Federal Aviation Administration

Version 2.1

July 26, 2023

Upper Class E Traffic Management (ETM) Communication, Navigation, and Surveillance (CNS) Summary Report

Developed for:

Federal Aviation Administration
Advanced Concepts Branch, ANG-C54
NextGen Technology Development & Prototyping Division
800 Independence Avenue SW
Washington, DC 20591

Developed by:

LS Technologies, LLC
490 L'Enfant Plaza SW, #3221
Washington, DC 20024

Table of Contents

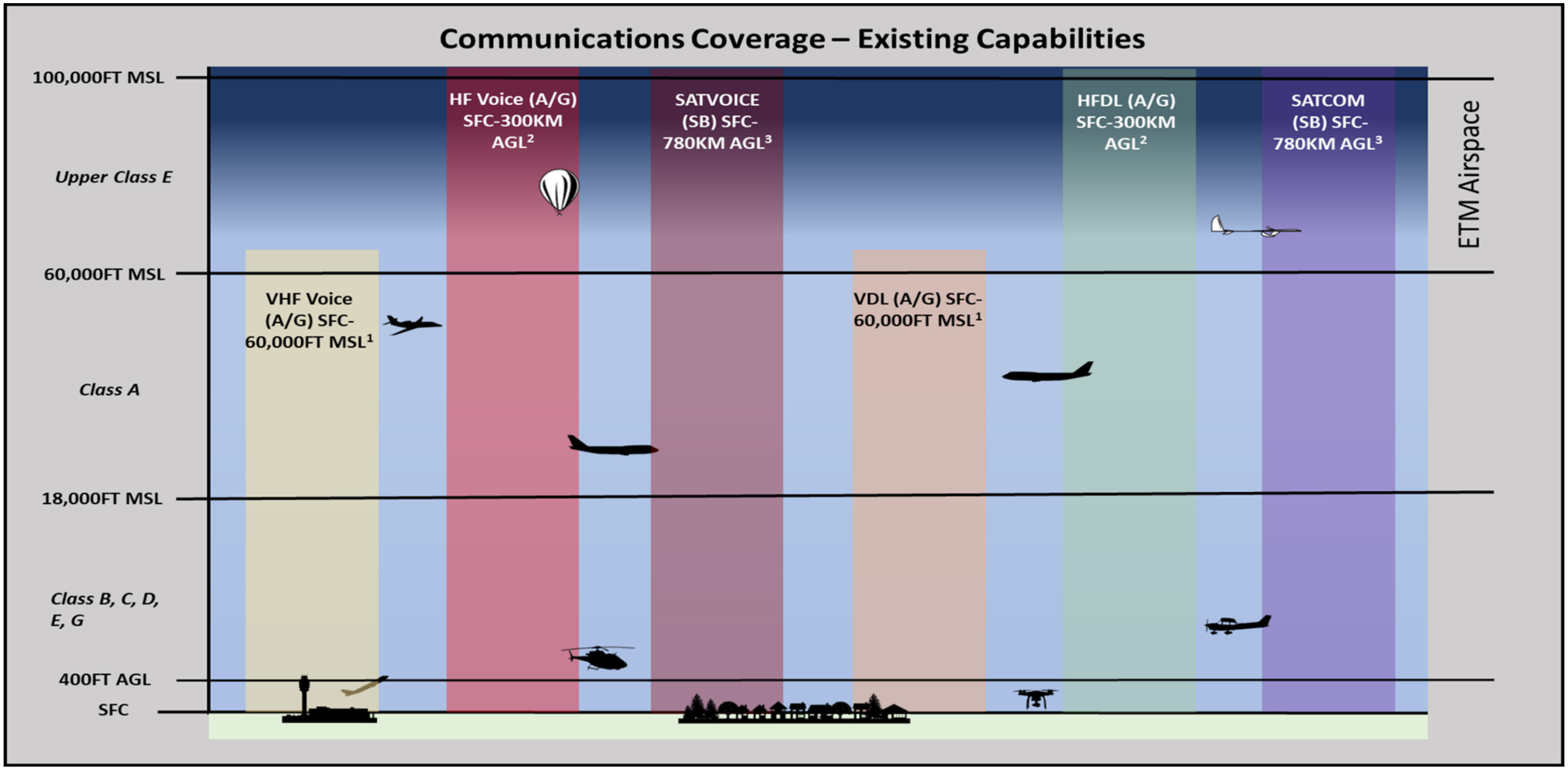
1 ETM Communications Capabilities ... 1

2 ETM Navigation Capabilities ... 5

3 ETM Surveillance Capabilities ... 9

Appendix A Acronyms ... 12

1 ETM Communications Capabilities



Communication Type	
