

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>

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

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

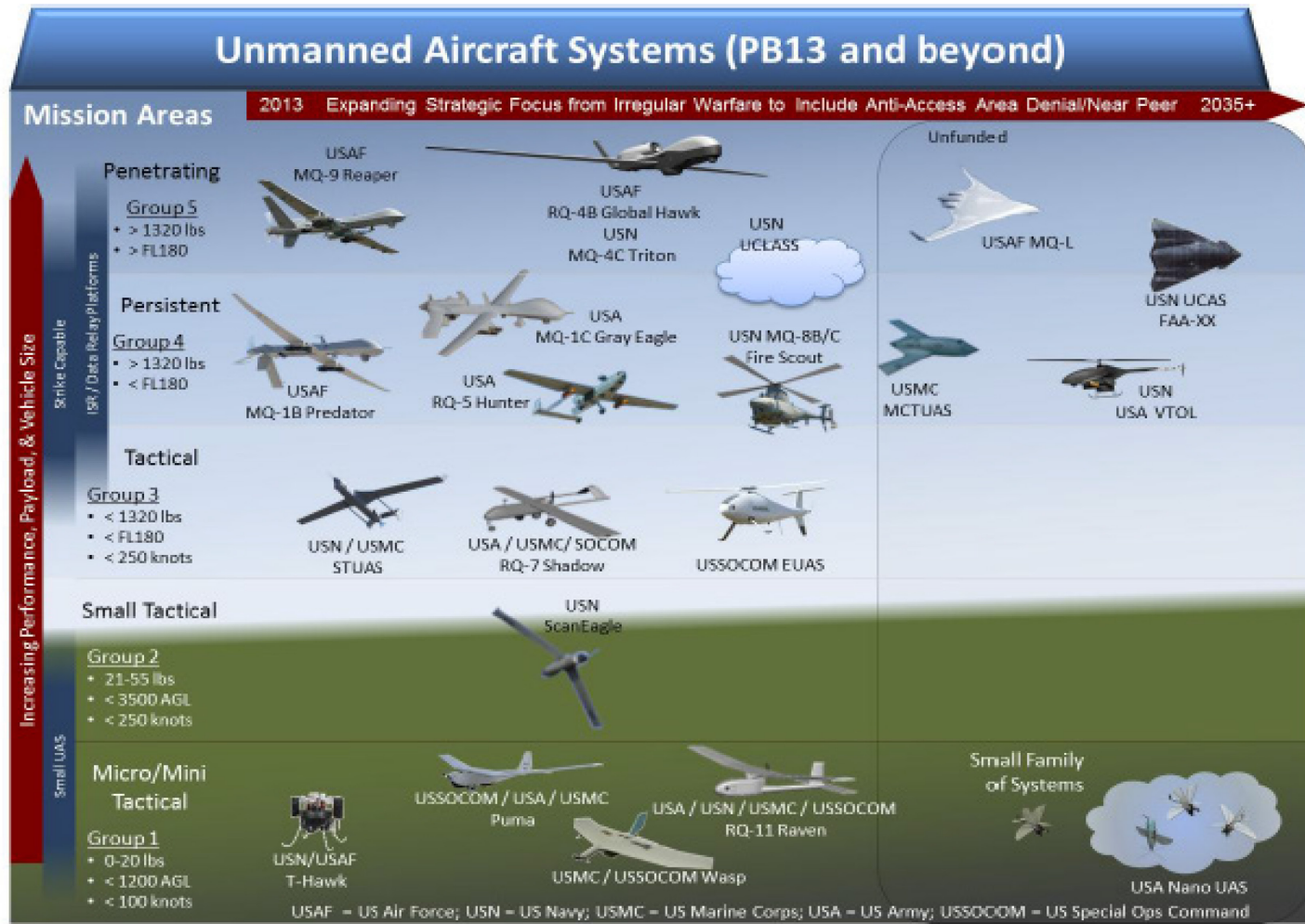
Our Goals

- ❑ 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

UAV Classification

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

1. DoD UAS Classification



DoD UAV Classification (Cont)

□ By weight, Altitude, and Speed

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

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

*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>

<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- ❑ Withdrawn

Ref: ASTM, "Standard Terminology for Unmanned Air Vehicle Systems (**Withdrawn 2014**)," ASTM F2395-07, 2 pages, available for purchase from ASTM.

