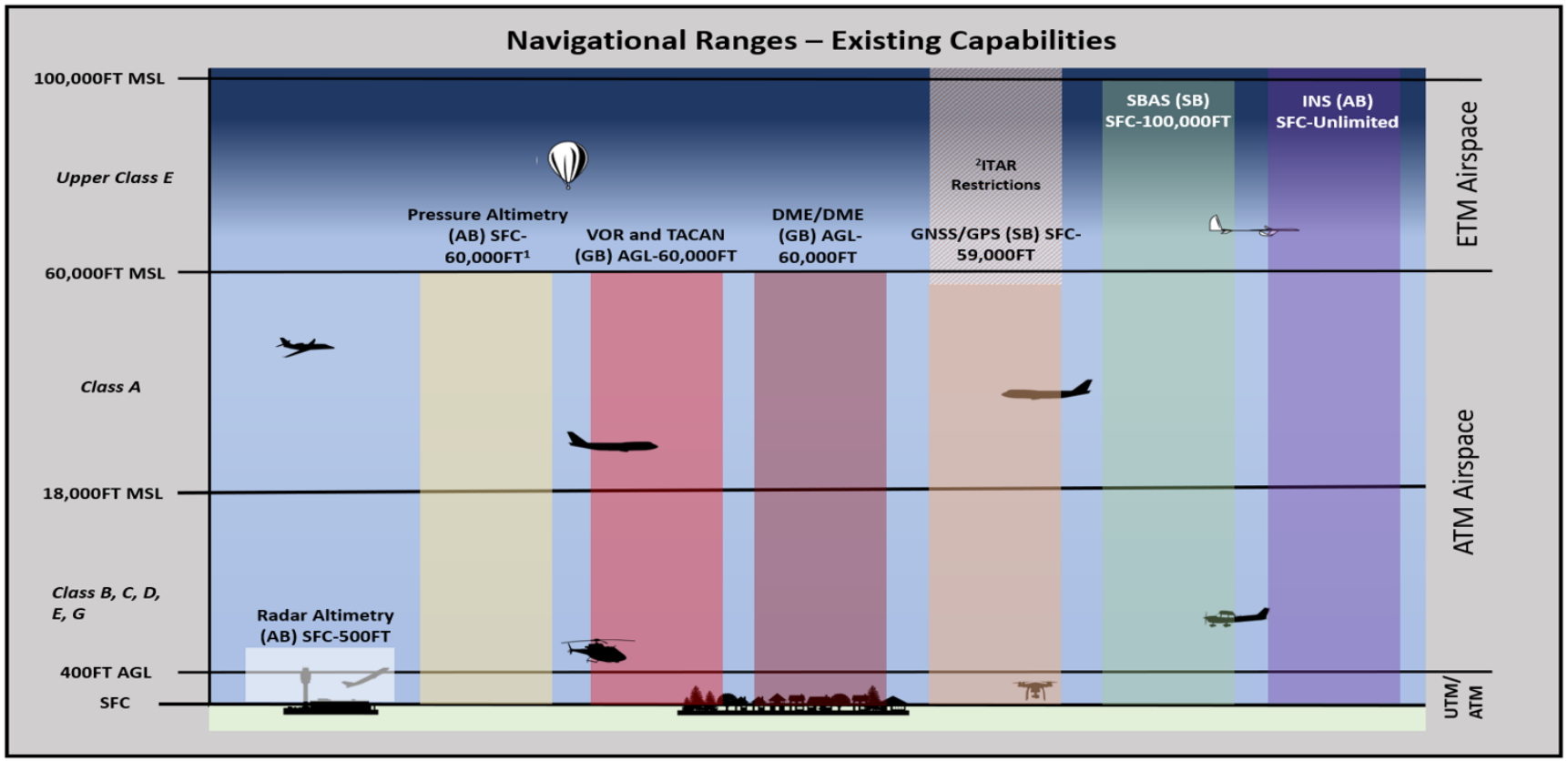
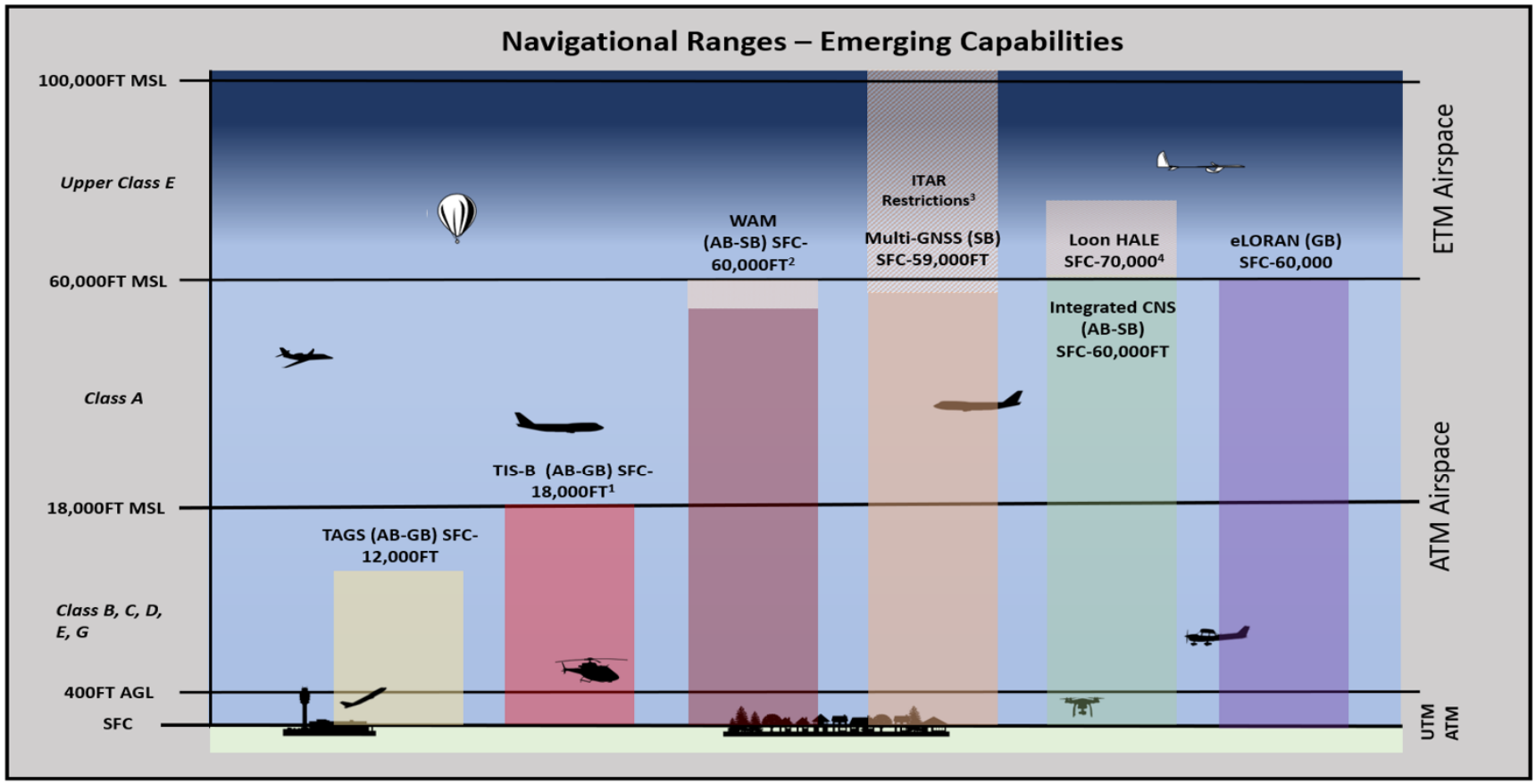
Upper Class E Traffic Management (ETM) Communication, Navigation, and Surveillance (CNS) White Paper Summary Report

