Ground Based Detect & Avoid

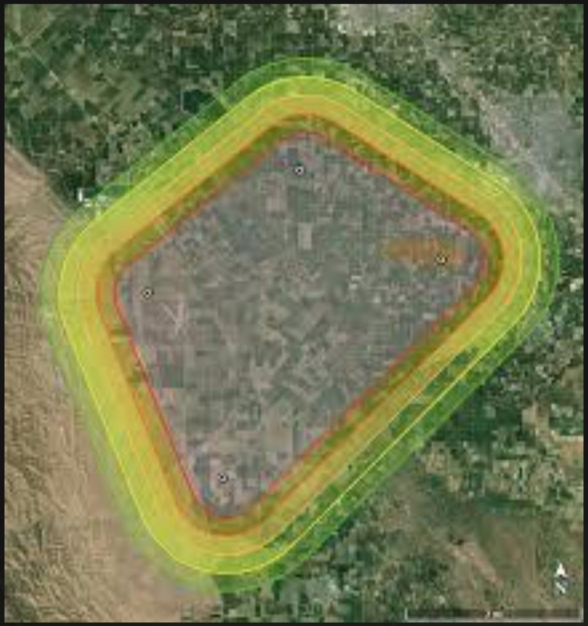
Final Report Presentation

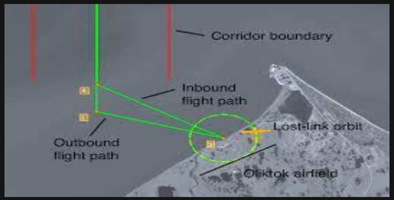
December 2018

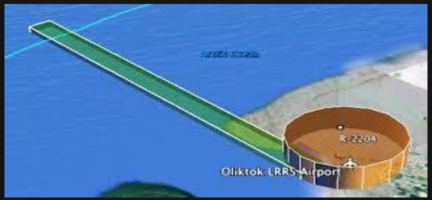
HF designworks
Human Factors Consulting & Software Development

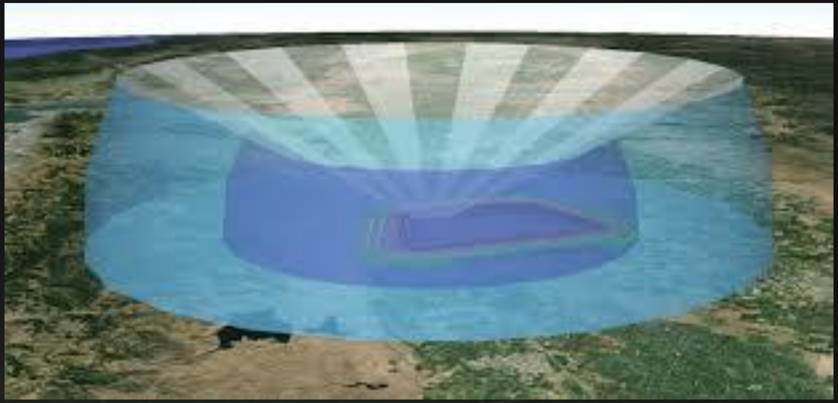
Presentation Outline

- Project Background
- Technologist, Vendor, Organization, UAS Test Site Interviews
- Findings and Observations
- Conclusions









Project Background

The Project

Given the relationship between GBDAA requirements, radar state-of-the-art performance, and concepts of operations, an industry survey was performed; to help inform future research.

HFDW Engagement

This project engaged HFDW to evaluate and summarize current-state of the present GBDAA systems. Areas identified for work include:

- System identification
- From July – September interviewed and surveyed technologists, vendors, organizations, and test sites

GBDAA Vendors, Technologists, Organizations, and Test Sites Interviewed

VENDORS, TECHNOLOGISTS, and ORGANIZATIONS

- SRC/Gryphon (Andrew Carter, now with CAL Analytics)
- Echodyne (Mo Swanson)
- Seamatica (Iryna Borshchova)
- Air Force/MITRE (John Belanger)
- DeTect (Jesse Lewis, Adam Kelly, Gary Andrews)
- MIT Lincoln Laboratory (Rod Cole, Emilie Cowen)
- Skysense (Robby de Candido)
- Fort Rucker (SFC David Mills, SSG Matthias Lang)
- MCR Solutions (Scott Brown)
- Raytheon (Robert Stamm)
- Air Force (Art Huber, AFRL and Springfield Ohio lead)
- FAA (Adam Hendrickson, he was with the Army, now with FAA)

UAS TEST SITES

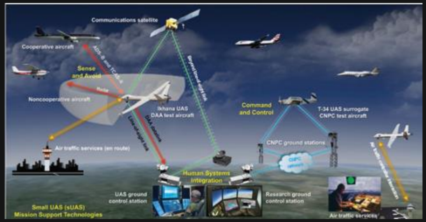
- New York UAS Test Site (Ray Young)
- Alaska UAS Test Site (Mike Hatfield)
- Nevada UAS Test Site (Brett Kanda)
- Virginia UAS Test Site (John Coggin)
- North Dakota UAS Test Site (Nick Flom, Chris Theisen)

Interview Questions

Interviews were conducted with technologists, vendors, organizations, and test sites.

The listed questions were adjusted slightly for each group to better fit their needs.

Each interview begin by working with the technologist, vendor, organization, or test site to develop and illustrate a GBDAA CONOPS. This exercise was used to inform the interview questions.



1. Do you have an existing CONOPS we can work through? If not, lets take a look at the attached image and use it to draw out your current CONOPS. As we work through your CONOPS lets also work to answer the following questions:

2. What airspace are you operating in?

3. What class of unmanned systems are you working with?

4. Who is your end user/target audience? Do you sell your system, integrate it, or sell the service?

5. Tell me about your system and its components (i.e., ADS-B, telemetry data from UAV, tracker, alerting/maneuver guidance, etc.)? Are there any other systems you are integrating with?

6. How many sensors are expected to be used with your system (i.e., single source vs. sensor array)?

7. Can you think of a recent or anticipated customer and given the needs for a system, what would the typical total coverage (surveillance volume) in that use case be?

8. What do your displays look like? Do you integrate with other displays or are you stand alone? What standards do your displays follow (i.e., SC-228 MOPS, GUI guidelines, MIL-STD 1472, etc.).

9. What size targets are you looking for?

10. How are you defining well-clear?

11. How do you deal with error with ownship and intruder positions?

12. When there is a collision avoidance maneuver, what are your rules pertaining to how and when return to course occurs?

