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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Overview

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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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

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UAV Classification

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

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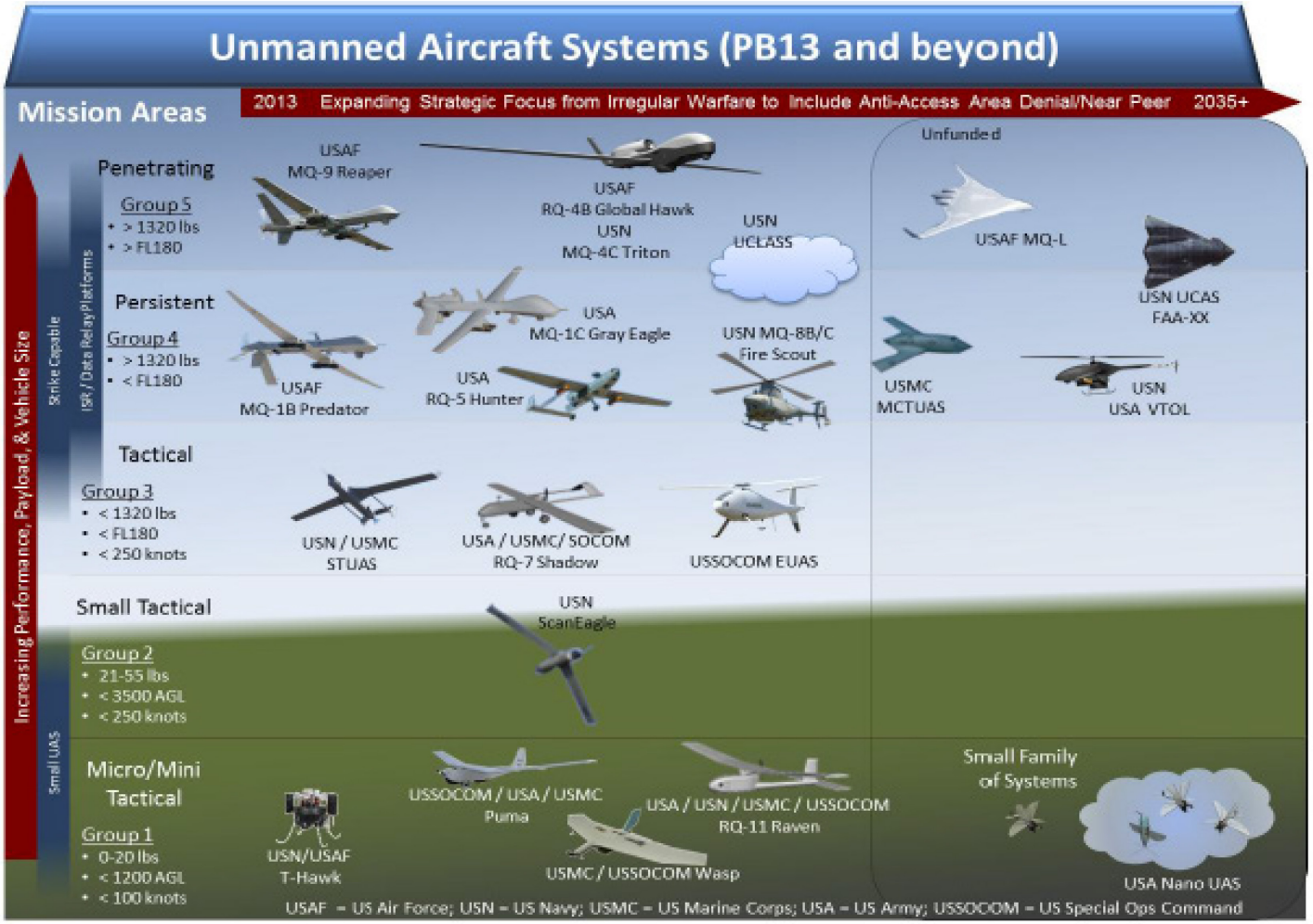
1. DoD UAS Classification



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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- Withdrawn

Ref: ASTM, "Standard Terminology for Unmanned Air Vehicle Systems (Withdrawn 2014)," ASTM F2395-07, 2 pages, available for purchase from ASTM.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

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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.
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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