A/G	Air-to-Ground
SB	Satellite Based

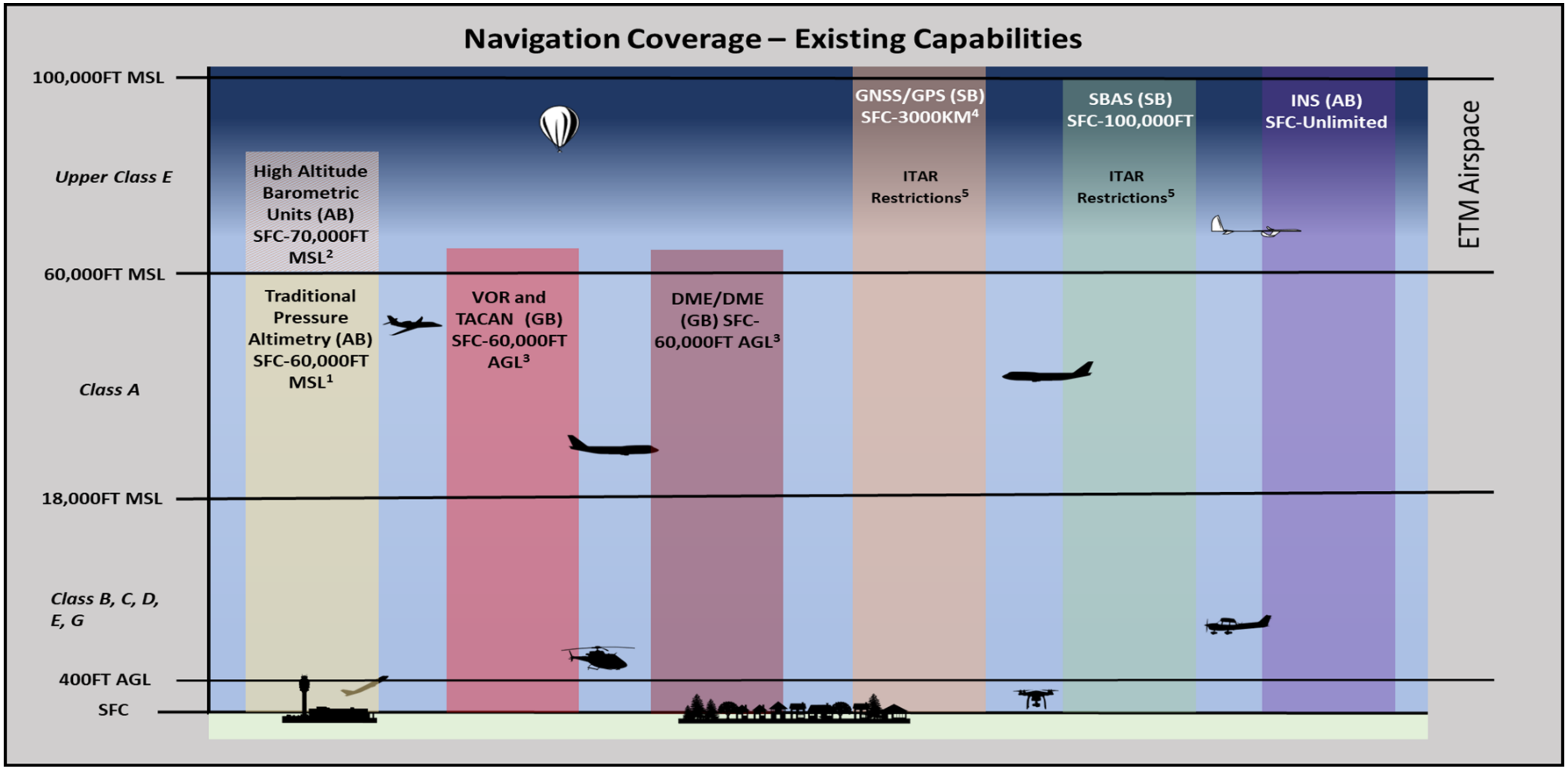
Limitations
[1]VHF service volumes defined up to FL600; voice and VDL propagation models indicate sufficient signal strength at 70,000 ft AGL; airborne equipment testing standards are limited to FL700
[2]Potential HF voice and HFDL ceilings in upper levels of the ionosphere; actual limits dependent on frequency and signal availability; airborne equipment testing standards are not specified above FL700
[3]Potential SATVOICE and SATCOM coverage ceilings based on the lower of two provider constellations; software/hardware limitations may reduce this; airborne equipment testing standards limited to FL700

