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

Overview

1. UAV Classification

2. Types of Missions

3. Levels of Autonomy

4. UA demand forecasts

5. ADS-B Capacity and Security
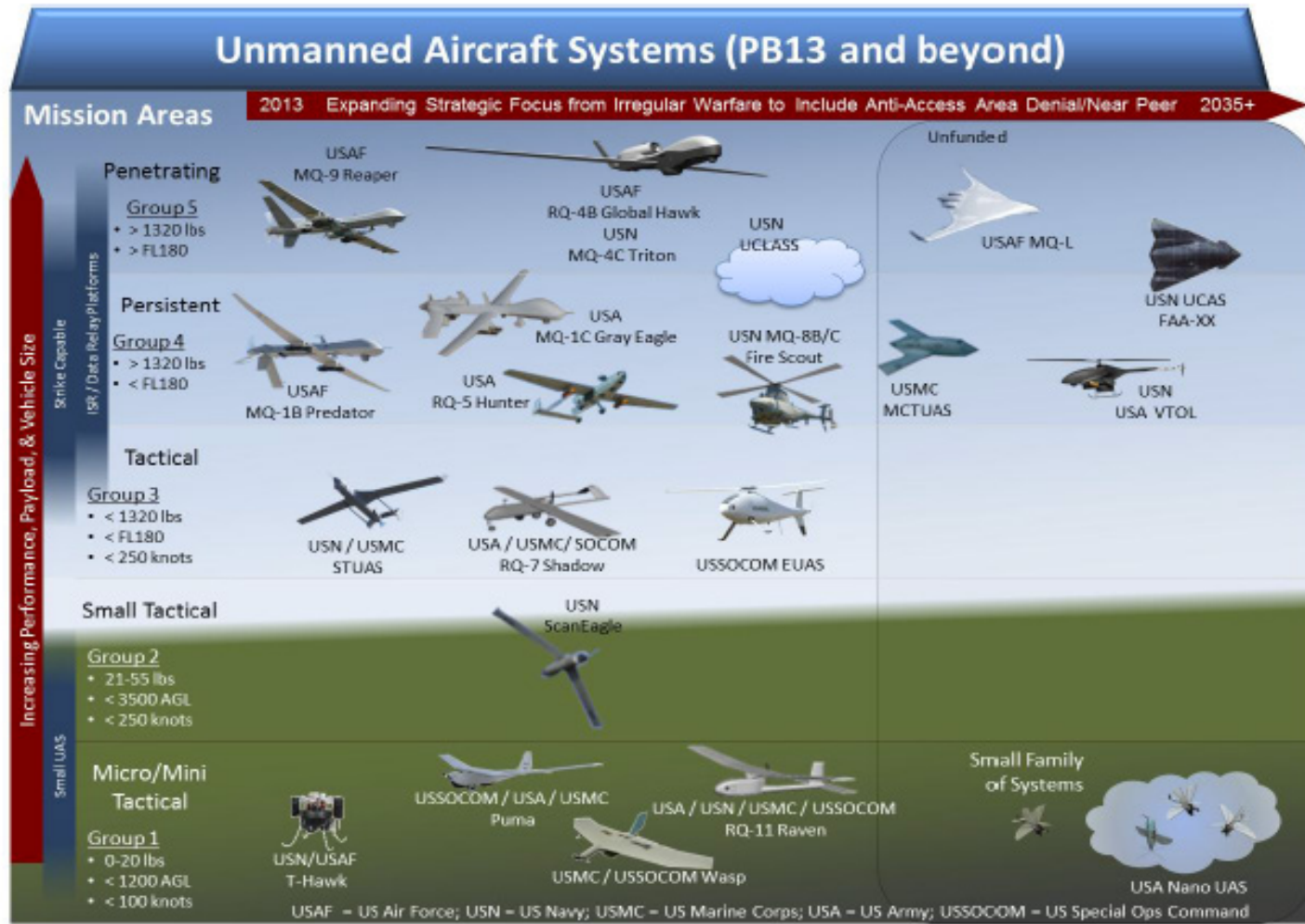
http://www.cse.wustl.edu/~jain/papers/icns17a.htm