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Types of Missions

1. EUROCAE
2. ITU
3. RTCA

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

1. EUROCAE Mission Classification

- European RTCA

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

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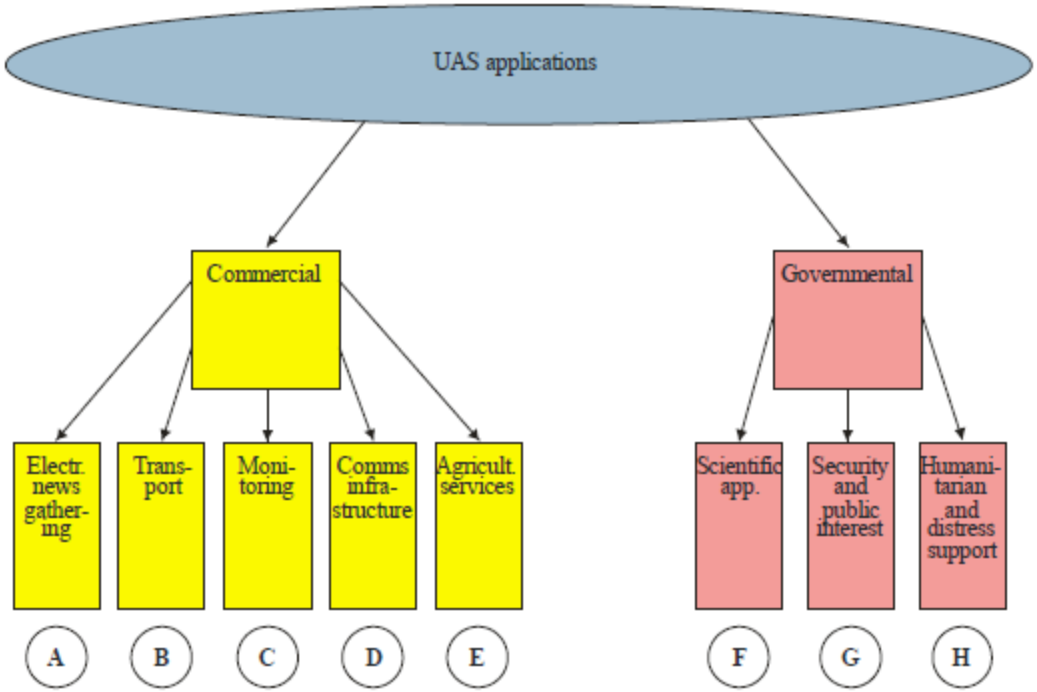
2. ITU M.2171 UAS Missions



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
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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, …

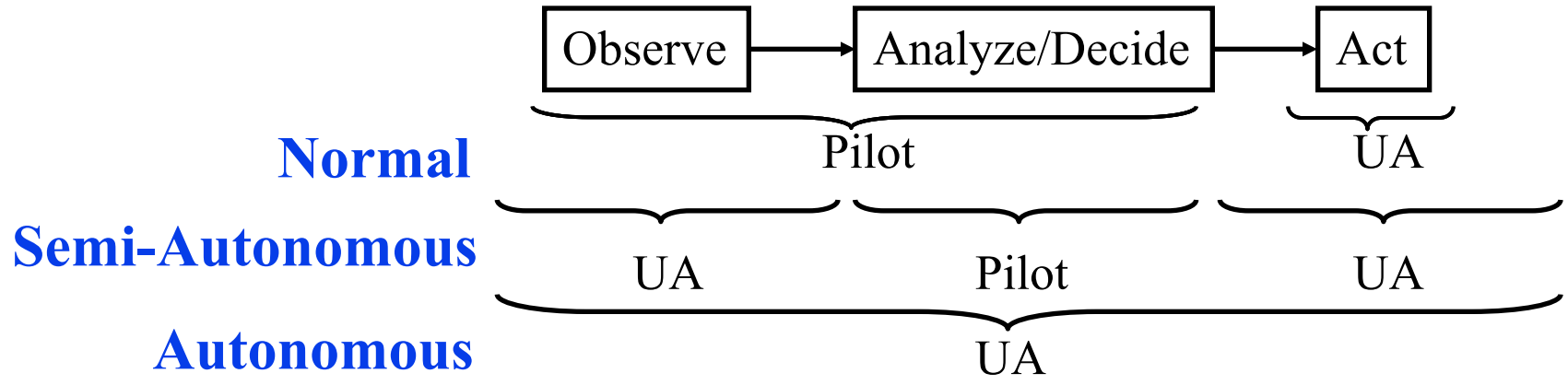
Ref: https://en.wikipedia.org/wiki/Unmanned_aerial_vehicle