ASTM, "Standard Terminology for Unmanned Air Vehicle Systems," ASTM F2395-05, 2 pages,

<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

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 \Rightarrow Kinetic energy
- Non-airport

□ Category D:

- Similar to manned aircrafts
- Access to NAS including civilian airports

□ Note: No weights

Ref: RTCA, "UAS Guidance Material and Considerations for Unmanned Aircraft Systems," DO-304, March 22, 2007, 314 pp.

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

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 QE unless approved operator with privilege
Manual of Operations mandatory to obtain approval

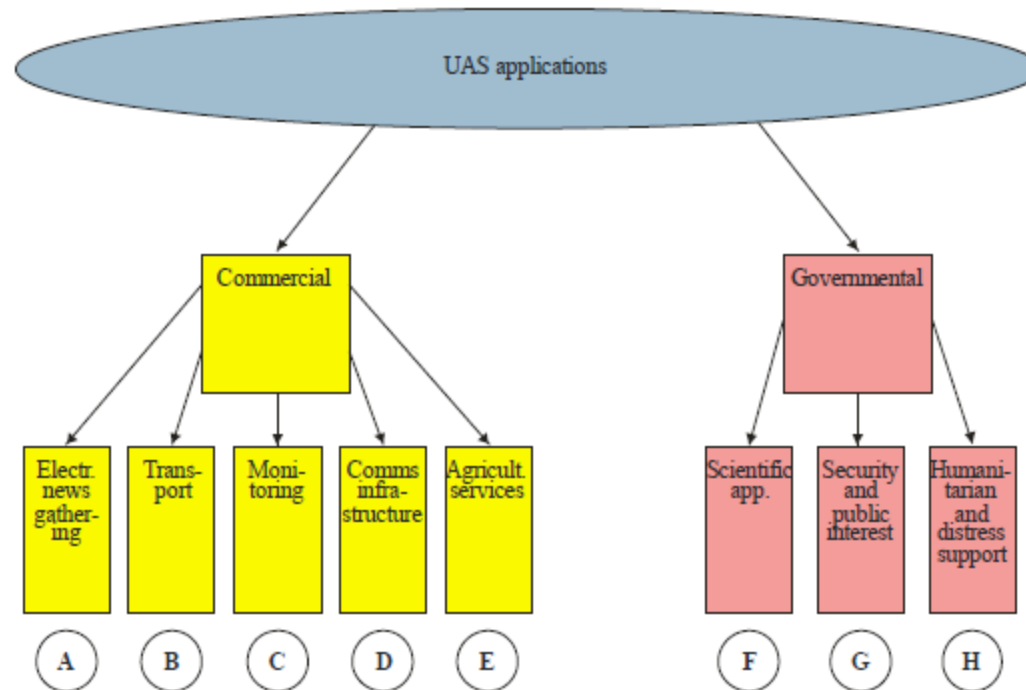


CERTIFIED

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

Ref: S. Rong, "EASA need for Standards and AMC for Unmanned Aircraft," EUROACE UAS Workshop, March 2016, 18 slides,
http://rpas-regulations.com/phocadownloadpap/02_14_EUROCAE/3_EUROCAE-UAS-Workshop_160304_EASA.pdf
<http://www.cse.wustl.edu/~jain/papers/icns17a.htm>