13. Can you tell me about your DAA algorithms? Do you know if they are Phase I MOPS compliant (DO-365)

14. Do you utilize geofencing? If so, do your DAA algorithms interact with the geofences and how?

15. Does your system rely on air/ground and ground/air hand off and do you fuse the data (i.e., AB->GB, GB->AB)? If so, what are the rules?

16. Who is the user of your system and how are they using it? How automated is your system?

17. By chance do you have any human performance data associated with your system that you could share?

18. What documentation/guidelines/standards did you rely on when developing your system?

19. What documentation was most helpful during the development process?

20. What additional information would have helped?

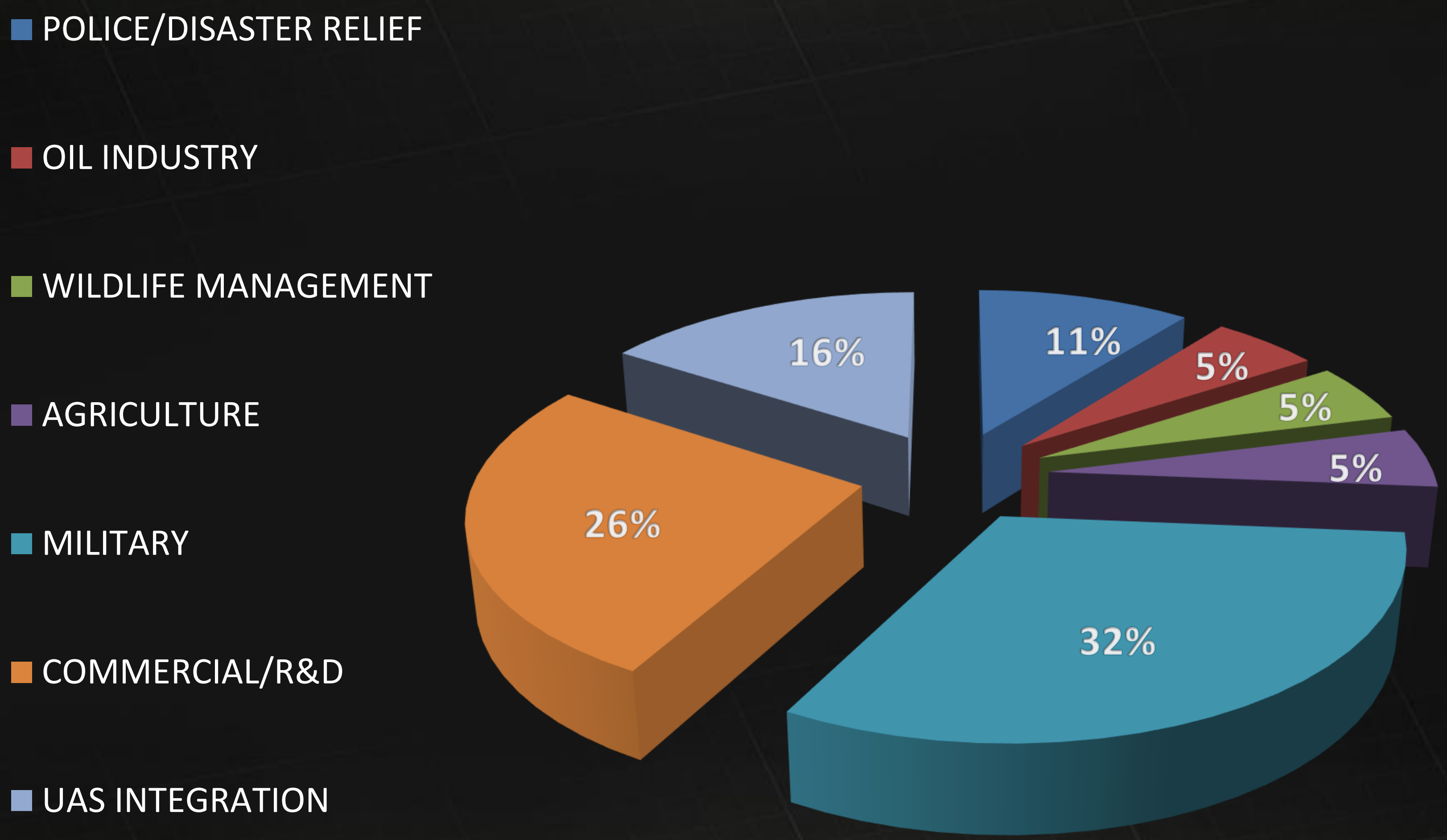
21. Have you interacted with the FAA? If yes, how could it be improved? If no, why not?

