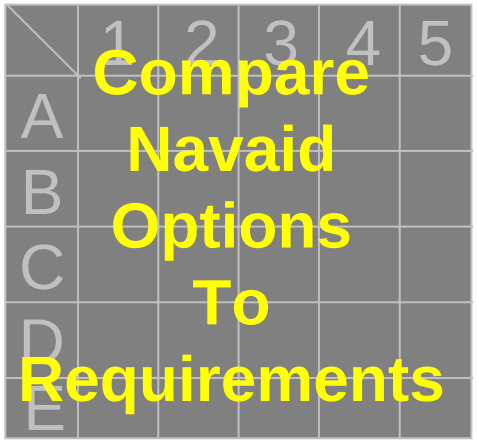
C
Inter-dependency
N S

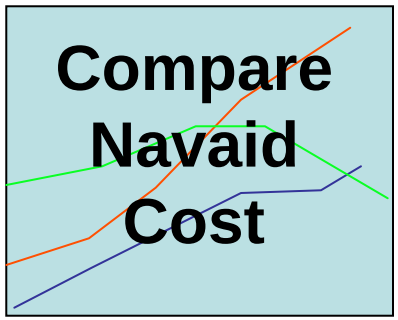
Consider ADS-B Backup

UPDATE LORAN INFO

Define a Set of Operational Requirements

- Timeframe ’09-’18
- Fleet Mix
- Traffic Growth





Define A Transition Strategy

GPS as a Target

- Target value dependent on ubiquitous use for PNT in absence of alternatives
- Target value grows with national dependency
- **First 30 minutes is a safety risk**, after that, it is an **economic** disruption
- Best defense is a little-to-no-impact backup strategy for air transportation

Backup's role is as an ***insurance policy*** against incapacitation Of GPS and the safety, capacity, and economic impacts that Could follow

Backup should be lowest cost to sustain continuing operations

Operational Requirements

- SAFETY — Aircraft shall be capable of safe flight to their destination or suitable alternate
- SAFETY — Instrument landings shall be guided by either:
  - An ILS for the runway or
  - RNP 0.3 non-precision approach
- CAPACITY / DETERRENCE — Air carrier, cargo carriers and high end general aviation shall continue to be able to depart from an airport and land at an airport experiencing interference
- WORKLOAD — Other general aviation aircraft may be restricted to visual flight rules in the presence of interference
- SAFETY / WORKLOAD — ATC shall not be required to provide radar vectors - surveillance shall not serve as a backup to intentional interference

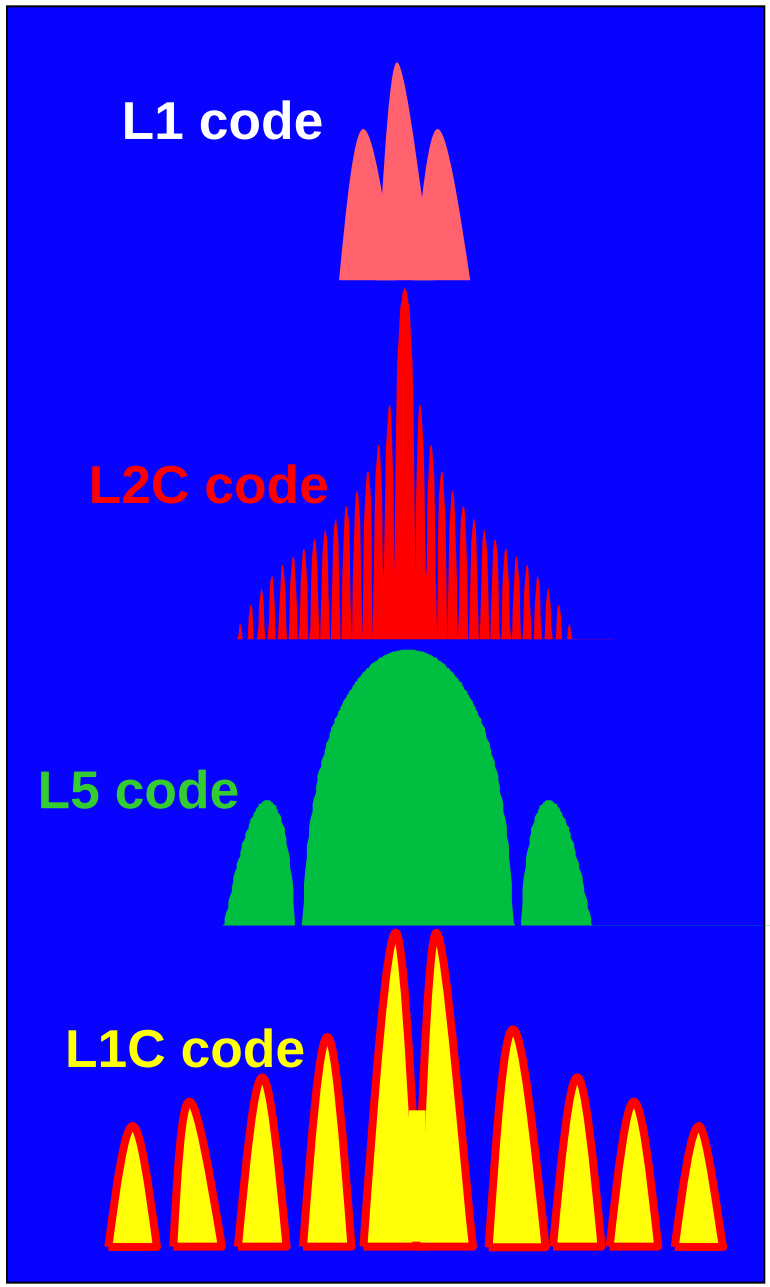
Where are we today?

