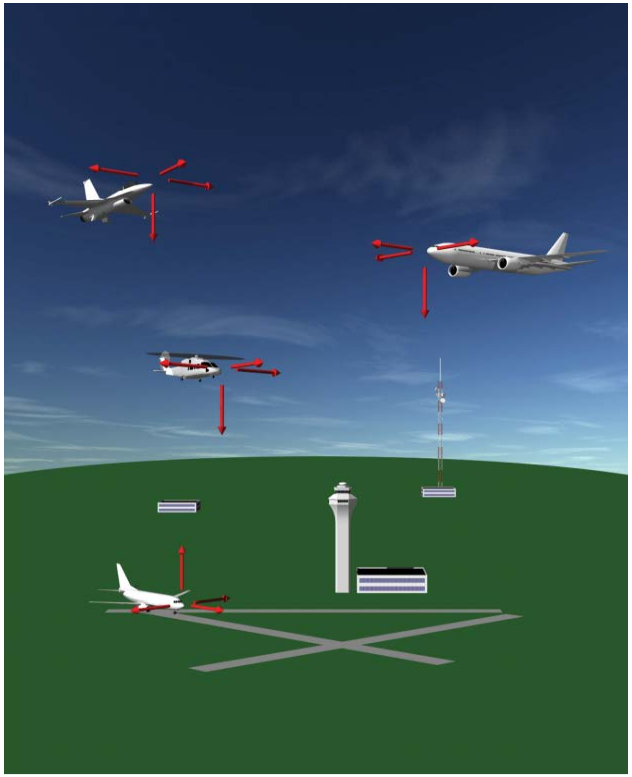
Overview of Automatic Dependent Surveillance-Broadcast (ADS-B) Out

Module Objectives

- Definition of ADS-B
- Overview of ADS-B OUT
- ADS-B Messages
- Aircraft Systems
- ADS-B Performance and Compliance

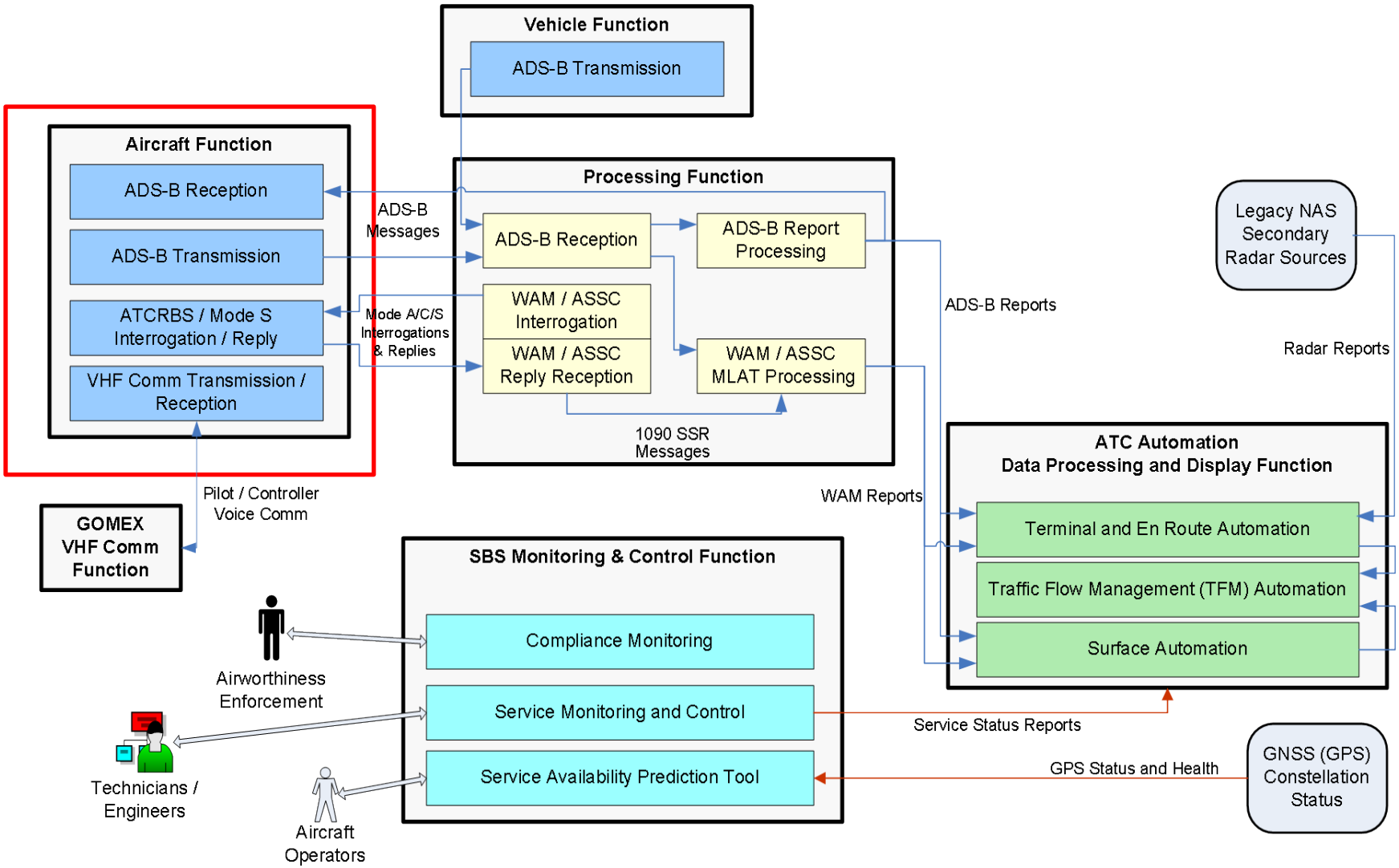
Automatic Dependent Surveillance - Broadcast (ADS-B)

- **A**utomatic
  - Periodically transmits information with no pilot or operator involvement required
- **D**ependent
  - Position and velocity vectors are derived from the Global Positioning System (GPS) or other suitable Navigation System (i.e., FMS)
- **S**urveillance -
  - A method of determining 3 dimensional position and identification of aircraft, vehicles, or other assets
- **B**roadcast
  - Transmitted information available to anyone with the appropriate receiving equipment



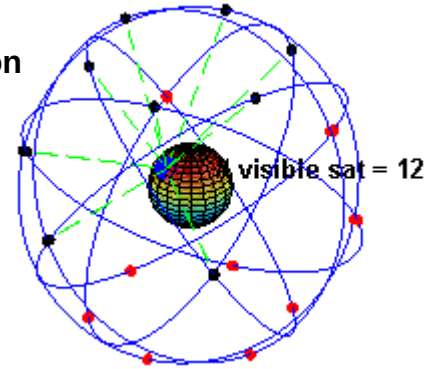
- **Satellite-based Cooperative Surveillance Technology**
- **Allows pilots and controllers to have a common picture of airspace**
- **Allows for common situational awareness to all equipped users of the airspace**

FAA Surveillance Functional Architecture

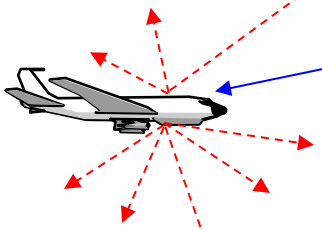


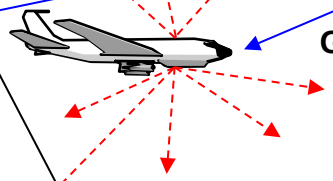
ADS-B “OUT”