22. How do you see GBDAA technologies evolving for future use in the NAS?

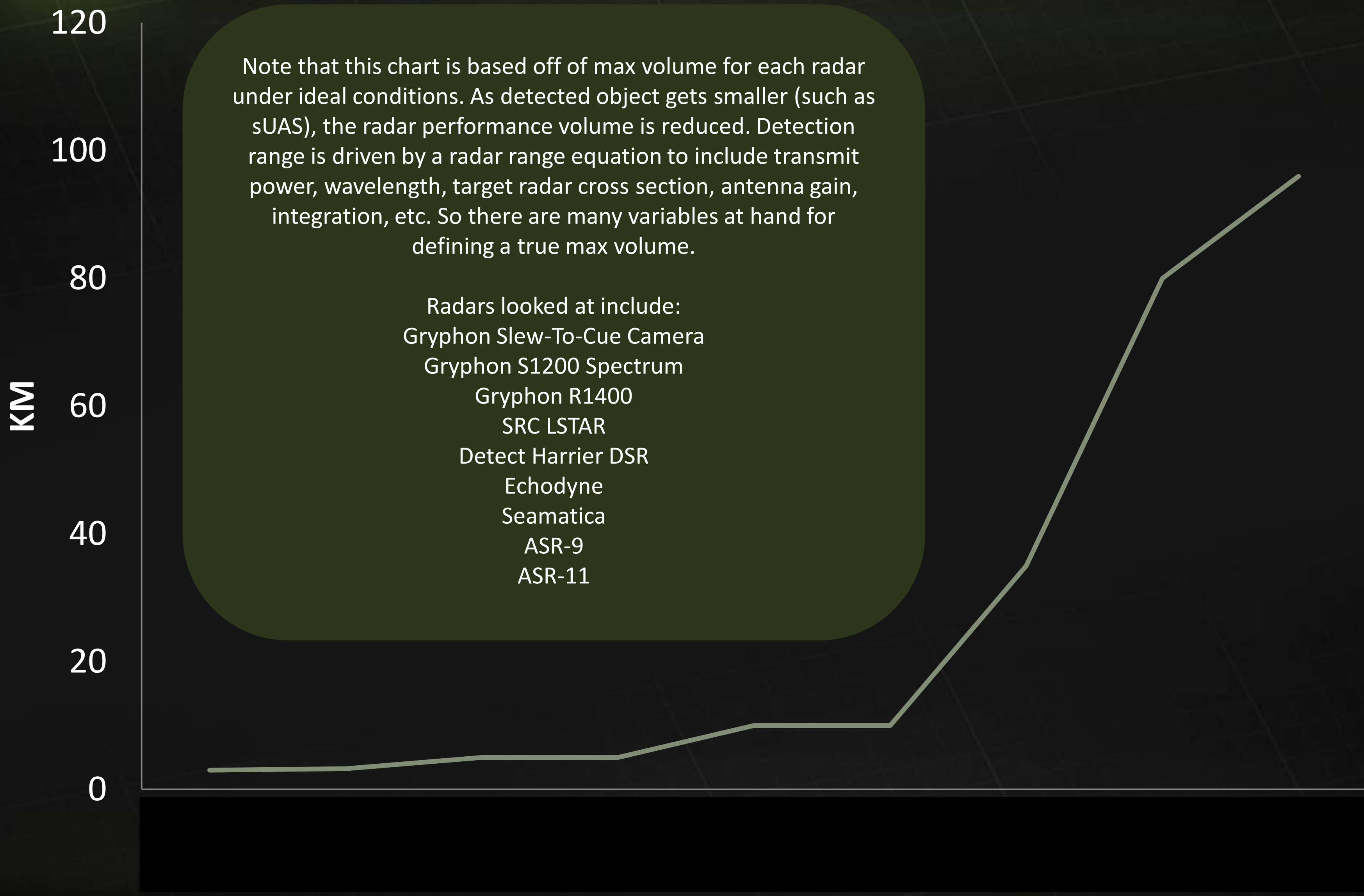
Top Findings from Interviews

- Not everyone follows MOPS, all are aware of them however
- Not everyone in industry is a member of RTCA
  - Other emerging organizations (ASTM Committee F38 Unmanned Aircraft Systems)
- More UAS testing desired
  - Testing in busier airspace
  - More real-world scenarios
- FAA relationships can be strained
  - FAA wants to help and is supportive, but….
    - Changes in personnel require frequent re-socialization
    - Not all the answers can be found within one person or department (sometimes there are no answers)
- No single source for requirements documentation
- Large delta between Test Site capabilities and experiences
  - Flight without chase plane vs. leveraging manned aircraft for testing radar characteristics
  - 3D radar vs. 2D radar
  - Custom software capabilities vs. COTS
  - Anti-drone technologies at one site
- Most sites rely on radar support from Gryphon and Echodyne
  - Some sites also use Raytheon STARS, Vigilant Spirit, IRIS Automation (airborne DAA), SRC LSTAR, ASR-9, ASR-11, and SAAB SR-3 radar
- Future GBDAA technology needs
  - Ground-Air and Air-Ground handoff
  - More UAS testing, and in busier airspace
  - More automation
  - Higher fidelity radar (comes at a financial cost)

Interview Questions: Today's End User Types



Interview Questions: Radar use and performance



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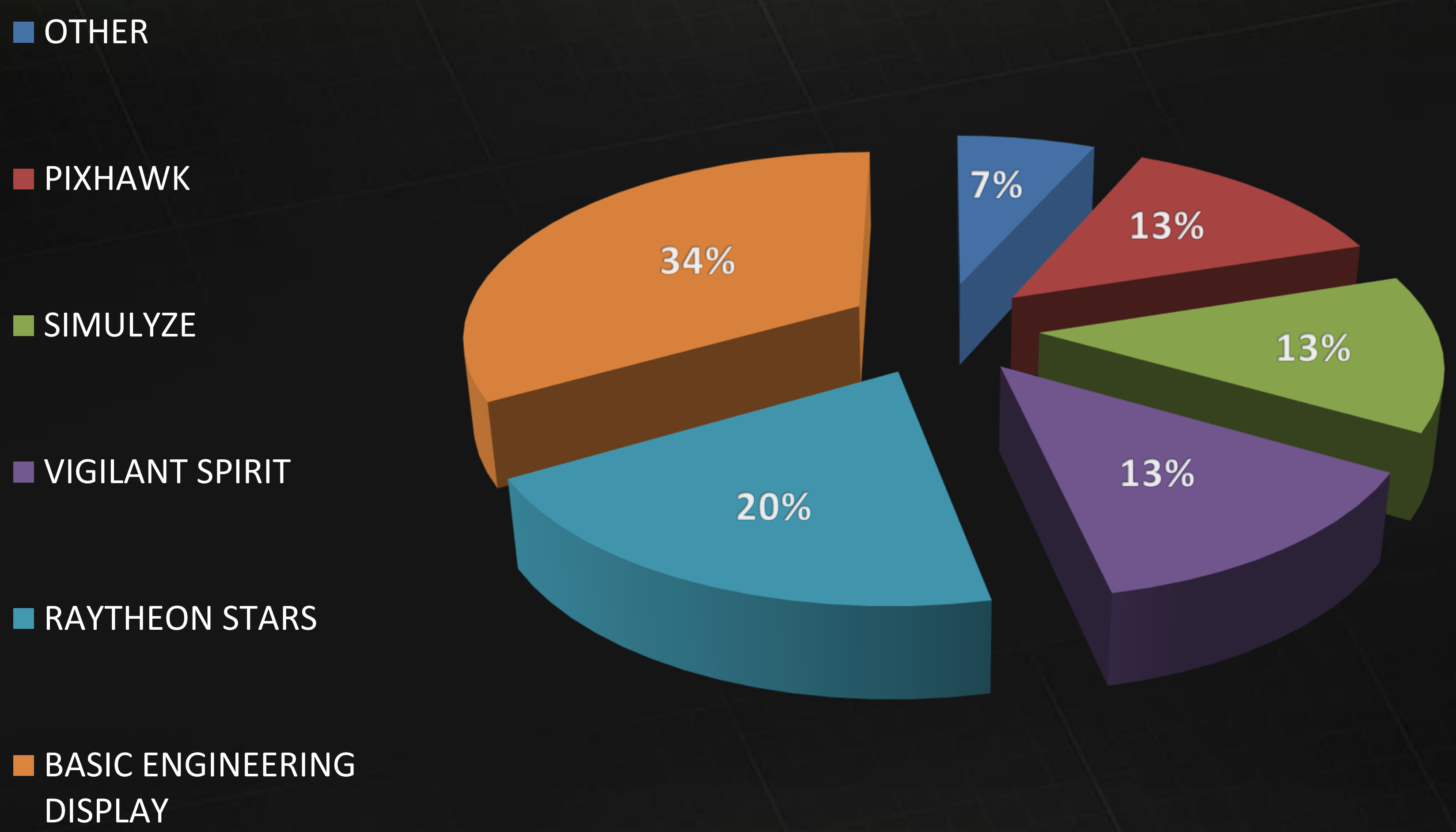
Note that this chart is based off of max volume for each radar under ideal conditions. As detected object gets smaller (such as sUAS), the radar performance volume is reduced. Detection range is driven by a radar range equation to include transmit power, wavelength, target radar cross section, antenna gain, integration, etc. So there are many variables at hand for defining a true max volume.