- There will be a GPS backup for aviation
- The GA answer may be a downsized VOR/ILS network ***OR*** eLoran
- The air carrier answer may be a more robust DME network with aircraft IRS/FMS avionics ***OR*** eLoran

- From cost and performance standpoint, eLoran seems to be the better solution
- From an operational perspective eLoran seems to be the better solution
  - VOR/ILS requires heavy controller workload in transitioning aircraft to a VOR direct route and vectors for ILS - some airspace problems avoiding TFRs
  - IRS/FMS/DME will not provide suitable continuity of coverage unless new DME technology is deployed with a more robust network

What is Different on the GPS Side

Waveforms - new power and additional frequencies addressing unintentional narrowband interference
More Satellites with Galileo Increases availability
Significant time gap for L2, L5 and L1C



Fleet Mix Considerations

Today

Approx 4,700 Air Carriers
- 1,200 - 1,300 with IRUs

>200,000 GA aircraft
- 70,000 Garmin panel mounted GPS units to be upgraded to GPS/WAAS

Air Carriers are a 63% user of the NAS
Military 5% user

2025

Air Carrier Fleet will double
- Over 1/2 of those flying today will still be flying

GA aircraft shifting in 4 directions:
1. Sport aviation
2. GA piston and single turbos with NextGen avionics
3. Fractional and Direct owner Jets
   - VLJs
   - Corporate Business Jets
4. Legacy aircraft

Air Carriers will be less than 50% of use

Performance and Issues Matrix

Technology	Political	Operational	Economic	Technical
GPS RNAV WAAS (for comparison) **E**	Well Supported Demand for Non-aviation Services Strong	Full RNAV RNP 0.11 for Approaches 200 feet and 1/2 mile Vis	Stimulating Economic Growth In Products And Services	Require ILS for Below 200 feet And 1/2 mile Vis
INS DME/DME RNAV **E**	On Board Autonomy For En Route And Terminal	Approach to ILS or VOR Landing Only	Recapitalization And Addition of More DME Near Airports	No INS Only Approaches Inertial Precession at 2 nm/hour
VOR Minimum Operating Network	Resistance to Removal of Selected VORs Harder than Full Removal	Not an RNAV Backup Requires Training and Procedures	Recapitalization Of Retained VORs	Coverage and Airports Yet To Be Identified
Retained ILSs	Congressional Resistance to Removal of Any ILSs	Backup for Landing Only	Retained for Capacity in Low-Vis Operations	Closely-Spaced Parallel Ops Impacted by Localizer Overlaps
eLoran **E**	Strong Congressional Support for Funding and Decision	Full RNAV RNP 0.3 for En Route and Approaches	CONUS Capitalized Lowest Operations Cost	RTCA Avionics Standards Required