2. ITU M.2171 UAS Missions



Ref: Report ITU-R M.2171, Characteristics of Unmanned Aircraft Systems and Spectrum Requirements to Support Their Safe Operation in Non-Segregated Airspace, December 2009, https://www.itu.int/dms_pub/itu-r/opb/rep/R-REP-M.2171-2009-PDF-E.pdf
<http://www.cse.wustl.edu/~jain/papers/icns17a.htm>

ITU M.2171 UAS Missions Examples

Mission type	Example description
(A)	Movie making, sports games, popular events like concerts.
(B)	Cargo planes with reduced man power (one-man-cockpit).
(C)	Inspections for industries, e.g. oil fields, oil platforms, oil pipelines, power line, rail line.
(D)	Provision of airborne relays for cell phones in the future.
(E)	Commercial agricultural services like crop dusting.
(F)	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).
(G)	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.
(H)	Famine relief, medical support, aid delivery. Search and rescue activities.

Ref: Report ITU-R M.2171, Characteristics of Unmanned Aircraft Systems and Spectrum Requirements to Support Their Safe Operation in Non-Segregated Airspace, December 2009, https://www.itu.int/dms_pub/itu-r/opb/rep/R-REP-M.2171-2009-PDF-E.pdf
<http://www.cse.wustl.edu/~jain/papers/icns17a.htm>

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

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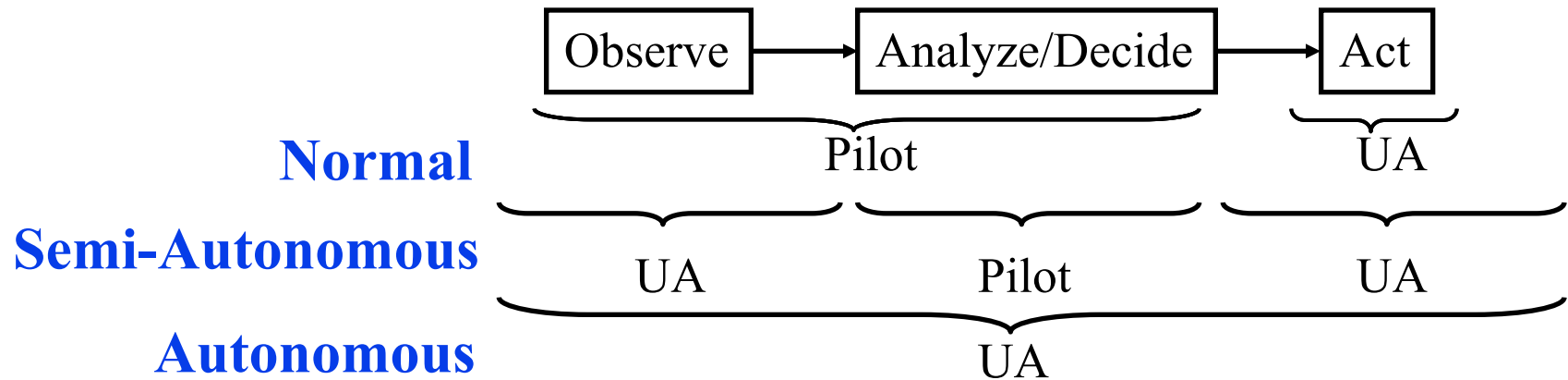