Radars looked at include:
Gryphon Slew-To-Cue Camera
Gryphon S1200 Spectrum
Gryphon R1400
SRC LSTAR
Detect Harrier DSR
Echodyne
Seamatica
ASR-9
ASR-11

Interview Questions: Radar use and performance

Westinghouse ASR-9	SRC LSTAR
Frequency: 2.7 to 2.9 GHz **Pulse Repetition Frequency (PRF):** 1000 Hz **Power:** 1.1 Megawatt **Instrumented range:** up to 111 km **Range resolution:** .137 km (450FT) **Beamwidth:** 1.4° **Antenna rotation:** 12.5 rpm	**Frequency:** L-Bzand **Power:** 1,800 W **Azimuth coverage:** 360° **Elevation coverage:** 0 – 30° **Instrumented range:** 35 km
Raytheon ASR-11	**SEAMATICA RADAR SYSTEM**
Frequency: 2.7 to 2.9 GHz **Peak power:** 25 kW **Average power:** 2.1 Kilowatt **Instrumented range:** 111 km **Range resolution:** 0.0926 km (303FT) **Beamwidth:** 1.4° **Antenna rotation:** 12 rpm	**Frequency:** 9.375 GHz **Azimuth coverage:** 60˚azimuth, ±3.9˚elevation **Field of view:** 120° **Instrumented range:** 555km (theoretical calculation) **Detection small target:** 18 km **Detection large target:** 27 km
DETECT HARRIER DSR	**ECHODYNE**
Detection small target: 3+ km	**Field of view** of their radar is ≥ 120° x 80° Elevation. **Large Cessna**: 3km~ **Large Drone**: 1.3km~ **Small Drone**: 750m~
GRYPHON R1400 RADAR	**GRYPHON S1200 SPECTRUM SENSOR**
Detection small target: 10 km (sUAS) **Detection large target:** 27 km (general aviation)	**Detection small target**: Up to 5 km **Coverage:** Up to 360°
GRYPHON SLEW-TO CUE CAMERA	
Detection: 3 km **Field of view:** 360° Pan rotation **Field of view:** 180° Tilt rotation	Note that additional systems such as Raytheon STARS and SAAB's SR-3 radar are also used at some of the sites.

Interview Questions: Displays



Interview Questions: Displays

Displays most commonly used (above and beyond basic engineering displays)

- Vigilant Spirit – multi monitor and multi window views
- Raytheon Stars – radar view
- Simulyze – map view with overlays
- Pixhawk working with Mavlink and QGroundControl – map view with overlays as well as multiple windows in a single monitor

UAS Test Site Current CONOPS

UAS Test Sites Interviewed

- New York
- North Dakota
- Virginia
- Nevada
- Alaska

Interview Questions: Types of testing among the facilities

- All sites support UAS customers but there are some specializations among sites due to location, state needs, etc.
  - Counter UAS
  - Oil pipeline inspection
  - Wildlife conservation and management
  - Radar performance
  - BVLOS with no chase plane
  - Automation technologies
  - Medical supply deliveries
  - Search and Rescue
  - Scientific and aeronautical research