E **Equipage required by significant segment of fleet**

NAVAID COMPARISONS

Aircraft Safe Recovery - IMC

NAVAID	En Route	Terminal	Approach &Landing
NDB	Value in Alaska with long-range NDB	No value with ongoing decommissioning	No value with ongoing decommissioning
VOR	VOR-to-VOR direct	Proceed direct hold at VOR	Execute non-precision approach (not RNP 0.3)
TACAN	Retained full recovery capability	Penetration approaches and arrival paths	Non-precision approach (not RNP 0.3)
Loran	RNAV/RNP 1.0	RNAV/RNP 1.0	RNP 0.3 approach
DME	No value without INS	No value without INS	No value without INS
ILS	Not applicable	No terminal area maneuvering guidance	Precision approach capability assuming RNAV or radar vectors to intercept the localizer
INS (no update)	Sufficient coast-to-coast (2nm/hour precession)	RNAV to ILS localizer intercept	Insufficient for RNAV approach without position update
INS (VOR/DME or DME/DME update)	Capable of RNP 2.0	RNAV to ILS RNAV approach	RNP 0.3 if updated during approach with multiple stations within 25 nautical miles of aircraft position and proper geometry
GPS for comparison	RNAV/RNP 1.0	RNAV/RNP 1.0	RNP 0.3 approach

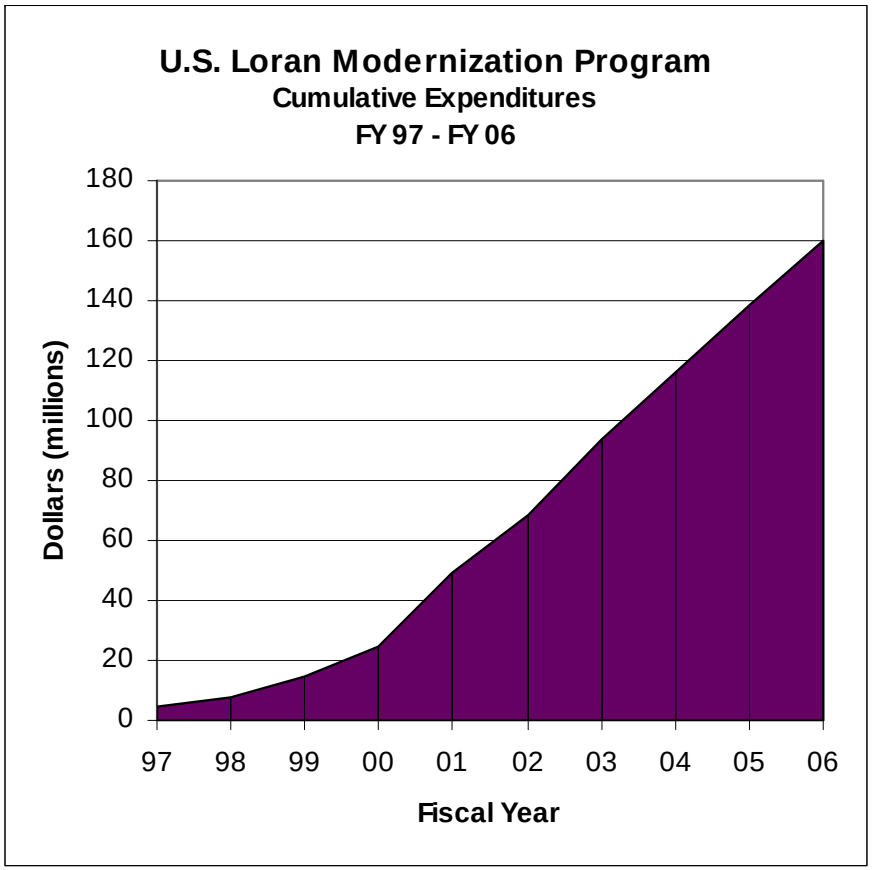
But… at the moment of failure transition is difficult

But… Missed Approach Guidance

Backup Cost Comparison

eLoran recapitalized by Congress
24 CONUS units complete
3 additional transmitters procured
4 Alaska units to be modernized

