Enabling Airspace Integration for High Density On-Demand Mobility Operations

Eric Mueller
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An incremental approach to airspace integration can achieve high-density on-demand mobility
On-demand mobility

Drive - Fly Mode Choice

Data source: BTS, “Long Distance Transportation Patterns: Mode Choice”, 2006
Airspace Integration Definition

Operating safely and efficiently in a given volume without unreasonably burdening existing airspace users or air traffic control
Airspace Integration Options

IFR (Instrument Flight Rules): under the supervision of air traffic control (ATC)
VFR (Visual Flight Rules): used largely by general aviation, not commercial operators
UTM (UAS Traffic Management): parallel ATC system for small, low altitude UAS

Simplified National Airspace System (NAS)

IFR
18,000 ft MSL - 60,000 ft MSL

Class A

Class G
Uncontrolled
Upper-limit varies

Small airports
Surface - 2,500 ft AGL

Class D
4 nautical mile radius

Class E
All airspace between Class A and Class G.

Class B
Busiest airports
Surface - 10,000 ft AGL

Class C
Moderately busy airports
Surface - 4,000 ft AGL
| 10 nautical mile radius |

UTM

*VMC/IMC = Visual/Instrument Meteorological Conditions

Image courtesy of Flight Test STEM
The IFR Airspace Integration Problem

- High-density reference mission in a single metropolitan area (30x40 nmi)
  - 1200 aircraft, 150,000 passengers per day, more operations than the entire NAS
  - Approximately one on-demand mobility aircraft per square mile

On-demand mobility density is \(~400\) times higher than the allowable IFR density
Airspace Integration for New Users
Airspace Integration Principles

1. Does not require additional air traffic control (ATC) infrastructure

2. Does not impose additional workload on human controllers (i.e. ATC)

3. Does not restrict operations of traditional airspace users

4. Will meet appropriate safety thresholds and requirements

5. Will prioritize operational scalability to reach high aircraft densities

6. Allows flexibility where possible and imposes structure where necessary
## Airspace Integration Approaches

Start where you are with what you have…

<table>
<thead>
<tr>
<th>Approach</th>
<th>Advantages</th>
<th>Disadvantages</th>
<th>Prognosis for urban mob.</th>
</tr>
</thead>
<tbody>
<tr>
<td>IFR</td>
<td>Air traffic services allow operation anywhere, anytime</td>
<td>Not scalable</td>
<td>Operationally incompatible, automated technologies and services may extend to urban mobility</td>
</tr>
<tr>
<td>VFR</td>
<td>Maximum autonomy from ATC for manned aircraft</td>
<td>Must provide own ATC services, no IMC ops, not scalable</td>
<td>Allows autonomy from ATC, but safety, scalability, and efficiency are too low</td>
</tr>
<tr>
<td>UTM</td>
<td>ATC ecosystem for small UAS provides all relevant services</td>
<td>Quality and availability of services for small UAS require extensions for manned aviation</td>
<td>Supplies most services necessary for high density urban mobility, but tech. and procedures still in research phase</td>
</tr>
</tbody>
</table>
How to get to High Density on-demand mobility

…make something of it and never be satisfied

1. Start by operating VFR according to today’s rules

2. Incrementally develop and certify aircraft-centric technologies to relieve operational constraints

3. Adopt UTM services as replacements for aircraft-centric technologies and VFR requirements
Approaches to Developing Capabilities

**Low Density**
- VFR-dominated operations, new procedures

**Medium Density**
- Advanced VFR with adapted UAS, IFR technologies

**High Density**
- Autonomous ops. with UTM services

**Contribution of Capability/Technology**

- *Low Density* Procedural (VFR)
- *Medium Density* Vehicle (IFR/UAS)
- *High Density* UTM

**Time (years)**

- **+N**
- **+2N**

- • See and avoid unsafe
- • Sequencing and spacing inefficient
- • IMC constraints

- • Aircraft tech. too costly,
- • Centralized coordination may be more efficient
- • Pilot needs to be remote
Capabilities Required for Airspace Integration

- Communications
- Navigation
- Surveillance
- Weather/Met. Data
- Security
- Airspace routes
- Airspace constructs
- Airspace classes
- Geofencing
- Take-off and landing areas

- Demand-capacity balancing
- Separation
  - aircraft, obstacles, terrain
- Scheduling, sequencing and spacing
  - to take-off and landing areas, corridors, ops. areas
- Trajectory planning
- Wake avoidance
- All-weather and night-time operations
- Contingency management
- Community impact (noise)
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Airspace Constructs (AC)

- Today, AC consist of procedures and rules that enhance safety or efficiency
  - Los Angeles special flight rules area (SFRA)
  - Mode-C veil, with ADS-B (i.e. satellite-based surveillance)
- For on-demand mobility, airspace constructs will compensate for technological limitations
- UTM will provide more efficient airspace access than AC
  - May allow dynamic ACs

**UTM would relieve the need to impose airspace constructs**
Sequencing, Scheduling, Spacing (SSS)

- Today, SSS is used to regulate the flow of traffic into constrained airspace
  - Airport (terminal) areas
    - VFR aircraft follow procedures and use vision
    - IFR aircraft sequenced far from the airport and merged by humans using advisory tools
  - Weather-impacted enroute sectors
- On-demand mobility will require an automated or distributed SSS capability for VTOLs
- UTM surveillance and trajectory prediction capabilities will directly support SSS functions

Traffic Management Advisor

UTM does not require SSS, but the services it provides could be extended to this capability
Separation Services

- Today, different aircraft types separate differently
  - VFR aircraft separate visually
  - IFR aircraft separated by ATC, but require visual and electronic collision avoidance
  - Right-of-way rules for aircraft classes
- On-demand mobility aircraft will assume responsibility for separation to avoid IFR capacity limitations
  - UAS detect-and-avoid (DAA) systems
  - Vehicle-to-vehicle (V2V) technologies
- UTM will provide surveillance and separation services, but tailored for small UAS

**UTM provides separation services, need to reduce risk to apply them to human-carrying aircraft**
Research Approach for Airspace Integration
Airspace Capacity Enablers

What capabilities will increase the capacity of the airspace?