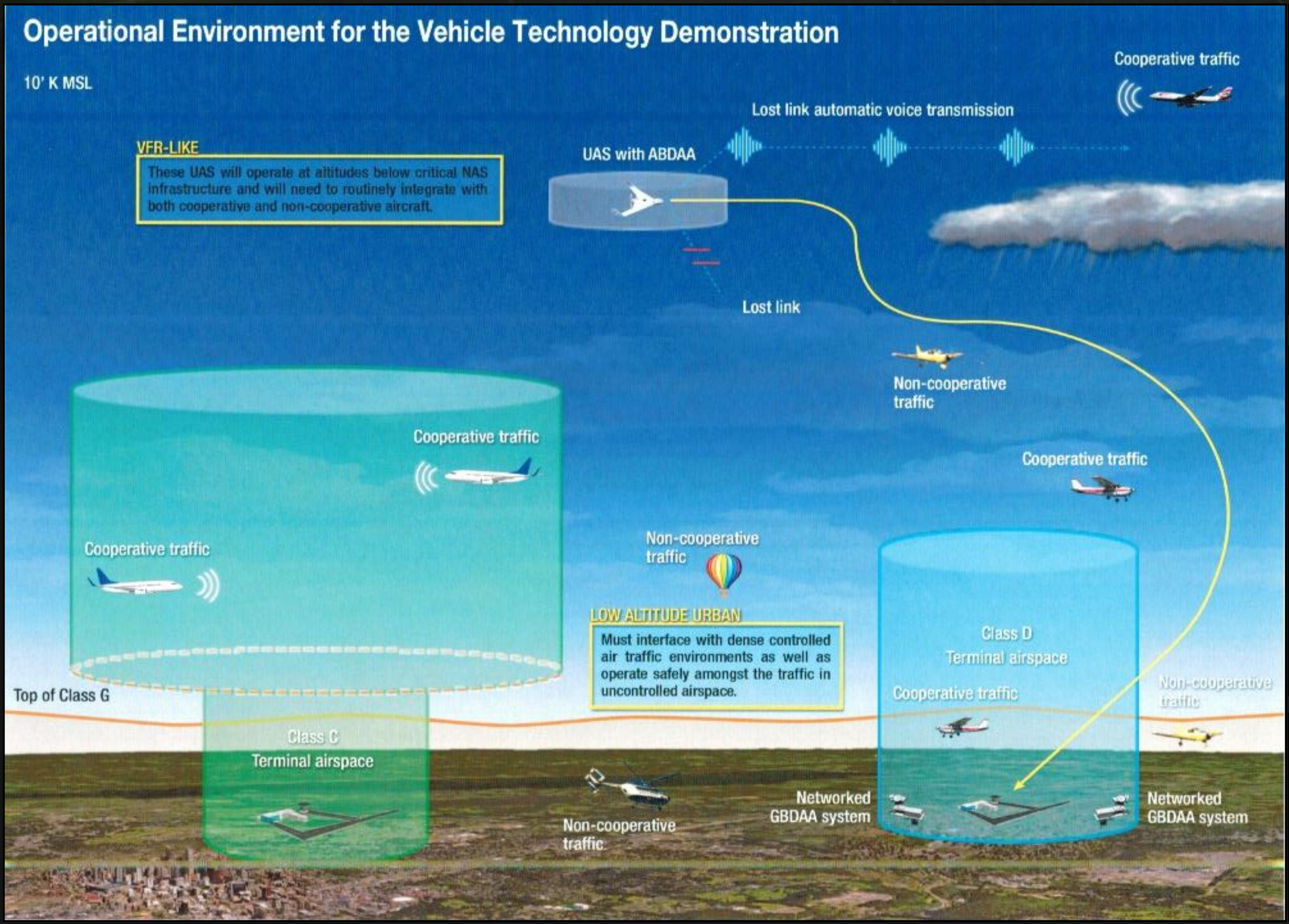
Radar Systems in use at the Test Sites

SYSTEM	AIRCRAFT CLASS*	TEST SITE
Echodyne	Class 1	Alaska
Echodyne, Iris (airborne)	Class 1, 2, and 3	Nevada
SRC LSTAR, Gryphon , Saab	Class 1, 2, and 3	New York
ASR-11	Class 3	North Dakota
Echodyne, Gryphon	Class 1	Virginia

Class 1 is <150kg, Class 2 is 150-600kg, and Class 3 is >600kg

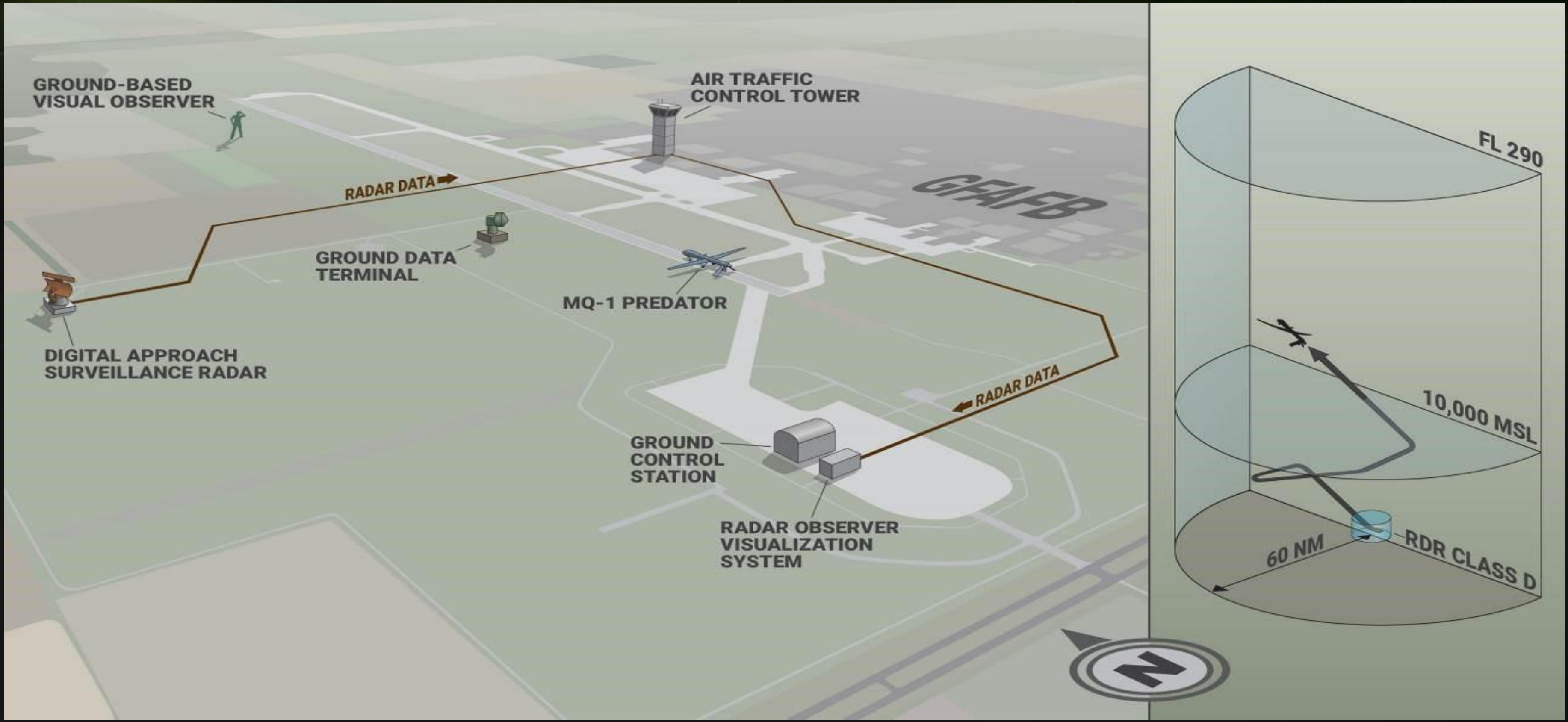
Note that additional systems such as Raytheon STARS, Vigilant Spirit, and SAAB's SR-3 radar are also used at some of the sites.

Example CONOPS from New York Test Site



The New York UAS Test Site is located at the Griffiss Airport, in Rome, NY. In addition to 3D radars, the New York UAS Test Site also takes advantage of a 2D surface movement radar from Saab, LSTAR (developed by SRC), Vigilant Spirit, and a third-party software development company that works from the site to assist with building custom applications.