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

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

1. DoD UAS Classification

Unmanned Aircraft Systems (PB13 and beyond)

2013 Expanding Strategic Focus from Irregular Warfare to Include Anti-Access Area Denial/Near Peer 2035+

USAF = US Air Force; USN = US Navy; USMC = US Marine Corps; USA = US Army; USSOCOM = US Special Ops Command

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❑ Withdrawn

Ref: ASTM, "Standard Terminology for Unmanned Air Vehicle Systems (Withdrawn 2014)," ASTM F2395-07, 2 pages, available for purchase from ASTM.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

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

Types of Missions

1. EUROCAE
2. ITU
3. RTCA

1. EUROCAE Mission Classification

❑ European RTCA

Categories of Operation

OPEN:	SPECIFIC	CERTIFIED
Low risk	Increased risk	Regulatory regime similar to manned aviation
No involvement of Aviation Authority	Approval based on Specific Operation Risk assessment (SORA)	Certified operations to be defined by implementing rules
Limitations (Visual line of sight, Maximum Altitude, distance from airport and sensitive zones)	Approved by NAA possibly supported by accredited QE unless approved operator with privilege	Pending criteria definition, EASA accepts application in its present remit
Flights over crowds not permitted except for harmless subcategory	Manual of Operations mandatory to obtain approval	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
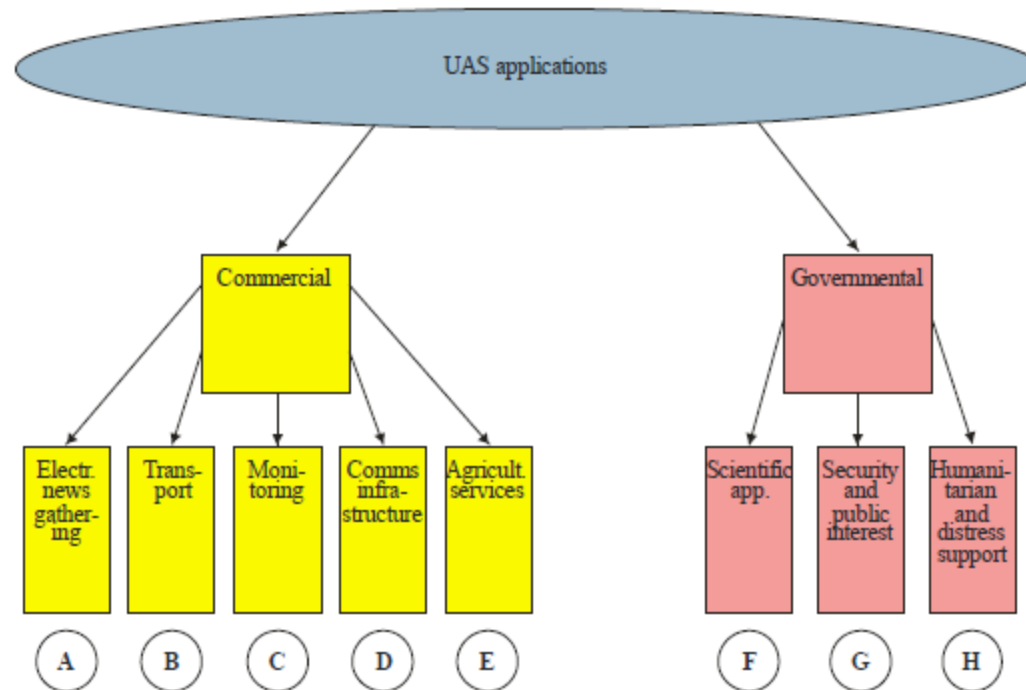
2. ITU M.2171 UAS Missions