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

300 UAV Applications

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

Levels of Autonomy

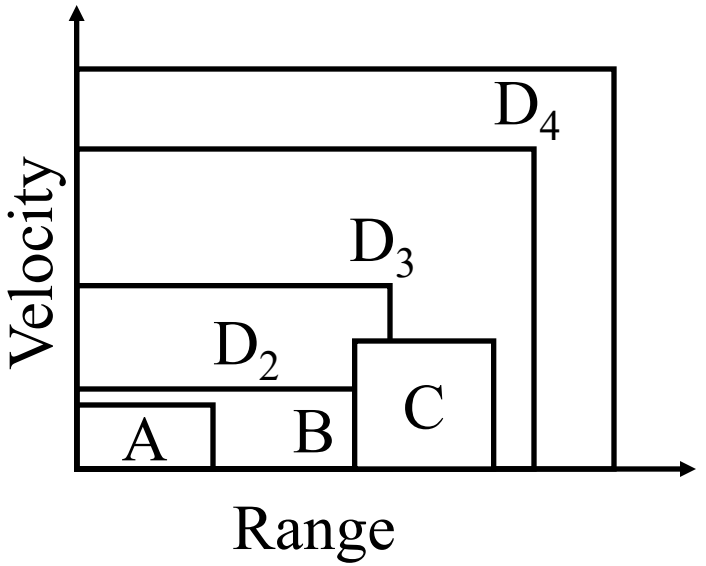


- Normal:
  - Self-Level at a particular altitude
  - Hover
  - Take-off and Landing
  - Return to home
  - Follow me
  - GPS waypoint navigation
- Semi-Autonomous: UA observes, reports to pilot, and acts as instructed. Significant communication overhead.
- Autonomous: Like self-driving cars. Lower communication overhead.

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 ⇒ 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



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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

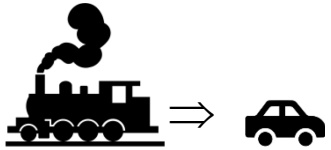
- *Single European Sky ATM Research* (*SESAR*)
- 7 million hobby drones
- 400,000 Commercial and Government missions in 2050

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, …)



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

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

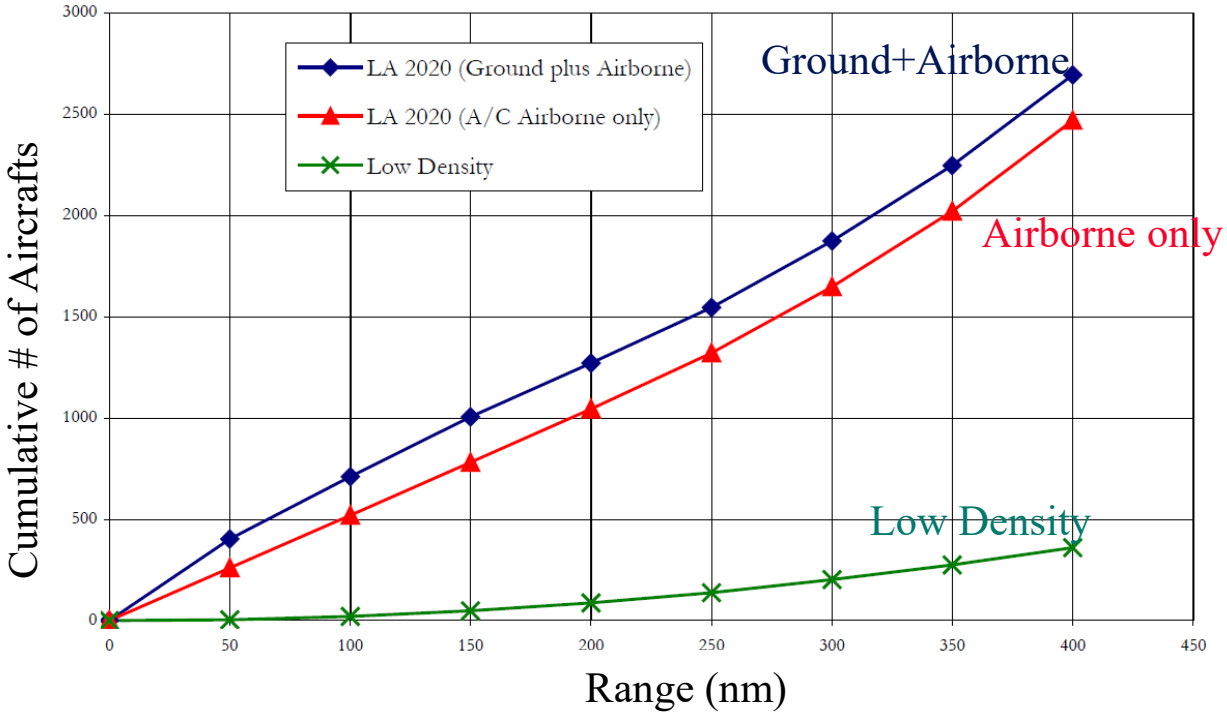
Sea-Tac Example

- 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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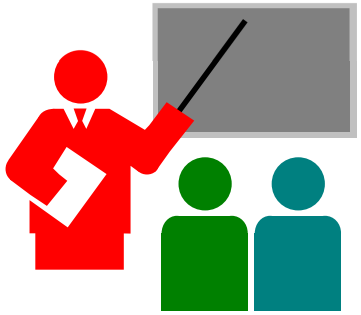
Security Considerations

- **Confidentiality**:
  - Flight number and positions are public
    $\Rightarrow$ 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 ⇒ 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