ETM Navigational Capabilities

### Navigational Ranges – Existing Capabilities

- **Upper Class E**
  - Pressure Altimetry (AB) SFC-60,000FT
  - VOR and TACAN (GB) AGL-60,000FT
  - DME/DME (GB) AGL-60,000FT
  - GNSS/GPS (SB) SFC-9,000FT
- **Class A**
- **Class B, C, D, E, G**
- **400FT AGL**
- **SFC**

### 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 9,000 ft.

*NOTE: Expanded Service Volumes may extend VOR, DME, and TACAN capabilities beyond 60,000 ft (AGL).*
Navigational Ranges – Emerging Capabilities

**Navigation Type**
- AB: Aircraft Based
- GB: Ground Based
- SB: Satellite Based

**Capability Limitations**
- TIS-B: navigation, based on secondary surveillance radar, is hypothetical and has not been studied in detail.
- 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.
- 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.
- Loon has operated constellations up to 70,000 ft (pressure altimetry and ITAR restrictions aside).
<table>
<thead>
<tr>
<th>Navigation Method</th>
<th>Type</th>
<th>Advantages</th>
<th>Disadvantages</th>
<th>ETM Feasibility</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radar Altimetry</td>
<td>AB</td>
<td>• Used in aviation for several decades</td>
<td>• Maximum operational altitude is relatively low.</td>
<td>• Not suitable</td>
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<tr>
<td>Pressure Altimetry</td>
<td>AB</td>
<td>• FAA-required for operations and comply with regulations</td>
<td>• Errors increase as the altitude and/or speed increases</td>
<td>• Limited use in ETM airspace</td>
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<td>• While devices are not generally required to operate above 50,000 ft, some systems may function up to 60,000 ft</td>
<td>• Minimal certification above 60,000 ft; test criteria for standards do not exceed 50,000 ft</td>
<td>• At least one system has been certified for use up to 70,000 ft based on extrapolation of requirements defined to 50,000 ft</td>
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<tr>
<td>VHF Omni-Directional Range (VOR)</td>
<td>GB</td>
<td>• Wide ranging coverage with established infrastructure supported by FAA</td>
<td>• Normal range up to 60 degrees in elevation angle (cone-of-confusion)</td>
<td>• VOR viable for lower ETM airspace only</td>
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<td></td>
<td></td>
<td>• Able to withstand jamming and spoofing</td>
<td>• Provides only azimuth information; altitude and distance information still required for comprehensive navigation</td>
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<td></td>
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<td>• Many have available signal up to at least 60,000 ft (AGL)</td>
<td>• Nearby objects may cause an erratic indication</td>
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<td></td>
<td></td>
<td>• Expanded Service Volumes may extend VOR capabilities beyond 60,000 ft (AGL)</td>
<td>• System and infrastructure are costly</td>
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<td></td>
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<td>• Decreased accuracy as distance increases</td>
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<tr>
<td>Distance Measuring Equipment (DME)</td>
<td>GB</td>
<td>• Wide ranging coverage with established infrastructure supported by FAA</td>
<td>• Provides only distance information: altitude and azimuth information is still required for comprehensive navigation</td>
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<tr>
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<td>• Able to withstand jamming and spoofing</td>
<td>• Decreased accuracy as distance increases</td>
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<td>• Expanded Service Volumes may extend DME capabilities beyond 60,000 ft (AGL)</td>
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<tr>
<td>System</td>
<td>Code</td>
<td>Advantages</td>
<td>Limitations</td>
<td>Operating Limitations</td>
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<td>---------------------------------------------</td>
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</tbody>
</table>
| 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
- **AB** Aircraft Based
- **GB** Ground Based
- **SB** Satellite Based

### Capability Limitations
- 1D WAM may provide capabilities up to and beyond 60,000 ft with appropriate software changes
- ADS-C installations provide coverage up to 100,000 ft; however, all SSRs are dependent on pressure altitude that is unrealizable above 60,000 ft
- Extant ADS-C installations (primarily in air transport category aircraft) are subject to previously published ITAR restrictions that prevent GPS output of latitudes, longitude, and velocity above altitudes of 60,000 ft
- Installations adhering to previously published ITAR restrictions
- 1090ES format limits altitude to 126,750 ft, horizontal velocity to 4,080 kts, and vertical rate to 32,608 fpm; UAT format limits altitude to 101,337 ft and vertical rate to 32,608 fpm - vehicles travelling more than 600 m/s shall be subject to current ITAR restrictions
<table>
<thead>
<tr>
<th>Surveillance Method</th>
<th>Type</th>
<th>Advantages</th>
<th>Disadvantages</th>
<th>ETM Feasibility</th>
</tr>
</thead>
</table>
| 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) |
| Automatic Dependent Surveillance – Contract (ADS-C) | ABGBSB | • 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 | • Commercial altimeter limitations above 60,000 ft impacts pressure altitude reported through 1090ES and UAT  
• Susceptible to jamming and spoofing  
• 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

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