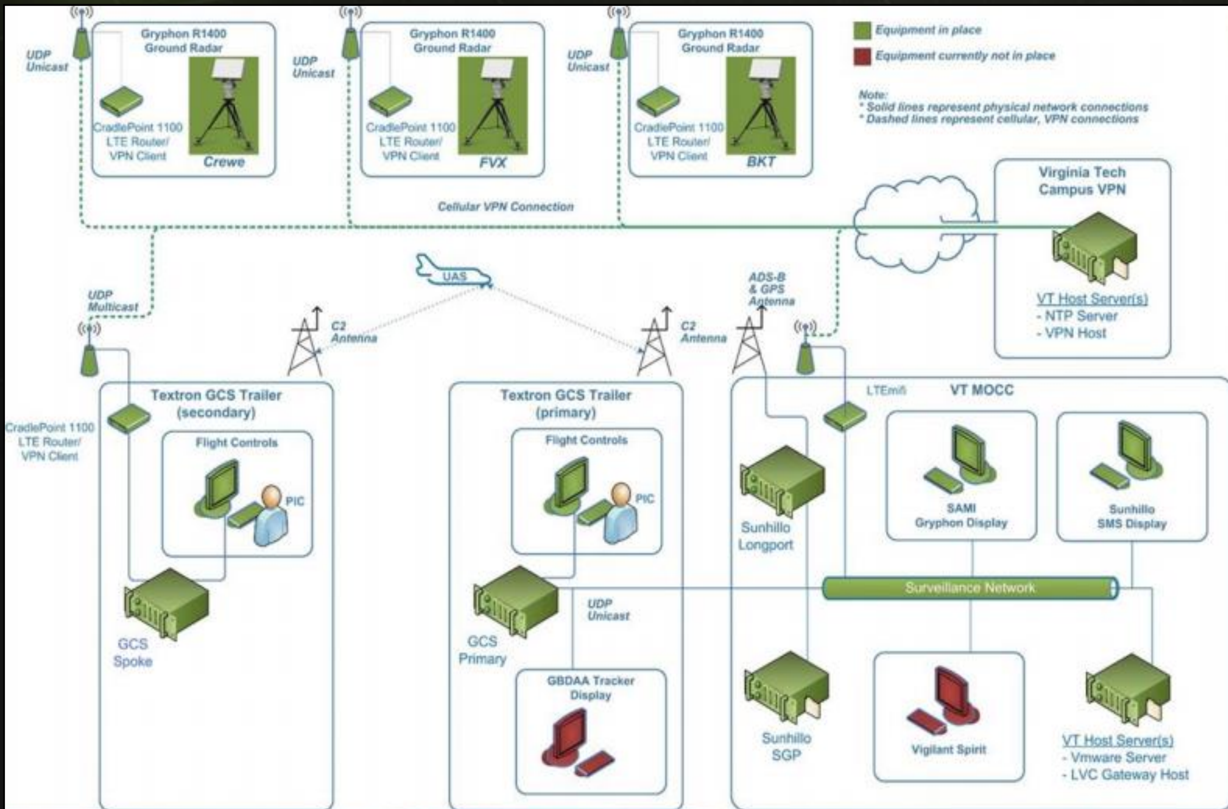
Example CONOPS from North Dakota Test Site

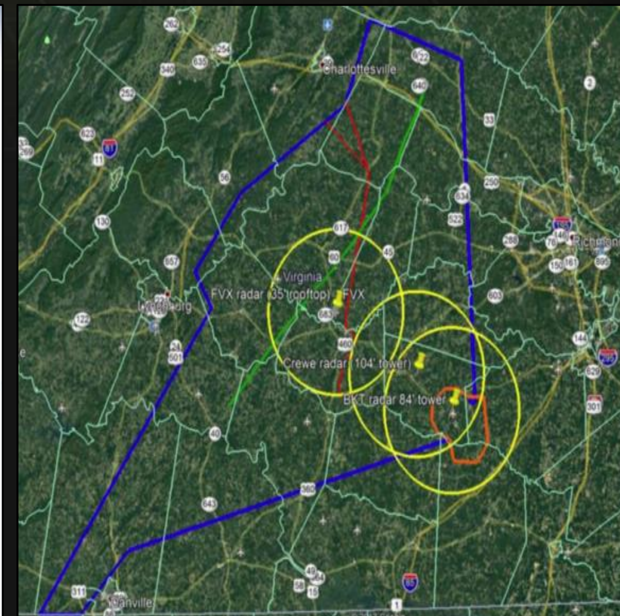


The North Dakota UAS Test Site is located near the University of North Dakota in Grand Forks, ND. This past August they successfully flew an MQ-1 without a chase plane over the course of 60 miles. This mission was a three-year process to get the appropriate equipment, people, and approvals in place. Their control station is a room with a few monitors, phones, and servers. The unmanned aircraft is tracked by 2D radar and a range ring is manually moved over the UAS as it flies. This range ring serves as the well clear horizontal separator for that ownship.

The site leverages Digital Airport Surveillance Radar (ASR)-11 from Ground Forks Air Force Base with other ground based surveillance systems. These systems are combined via the Harris RangeVue system.

Example CONOPS from Virginia Test Site





"First we need to define a surveillance volume where we can identify non-cooperative aviation traffic with a high degree of confidence."

The Mid-Atlantic Aviation Partnership (MAAP) is a FAA UAS Test Site located at Virginia Tech in Blacksburg, VA. The VA test site is currently working to understand the characteristics of their radar systems, appropriate surveillance volumes, as well as the ability of the system components to meet the MOPS. Testing is currently performed with manned aircraft as they work with the FAA to gain appropriate spectrum allocation for UAS.

Example CONOPS from Nevada Test Site

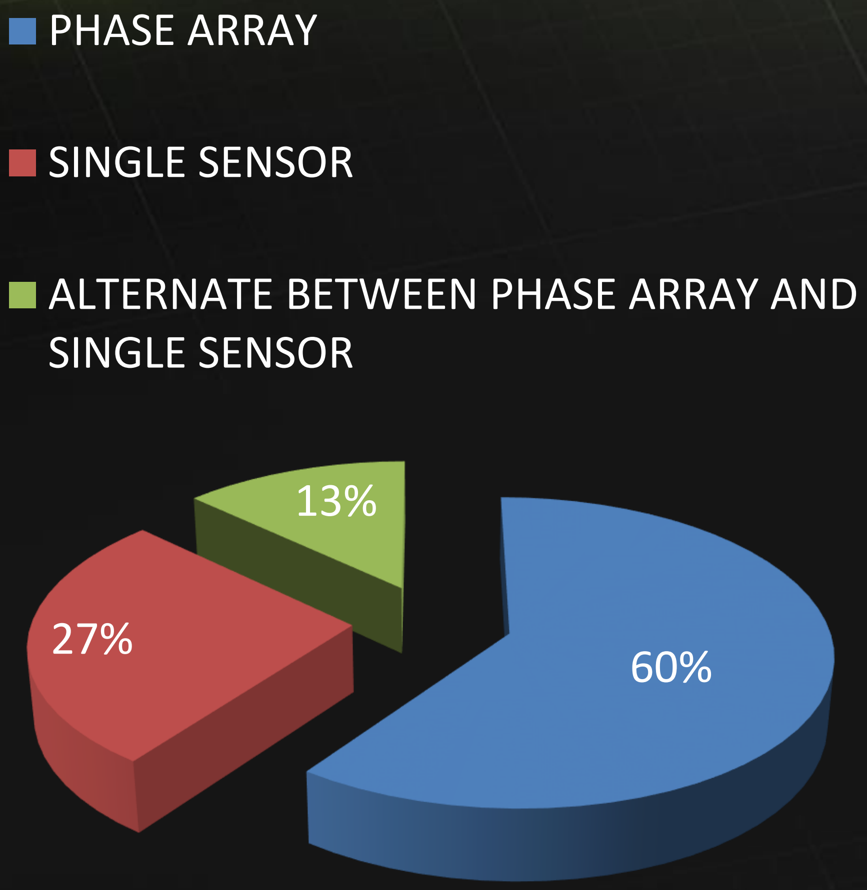
The Nevada facility is in Las Vegas, just a few miles from McCarran international airport. There are a series of airports within Nevada that are used for testing various classes (class 1 – class 3 UAS). In addition to A-B route testing, some UAS intruder detection (e.g., counter UAS) research occurs as well. This test site uses Echodyne radars, as well as Iris Automation for airborne automated collision avoidance (ACA) to achieve ground based -> air based, and air based -> ground based handoffs.