GPS position



GNSS Satellite constellation



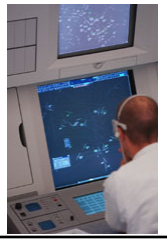


GPS position

ADS-B transmissions

ADS-B Station

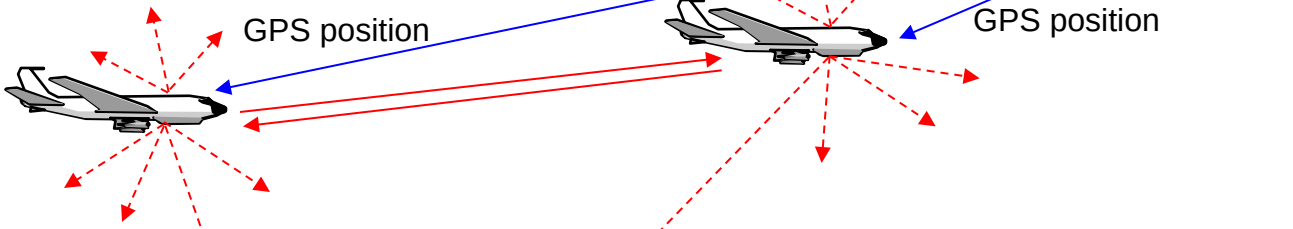
(multi-sensor) Surveillance Data Processing

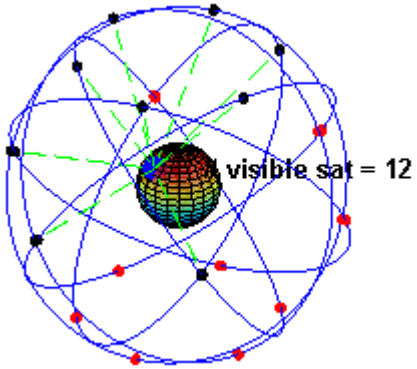


ATC Center

ADS-B “IN” Overview

ADS-B “out” ➔ ADS-B “in”
Requires in the aircraft:
- **ADS-B receiver**
- **ADS-B data processing**
- **Cockpit Display**





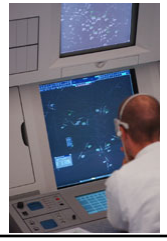
GNSS Satellite constellation

ADS-B transmissions

ADS-B data from certified 1090ES transponder

ADS-B Station

(multi-sensor) Surveillance Data Processing



ATC Center

ATCO remains responsible for separation

ADS-B Components

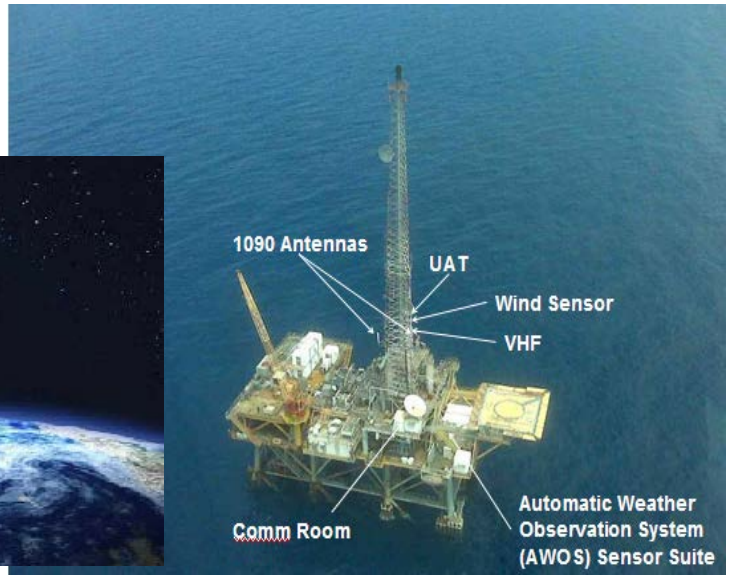
ADS-B OUT - airborne

- Mode S Transponder
- Extended Squitter enabled

ADS-B OUT - receiver

- Antenna + Receiver
- Adapted Surveillance Processor

FAA ADS-B Receiver Systems



ADS-B Technologies

- 1090 MHz Extended Squitter (1090ES)
  - Implemented widely on commercial traffic
  - Initial carriage facilitated by European Mode S mandate and the FAA ADS-B OUT Final Rule publications
  - 1090 MHz Extended Squitter is the preferred International link
- UAT
  - UAT = Universal Access Transceiver at 978 MHz
  - Used in USA (mainly for General Aviation aircraft)
  - Regional implementations
- VDL Mode 4
  - VDL = VHF Digital Link, Mode 4
  - Regional implementation

*** It is important to note that 1090 MHz is the internationally approved frequency**

ADS-B Out Messages

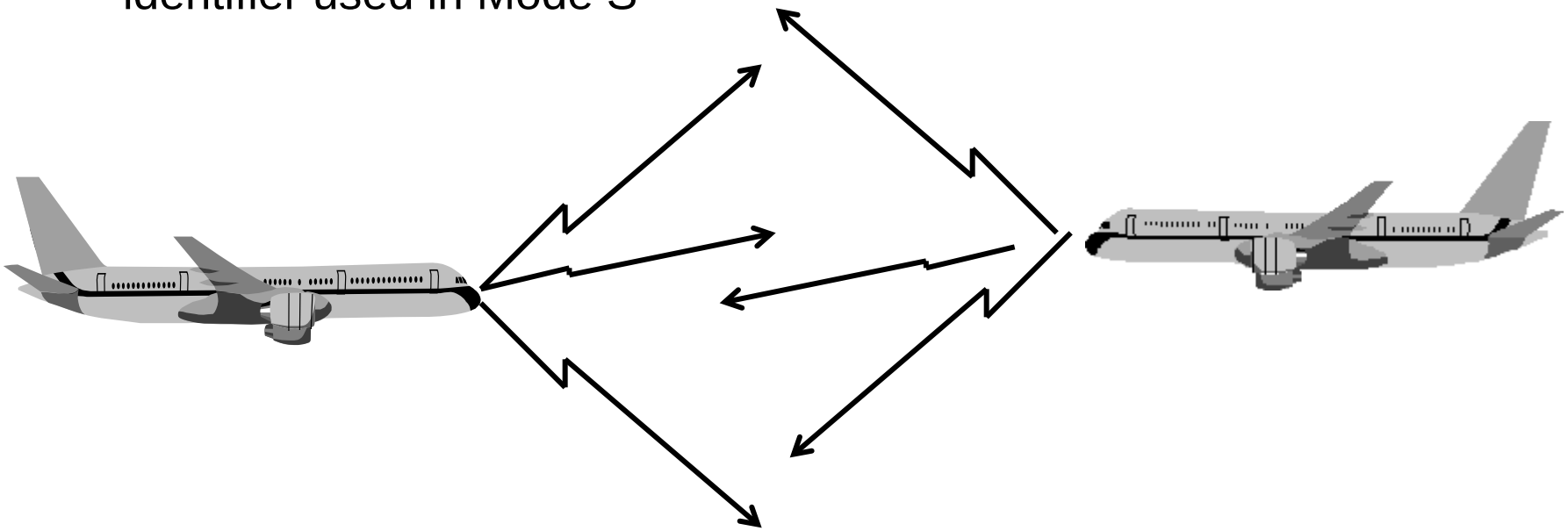
- The ADS-B Out equipment is designed to transmit two different message sets:
  - “Short Squitter” (also known as the Mode S Acquisition Squitter)
  - Extended Squitter

- Acquisition squitters include minimal information and allow systems on other aircraft (e.g., ACAS) to acquire a target without the need to interrogate.

