CONSIDERATIONS FOR AN INTEGRATED UAS CNS ARCHITECTURE

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These slides and a recording of this talk are available at
http://www.cse.wustl.edu/~jain/papers/icns17a.htm

http://www.cse.wustl.edu/~jain/papers/icns17a.htm
Overview

1. UAV Classification
2. Types of Missions
3. Levels of Autonomy
4. UA demand forecasts
5. ADS-B Capacity and Security

Acknowledgement: This work was conducted under NASA contract NNA16BD84C titled: “Revolutionary, Advanced universal, reliable, always available, cyber secure and affordable Communication, Navigation, Surveillance (CNS) Options for all altitudes of UAS operations.”

http://www.cse.wustl.edu/~jain/papers/icns17a.htm
Our Goals

- To develop the requirements for Integrated UAS CNS architecture
- Need to classify missions and UAS types
- To study what has been done and make changes only where necessary

http://www.cse.wustl.edu/~jain/papers/icns17a.htm
UAV Classification

1. DoD
2. ASTM
3. EUROCAE
4. RTCA

http://www.cse.wustl.edu/~jain/papers/icns17a.htm
1. DoD UAS Classification

http://www.cse.wustl.edu/~jain/papers/icns17a.htm
DoD UAV Classification (Cont)

- By weight, Altitude, and Speed

### Table 1 UAVs Classification according to the US Department of Defense (DoD)

<table>
<thead>
<tr>
<th>Category</th>
<th>Size</th>
<th>Maximum Gross Takeoff Weight (MGTW) (lbs)</th>
<th>Normal Operating Altitude (ft)</th>
<th>Airspeed (knots)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group 1</td>
<td>Small</td>
<td>0-20</td>
<td>&lt;1,200 AGL*</td>
<td>&lt;100</td>
</tr>
<tr>
<td>Group 2</td>
<td>Medium</td>
<td>21-55</td>
<td>&lt;3,500</td>
<td>&lt;250</td>
</tr>
<tr>
<td>Group 3</td>
<td>Large</td>
<td>&lt;1320</td>
<td>&lt;18,000 MSL**</td>
<td>&lt;250</td>
</tr>
<tr>
<td>Group 4</td>
<td>Larger</td>
<td>&gt;1320</td>
<td>&lt;18,000 MSL</td>
<td>Any airspeed</td>
</tr>
<tr>
<td>Group 5</td>
<td>Largest</td>
<td>&gt;1320</td>
<td>&gt;18,000</td>
<td>Any airspeed</td>
</tr>
</tbody>
</table>

*AGL = Above Ground Level  
**MSL = Mean Sea Level

Note: If the UAS has even one characteristic of the next level, it is classified in that level.

Source: “Eyes of the Army” U.S. Army Roadmap for UAS 2010-2035

Ref: [https://www.e-education.psu.edu/geog892/node/5](https://www.e-education.psu.edu/geog892/node/5)  
[http://www.cse.wustl.edu/~jain/papers/icns17a.htm](http://www.cse.wustl.edu/~jain/papers/icns17a.htm)
2. ASTM F2395-05 UAV Systems

- **Light-UAV**: UAV with a maximum gross takeoff weight of 1320 lbs or less
- **Mini-UAV**: UAV with a maximum gross takeoff weight of 55 lbs or less (sUAS)
  - Under 2 Kg
  - at 10 Kg
  - at 25 Kg (55 lbs)
- Weight limits similar to DoD
- Withdrawn

ftp://185.72.26.245/Astm/2/01/Section%2015/ASTM1507/PDF/F2395.pdf
http://www.cse.wustl.edu/~jain/papers/icns17a.htm
3. EUROCAE Classification

- European counterpart of RTCA in USA

- Open:
  - Less than 250g = 0.5 lbs
  - Less than 1kg
  - Less than 4kg
  - Less than 25 kg = 55 lbs

- Many countries regulations based on this:
  - US requires registration of sUAS (250g to 25kg)
  - Irish Aviation Authority requires registration of over 1kg and pilot license for over 4kg
  - South Africa allows up to 7 kg and 500m without registration or license

http://www.cse.wustl.edu/~jain/papers/icns17a.htm
4. RTCA Categorization of UA

- **Category A:**
  - Privately owned for recreation or sport.
  - Unregulated but guided