FAA annual cost range $24-27M
USCG annual cost range $34-35M
Megapulse Proposal $58M for 5 years



Navaid Category	Number in NAS	Total O&M
DME	972 **Add More**	$25,534,166
ILS (includes marker beacons, glide slope and localizer)	1134 **Retain**	$117,526,154
VOR (including VOT but not TACAN)	1141 **Recapitalize a Subset**	$47,253,799
eLoran	28	$24 Š 27 million

Source: FAA Operations Budget Allocation FY 2004

Some Thoughts on ADS-B

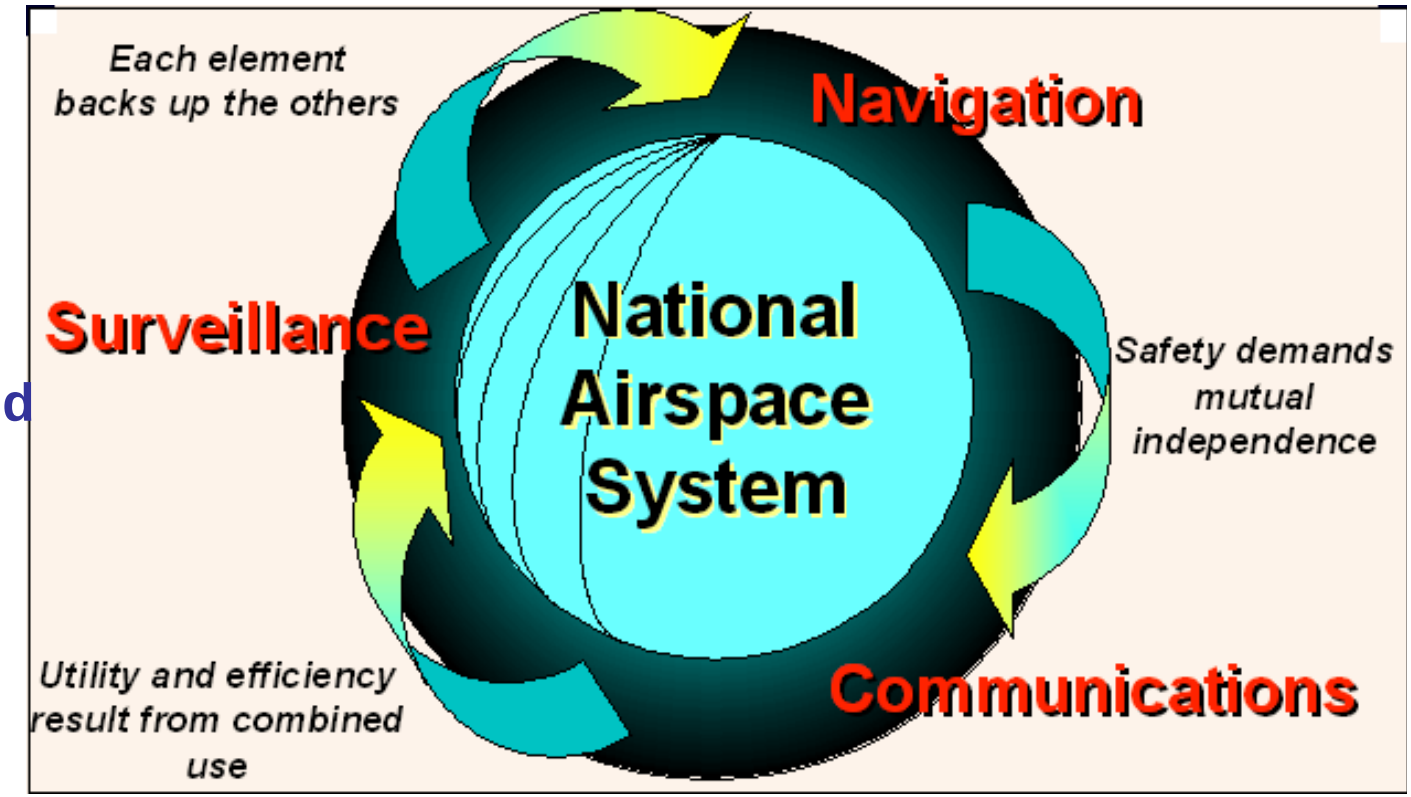
Choices

Aircraft carries the backup for both navigation and surveillance
- Independent system, but integrated in nav solution