- Extended squitters provide additional information based on the Minimum Operational Performance Standards (MOPS) that the avionics system is designed to:
  - DO-260 (Version 0)
  - DO-260A (Version 1)
  - DO-260B (Version 2)
  - DO-260C (Version 3), approved December 2020

Acquisition Squitter

- The Mode S transponder outputs an unsolicited transmission once per second to enable ACAS to acquire Mode S equipped aircraft
  - carries only the ICAO 24 bit a/c address, which is a unique aircraft identifier used in Mode S



MODE S SHORT SQUITTER (56 BITS)

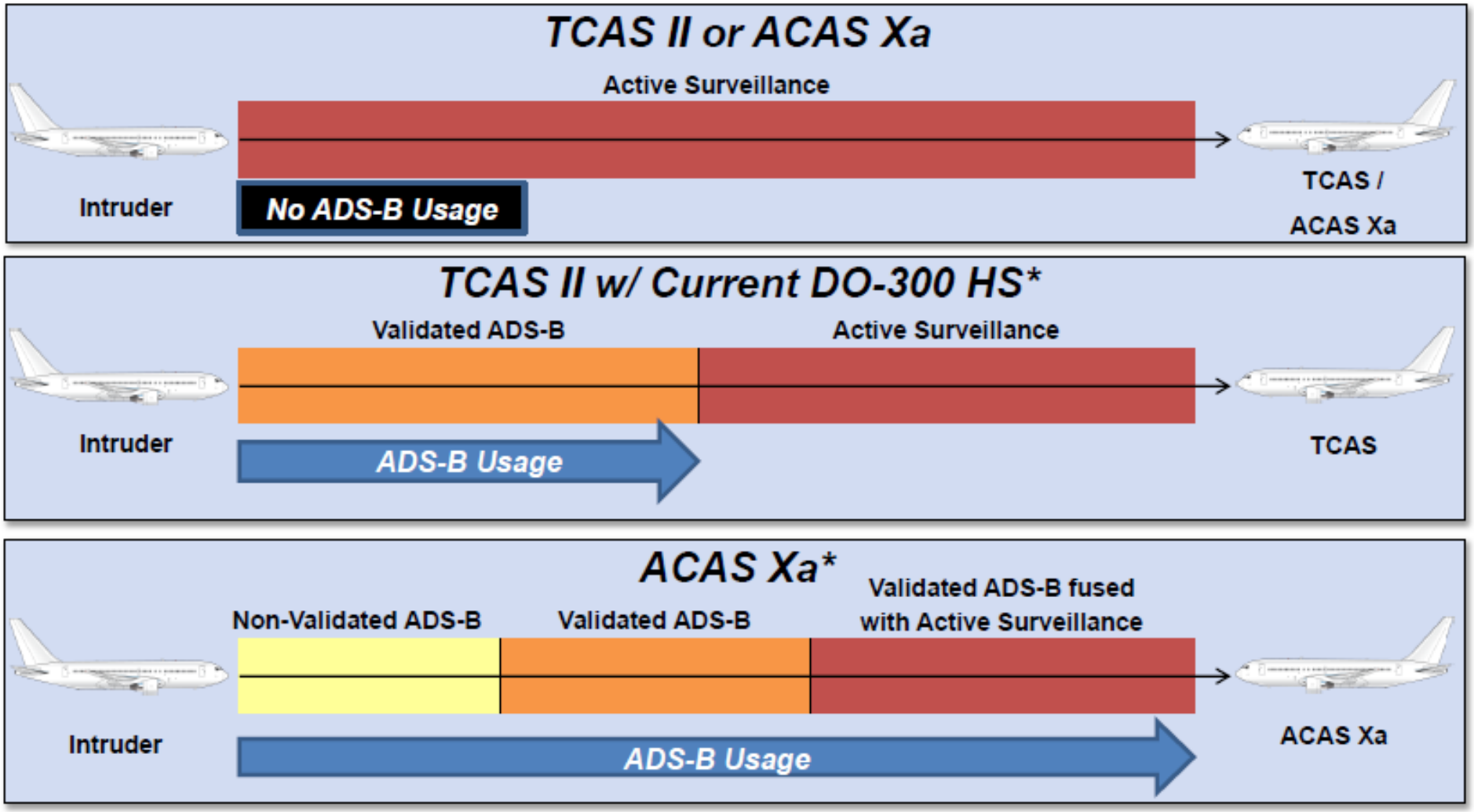
8 bit CONTROL	24 bit A/C ADDRESS	24 bit PARITY

TRANSMITTED ONCE PER SECOND

ACAS X Overview

- ACAS X is a family of next generation aircraft collision avoidance systems.
  - Backward / forward compatible
  - ACAS Xa and Xo MOPS have been published (RTCA DO-385 MOPS)
- Provides the same general role as TCAS II:
  - Surveillance of nearby aircraft
  - Generation of Traffic Advisory/Resolution Advisory
  - Coordination with other aircraft collision avoidance systems
- Supports New Capabilities:
  - Leverages Additional Surveillance Sources (e.g., ADS-B)
  - Intended for multiple types of host aircraft (commercial, general aviation, rotorcraft, UAS)