- **Category B:**
  - Non-recreational, VLOS
  - May share space with low-flying aircrafts
  - Regulated, non-airport

- **Category C:**
  - Beyond VLOS
  - Larger than category B ⇒ Kinetic energy
  - Non-airport

- **Category D:**
  - Similar to manned aircrafts
  - Access to NAS including civilian airports

- Note: No weights

Proposed Categorization of UA

- **Category A**: Recreational below 55 lbs
  - Privately owned for recreation or sport.
  - Unregulated but guided

- **Category B**: Commercial below 55 lbs
  - Non-recreational, VLOS
  - May share space with low-flying aircrafts
  - Regulated, non-airport

- **Category C**: Commercial above 55-1320 lbs
  - Beyond VLOS
  - Larger than category B $\Rightarrow$ Kinetic energy
  - Non-airport

- **Category D**: Commercial above 1320 lbs
  - Similar to manned aircrafts
  - Access to NAS including civilian airports
Types of Missions

1. EUROCAE
2. ITU
3. RTCA
1. EUROCAE Mission Classification

- European RTCA

### Categories of Operation

- **OPEN:**
  - Low risk
  - No involvement of Aviation Authority
  - Limitations (Visual line of sight, Maximum Altitude, distance from airport and sensitive zones)
  - Flights over crowds not permitted except for harmless subcategory

- **SPECIFIC:**
  - Increased risk
  - Approval based on Specific Operation Risk assessment (SORA)
  - Approved by NAA possibly supported by accredited GSE unless approved operator with privilege
  - Manual of Operations mandatory to obtain approval

- **CERTIFIED:**
  - Regulatory regime similar to manned aviation
  - Certified operations to be defined by implementing rules
  - Pending criteria definition, EASA accepts application in its present remit
  - Some systems (DataLink, Detect and Avoid, ...) may receive an independent approval

[http://www.cse.wustl.edu/~jain/papers/icns17a.htm](http://www.cse.wustl.edu/~jain/papers/icns17a.htm)
2. ITU M.2171 UAS Missions

<table>
<thead>
<tr>
<th>Mission type</th>
<th>Example description</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Movie making, sports games, popular events like concerts.</td>
</tr>
<tr>
<td>B</td>
<td>Cargo planes with reduced man power (one-man-cockpit).</td>
</tr>
<tr>
<td>C</td>
<td>Inspections for industries, e.g. oil fields, oil platforms, oil pipelines, power line, rail line.</td>
</tr>
<tr>
<td>D</td>
<td>Provision of airborne relays for cell phones in the future.</td>
</tr>
<tr>
<td>E</td>
<td>Commercial agricultural services like crop dusting.</td>
</tr>
<tr>
<td>F</td>
<td>Earth science and geographic missions (e.g. mapping and surveying, aerial photography) biological, environmental missions (e.g. animal monitoring, crop spraying, volcano monitoring, biomass surveys, livestock monitoring, tree fertilization).</td>
</tr>
<tr>
<td>Q</td>
<td>Coast line inspection, preventive border surveillance, drug control, anti-terrorism operations, strike events, search and rescue of people in distress, and national security. Public interest missions like remote weather monitoring, avalanche prediction and control, hurricane monitoring, forest fires prevention surveillance, insurance claims during disasters and traffic surveillance.</td>
</tr>
<tr>
<td>H</td>
<td>Famine relief, medical support, aid delivery. Search and rescue activities.</td>
</tr>
</tbody>
</table>

UAV Applications

- Aerial crop surveys, Aerial photography, Search and rescue, Inspection of power lines and pipelines, Counting wildlife, Delivering medical supplies, Detection of illegal hunting, Reconnaissance operations, Cooperative environment monitoring, Border patrol missions, Convoy protection, Forest fire detection and monitoring, Surveillance, Coordinating humanitarian aid, Plume tracking, Land surveying, Fire and large-accident investigation, Landslide measurement, Illegal landfill detection, Construction industry, Crowd monitoring, Patrol borders, Scout property, Locate fugitives, Law enforcement, Search and rescue, Scientific research, Anti-poaching, Anti-whaling, Pollution monitoring, Surveying, Oil, gas and mineral exploration and production, Disaster relief, Archaeology, Cargo transport, Passenger transport, Criminal and terrorism, ...