ETM Navigational Capabilities



Navigation Type	
AB	Aircraft Based
GB	Ground Based
SB	Satellite Based

Capability Limitations
[1]Devices are not generally required to operate above 50,000 ft; however, some systems are expected to function up to 60,000 ft (e.g. business jets)
[2]Current ITAR restrictions mandate that airborne GNSS receivers be disabled at speeds exceeding 600 m/s (~1,200 knots); systems adhering to pre-2016 ITAR restrictions have an altitude limitation of 59,000 ft
NOTE: Expanded Service Volumes may extend VOR, DME, and TACAN capabilities beyond 60,000 ft (AGL)



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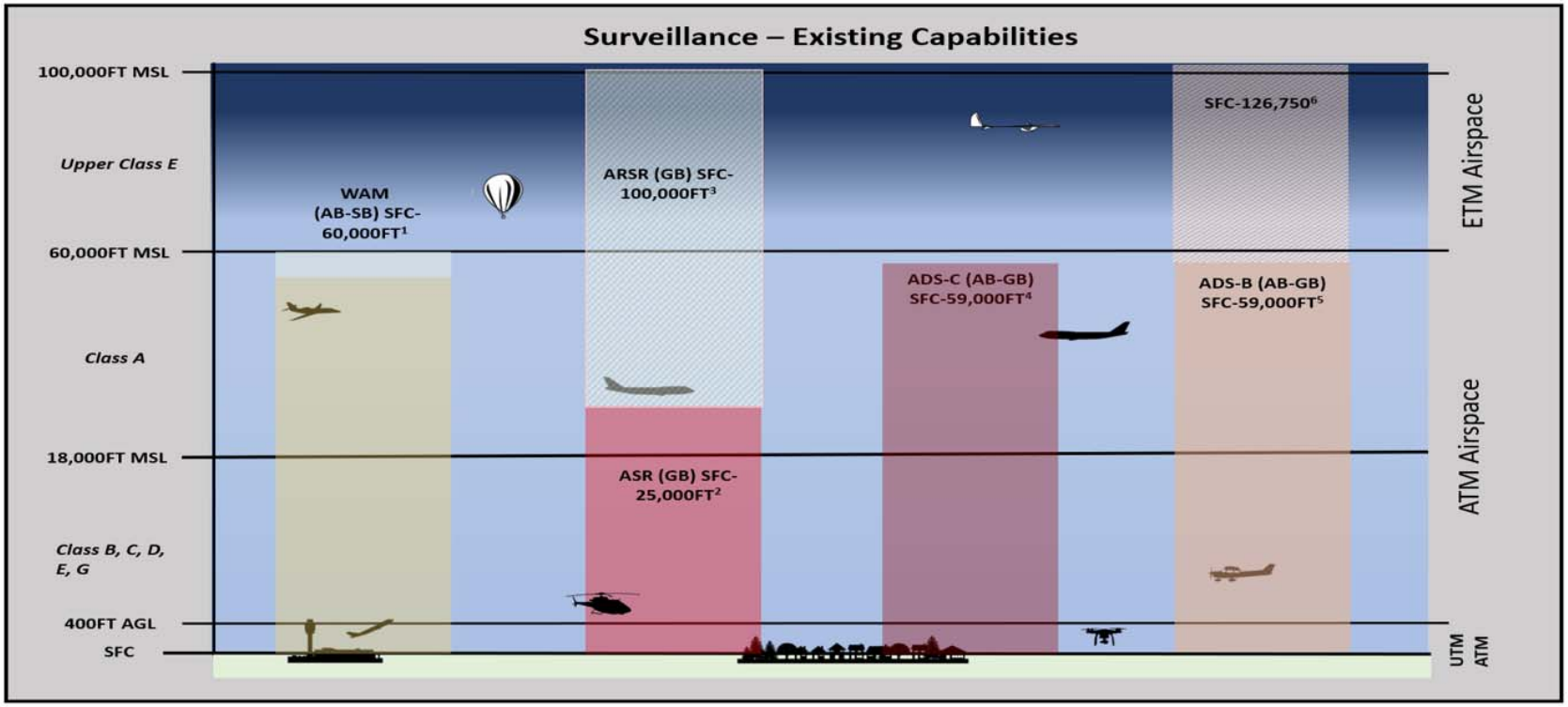
Capability Limitations
[1]TIS-B navigation, based on secondary surveillance radar, is hypothetical and has not been studied in detail
[2]Potential limit of 2D WAM based on pressure altimeter performance requirements (50,000 ft); 3D WAM may provide capabilities up to and beyond 60,000 ft with appropriate software changes
[3]Current ITAR restrictions mandate that airborne GNSS receivers be disabled at speeds exceeding 600 m/s (~1,200 knots); systems adhering to pre-2016 ITAR restrictions have an altitude limitation of 59,000 ft
[4]Loon has operated constellations up to 70,000 ft (pressure altimetry and ITAR restrictions aside)