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

© Unmanned Vehicle University

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

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

❑ Very little difference among applications in terms of CNS ⇒ Categories

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

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

Levels of Autonomy

Observe	Analyze/Decide	Act

Normal   Pilot   UA

Semi-Autonomous   UA   Pilot   UA
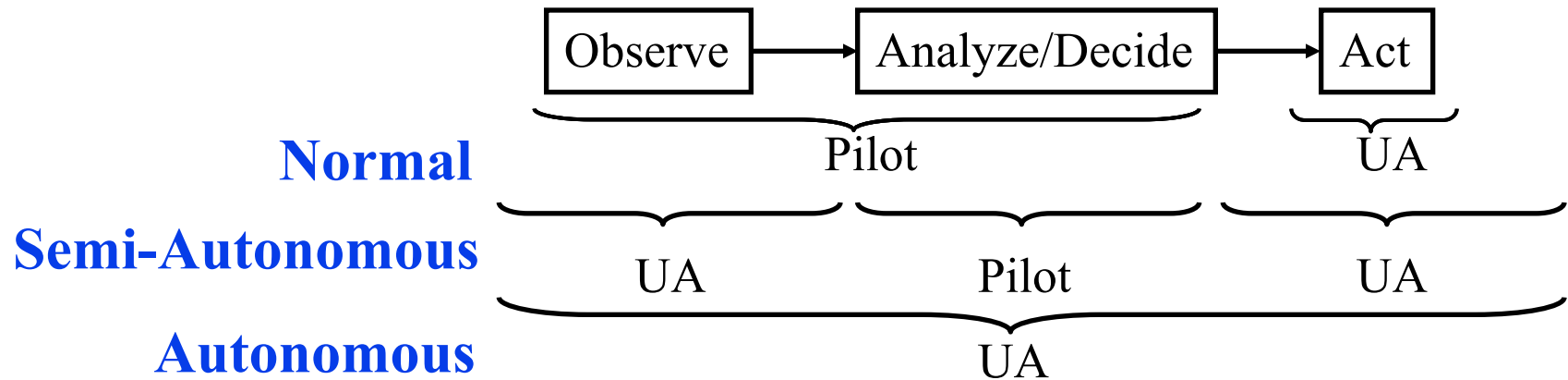
Autonomous   UA

- 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.

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

Proposed Mission Categories

- **Category A**:
  - For recreation or sport
  - Unregulated but guided
  - VLOS, 200 AGL, Low Velocity
- **Category B**:
  - Commercial/Governmental, VLOS
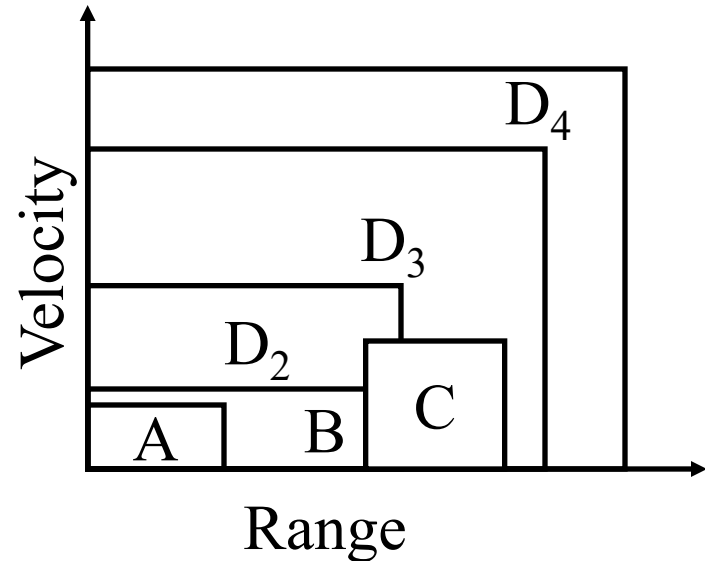 - Regulated, non-airport, 400 AGL, Low Velocity
- **Category C**:
  - Beyond VLOS
  - Larger than category B $\Rightarrow$ Kinetic energy
  - Non-airport, 400 AGL, Higher velocity
- **Category D**:
  - Similar to manned aircrafts
  - Access to NAS including civilian airports, >700 AGL
    1. On-Ground
    2. Taxi and Take-off
    3. En-Route
    4. Oceanic