Ref: https://en.wikipedia.org/wiki/Unmanned_aerial_vehicle

http://www.cse.wustl.edu/~jain/papers/icns17a.htm
300 UAV Applications

300 Commercial UAV Applications
Save 10X Time, Save 10X Money, Save Lives

- Military
- Energy
- Agriculture
- Transportation
- Public Safety
- Environmental Monitoring
- Scientific Research
- Film & Media
- Construction
- Surveying
- Emergency Services
- Entertainment

Ref: https://www.uxvuniversity.com/careers/
http://www.cse.wustl.edu/~jain/papers/icns17a.htm

Very little difference among applications in terms of CNS ⇒ Categories
Levels of Autonomy

- Normal:
  - Self-Level at a particular altitude
  - Hover
  - Take-off and Landing
  - Return to home
  - Follow me
  - GPS waypoint navigation

- Semi-Autonomous: UA observes, reports to pilot, and acts as instructed. Significant communication overhead.

- Autonomous: Like self-driving cars. Lower communication overhead.
Proposed Mission Categories

- **Category A:**
  - For recreation or sport
  - Unregulated but guided
  - VLOS, 200 AGL, Low Velocity

- **Category B:**
  - Commercial/Governmental, VLOS
  - Regulated, non-airport, 400 AGL, Low Velocity

- **Category C:**
  - Beyond VLOS
  - Larger than category B ⇒ Kinetic energy
  - Non-airport, 400 AGL, Higher velocity

- **Category D:**
  - Similar to manned aircrafts
  - Access to NAS including civilian airports, >700 AGL
    1. On-Ground
    2. Taxi and Take-off
    3. En-Route
    4. Oceanic

[Diagram of proposed mission categories]

[Diagram showing the range and velocity for categories A to D]

[Links to additional resources]
http://www.cse.wustl.edu/~jain/papers/icns17a.htm
Demand Forecast

1. ITU M.2171
2. RTCA
3. SESAR

http://www.cse.wustl.edu/~jain/papers/icns17a.htm
RTCA Counts of Aircrafts in 2030

<table>
<thead>
<tr>
<th>Altitude</th>
<th># of UAs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Below 3000 ft</td>
<td>24,038</td>
</tr>
<tr>
<td>Between 3000 ft and 12,000 ft</td>
<td>29,631</td>
</tr>
<tr>
<td>Between 12,000 ft and 30,000 ft</td>
<td>988</td>
</tr>
<tr>
<td>Above 30,000 ft</td>
<td>2,560</td>
</tr>
</tbody>
</table>

- These do not include public aircrafts that will not be using ITU-R allocated UAS Safety Spectrum
- 50% of these are small UAS operating beyond VLOS
- Satellite CNPC Links:
  - 80% of aircrafts above 12kft will use satellite
  - 50% of aircrafts between 3kft and 12kft

Ref:
1. ITU-R M.2171, Characteristics of Unmanned Aircraft Systems and Spectrum Requirements to Support Their Safe Operation in Non-Segregated Airspace
2. RTCA DO-320, Operational Services and Environmental Definition (OSED) for Unmanned Aircraft Systems,
3. JPDO IPSA results, and
4. VOLPE service demand projections report.

http://www.cse.wustl.edu/~jain/papers/icns17a.htm
SESAR Forecast

- Single European Sky ATM Research (SESAR)
- 7 million hobby drones
- 400,000 Commercial and Government missions in 2050

<table>
<thead>
<tr>
<th>Sector</th>
<th>Forecast</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agriculture</td>
<td>100,000</td>
</tr>
<tr>
<td>Energy</td>
<td>10,000</td>
</tr>
<tr>
<td>Delivery</td>
<td>100,000</td>
</tr>
<tr>
<td>Public safety and security</td>
<td>50,000</td>
</tr>
</tbody>
</table>

http://www.cse.wustl.edu/~jain/papers/icns17a.htm
Problem with Current Forecasts

- Assumption: Unmanned demand is similar to manned demand.
  - Like forecasting car demands based on train demands
- But unmanned
  - Applications are very different from manned
  - Too numerous,
  - Price points are also very different
  - Technology is advancing too fast
- Unmanned limited artificially by regulators
- Unmanned traffic will grow much faster than any current forecast
- Unmanned more similar to self-driving cars than to airplanes
  - Both technology wise, price points, applications
    (Agriculture, news gathering, …)