Communications Capabilities				
Communications Method	**Type**	**Advantages**	**Disadvantages**	**Upper Class E Traffic Management (ETM) Feasibility**
Voice: Very High Frequency (VHF)	Air-to-Ground (A/G)	• Used by the Federal Aviation Administration (FAA) and industry for decades • Established infrastructure	• Radio line of site between transmitter and receiver is required, which may affect coverage • Potential signal interference outside of Frequency Protected Service Volumes (FPSVs) • Does not support oceanic operations (requires ground infrastructure) • Testing standards for airborne equipment only specified to Flight Level (FL) 700	• May be able to use in lower ETM environment due to potential signal availability up to 70,000 ft Above Ground Level (AGL) • Civilian variant of the Global Hawk Uncrewed Aircraft System (UAS) was equipped with a VHF/UHF voice relay for operations above FL600
Voice: Ultra High Frequency (UHF)	A/G	• Used by the U.S. military and supported by the FAA for decades • Established infrastructure	• Channels reserved for military aviation • Radio line of site between transmitter and receiver is required • Potential signal interference outside of FPSVs • Does not support oceanic operations • Testing standards for airborne equipment only specified to FL700	• Not feasible for commercial aviation

Communications Capabilities				
Communications Method	**Type**	**Advantages**	**Disadvantages**	**Upper Class E Traffic Management (ETM) Feasibility**
Voice: High Frequency (HF)	A/G	• Signal range is greater than VHF/UHF capability • Supports international airspace beyond VHF range	• Not approved for use over land in the U.S. if VHF communications are available • Signal may not be available due to sporadic nature of ionospheric layers • Testing standards for airborne equipment only specified to FL700	• Availability of the HF signal would theoretically be greater in the ETM environment
Voice: Satellite (SATVOICE)	Satellite-Based (SB)	• Global coverage via networks of satellites in Low Earth Orbit (LEO) and Geostationary Earth Orbit (GEO) • Unaffected by ionospheric changes	• Possible latency issues • Not approved for use over land in the U.S. • Testing standards for airborne equipment only specified to FL700	• Viable and presently in use by UAS • Could be problematic with supersonic and hypersonic aircraft due to speed limitations (potential doppler shift above Mach 1.4 to Mach 1.66 depending on service provider)
Data: VHF Data Link (VDL)	A/G	• Provides air traffic service data messages in airport and some en route environments • Reduces communication errors and radio congestion • Increases communication efficiency • Established support infrastructure	• Limited to continental use • Does not permit real-time communications like voice • Coverage affected by proximity to ground facilities	• Theoretically, signal strength should be sufficient to 70,000 ft over corresponding ground infrastructure