Ground provides the backup for surveillance
- Independent of aircraft positioning

If Nav Backup can generate the position for ADS-B in absence of GPS,

Then en route ground infrastructure is unnecessary



GNSS Transition Snapshot

16 Block II/IIA
13 Block IIR
29 Operational
(June 2006)

Civil Service
Course Acquisition Code
Navigation
Precision Service
Y-Code Navigation

C/A
L1
(L1Y)
(L2Y)

Current GPS Services

Block II R - M
C/A
Adds L2C
Reduces Interference

Block IIF
C/A
Adds L5
Higher Power

Block III
C/A for Backward Compatibility
Binary Offset Carrier [BOC]
Common Baseline L1C Open Service

C/A
L1
M-Codes
L2C
Second Civil Frequency

First
Block II
R-M
(8 Birds)

C/A
L1
M-Codes
L2C
Second Civil Frequency

Second
Block II
R-M
(6 To Go)

C/A
L1
M-Codes
L2C
L5
Third Civil
Frequency

First
Block IIF
(16 Birds)

C/A
L1
L2C
L5
L1C
Galileo-compatible
Fourth Civil Frequency

First
Block III

L5 to Reach 24 Satellites

L2C to Reach 24 Satellites

Avionics Nexus

?

?

2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018

Test Sat 1

Galileo

5/08 - 1/09 As of 9/06

24 Operational

30 Satellites

Forward Compatible Standards

Manufacturing and Equipage

Nexus Direction

- GPS/WAAS with eLoran backup
- L2 and L5 interfaces - L1C interfaces for Galileo
- RNP capable
- RNAV backup to RNAV solution to CAT I ILS equivalent
- No eLoran? What are the DME/DME and VOR-VOR direct networks

What is needed?

- Standards to integrate backup into GNSS
- Decision on continuation of Loran
- Educational effort on rationale for backup
- Linking an integrated P,N&T strategy with NGATS
- Reduced operating cost of backup through outsourcing
- Government retains oversight on quality of signal

Backup Information

Operational Requirements Compared to Alternatives

Nexus Forward Fit

GNSS Transition Schedule

Global Loran Coverage

NAVAID COMPARISONS

Aircraft Safe Recovery - IMC

NAVAID	En Route	Terminal	Approach &Landing
NDB	Value in Alaska with long-range NDB	No value with ongoing decommissioning	No value with ongoing decommissioning
VOR	VOR-to-VOR direct	Proceed direct hold at VOR	Execute non-precision approach (not RNP 0.3)
TACAN	Retained full recovery capability	Penetration approaches and arrival paths	Non-precision approach (not RNP 0.3)
Loran	RNAV/RNP 1.0	RNAV/RNP 1.0	RNP 0.3 approach
DME	No value without INS	No value without INS	No value without INS
ILS	Not applicable	No terminal area maneuvering guidance	Precision approach capability assuming RNAV or radar vectors to intercept the localizer
INS (no update)	Sufficient coast-to-coast (2nm/hour precession)	RNAV to ILS localizer intercept	Insufficient for RNAV approach without position update
INS (VOR/DME or DME/DME update)	Capable of RNP 2.0	RNAV to ILS RNAV approach	RNP 0.3 if updated during approach with multiple stations within 25 nautical miles of aircraft position and proper geometry
GPS for comparison	RNAV/RNP 1.0	RNAV/RNP 1.0	RNP 0.3 approach

But… at the moment of failure transition is difficult

But… Missed Approach Guidance

NAVAID COMPARISONS

Aircraft Safe Recovery - VMC

NAVAID	En Route	Terminal	Approach &Landing
NDB	Value in Alaska with long-range NDB	No Value	No Value
VOR	Navigate VOR-to-VOR	Orient visually to airport if VOR on airport	Not needed for visual
TACAN	Retained full recovery capability	Penetration approaches and arrival paths	Non-precision approach (not RNP 0.3)
Loran	RNAV available like GPS	RNAV available like GPS	RNAV available like GPS
DME	No Value	No Value	No Value
ILS	Not applicable	Not Applicable	Not needed for visual
INS (no update)	Full RNAV capability	RNAV supports visual acquisition of airport and runway	Not needed for visual
INS (VOR/DME or DME/DME update	Full RNAV capability	RNAV supports visual acquisition of airport and runway	Not needed for visual
GPS comparison	RNAV/RNP	RNAV/RNP	RNAV/RNP