http://www.cse.wustl.edu/~jain/papers/icns17a.htm
## sUAS: Demand Forecast

### NASA UTM+ FAA: In Million Units

<table>
<thead>
<tr>
<th></th>
<th>2016</th>
<th>2017</th>
<th>2018</th>
<th>2019</th>
<th>2020</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Recreational</strong></td>
<td>1.9</td>
<td>2.3</td>
<td>2.9</td>
<td>3.5</td>
<td>4.3</td>
</tr>
<tr>
<td><strong>Commercial</strong></td>
<td>0.6</td>
<td>2.5</td>
<td>2.6</td>
<td>2.6</td>
<td>2.7</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>2.5</td>
<td>4.8</td>
<td>5.5</td>
<td>6.1</td>
<td>7.0</td>
</tr>
</tbody>
</table>

Ref: FAA, "FAA Aerospace Forecast, FY 2016-2036,"
https://www.faa.gov/data_research/aviation/aerospace_forecasts/media/FY2016-36_FAAR_Aerospace_Forecast.pdf


http://www.cse.wustl.edu/~jain/papers/icns17a.htm
Sea-Tac Example

- Seattle-Tacoma International Airport
- 3 Square miles – mostly airfield and runway
- Assume 1 Square miles of terminal space
- Services $O(10^4)$ passengers per hour
- Assume 10% of passengers use 4G+WiFi services
  $\Rightarrow O(10^3)$ devices per hour per square mile

Ref: Port of Seattle, 2015, 2015 Airport Statistics (2015 Airport Activity Highlights),
https://www.portseattle.org/About/Publications/Statistics/Airport-Statistics/Pages/default.aspx
http://www.cse.wustl.edu/~jain/papers/icns17a.htm
ADS-B Capacity Requirements

- Peak traffic based on Los Angeles Basin 2020 scenario


http://www.cse.wustl.edu/~jain/papers/icns17a.htm
### ADS-B Capacity Requirements (Cont)

<table>
<thead>
<tr>
<th>Range (NM)</th>
<th>LA Basin 2020</th>
<th>Low Density</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>On-the-Ground</td>
<td>Airborne Only</td>
</tr>
<tr>
<td>50</td>
<td>143</td>
<td>260</td>
</tr>
<tr>
<td>100</td>
<td>190</td>
<td>520</td>
</tr>
<tr>
<td>150</td>
<td>225</td>
<td>781</td>
</tr>
<tr>
<td>200</td>
<td>225</td>
<td>1,045</td>
</tr>
<tr>
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<td>225</td>
<td>1,321</td>
</tr>
<tr>
<td>300</td>
<td>225</td>
<td>1,648</td>
</tr>
<tr>
<td>350</td>
<td>225</td>
<td>2,021</td>
</tr>
<tr>
<td>400</td>
<td>225</td>
<td>2,469</td>
</tr>
</tbody>
</table>


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### ADS-B Capacity Requirements (Cont)

<table>
<thead>
<tr>
<th>Range (NM)</th>
<th>LA Basin 2020</th>
<th>Low Density</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>On-the-Ground</td>
<td>Total Units</td>
</tr>
<tr>
<td>50</td>
<td>143</td>
<td>260</td>
</tr>
<tr>
<td>100</td>
<td>190</td>
<td>520</td>
</tr>
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<td>150</td>
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Security Considerations

- **Confidentiality:**
  - Flight number and positions are public
  -VIPs and Businesses can be targeted

- **Integrity:**
  - Insertion of false messages, alarms, traffic information
  - Alteration of messages
  - Deletion of messages

- **Availability:**
  - Jamming of ground station
  - Jamming of GPS Signals
  - DoS attacks by saturating the channel with false messages

http://www.cse.wustl.edu/~jain/papers/icns17a.htm
Summary

1. UA categories A, B, C, D with weight + AGL
2. Mission categories A, B, C, D with multiple phases (taxiing/takeoff, en-route)
3. Requirements depend significantly on the mission type: A, B, C, D₁, D₂, D₃, and D₄
4. Use of larger UASs and BLOS applications is restricted ⇒ Demand forecasts are too low
5. Significant security issues with ADS-B

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References