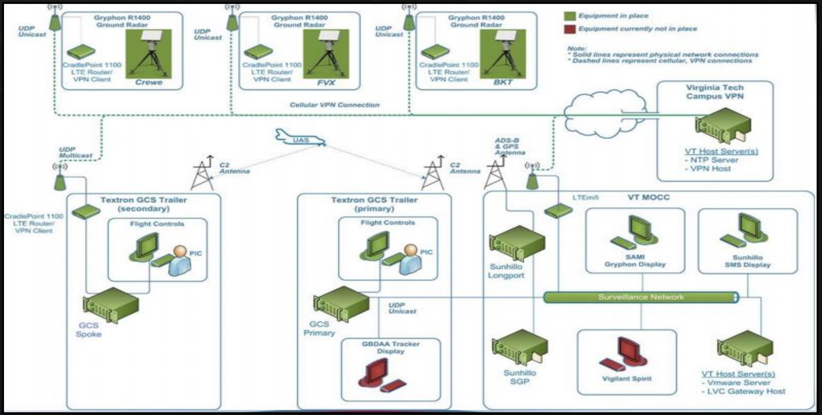
Example CONOPS from Alaska Test Site

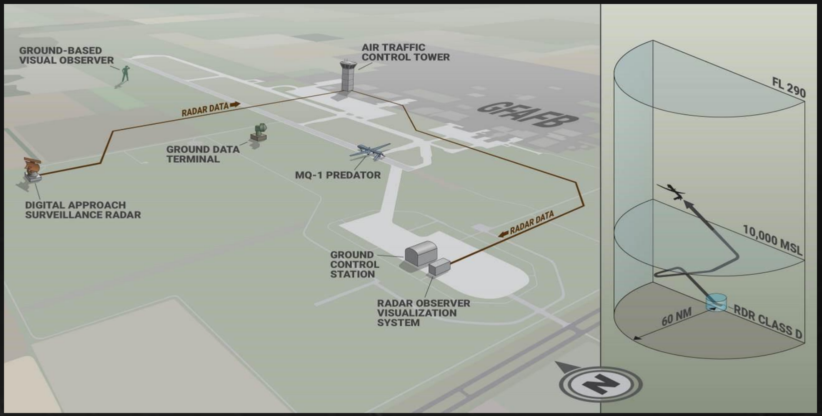
The Alaska facility works with State and Federal agencies in addition to commercial partners to expand the use of UAS for missions of concern to Alaska including monitoring pipelines, medical supply deliveries, wildlife management, search and rescue, and scientific and aeronautical research. The Alaska site also hosted the most recent Test Site Technical Interchange Meeting (TIM), this past September. The Test Site TIM is held twice a year and pulls in representatives from all seven UAS test sites as well as the FAA.

The Alaska site uses the Pixhawk opensource autopilot as well as the Simulyze Mission Insight software. Some of the data sources that Mission Insight can interpret, standardize and fuse include: sensory data, weather, Global Positioning System (GPS) tracking, video metadata, radar skin track UAS data, databases, and imagery. The software delivers a range of analytics, from calculations such as distance and proximity, to complex terrain analysis. The software also contains a tool suite designed for the command and control of remote sensors within the COP. The software also provides customizable alerting functions including geo-fences, relative movement, and position reports.

Sensor Usage (single vs. phase array)







Sensor Handoff Challenges

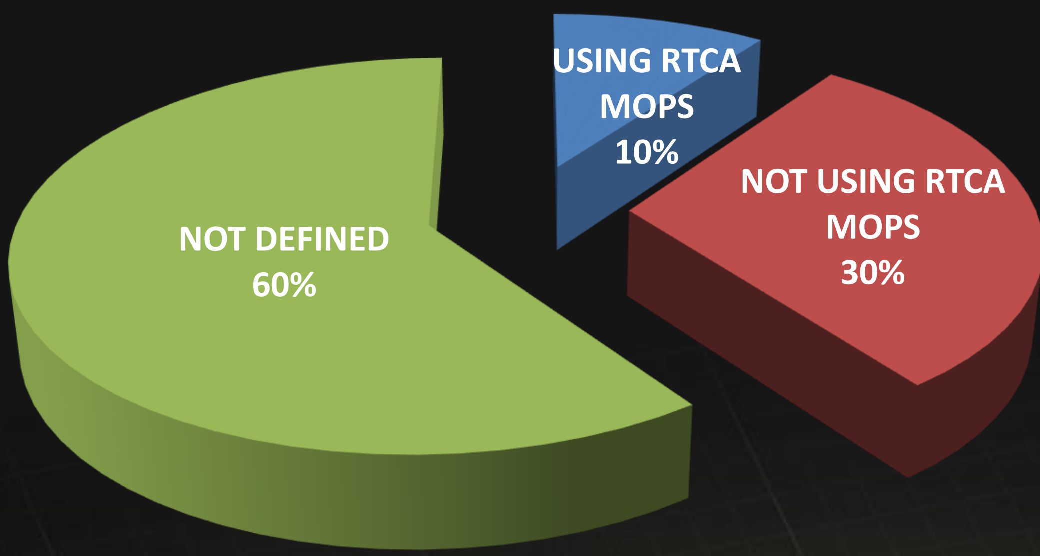
Difficulties That Occur with Sensor Handoff
Whether ground to ground or ground to air/air to ground, "…there's a whole bunch of stuff we need to be able to do; looking at the processing, considering the orientation of the aircraft, the angle of the radars, changing the tracking information in the radar, etc."
Saturation – need to reduce the power output at times to reduce saturation. "Also need to reduce the frequency of the volume test from every second to every three seconds especially with a lot of civilian aircraft nearby."
Ground clutter – as the ownship gets lower (i.e., 5,000 feet AGL) "you've got to worry about ground clutter."
False tracks and false detections – "If I've got one sensor that does an okay job, and another sensor that does an okay job, and I fuse them to get a better track on an aircraft I also have to address possibly twice the amount of clutter from the two sensors, twice the amount of false tracks and false detections."
Data sources – depending on where the data is coming from (ground vs. air) there could be latency.