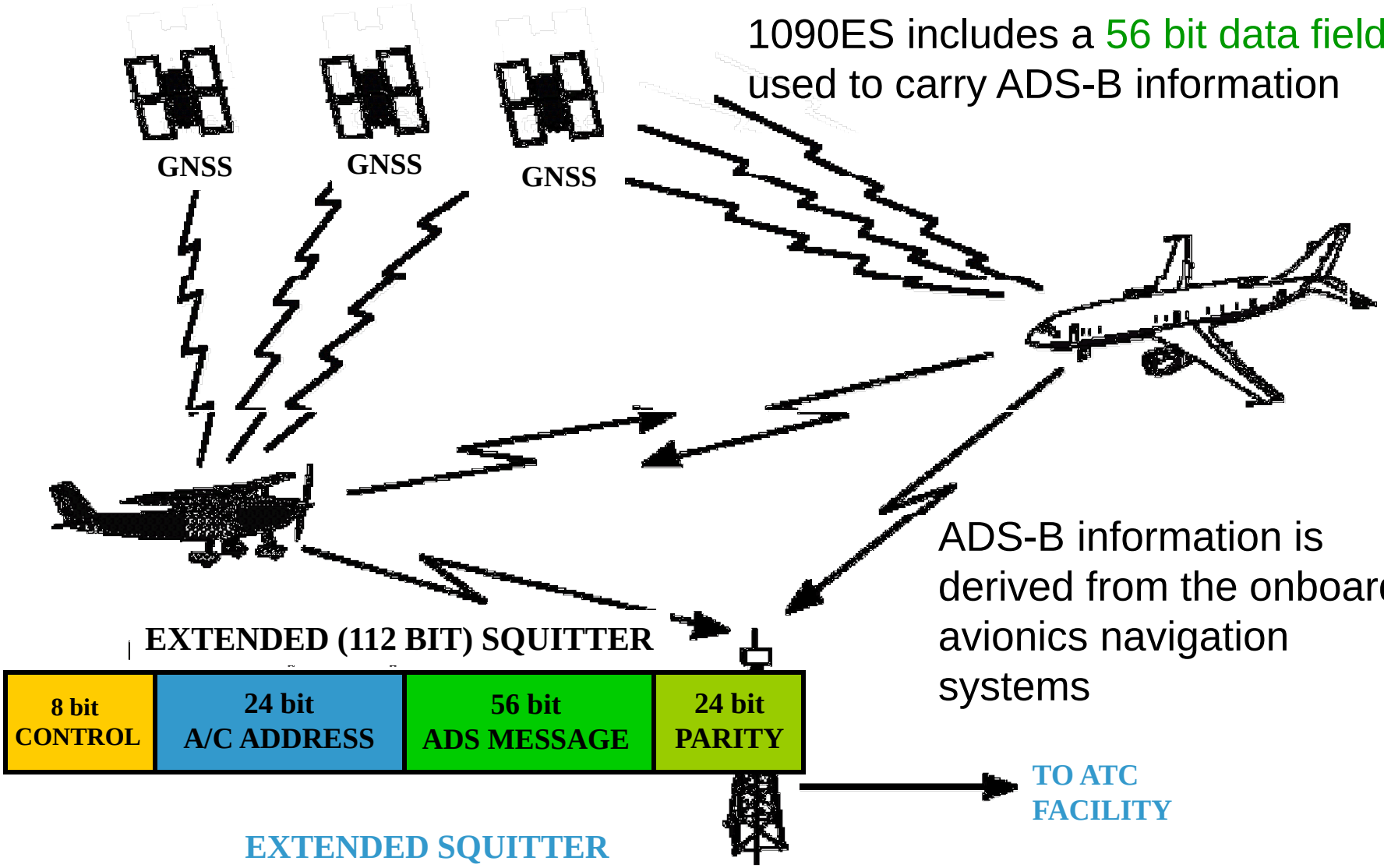
Use of 1090ES for Surveillance



*** Requires hardware that can receive and decode 1090ES DF17 messages**

1090ES Message Format

1090ES includes a 56 bit data field used to carry ADS-B information



ADS-B information is derived from the onboard avionics navigation systems

BDS Registers

- BDS Registers are specified in ICAO Doc 9871, Edition 2, and the Mode S SARPs
  - BDS registers are also referred to as GICB registers because they can be downlinked via “Ground Initiated Comm B transactions”
- Each register contains the data payload of a particular Mode S reply or extended squitter
- Registers not updated within a fixed period are cleared by the transponder
- Registers are identified by a two digit hex number
  - for example BDS 05h or BDS 0,5 is the position squitter
- Certain BDS registers refer specifically to 1090ES

BDS Registers in ED-102A/DO-260B

Table 2-79: 1090 MHz Extended Squitter ADS-B Message Broadcast Rates

			Broadcast Rate		
Transponder Register	Event-Driven Message Priority	1090ES ADS-B Message	On-the-Ground, not moving	On-the-Ground and moving	Airborne
BDS 0,5	N/A	Airborne Position	N/A	N/A	2 / 1 second (0.4 – 0.6 sec)
BDS 0,6	N/A	Surface Position	LOW RATE 1 / 5 seconds (4.8 – 5.2 sec)	HIGH RATE 2 / 1 second (0.4 – 0.6 sec)	N/A
BDS 0,8	N/A	Aircraft Identification and Category	LOW RATE 1 / 10 seconds (9.8 – 10.2 sec)	HIGH RATE 1 / 5 seconds (4.8 – 5.2 sec)	HIGH RATE 1 / 5 seconds (4.8 – 5.2 sec)
BDS 0,9	N/A	Airborne Velocity	N/A	N/A	2 / 1 second (0.4 – 0.6 sec)
BDS 6,1	TCAS RA = 1 Emergency = 2	Aircraft Status (Emergency/Priority Status, Subtype=1) (TCAS RA Broadcast, Subtype=2)	TCAS RA or Mode A Code Change 0.7 – 0.9 seconds		
			No TCAS RA, No Mode A Change 4.8 – 5.2 seconds		
			No TCAS RA, No Mode A Change, No Emergency, Mode A Code set to 1000_8 No Transmission		
BDS 6,2	N/A	Target State and Status (TSS)	N/A	N/A	1.2 – 1.3 seconds
BDS 6,5	N/A	Aircraft Operational Status	4.8 – 5.2 seconds	No change NIC_{SUPP}/NAC/SIL 2.4 – 2.6 seconds	TSS being broadcast or not No change TCAS/NAC/SIL/NIC_{SUPP} 2.4 – 2.6 seconds
				Change in NIC_{SUPP}/NAC/SIL 0.7 – 0.9 seconds	TSS being broadcast Change in TCAS/NAC/SIL/NIC_{SUPP} 2.4 – 2.6 seconds
					TSS not broadcast [2] Change in TCAS/NAC/SIL/NIC_{SUPP} 0.7 – 0.9 seconds

N/A = Not Applicable

BDS Registers in ED-102B/DO-260C

Table 2-79: 1090 MHz Extended Squitter ADS-B Message Broadcast Rates

Transponder Register	1090ES ADS-B Message	Broadcast Rate		
		Surface, not moving	Surface and moving	Airborne
BDS 0,5	Airborne Position (see Note 5)	N/A	N/A	2 / 1 second (0.4 – 0.6 sec)
BDS 0,6	Surface Position	LOW RATE 1 / 5 seconds (4.8 – 5.2 sec)	HIGH RATE 2 / 1 second (0.4 – 0.6 sec)	N/A
BDS 0,8	Aircraft Identification and Category	LOW RATE 1 / 10 seconds (9.8 – 10.2 sec)	HIGH RATE 1 / 5 seconds (4.8 – 5.2 sec)	HIGH RATE 1 / 5 seconds (4.8 – 5.2 sec)
BDS 0,9	Airborne Velocity (see Note 6)	N/A	N/A	2 / 1 second (0.4 – 0.6 sec)
BDS 3,0	Aircraft Status (Subtype=2 "TCAS RA Broadcast") (see Note 1)	N/A	N/A	0.7 – 0.9 seconds
BDS 6,1	Aircraft Status (Subtype=1 "Emergency/Priority Status and Mode A Code")	Mode A Code Change/Emergency Active 0.7 – 0.9 seconds		
		No Mode A Change and No Emergency Active 4.8 – 5.2 seconds		
BDS 6,2	Target State and Status (TSS)	N/A	N/A	1.2 – 1.3 seconds
BDS 6,3	Aircraft Status (Subtype=4 "UAS/RPAS Contingency" Current/Next TCP) (see Notes 1, 2 and 7)	N/A	N/A	4.8 – 5.2 seconds
BDS 6,4				
BDS 6,5	Aircraft Operational Status	4.8 – 5.2 seconds	No change NIC_{SUPP}/NAC/SIL 2.4 – 2.6 seconds	TSS being broadcast or not No change CAS/NAC/SIL/NIC_{SUPP} 2.4 – 2.6 seconds
			Change in NIC_{SUPP}/NAC/SIL 0.7 – 0.9 seconds	TSS being broadcast Change in CAS/NAC/SIL/NIC_{SUPP} 2.4 – 2.6 seconds
				TSS not broadcast Change in CAS/NAC/SIL/NIC_{SUPP} 0.7 – 0.9 seconds