System viability

Airspace Capacity

- Low density, procedures and algorithms (e.g., VFR, SFRA, SSS)
- Medium density, aircraft technologies, some UTM (e.g., DAA, IMC ops, V2V)
- High density, UTM, autonomy, self-piloted (e.g., UTM, self-piloted)

Deliver validated data on the cumulative benefits and costs of these capabilities
Airspace Capacity Enablers

What capabilities will increase the capacity of the airspace?

System viability

Airspace Capacity

VFR

Self-piloted

Time (years)

+N

+2N

Deliver validated data on the cumulative benefits and costs of these capabilities
Next Steps

1. Organize a community of interest for airspace integration
2. Develop a roadmap of airspace integration solutions by density level
3. Develop required airspace services, whether aircraft-centric or in UTM
4. Create analysis, modeling, simulation, flight test infrastructure
5. Verify scalability of airspace solutions through simulations
6. Validate deployability of solutions through flight tests

An incremental approach to airspace integration can achieve high-density on-demand mobility

Eric.Mueller@nasa.gov
Backup
UTM Architecture
Airspace Integration Research Approach

Technology and Procedure Candidates

UAM Corridors | Aircraft | UTM | V2V/DSRC | Separation
---|---|---|---|---
DAA systems | | | | |
High-maturity (TRL) capabilities | | | | |
Low-maturity capabilities | | | | |
Deployability | Technology Integration | HitL Evaluation | Scalability | NAS-wide Simulation
Flight Test | | | | |
Airspace Integration R&D Goals

• Provide concepts, technologies and procedures that enable orders of magnitude increases in the capacity of the airspace for novel vehicle types and operations through cooperative airspace traffic management that does not require additional ATM infrastructure

• Flight test demonstration of integrated system deployability at successively higher traffic densities

• Simulation demonstration of concept scalability with novel capabilities at successively higher densities
### Mapping Approaches to Capabilities

<table>
<thead>
<tr>
<th>Barrier</th>
<th>Procedural</th>
<th>Vehicle</th>
<th>UTM</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Information gathering and exchange</strong></td>
<td>Charted routes, GPS &amp; radio beacons, pilot SAA &amp; ADS-B, FIS, VHF</td>
<td>V2V state &amp; intent exchange, 802.11p, aGPS + WAAS, DAA, VDL, cell net.</td>
<td>UTM-aggregated data, V2V backup, limited DAA, aGPS + GBAS, cell net., sat. comm.</td>
</tr>
<tr>
<td><strong>Airspace design</strong></td>
<td>UAM corridors in terminal airspace, public helipads</td>
<td>High density corridors enroute, reserved airspace, municipality TOLAs</td>
<td>No UAM structure, some traditional users excluded, neighborhood TOLAs</td>
</tr>
<tr>
<td><strong>Airspace Services</strong></td>
<td>Pilot SAA, traditional flight planning</td>
<td>DAA for separation &amp; SSS, AR wake avoidance</td>
<td>UTM-provided services &amp; traj. planning, backup DAA</td>
</tr>
<tr>
<td><strong>Resilience, scalability</strong></td>
<td>NOTAMs, scripted contingency ops, daytime only, VMC</td>
<td>V2V-coordinated contingency ops, IMC, night-time</td>
<td>FIMS, dynamic contingency ops, all weather, all times</td>
</tr>
</tbody>
</table>
### UAM Separation Services

- **Separation between different types of aircraft handled differently**

<table>
<thead>
<tr>
<th>Aircraft pairs</th>
<th>Low Density</th>
<th>Medium Density</th>
<th>High Density</th>
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<tr>
<td><strong>UAM-UAM</strong></td>
<td>SAA, AC, ADS-B</td>
<td>DAA, V2V, AC</td>
<td>UTM, V2V, DAA</td>
</tr>
<tr>
<td><strong>UAM-IFR</strong></td>
<td>Segregation, SAA, ADS-B</td>
<td>DAA, ADS-B</td>
<td>UTM, DAA</td>
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<td><strong>UAM-VFR</strong></td>
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UTM Architecture and Services

Flexibility where possible, structure where necessary

UTM SYSTEM

AIRCRAFT
- SEPARATION
- TOLA OPERATIONS
- ENHANCED FLIGHT RULES

AIR NAVIGATION SERVICE PROVIDER
- DIRECTIVES
- DEMAND/CAPACITY MANAGEMENT
- AIRSPACE CONSTRAINTS
- MANAGED BY EXCEPTION

SUPPORT SERVICE SUPPLIERS
- WEATHER
- TRACKING
- SEPARATION
- 3D MAPS
- SPACING
- COMMUNICATION

OPERATIONS CENTER
- TRAJECTORY PLANNING
- SCHEDULING
- DYNAMIC ROUTING
- FLEET MONITORING
- CONTINGENCIES

Flexibility where possible, structure where necessary