(Existing) Navigation				
Navigation Method	**Type**	**Advantages**	**Disadvantages**	**ETM Feasibility**
Radar Altimetry	AB	• Used in aviation for several decades	• Maximum operational altitude is relatively low.	◦ Not suitable
Pressure Altimetry	AB	• FAA-required for operations • While devices are not generally required to operate above 50,000 ft, some systems may function up to 60,000 ft	• Errors increase as the altitude and/or speed increases • Minimal certification above 60,000 ft; test criteria for standards do not exceed 50,000 ft	◦ Limited use in ETM airspace ◦ At least one system has been certified for use up to 70,000 ft based on extrapolation of requirements defined to 50,000 ft
VHF Omni-Directional Range (VOR)	GB	• Wide ranging coverage with established infrastructure supported by FAA • Able to withstand jamming and spoofing • Many have available signal up to at least 60,000 ft (AGL) • Expanded Service Volumes may extend VOR capabilities beyond 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	◦ VOR viable for *lower* ETM airspace **only**
Distance Measuring Equipment (DME)	GB	• Wide ranging coverage with established infrastructure supported by FAA • Able to withstand jamming and spoofing • Many have available signal up to at least 60,000 ft (AGL) • Expanded Service Volumes may extend DME capabilities beyond 60,000 ft (AGL)	• Provides only distance information: altitude and azimuth information is still required for comprehensive navigation • Decreased accuracy as distance increases	◦ DME viable for *lower* ETM airspace **only** ◦ DME/DME/INS (using two or more DMEs and INS to determine aircraft location) appears to 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 FAA • Able to withstand jamming and spoofing • Many have available signal up to at least 60,000 ft (AGL) • Expanded Service Volumes may extend TACAN capabilities beyond 60,000 ft (AGL)	• Azimuth information limited to military aircraft • Protected up to maximum of 60,000 ft (AGL) • Decreased accuracy with increase in distance from the TACAN	◦ Coverage limits extend above 60,000 ft AGL; thus, it is possible TACANs may be used for some ETM operations
Space Based Augmentation System (SBAS)	SB	• Widespread use in civil aviation • Provides alerts if significant GPS issues are detected	• Vulnerable to jamming, spoofing, natural interference • Subject to ITAR restrictions • Not consistently deployed across the ATM fleet	◦ All subsonic ETM vehicles operating up to 100,000 ft within an appropriate coverage volume should be able to employ SBAS navigation
Global Positioning System (GPS)	SB	• Decades of use supporting commercial and military navigation • Key enabler of NextGen program • Satellite signal continuously available up to altitudes of 3,000 km	• Vulnerable to jamming, spoofing, and solar activity • ITAR restrictions mandate that airborne GNSS receivers be disabled at speeds exceeding 600 m/s (~1,200 knots)	◦ Currently used for navigation and surveillance (Loon HALE to altitudes of 70,000 ft) ◦ (Albeit classified) currently used for navigation and surveillance of unmanned military vehicles
Inertial Navigation System (INS)	AB	• Established technology (present since the 1940's) • Completely self-contained • Operates at any altitude • Not subject to jamming or spoofing	• Gyro drift: small errors that accumulate over time and become large enough to render INS position untrustworthy; however, other technologies (e.g. DME/DME) can be used to compensate	◦ Well suited to ETM airspace as there is no upper altitude limit for use