N/A = Not Applicable

BDS Registers in ED-102B/DO-260C

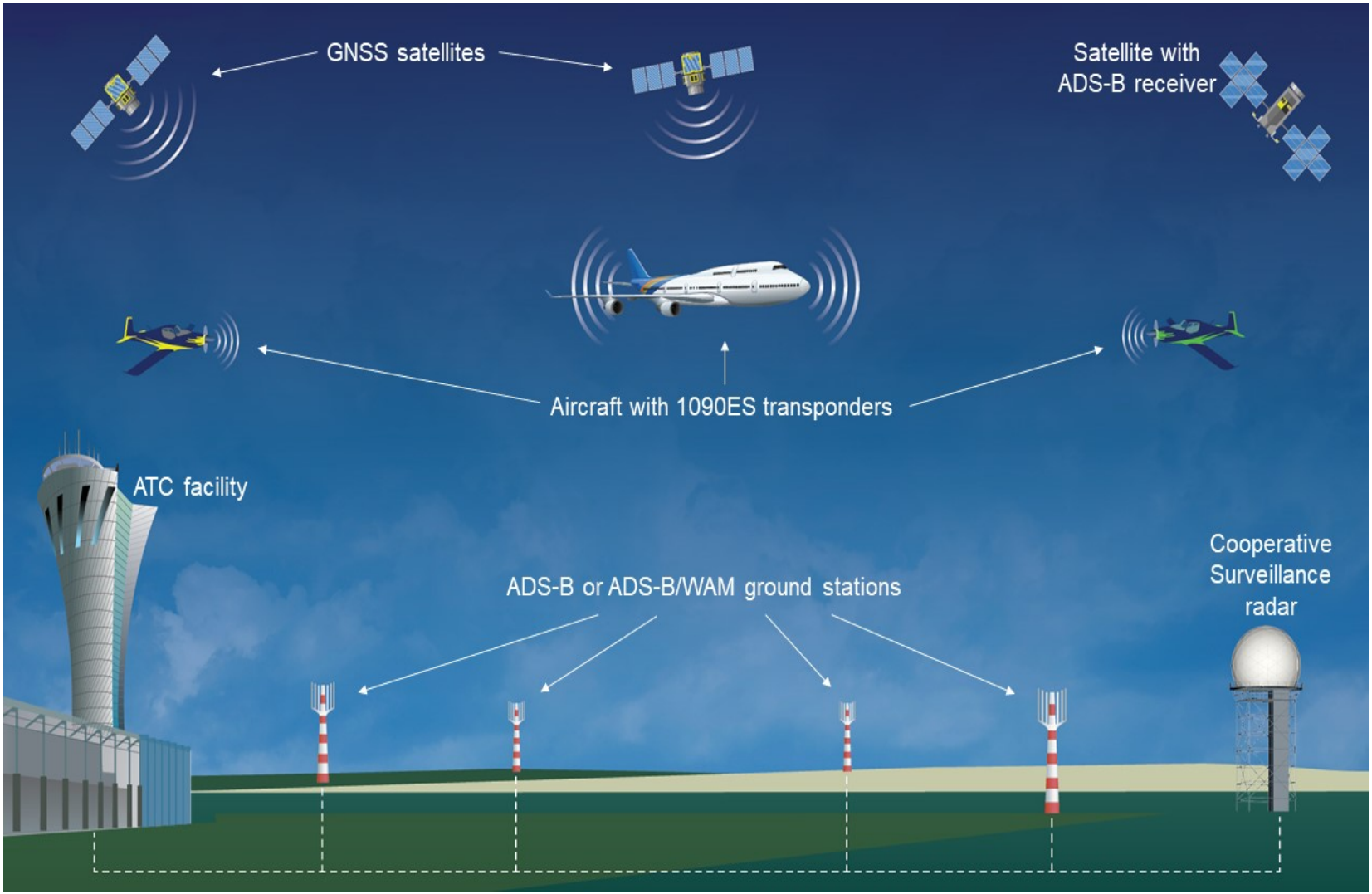
Table 2-79: 1090 MHz Extended Squitter ADS-B Message Broadcast Rates

N/A = Not Applicable

Transponder Register	1090ES ADS-B Message	Broadcast Rate: Surface, not moving	Broadcast Rate: Surface and moving	Broadcast Rate: Airborne
BDS 6,8	ADS-Wx AIREP (Subtype=0 "Aircraft State") (see Note 7)	LOW RATE 1 / 10 seconds (9.8 – 10.2 sec)	HIGH RATE 1 / 5 seconds (4.8 – 5.2 sec)	HIGH RATE 1 / 5 seconds (4.8 – 5.2 sec)
BDS 6,9	ADS-Wx AIREP (Subtype=1 "Weather State") (see Notes 4 and 7)	N/A	N/A	1 / 2.2 seconds (2.1 – 2.3 seconds)
BDS 6,A	ADS-Wx AIREP (Subtype=2 "Alternate Weather State") (see Notes 4 and 7)			
BDS 6,B	ADS-Wx PIREP (Subtype=0 "Flight Weather") (see Notes 1, 3 and 7)	PIREP Active 3 / 10 seconds (3.1 – 3.5 seconds)		
BDS 6,C	ADS-Wx PIREP (Subtype=1 "Temp, Wind & Turbulence") (see Notes 1, 3 and 7)			
BDS 6,D	ADS-Wx PIREP (Subtype=2 "Hazardous Weather") (see Notes 1, 3 and 7)			
BDS 6,E	High Velocity and/or Altitude (Subtype=0 "HVA Position") (see Notes 5 and 7)	N/A	N/A	2 / 1 second (0.4 – 0.6 sec)
BDS 6,F	High Velocity and/or Altitude (Subtype=1 "HVA Velocity") (see Notes 6 and 7)	N/A	N/A	2 / 1 second (0.4 – 0.6 sec)

Notes for Table 2-79:

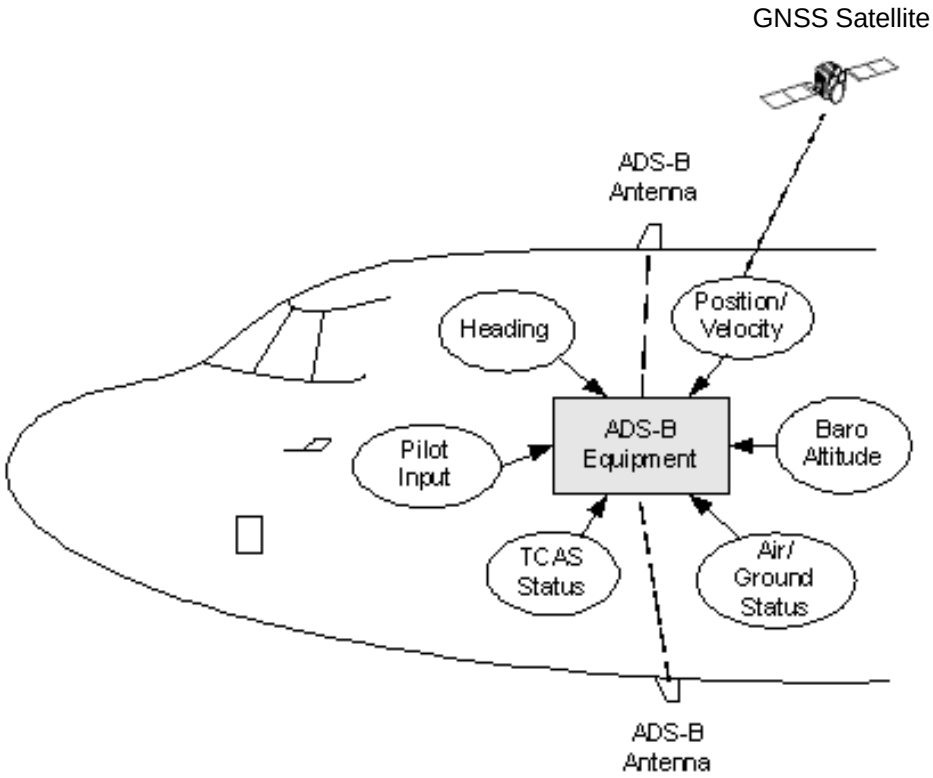
1. *Aircraft Status – Subtype 2, Aircraft Status – Subtype 4, and the ADS-Wx PIREPs are On-Condition Messages that are only transmitted when certain conditions apply (see §2.2.3.3.2.7).*
2. *The UAS/RPAS Contingency Message alternates transmission of the Current and Next TCP until the last TCP has been sequenced.*
3. *If more than one PIREP subtype message is valid, the messages are interleaved as specified in §2.2.3.3.2.7.3).*
4. *The ADS-Wx AIREP Weather State and Alternate Weather State Messages are not transmitted concurrently (see §2.2.3.3.2.6.4.2).*
5. *The Airborne Position and HVA Position Messages are not transmitted concurrently.*
6. *The Airborne Velocity and HVA Velocity Messages are not transmitted concurrently.*
7. *The HVA Position & Velocity, UAS/RPAS Contingency, ADS-Wx AIREP and ADS-Wx PIREP Messages are optional.*


GNSS satellites
Satellite with
ADS-B receiver
Aircraft with 1090ES transponders
ATC facility
ADS-B or ADS-B/WAM ground stations
Cooperative
Surveillance
radar

Aircraft Systems

- In order to populate each of the messages, the ADS-B device relies on other aircraft systems

- The following is an example of some of the avionics systems providing information to the ADS-B avionics



Aircraft Equipage

- Aircraft equipage is a key element that the Civil Aviation Authority (CAA) and Air Navigation Service Providers (ANSPs) must consider

- The type of ADS-B implementation may drive additional considerations on the type of equipage required in order to ensure proper aircraft detection

- For example:
  - ground system implementations may be satisfied with a bottom only antenna
  - Space Based implementation would require aircraft to have an antenna visible to the satellites

Quality Indicators

- Quality Indicators are used by the ATC Processing System to determine
  - whether ADS-B Surveillance reports (and therefore the derived target position) can be used to support the various functions in the provision of Air Traffic Services, and in particular,
  - whether the defined ATC Surveillance Separation standard can be supported
- These indicators are either calculated by the ADS-B device (e.g., NIC/NUCp) or configured at installation (e.g., SIL, SDA, Length/Width Code)

Navigation Integrity Category (NIC)

Airborne Position Message "ME" Field								
Msg Bit #	33 -37	38 ---------- 39	40	41 ----- 52	53	54	55 ---- 71	72 ---- 88
"ME" Bit #	1 – 5	6 ---------- 7	8	9 ----- 20	21	22	23 --- 39	40 --- 56
Field Name	**TYPE Code [5]**	**Surveillance Status [2]**	**NIC Supplement-B [1]**	**Altitude [12]**	**Time (T) [1]**	**CPR Format (F) [1]**	**CPR Encoded Latitude [17]**	**CPR Encoded Longitude [17]**
	MSB LSB	MSB LSB		MSB LSB			MSB LSB	MSB LSB

Aircraft Operational Status ADS-B Message "ME" Field Format														
MSG BIT #	33 - 37	38 - 40	41 - 52	53 - 56	57 - 72	73 - 75	76	77 - 80	81 - 82	83 - 84	85	86	87	88
"ME" BIT #	1 - 5	6 - 8	9 - 20	21 - 24	25 - 40	41 - 43	44	45 - 48	49 - 50	51 - 52	53	54	55	56
FIELD NAME	**TYPE=31 [5]**	**Subtype=0 [3]**	**Airborne Capability Class (CC) Codes [16]**		**Airborne Operational Mode (OM) Codes [16]**	**MOPS Version Number [3]**	**NIC Supplement-A [1]**	**NAC_P [4]**	**GVA [2]**	**Source Integrity Level (SIL) [2]**	**NIC_{BARO} [1]**	**HRD [1]**	**SIL Supp [1]**	**Reserved [1]**
		Subtype=1 [3]	**Surface CC Codes [12]**	**L/W Codes [4]**	**Surface Operational Mode (OM) Codes [16]**				**Reserved [2]**		**TRK/HDG [1]**			
	MSB LSB	MSB LSB	MSB LSB	MSB LSB	MSB LSB	MSB LSB		MSB LSB	MSB LSB	MSB LSB				

- The Navigation Integrity Category (NIC) is calculated solely based on the containment radius
- This value in combination with the NIC Supplement A & B determines the Type Code to be transmitted in the Airborne Position Message

NUCp to NIC Conversion

Horizontal Protection Limit (DO-260)	Nuc_p (DO-260)	Type Code (DO-260)	Horizontal Containment Radius (Rc) (DO-260A)	NIC (DO-260A)	NIC Supplement (DO-260A)	Type Code (DO-260A)	Horizontal Containment Radius (Rc) (DO-260B)	NIC (DO-260B)	NIC Supplement A,B (DO-260B)	Type Code (DO-260B)
HPL < 7.5 m	9	9	Rc < 7.5 m **and** VPL < 11 m	11	0	9	Rc < 7.5 m	11	0, 0	9
HPL < 25 m	8	10	Rc < 25 m **and** VPL < 37.5 m	10	0	10	Rc < 25 m	10	0, 0	10
HPL < 0.1 NM	7	11	Rc < 75 m **and** VPL < 112 m	9	1	11	Rc < 75 m	9	1,1	11
HPL < 0.2 NM	6	12	Rc < 0.1 NM	8	0		Rc < 0.1 NM	8	0,0	
HPL < 0.5 NM	5	13	Rc < 0.2 NM	7	0	12	Rc < 0.2 NM	7	0,0	12
HPL < 1.0 NM	4	14	Rc < 0.6 NM	6	1	13	Rc < 0.3 NM	6	0,1	13
HPL < 2.0 NM	3	15	Rc < 0.5 NM	6	0		Rc < 0.5 NM	6	0,0	
HPL < 10 NM	2	16	Rc < 1.0 NM	5	0	14	Rc < 0.6 NM	6	1,1	
HPL < 20 NM	1	17	Rc < 2 NM	4	0	15	Rc < 1.0 NM	5	0,0	14
HPL ≥ 20 NM	0	18	Rc < 4 NM	3	1	16	Rc < 2 NM	4	0,0	15
			Rc < 8 NM	2	0		Rc < 4 NM	3	1,1	16
			Rc < 20 NM	1	0	17	Rc < 8 NM	2	0,0	
			Rc ≥ 20 NM or unknown	0	0	18	RC < 20 NM	1	0,0	17
							Rc ≥ 20 NM or unknown	0	0,0	18