Communications Capabilities				
Communications Method	**Type**	**Advantages**	**Disadvantages**	**Upper Class E Traffic Management (ETM) Feasibility**
Data: HF Data Link (HFDL)	A/G	• Complements VDL and Satellite Communications (SATCOM) through 15 ground stations to extend communication coverage • Newer onboard HF data systems can search for best available signal • Supplements SATCOM in polar regions and provides data link backup	• Still some unpredictable signal reception • Lowest data transfer rate • Not approved for data link over domestic U.S.	• Availability of the HF signal would theoretically be greater in the ETM environment
Data: Satellite Communications (SATCOM)	SB	• Provides worldwide data communications coverage • Higher data transfer rate than VDL and HFDL	• Not approved for use over land in the U.S. • Possible latency issues	• Viable and presently in use for UAS command and control data • Speed limitations similar to SATVOICE

2 ETM Navigation Capabilities



Navigation Type	
AB	Aircraft Based
GB	Ground Based
SB	Satellite Based

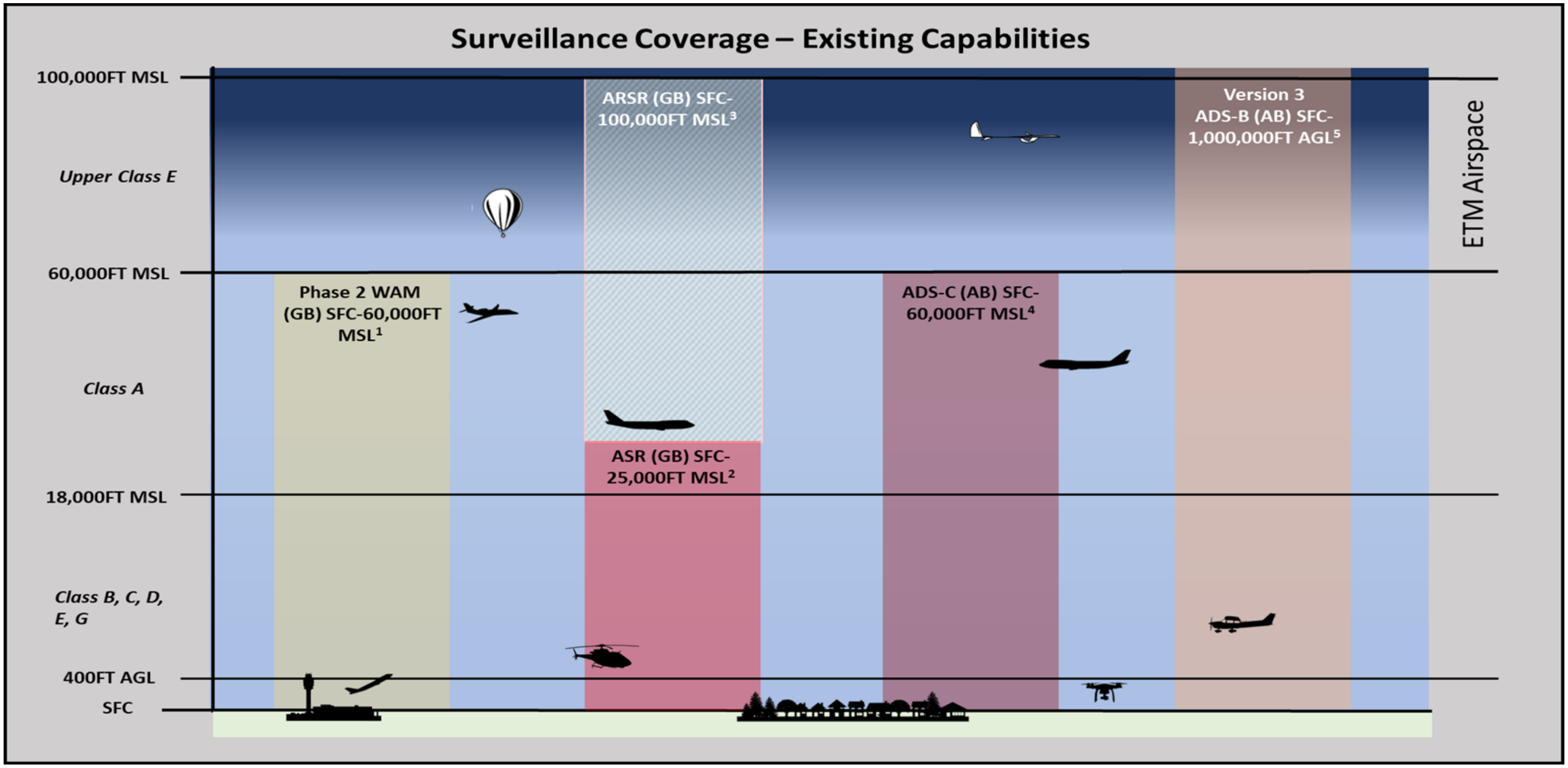
Limitations
[1]Devices are not generally required to operate above FL500; however, many systems are expected to function up to FL600
[2]One operator obtained approval and used high altitude pressure altimeters that functioned to FL700 ft based on extrapolated Air Data Computer / barometric altimeter error requirements
[3]Limited to "High" installations where transmitters are located at sufficient heights above ground level
[4]GPS Terrestrial Service Volume (TSV) upper bound; altitude provided by GNSS is not approved for use as a primary means of vertical navigation
[5]Current ITAR restrictions mandate that airborne GNSS receivers be disabled at speeds exceeding 600 m/s (1166 kts or Mach 2.03)