ETM Surveillance Capabilities



Navigation Type	
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Capability Limitations
[1]Potential limit of 2D WAM based on pressure altimeter performance requirements (50,000 feet); 3D WAM Phase 2 may provide capabilities up to and beyond 60,000 ft with appropriate software changes
[2]ASR software (e.g. Terminal Automation) coverage limited up to 25,000 ft
[3]Some ARSR installations provide coverage up to 100,000 ft; however, all SSRs are dependent on pressure altitude that is unreliable above 60,000 ft
[4]Extant ADS-C installations (primarily in air transport category aircraft) are subject to previously published ITAR restrictions that prevent GPS output of latitude, longitude, and velocity above altitudes of 59,000 ft
[5]Installations adhering to previously published ITAR restrictions
[6]1090ES format limits altitude to 126,750 ft, horizontal velocity to 4,086 kts, and vertical rate to 32,608 fpm; UAT format limits altitude to 101,337 ft and vertical rate to 32,608 fpm - vehicles traveling more than 600 m/s shall be subject to current ITAR restrictions

Surveillance				
Surveillance Method	**Type**	**Advantages**	**Disadvantages**	**ETM Feasibility**
Radar (ASR, ARSR)	GB	• Most of CONUS covered by radar surveillance at altitude of 18,000 ft • Some ARSR capabilities to 100,000 ft • Less susceptible to jamming or spoofing • Secondary surveillance radar provides critical input to ATC automation systems	• Position errors increase with range • Velocity errors (radar lag) • Dependency on commercial barometric altimeters that may not function above 60,000 ft • Coverage of oceanic airspace limited to coastal regions/areas surrounding select islands • (ASR) coverage limited by software (e.g. 25,000 ft)	◦ Upper Class E airspace coverage is limited based on pressure altimeter, software, and hardware constraints ◦ Some ARSR installations may be capable of determining 3D ETM vehicle position based on stacked beam technology
Wide Area Multilateration (WAM)	GB	• Phase 1 and Phase 2 WAM operational in multiple locations within the U.S. • Provides accurate surveillance in areas that preclude radar deployment (e.g. mountainous terrain) • Phase 2 corrects pressure altitude with weather forecast data	• Accurate surveillance limited to a 16,000 ft ceiling (Phase 1); Phase 2 systems are not configured to provide surveillance above 60,000 ft • Horizontal position accuracy decreases at higher altitudes • Coverage represents a fraction of total area surveilled by radar and ADS-B	◦ Phase 1 WAM not applicable to ETM operations due to low ceiling ◦ Phase 2 limited by system configurations and pressure altimeter constraints; however, may be expanded to upper Class E airspace with high altitude pressure altimetry or 3D positioning
Automatic Dependent Surveillance – Broadcast (ADS-B)	AB GB SB	• International adoption of 1090ES technology • Space-based variant offers potential for worldwide surveillance • Surveillance coverage ceiling of 126,750 ft based on encoding; **Version 3** is expected to increase this value significantly	• Similar to radar, oceanic surveillance is limited (SBS ground based system) • Update rates are reduced in high 1090 MHz interference environments that occur in dense airspace • ITAR restrictions apply (GNSS inputs invalidated at speeds > 600 m/s)	◦ Commercial vehicles currently operating in upper Class E airspace employ ADS-B and a certified high altitude pressure altimeter ◦ Supersonic vehicles may be capable of employing ADS-B (if ITAR restrictions are waived)