Airborne Position

ADS-B Position Message

Horizontal Protection Limit (DO-260)	Nuc_p (DO-260)	Type Code (DO-260)	Horizontal Containment Radius (DO-260A)	NIC (DO-260A)	NIC Supplement (DO-260A)	Type Code (DO-260A)	Horizontal Containment Radius (DO-260B)	NIC Supplement A,C (DO-260B)	NIC (DO-260B)	Type Code (DO-260B)
HPL < 7.5 m	9	5	Rc < 7.5 m	11	0	5	Rc < 7.5 m	0,0	11	5
HPL < 25 m	8	6	Rc < 25 m	10	0	6	Rc < 25 m	0,0	10	6
HPL < 0.1 NM	7	7	Rc < 75 m	9	1	7	Rc < 75 m	1,0	9	7
HPL ≥ 0.1 NM	6	8	Rc < 0.1 NM	8	0	7	Rc < 0.1 NM	0,0	8	
			Rc ≥ 0.1 NM or unknown	0	0	8	Rc < 0.2 NM	1,1	7	8
							Rc < 0.3 NM	1,0	6	
							RC < 0.6 NM	0,1		
							Rc ≥ 0.6 NM or uknown	0,0	0	

Surface Position

Monitoring of Regulatory Compliance

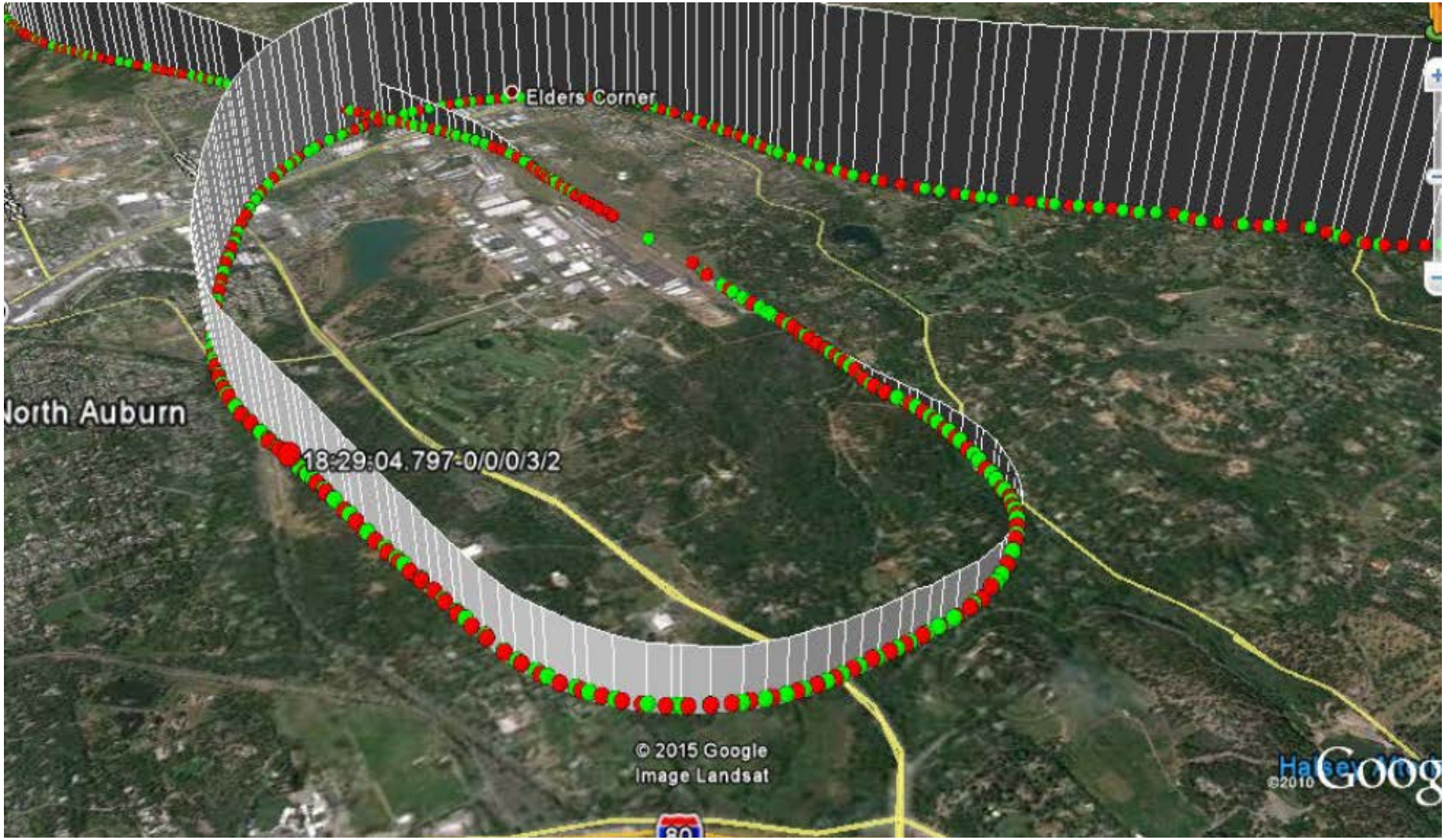
- FAA* uses a tool called the ADS-B Performance Monitor (APM) to detect:
- Non-Equipped operations in ADS-B Out required airspace
  - Including improperly equipped aircraft (e.g., Version 0 or Version 1)
- Improper ADS-B Operation
  - Equipment must be on at all times
    - Subject to revised 91.225 (f)
  - Proper procedures for pilot entered data (e.g., Flight ID)
    - Call Sign Mis-Match (CSMM)
- Non-performing equipment (NPE)
  - Airworthiness issues, monitored by FAA Flight Standards

*Inspectors from aircraft Maintenance and Flight Technologies and Procedures Divisions in the Office of Safety Standards