Navigation Capabilities				
Navigation Method	**Type**	**Advantages**	**Disadvantages**	**ETM Feasibility**
Pressure Altimetry	Aircraft Based (AB)	• Required for operations • While devices are not generally required to operate above FL500, some systems have been certified for use between FL500 and FL600 (e.g., business jets and Concorde) • At least one commercial pressure altimeter was approved for use up to FL700	• Errors increase as altitude and/or speed increases • Minimal certification above FL600; test criteria for standards do not exceed FL500 • It is generally believed that most traditional civilian systems do not provide useful information above FL600 • Beyond FL800, it is possible that atmospheric density is too low to support accurate pressure altimetry measurements	• One operator demonstrated that modern high-altitude barometric units can support repeated, global operations up to FL700 • Some military barometric altimeters were also required to indicate pressure altitude up to FL800 per MIL-STD-8439 (now cancelled)
VHF Omni-Directional Range (VOR)	Ground Based (GB)	• Wide ranging coverage with established infrastructure supported by the FAA • Able to withstand jamming and spoofing • Many have available signal up to at least 60,000 ft (AGL)	• Normal range up to 60 degrees in elevation angle (cone-of-confusion) • Provides only azimuth information; altitude and distance information still required for comprehensive navigation • Nearby objects may cause an erratic indication • System and infrastructure are costly • Decreased accuracy as distance increases; poor accuracy in comparison to Global Positioning System (GPS)/Global Navigation Satellite System (GNSS)	• VOR is potentially viable for lower ETM airspace • Limited to “High” installations where transmitters are located at sufficient heights above ground level

Navigation Capabilities				
Navigation Method	**Type**	**Advantages**	**Disadvantages**	**ETM Feasibility**
Distance Measuring Equipment (DME)	GB	• Wide ranging coverage with established infrastructure supported by the FAA • Able to withstand jamming and spoofing • Many have available signal up to at least 60,000 ft (AGL)	• Provides only distance information; altitude and azimuth information still required for comprehensive navigation • Decreased accuracy as distance increases; poor accuracy in comparison to GPS/GNSS	• DME is potentially viable for lower ETM airspace • Limited to "High" installations where transmitters are located at sufficient heights above ground level • DME/DME (using two or more DMEs to determine aircraft location) may be the best existing GB navigation system for lower ETM operations
Tactical Air Navigation System (TACAN)	GB	• Wide ranging coverage supporting commercial and military navigation; established infrastructure supported by the FAA • Able to withstand jamming and spoofing • Many have available signal up to at least 60,000 ft (AGL)	• Azimuth information limited to military aircraft • Decreased accuracy with increased distance from ground stations; poor accuracy in comparison to GPS/GNSS	• It is possible TACANs may be used for some ETM operations • Limited to "High" installations where transmitters are located at sufficient heights above ground level
Global Positioning System (GPS)	Satellite Based (SB)	• Decades of use supporting commercial and military navigation • Key enabler of the NextGen program • Satellite signal continuously available up to altitudes of 3,000 km	• Vulnerable to jamming, spoofing, and solar activity • International Traffic in Arms Regulations (ITAR) mandate that airborne GNSS receivers be disabled at speeds exceeding 600 m/s (~Mach 2.03)	• All ETM operations traveling less than Mach 2.03 should be able to employ GPS navigation in the horizontal dimension • Used by one operator for navigation and surveillance of flights up to FL700 • Used for Global Hawk planned missions and flight tests between 65,000 ft and 67,500 ft (respectively)