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

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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

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, …)
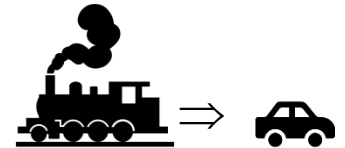
sUAS: Demand Forecast

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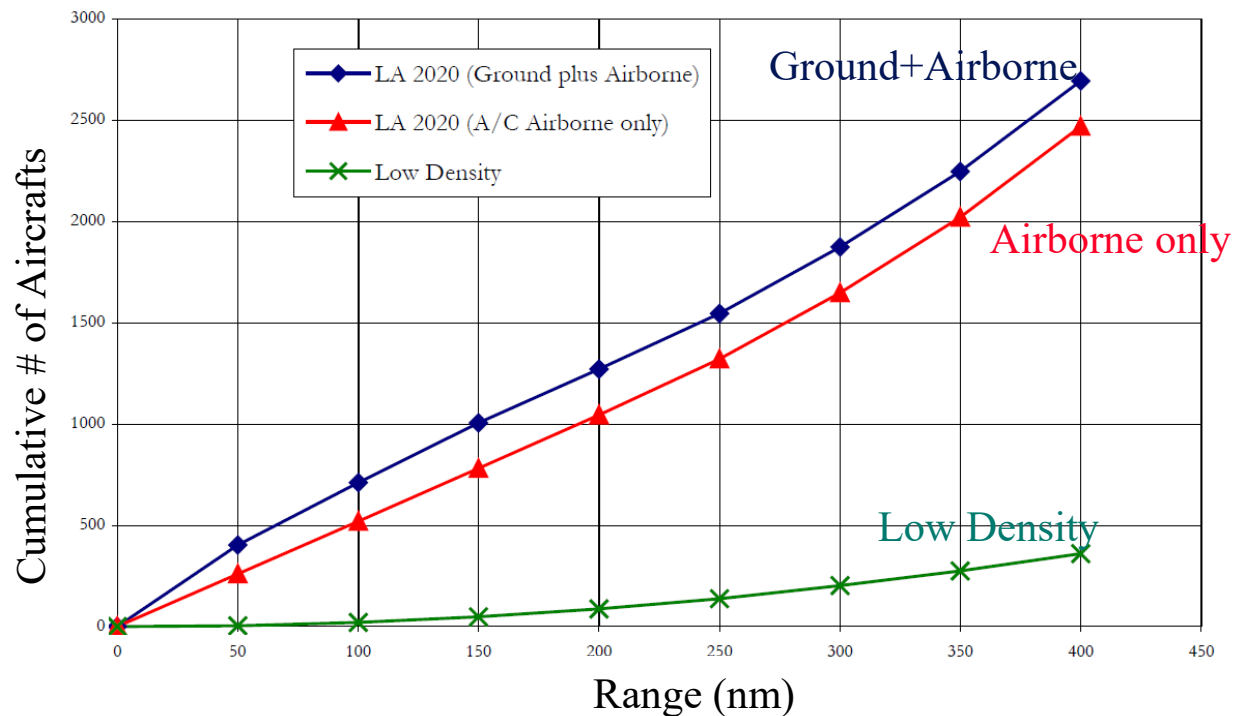
http://www.cse.wustl.edu/~jain/papers/icns17a.htm

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
  $\Rightarrow O(10^3)$ 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

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.

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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

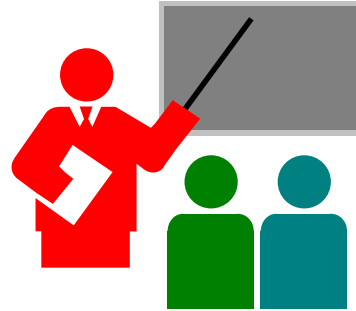   ➢ Deletion of messages

❑ **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

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

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