- Precision Agriculture
- Cell Tower Inspect
- Airborne Wind Turbine
- Cloud Seeding
- Plant Water Content
- Plant Disease Detect
- Weed Mapping
- Invasive Plants
- Insect Attack Warning
- Vegetation Identification
- Selective Harvesting
- Canopy Management
- Herd Tracking
- Telecommunications
- High Altitude Imagery
- Maritime Surveillance
- Media
- Traffic Monitoring
- Disaster Management
- Real Estate Photography
- Meteorology
- Hurricane Monitoring
- Cryospheric Research
- Bridge Inspection
- Transmission Line Inspect
- HAZMAT Inspection
- Emergency Medical Supply
- Aerial Surveying
- Damage Assessment
- Insurance Claim Appraisal
- Concert Security
- Sports Video
- Runway Inspection
- Virtual Tours
- Coffee Harvest
- Shark Watch
- Shark Warning
- Shark Repelling
- Cinematography
- Pollution Monitoring
- Hydrologic Modeling
- Geomorphic Model
- Flood Risk Assess
- Law Enforcement
- Pollution Monitor
- Photogrammetry
- Tidal Zone Modeling
- Solar Panel Inspect
- Anti-Piracy
- Algae Proliferation
- Rail Track Bed Inspect
- Ocean Research
- Saltwater Infiltration
- Landmark Inspection
- Illegal Ship Bilge Venting
- Emergency Com
- Terrain Mapping
- Sand Bank Shift
- Hydrometric Mapping
- Traffic Accident Analysis
- Highway Design
- Parking Utilization
- FedEx Unmanned Cargo
- Instant Consumer Grat
- Advertising
- Coastline Surveillance
- Pavement Roughness
- Animal Rights Groups
- Prevent Extinction
- Ant-Whaling
- Aerial Biology
- Flood Warning
- Fireworks Dropping
- Mosquito Breed Detect
- Crime Scene Photography
- Climate Monitoring
- Feral Hog Fighting
- Entomology
- Forest Inspection
- Fisheries Management
- Wildlife Conservation
- Wildlife Inventory
- Mineral Exploration
- Aerial Survey
- Forest Fire Surveillance
- Forest Fire Mapping
- Volcano Monitoring
- Aerial Mapping
- Oil Spill Tracking
- Avalanche Prevention
- Ice Pack Monitoring
- Poaching Patrol
- Landfill Monitoring
- Public Safety
- Firefighting
- Golf Resort Market
- Search and Rescue
- Training
- Cloud Seeding
- Stadium Events
- Pipeline Inspection
- Power Restoration
- Newspaper Delivery
- Fire Prevention
- Wind Turbine Blade
- River Discharge
- Marine Sanctuary
- River Discharge
- Ship Collision
- Maritime Mammals
- Train Crash
- Alligator Patrol
- Flying Sightings
- Cruise Ship Com
- Climate Monitoring
- Medical Supply Deliver
- Chimney Inspection
- Air Pollution Reduction
- Motion Pictures
- Audio Drones
- Aerial Photography
- Flotation Aid Drop
- Count Sheep
- Iceberg Monitoring
- Real Estate Marketing
- Crop Dusting
- Mining Volumes
- Water Trough Leakage
- Surveillance
- Earthquake Prediction
- Wildlife Research
- Archaeology
- Food Delivery
- Gunshot Triangulation
- Strip Mining
- Oil Rig Inspection
- Sinkhole Forecast
- Anti-Looting Control
- Landslide Prediction
- Gamer Drones
- Criminal Car Tracking
- Forest Management
- Cloud Properties
- Aerosol Measurement
- Coastal Water Quality
- Maritime Surveillance
- Construction Document
- Tree Growth
- Geophysical Survey
- Plant Phenotyping
- Biotelemetry
- Climate Monitoring
- Dam Inspection
- Urban Planning
- Culture Preservation
- Petroglyph Preservation
- Oil Discovery
- Quake Fault Discovery
- Traffic Flow Analysis
- Prevent Graffiti
- Journalism
- Crop Pests Detection
- Roof Inspection
- Wind Turbine Gearbox Insp
- Cartography
- Defibrillator Delivery
- Water Sampling
- Insect Detection
- Power Line Inspect
- Postal Service
- Tsunami Detection
- Locust Monitoring
- Drone Leasing
- Irrigation Mapping
- Radiation Monitoring
- Sea Level Change
- Water Tower Inspect
- Antenna Pattern Measure
- Aeromagnetic Survey
- Tsunami Debris
- GIS Data Capture
- Tour Guide
- Cell Tower LOS
- Tornado Measure
- Forest Regeneration
- Poverty Mapping
- Tree Growth
- Crowd Control
- VIP Security
- Topographic Maps
- Athletic Perf Improve
- Predator Control
- Biological Agent Det
- Event Security
- Port Security
- Pirating
- Avalanche Rescue
- Customs & Border
- Atmospheric Profile
- Hurricane Genesis
- Package Delivery
- Seismology
- Bank Erosion
- Pharmacy Delivery
- Airborne Pathogen
- Ecology Research
- Tourist Guide
- Lighting Area
- Radiation Cleanup
- Fire Investigation
- UAV Sensor Research
- Water Tower Inspect
- Antenna Pattern
- Magnetic Field Survey
- Crime Forensics
- Power Plant Emission
- Cell Tower LOS
- River Re-naturalization
- Follow Kid to Bus Stop
- Smoke Sampling
- Direction Finding
- Pizza Delivery
- Document Delivery
- Textbook Delivery
- Sushi Delivery
- Insect Shoot Down
- NASA
- Paparazzi Drones
- Department of Energy
- Kid Monitor
- Soil Volumetrics
- Change Detection
- Defibrillator Delivery
- UAV Tracking
- Environment Assessment
- Equipment Inventory
- Gas Plant Inspection
- Pressure Tanks
- Grass Dry Matter Measure
- Boating Drone
- FEMA
- Volcanic Ash Measure
- Drug Smuggling
- Explosives Detection
- VIP Monitoring
- SWAT
- Emergency Response Team
- Terrorist Attack
- Heat Loss
- Cooling Tower Inspect
- Human Trafficking Control
- Airborne WiFi
- Planetary Radiation
- Forest Fire Retardant
- Coast Guard
- Railroad Monitor
- Merchant Marine
- Civil Air Patrol
- Army Corps of Engineers
- Dept. of Transportation
- Environmental Protection
- National Guard
- Drug Enforcement Agency
- State Department
- FBI
- Bureau of Land Mgt
- Department of Energy
- Soil Moisture Level
- Taco Copter
- Burrito Bomber
- Beer Delivery
- Flower Delivery
- Hunting
- Fishing
- Load Transportation
- Conflict Monitor
- Alzheimer Search
- Play Music
- Whale Watching
- Code of Conduct
- Tornado Prediction
- Weather Modification
- Invisible UAV
- Airborne Internet
- Aerial Sports
- Three D Printed
- Pseudo-Satellite
- Power by the Hour
- Multi-Modal UAV
- Dronestagram
- Simulated Weather
- Drone Art
- Pocket Drone
- Location Scouting
- Protection
- Audio Surveillance
- Find Parking
- Home Security
- Weather Measurement
- One Step Processing
- Autonomous Soaring
- Wing Flapping
- Tethered Power
- Nuclear Inspection