Navigation Capabilities				
Navigation Method	**Type**	**Advantages**	**Disadvantages**	**ETM Feasibility**
Space Based Augmentation System (SBAS)	SB	• Widespread use in civil aviation • Improves GPS accuracy and integrity • Provides alerts if significant GPS issues are detected • Wide Area Augmentation System (WAAS) coverage up to 100,000 ft for the region encompassing the Contiguous U.S. (CONUS), Alaska, Hawaii, the Caribbean islands, and a large portion of oceanic airspace	• Vulnerable to jamming, spoofing, natural interference • Subject to the same ITAR restrictions as standard GNSS	• All ETM operations traveling less than Mach 2.03, operating up to 100,000 ft within an appropriate coverage volume should be able to employ WAAS navigation in the horizontal dimension
Inertial Navigation System (INS)	AB	• Established technology (present since the 1940s) • Completely self-contained • Operates at any altitude • Not subject to jamming or spoofing	• Gyro drift errors that accumulate over time can render INS position untrustworthy	• Well suited for ETM operations as there is no upper altitude limit for use; however, other technologies (e.g., DME/DME) may be needed to compensate for errors

3 ETM Surveillance Capabilities



Surveillance Type	
AB	Aircraft Based
GB	Ground Based
SB	Satellite Based

Limitations
[1]Potential limit of 2D WAM based on traditional pressure altimeter performance and system configuration
[2]ASR coverage limited to roughly 25,000 ft by automation software (e.g., altitude filters)
[3]Some ARSR installations are capable of coverage up to 100,000 ft; dependent on valid pressure altitude
[4]ADS-C installations are postulated to provide reliable aircraft positions up to the limit of traditional pressure altimeters (60,000 ft)
[5]Version 3 1090ES ADS-B optionally supports altitude to roughly 1,000,000 ft; however, vehicles traveling more than 600 m/s are subject to ITAR restrictions

Surveillance Capabilities				
Surveillance Method	**Type**	**Advantages**	**Disadvantages**	**ETM Feasibility**
Radar (Airport Surveillance Radar (ASR) and Air Route Surveillance Radar (ARSR))	GB	• Most of CONUS covered by radar surveillance at 18,000 ft • Some ARSR capabilities to 100,000 ft • Less susceptible to jamming or spoofing • Secondary Surveillance Radar (SSR) provides critical input to Air Traffic Control (ATC) automation systems	• Position errors increase with range • Velocity errors can be significant, notably in turns (radar lag) • Dependency on commercial barometric altimeters, many of which do not function well above 60,000 ft • Coverage of oceanic airspace limited to coastal regions/areas surrounding select islands • Coverage limited by software (e.g., 25,000 ft for some ASRs)	• Historical Concorde operations at the boundary of Class A and upper Class E airspace were surveilled by long-range radars while supersonic, albeit with limitations • Upper Class E airspace coverage exists, but can be limited based on pressure altimeter, software, and hardware constraints
Wide Area Multilateration (WAM)	GB	• Phase 2 WAM operational in Charlotte, NC, and Los Angeles, CA; Phase 1 installations in CO and AK are being transitioned to Phase 2 • Provides accurate surveillance in areas that preclude radar deployment (e.g., mountainous terrain) • Phase 2 corrects pressure altitude with weather forecast data	• Phase 2 systems are not configured to provide surveillance above 60,000 ft • Horizontal position accuracy worsens at higher altitudes • Coverage represents a fraction of total area surveilled by radar and Automatic Dependent Surveillance – Broadcast (ADS-B)	• Coverage of operations in transit to/from ETM airspace may be possible • Phase 2 WAM limited by system configurations and pressure altimeter constraints
Automatic Dependent Surveillance – Broadcast (ADS-B)	AB	• International adoption of 1090 MHz Extended Squitter (1090ES) technology • Space-based variant offers potential for worldwide surveillance	• Oceanic surveillance is limited (SBS ground-based system) • Update rates are reduced in high 1090 MHz interference environments (dense airspace)	• Commercial vehicles that operated up to FL700 employed ADS-B with valid altitude measurements