Instrument Landings

NAVAID COMPARISONS

NAVAID	Precision	Non-Precision	RNP Š 0.3
NDB	No	Yes	No
VOR	No	Yes	No
TACAN	No	Yes	No
Loran	No	Yes	Yes
DME	No	No	No
ILS	Yes	Yes	Yes
INS (no update)	No	Yes	No
INS (VOR/DME or DME/DME update	No	Yes	Yes (update with DMEs located within 25 nautical miles and acceptable geometry)
GPS/WAAS	Yes	Yes	Yes

NAVAID COMPARISONS

Continuing Operations - IMC

NAVAID	Departure	En Route	Approach	Landing
NDB	No	No	Yes	Yes
VOR	Yes (SID)	Yes	Yes (STAR)	Yes
TACAN	Yes (SID)	Yes	Yes (STAR)	Yes
Loran	Yes (RNAV)	Yes (RNAV)	Yes (RNAV)	Yes (RNAV)
DME	No	No	No	No
ILS	No	No	No	Yes
INS (no update)	Yes	Yes	Yes	No
INS (VOR/DME or DME/DME update	Yes (RNAV)	Yes (RNAV)	Yes (RNAV)	Yes (RNAV)
GPS	Yes	Yes	Yes	Yes

Except Alaska

IMC to VMC Only

But… time of outage

NAVAID COMPARISONS

Dependency on Radar Vectors

But… at the moment of failure transition is difficult

NAVAID	En Route	Terminal	Approach &Landing
NDB	No vectors required	No vectors required	No vectors required
VOR	No vectors required	No vectors required	Vectors to ILS
TACAN	Jet Routes or Direct No vectors required	Non-precision No vectors required	Ceiling 500 ft and 3/4 mile visibility
Loran	RNAV no vectors required	RNAV no vectors required	RNAV/RNP 0.3 No vectors required
DME	Vectors required	Vectors required	Vectors required
ILS	Vectors to localizer intercept	Vectors to localizer intercept	Vectors for missed approach
INS (no update)	2 nm per hour acceptable for 2 hours	Approach and landing vectors required	Approach and landing vectors to suitable other navaid for approach
INS (VOR/DME or DME/DME update	No vectors required	No vectors required	No vectors required if within 20 minutes of outage, vectors for missed approach to a suitable navaid for next approach
GPS (no interference)	RNAV no vectors required	RNAV no vectors required	RNAV/RNP 0.3 No vectors required

GNSS Transition Snapshot

16 Block II/IIA
13 Block IIR
29 Operational
(June 2006)

Civil Service
Course Acquisition Code C/A
Navigation L1
Precision Service (L1Y)
Y-Code Navigation (L2Y)

Current GPS Services

Block II R - M
C/A
Adds L2C
Reduces Interference

Block IIF
C/A
Adds L5
Higher Power

Block III
C/A for Backward Compatibility
Binary Offset Carrier [BOC]
Common Baseline L1C Open Service

C/A
L1
M-Codes
L2C
Second Civil Frequency

C/A
L1
M-Codes
L2C
L5
Third Civil Frequency

C/A
L1
L2C
L5
L1C
Galileo-compatible
Fourth Civil Frequency

First Block II R-M (8 Birds)

Second Block II R-M (6 To Go)

First Block IIF (16 Birds)

First Block III

L5 to Reach 24 Satellites

L2C to Reach 24 Satellites

?

?