Ref: <https://www.uxvuniversity.com/careers/>

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

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

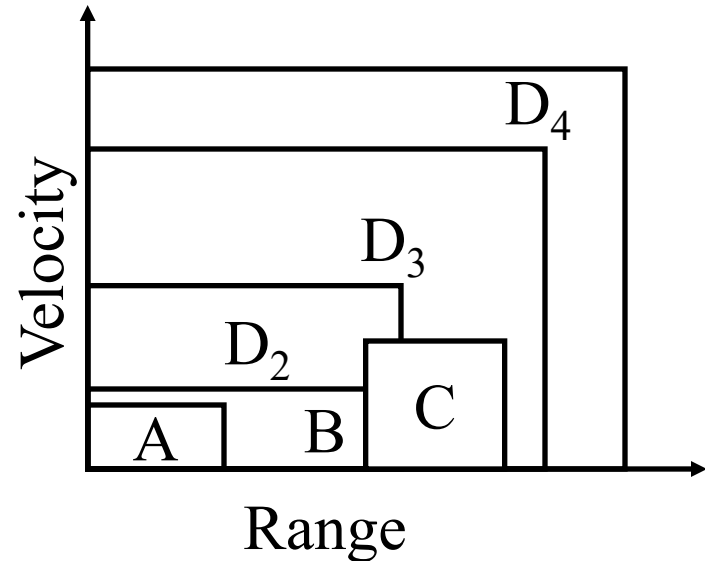
□ Category C:

- Beyond VLOS
- Larger than category B \Rightarrow 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



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

Demand Forecast

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

RTCA Counts of Aircrafts in 2030

Altitude	# of UAs
Below 3000 ft	24,038
Between 3000 ft and 12,000 ft	29,631
Between 12,000 ft and 30,000 ft	988
Above 30,000 ft	2,560

- ❑ 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

Sector	Forecast
Agriculture	100,000
Energy	10,000
Delivery	100,000
Public safety and security	50,000

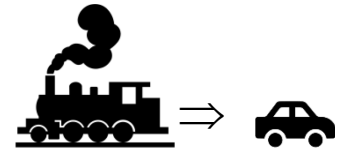
Ref: SESAR, 2016, European Drone Outlook Study - SESAR Joint Undertaking, 93 pp.

http://www.sesarju.eu/sites/default/files/documents/reports/European_Drones_Outlook_Study_2016.pdf

<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, ...)



sUAS: Demand Forecast

□ NASA UTM+ FAA: In Million Units

	2016	2017	2018	2019	2020
Recreational	1.9	2.3	2.9	3.5	4.3
Commercial	0.6	2.5	2.6	2.6	2.7
Total	2.5	4.8	5.5	6.1	7.0

Ref: FAA, "FAA Aerospace Forecast, FY 2016-2036,"

https://www.faa.gov/data_research/aviation/aerospace_forecasts/media/FY2016-36_FAA_Aerospace_Forecast.pdf

Kopardekar, P, et. al., "Unmanned Aircraft System Traffic Management (UTM) Concept of Operations", AIAA Aviation Forum, 13-17 June 2016, Washington, D.C.

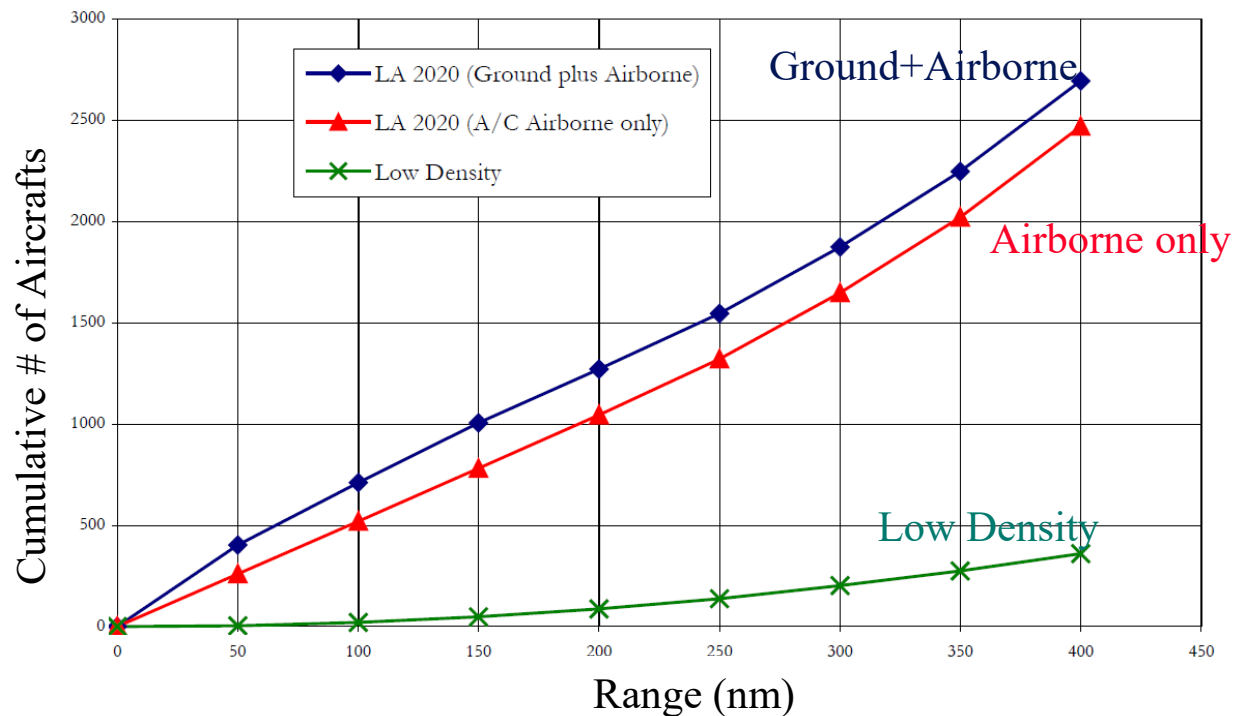
<http://www.cse.wustl.edu/~jain/papers/icns17a.htm>