			• Commercial altimeter limitations above 60,000 ft impacts pressure altitude reported through 1090ES and UAT • Susceptible to jamming and spoofing	
Automatic Dependent Surveillance – Contract (ADS-C)	AB GB SB	• Provides surveillance in oceanic and remote continental regions • Established input to 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	• Not approved for tactical separation • Does not provide coverage over the poles • Lowest achievable update interval is 64 seconds • Fees incurred by operators based on message frequency • High latency in comparison to other surveillance capabilities	◦ May be a feasible surveillance mechanism in upper Class E airspace with appropriate altimetry; however, service provider, operator, and automation software and hardware changes will be necessary and may be costly

ETM Communications Capabilities

Communications				
Communications Method	**Type**	**Advantages**	**Disadvantages**	**ETM Feasibility**
Voice: Very High Frequency (VHF)	A/G[1]	• Used by FAA and industry for decades • Established infrastructure	• Radio line of site between transmitter and receiver is required, which may affect coverage • Frequency engineering is required to mitigate the possibility of signal interference • Does not support oceanic operations	◦ May be able to use in lower ETM environment ◦ If more use in ETM environment desired, could increase power output/ sensitivity, or make ground antenna changes. ◦ Requires frequency engineering and coordination to mitigate the possibility of signal interference ◦ Operations above 70,000 ft will require new testing standards
Voice: Ultra High Frequency (UHF)	A/G	• Used by FAA and industry for decades • Established infrastructure	• Channels reserved for military aviation • Radio line of site between transmitter and receiver is required • Frequency engineering is required to mitigate the possibility of signal interference • Does not support oceanic operations	◦ May be able to use in lower ETM environment ◦ Not feasible for commercial aviation ◦ If more use in ETM environment desired, could increase power output / sensitivity, or make ground antenna changes. ◦ Requires frequency engineering and

[1] Air-to-Ground

				◦ coordination to mitigate the possibility of signal interference. ◦ Operations above 70,000 ft will require new testing standards
Voice: High Frequency (HF)	A/G	• Signal range is greater than VHF/UHF capability • International airspace beyond VHF range	• Not approved for use over continental U.S. if VHF communications are available • Signal may be not be available due to sporadic nature of ionospheric layers	◦ Availability of the HF signal would theoretically be greater in the ETM environment than the ATM environment ◦ Operations above 70,000 ft will require new testing standards
Voice: Satellite (SATVOICE)	SB[2]	• Global coverage via network of satellites in low Earth orbit • Unaffected by ionospheric changes	• Possible latency issues • Not approved for use over continental U.S.	◦ Viable and presently in use by UAS. ◦ Could be problematic to super/hypersonic aircraft due to speed limitations ◦ New testing standards needed for operations above 70,000 ft

[2] Satellite Based

Data: VHF Data Link (VDL)	A/G	• Provides air traffic services data messages in airport and in some en route environments • Reduces communication errors and radio congestion • Increase 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 ◦ New testing standards needed for operations above 70,000 ft
Data: HF Data Link (HFDL)	A/G	• Compliments VDL and SATCOM through fifteen ground stations to extend communication coverage • Newer onboard HF data systems can search for best available signal • Supplements SATCOM in polar regions and provides it data link backup	• Still some unpredictable signal reception • Low data transfer rate • Not yet approved for Data Link over domestic U.S.	◦ Operational testing of radio equipment is required to ensure ETM feasibility ◦ Operations above 70,000 ft will require new testing standards
Data: Satellite (SATCOM)	SB	• Provides worldwide data communications coverage • Higher rate of transfer data than either VDL or HFDL	• Not approved for use over continental U.S. • Possible latency issues	◦ Viable and presently in use for UAS command and control data ◦ Speed limitations similar to SATVOICE