2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018

Test Sat 1

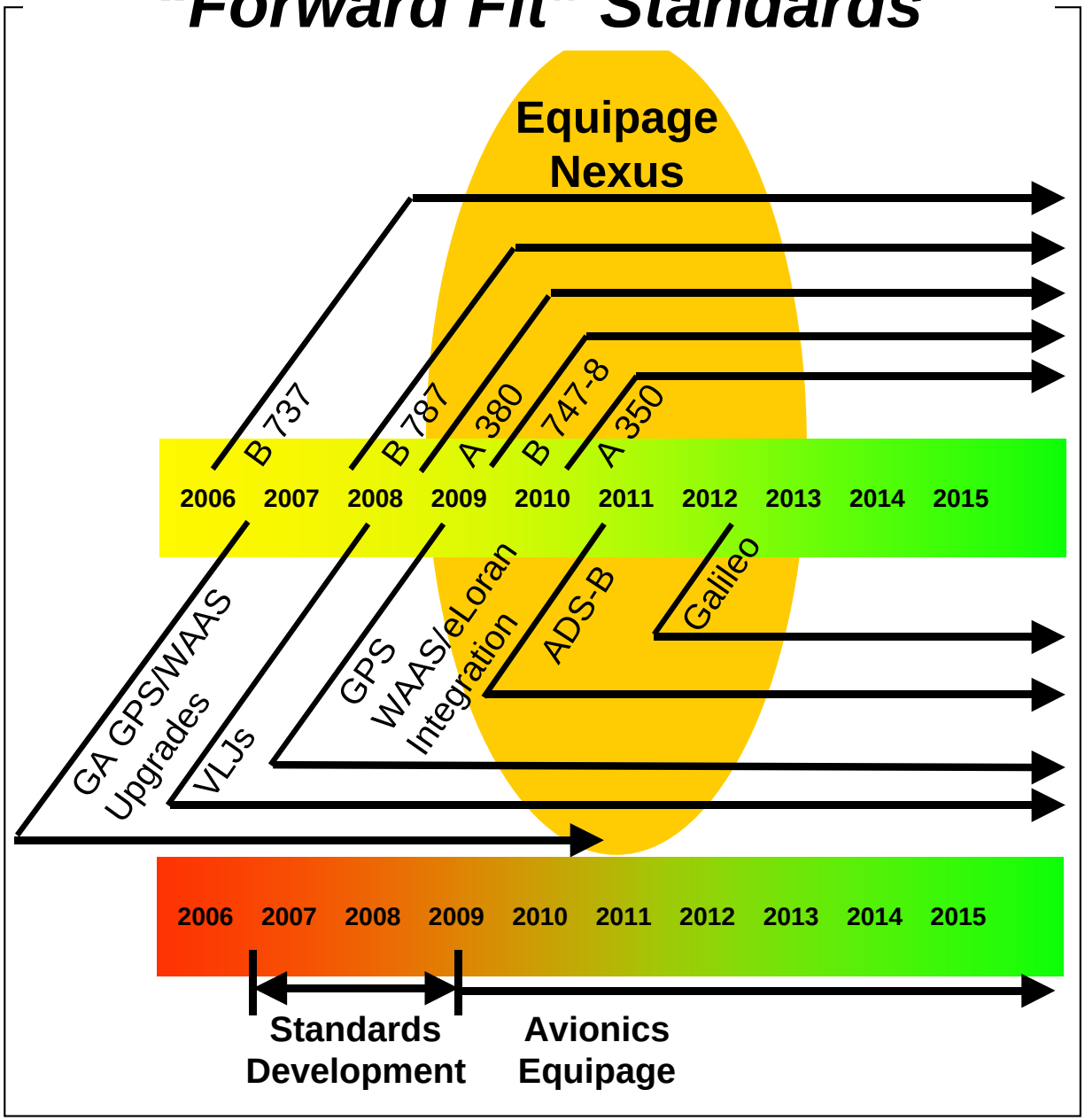
Galileo

24 Operational

30 Satellites

5/08 - 1/09
As of 9/06

This Nexus Requires Action on "Forward Fit" Standards



Fleet Age Considerations

Airline	Fleet Age	Number
AirTran	3.7	108
Alaska	10.0	110
Aloha	15.4	19
America West	11.9	108
American	13.3	699
American Eagle	5.3	267
ATA	6.6	25
Continental	8.5	356
Delta	13.1	434
Horizon	5.6	67
Jet Blue	2.8	97
Midwest	9.3	35
Northwest	10.8	266
Southwest	9.4	445
United	11.7	401
US Airways	10.4	248

3,685

Source: AirSafe.com, as of April 2006

What's flying today we will be there in 2018

Global Interoperability
Loran Coverage Where Most Flights Exist