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
⇒ $O(10^3)$ devices per hour per square mile

ADS-B Capacity Requirements

- Peak traffic based on Los Angeles Basin 2020 scenario



Ref: RTCA, 2002, Minimum Aviation system Performance Standards for Automatic Dependent Surveillance Broadcast (ADS-B), DO-242A, 475 pp.

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

ADS-B Capacity Requirements (Cont)

Range (NM)	LA Basin 2020			Low Density
	On- the- Ground	Airborne Only	Total Units	Total Units
50	143	260	403	4
100	190	520	710	20
150	225	781	1,006	48
200	225	1,045	1,270	88
250	225	1,321	1,546	138
300	225	1,648	1,873	203
350	225	2,021	2,246	274
400	225	2,469	2,694	360

Ref: RTCA, 2002, Minimum Aviation system Performance Standards for Automatic Dependent Surveillance Broadcast (ADS-B), DO-242A, 475 pp.

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

Security Considerations

❑ Confidentiality:

- Flight number and positions are public
⇒ VIPs and Businesses can be targetted

❑ Integrity:

- Insertion of false messages, alarms, traffic information
- Alteration of messages
- Deletion of messages

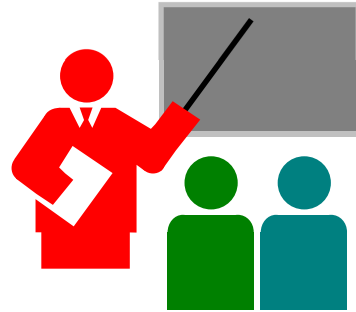
❑ Availability:

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

Ref: ICAO, 2008, Guidance Material: Security Issues Associated with ADS-B, 6 pp.

<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, D_1 , D_2 , D_3 , and D_4
4. Use of larger UASs and BLOS applications is restricted \Rightarrow Demand forecasts are too low
5. Significant security issues with ADS-B

References

- ❑ Templin, Fred L., Raj Jain, Greg Sheffield, Pedro Taboso-Ballesteros, and Denise Ponchak, “**Considerations for an Integrated UAS CNS Architecture**,” 2017 Integrated Communications Navigation and Surveillance (ICNS) Conference, Washington D. C., 11 pp., <http://www.cse.wustl.edu/~jain/papers/icns17a.htm>
- ❑ Templin, Fred L., Raj Jain, Greg Sheffield, Pedro Taboso-Ballesteros, and Denise Ponchak, “**Requirements for an Integrated UAS CNS Architecture**,” 2017 Integrated Communications Navigation and Surveillance (ICNS) Conference, Washington D. C., 11 pp., <http://www.cse.wustl.edu/~jain/papers/icns17b.htm>