Surveillance Capabilities				
Surveillance Method	**Type**	**Advantages**	**Disadvantages**	**ETM Feasibility**
		• V2 (most common deployment) coverage ceiling of 126,750 ft based on altitude encoding limits • V3 coverage ceiling extended to roughly 1,000,000 ft with additional support for supersonic and hypersonic velocities	• ITAR restrictions apply at speeds greater than Mach 2.03 (e.g., state data may not be populated) • Potential barometric altimeter limitations above FL600 impact pressure altitude reported through 1090ES and Universal Access Transceiver (UAT) • Geometric altitude provided by V3 messages up to roughly 1,000,000 ft is not approved for separation • Susceptible to jamming and spoofing	• Most vehicles traveling less than Mach 2.03 in ETM airspace could employ ADS-B with a dependency on accurate pressure altitude reporting
Automatic Dependent Surveillance – Contract (ADS-C)	AB	• Provides surveillance in oceanic and remote continental regions • Established input to Advanced Technologies and Oceanic Procedures (ATOP) automation system • Theoretical surveillance coverage up to 60,000 ft, subject to service provider and automation filters and/or configurations and pressure altimetry constraints • Enhanced ADS-C is being considered for reduced oceanic separation minima	• Not approved for tactical separation • Does not provide coverage over the poles • Lowest achievable update interval is 64 seconds; the lowest update interval required for minimum separation in oceanic airspace is currently 10 minutes • Fees incurred by operators based on message frequency • Greater latency in comparison to other surveillance capabilities	• May be a feasible surveillance mechanism in the lower ETM environment with appropriate altimetry; however, service provider and automation configurations may limit coverage

Appendix A Acronyms

Acronym	Definition
AB	Aircraft Based
ADS-B	Automatic Dependent Surveillance – Broadcast
ADS-C	Automatic Dependent Surveillance – Contract
AGL	Above Ground Level
AK	Alaska
ARSR	Air Route Surveillance Radar
ASR	Airport Surveillance Radar
ATC	Air Traffic Control
ATOP	Advanced Technologies and Oceanic Procedures
CA	California
CO	Colorado
CONUS	Contiguous United States
DME	Distance Measuring Equipment
ETM	Upper Class E Traffic Management
FAA	Federal Aviation Administration
FL	Flight Level
FPSV	Frequency Protected Service Volume
ft	Feet
GB	Ground Based
GEO	Geostationary Earth Orbit
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
HF	High Frequency
HFDL	HF Data Link
INS	Inertial Navigation System
ITAR	International Traffic in Arms Regulations
LEO	Low Earth Orbit
MH	Megahertz
NC	North Carolina
SATCOM	Satellite Communications

Acronym	Definition
SATVOICE	Satellite Voice
SB	Satellite Based
SBAS	Space Based Augmentation System
SBS	Surveillance Broadcast Services
SSR	Secondary Surveillance Radar
TACAN	Tactical Air Navigation System
UAS	Uncrewed Aircraft System
UAT	Universal Access Transceiver
UHF	Ultra High Frequency
VDL	VHF Data Link
VHF	Very High Frequency
VOR	VHF Omni-Directional Range
WAAS	Wide Area Augmentation System
WAM	Wide Area Multilateration