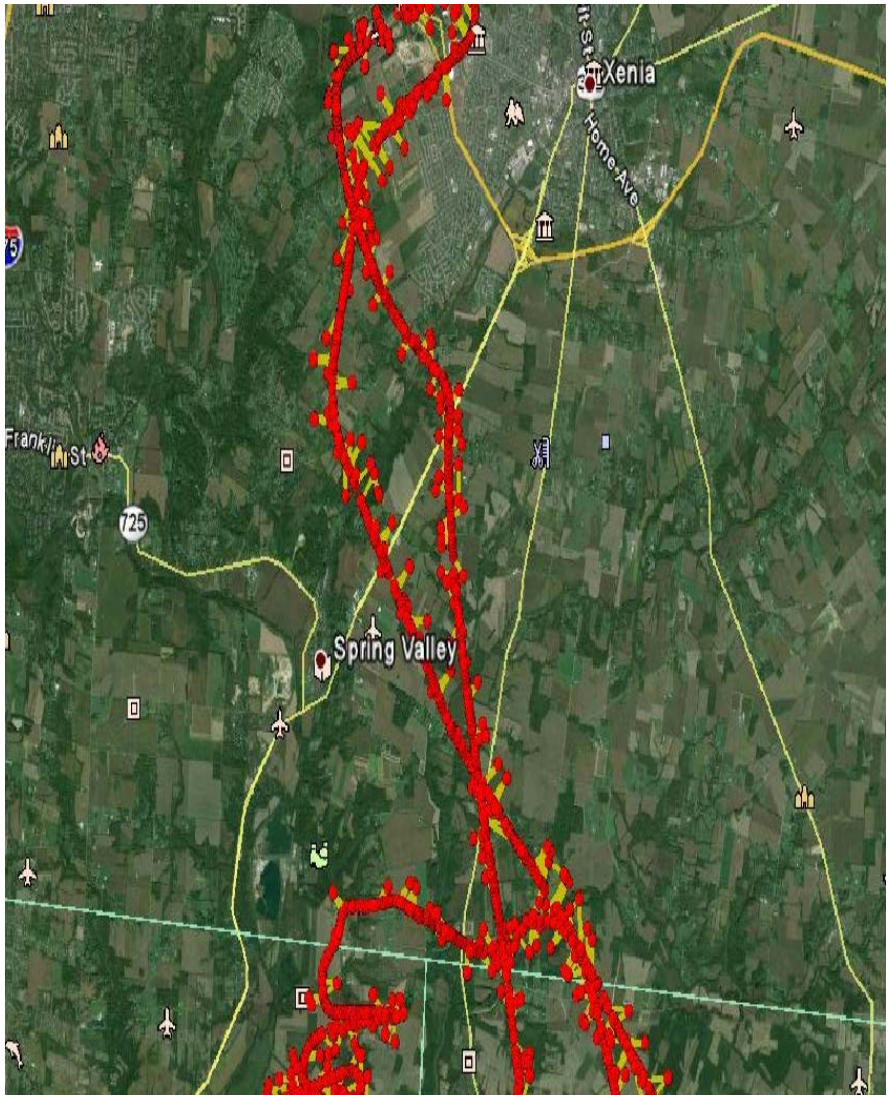
Monitoring of Regulatory Compliance

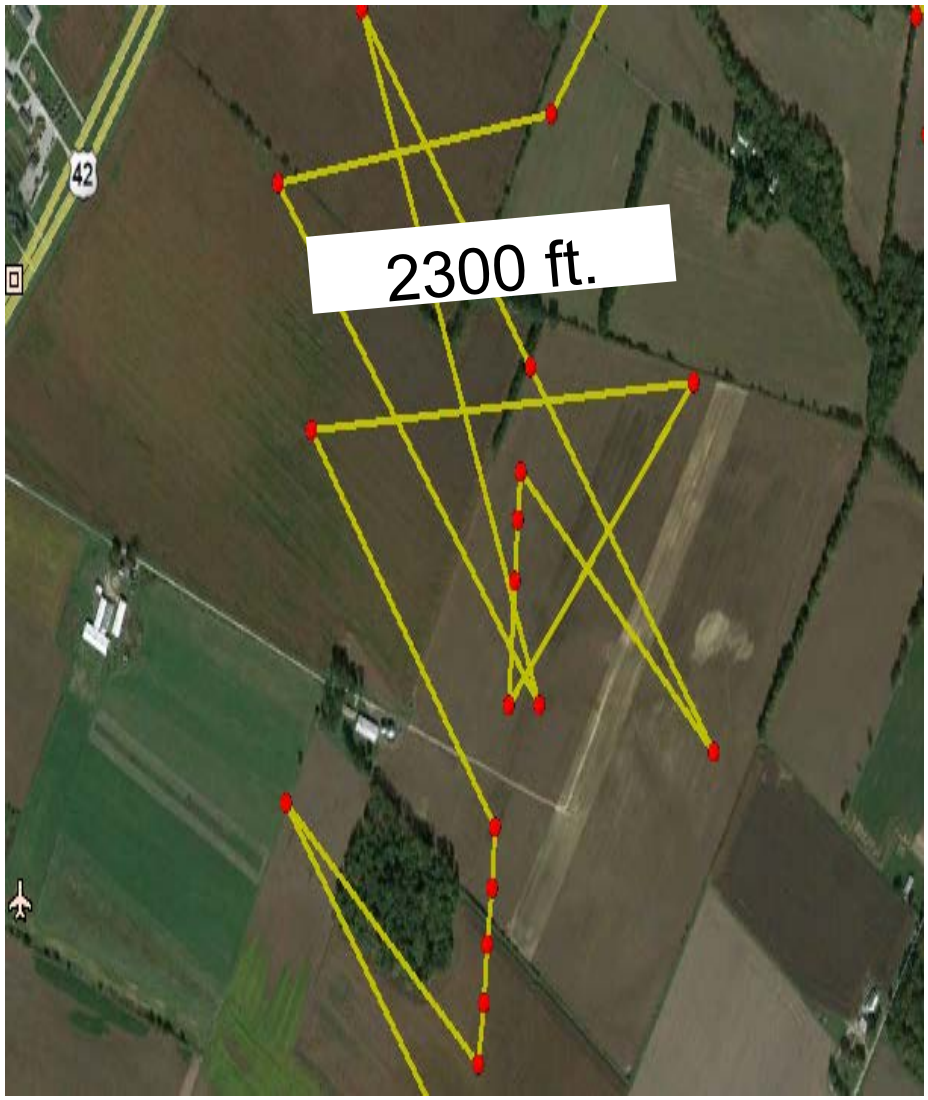
- In order to identify NPE's, the APM leverages the ADS-B Out information to identify aircraft operating in U.S. airspace that are not meeting the performance standards specified in 14 CFR 91.227.
  - Checks integrity and accuracy of position information
    - Compliant NIC, NACp, NACv, SIL, SDA
  - Checks for required message elements
    - Lat/Long, Velocity, Baro & Geo Altitude, Mode 3/A, Flight ID, proper ICAO 24-bit address, Emitter Category, Length/Width code, etc.
  - Performs validity checks (Kinematics) on position, velocity, altitude

ADS-B Performance Monitor



ADS-B Performance Monitor





Monitoring of Regulatory Compliance

- When the FAA learns of a suspected violation, via the APM or any other means, the following is initiated:
  - Relevant information is sent to an investigating office (e.g., Flight Standards District Office (FSDO), Certificate Management Office (CMO), or International Field Office (IFO))
    - If detected by APM, information will be sent from the Aircraft Maintenance Division or Flight Procedures and Technologies Division
  - Responsible FAA office conducts investigation following procedures established in FAA Orders 8900.1 and 2150.3C

- After the investigation occurs, the responsible FAA office takes appropriate actions to address the apparent violations
  - Compliance, administrative, or legal enforcement actions, in accordance with established policy

FAA Surveillance Functional Architecture