Target Size

Manned Aircraft	Small UAVs	Birds
Majority of vendors and test sites stated that their target size of interest is manned aircraft	Majority of vendors and test sites stated that they were less interested in targeting UAVs and more concerned with manned aircraft. There was also mention of difficulty discriminating between sUAS and birds (although it can be done)	Majority of vendors and test sites stated objects as small as birds are detectable but described them as clutter or stated that they wanted to exclude birds but do not always have the ability to discriminate
”This is not a system to look out for other small UAVs. So the traffic we’re looking at is the same traffic that an ATC is looking at, they’re looking for all the general aviation.”	“Everything from other aircraft down to birds, we’d like to be able to discriminate and exclude birds, our main thing is very small UAS (4-6 lb. quadcopters hopefully).”	“While we can identify flocks of birds but we don’t, our CONOPS isn’t to maneuver around them. We’re only maneuvering this airplane. We can't technically tell the difference between a bird and a small UAS.”
“We want to detect things as small as hang gliders, if it carries a person we want to see it. The goal is not to run into airplanes that are carrying a person.”	“I think some wise person recognized early on that if you want to be good at tracking GA you don’t wanna be dialed in for UA.”	“We have a classifier that is supposed to take out the clutter such as birds.”
”We are probably looking for that GA aircraft right now.”		“We want to detect everything from other aircraft down to birds. We’d like to be able to discriminate and exclude birds.”
“We are usually going to focus on the manned aircraft intruders, all those general aviation aircrafts.”		“We are trying to track non-metal shiny things such as birds. We are working on a couple different ways to do a really basic classification of bird vs. drone. We do have a filter that we can use so if we’re only looking for manned aircraft we can raise that filter and maybe cut out a couple of bird tracks but up to a certain distance we might be able to say yeah that’s a bird or yeah that’s a drone.”

Well Clear Definition

Using RTCA MOPS	Not Using RTCA MOPS	Not Defined
“Well-clear we defined similarly to what RTCA does. Based on the closure rates, velocities, headings, in a very similar fashion as RTCA defines it.”	“We’ve been in contact with RTCA and initially we are proposing much more conservative values than what they are proposing. So I think if I remember correctly our system is going to have a 10’ lateral separation with a 1,000’ or 2,000’ vertical separation. They’re [RTCA] proposing a much more liberal requirement than that. I think they’re more like 1,000’ and maybe 200’ lateral separation. So we’re well within what they’re proposing for to the FAA.”	“It’s not defined. Generally speaking we operate under part 107 and we operate under our test site COAS. There are no provisions as far as that goes, it’s basically just the right of way and you have to yield to any manned aircraft.”
	“We could use the well-clear definition that the safety group came up with which I think is 200’ horizontal and 250’ vertical and like a hockey puck so that’s what we sorta tossed around here. It’s just kinda like we have to take the conversations that you’ve heard in all the different policy groups and talk about okay for this test we’ll consider this to be our well-clear and this to be our collision avoidance hockey puck.”	“We don’t define well-clear, we’re just giving the positions to other people and letting them define well-clear. And I think the definition is different for different use cases (i.e, UTM definition vs. SC-228).”
	“Right now it’s an alert of a potential interaction anywhere, depending on the location, anywhere between 36 seconds and 102 seconds, the 102 seconds for being the slower aircraft which have a bit more time to maneuver. It’s more substantial than just the 4,000’ foot closest point of approach.”	“We just set a distance that was going to be our trigger distance.”
		“I don’t have an answer for that because it depends. It took 6-9 months in SC-228 to define well-clear for large UAS so we came up with a definition, but I think that for small UAS operating at low altitudes and in different threat environments there’s no one answer that you can define.”
		“We’re not even there yet. We’re just trying to understand where the radars performance is and whether or not it’s good enough to begin formulating those volumes.”
		“We aren’t concerned with that right now it’s just can we detect something.”



Example Rules

Examples of Rules In Place Determined By Test Site
“If a non-cooperative is in an ownship’s airspace and well clear is compromised the ownship will return home (under current CONOPS).”
“After propagating the uncertainty from the sensor and determining the risk bubble we figure out if there is a collision or not and then if not, then UAS just keeps going until the next collision prediction occurs and if there is a collision then the time to maneuver should be initiated as calculated. Once the maneuver is acquired, the pilot in command is notified and then the pilot makes the decision.”
“You could see the position of the intruder and they had a projected arrow coming out in front of the radar track so then they could sort of click on another location and the drone would choose how to get there.”
“Generally speaking we operate under part 107 and we operate under our test site COAs. There are no provisions as far as that goes, it’s basically just the right of way and you have to yield to any manned aircraft. There is not a specific provision to a distance that you have to maintain from manned aviation it’s just giving them the right of way.”
“There is neither a recommendation of a maneuver nor an automated maneuver response. It is up to that pilot and GBDAA operator.”

Conclusions

- Great work is being done by organizations such as RTCA to bring together the right people to develop requirements and guidelines for successful integration of UAS into the NAS.
    - As these requirements are being created, so too are the systems.
    - Oftentimes these are not joint efforts. Many in industry do not attend the meetings.
        - “Not sure when the next one is.”
        - “I know I should but I don’t have time.”
        - “Not sure what they would want from me.”
    - Some redundancy – ASTM has recently started a sUAS detect and avoid group called F 38 for instance (does not appear to be well known in the industry however).
    - Many requirements have been in existence through other agencies yet because there is not one central source for all these requirements, they are oftentimes not utilized.
    - Or when they are, understanding the requirements can be a challenge (one interviewee stated that specialized contractors had to be hired to help understand the requirements).

Conclusions, continued

- The UAS test sites all operate fairly differently from one another
  - Each site has their own needs (oftentimes based on area, state, and commercial client needs).
  - The sites are also in various stages
    - One has flown BVLOS without a chase plane, one is testing radar characteristics with manned aircraft as they work with the FAA to gain appropriate spectrum allocation for UAS.

- There is limited UAS collaboration
  - The sites hold technical interchange meetings twice a year
  - FAA is often in attendance as well
  - Many of the participants interviewed were unaware of these TIMs however (even though representatives from their locations attended). Are the correct representatives attending?
    - "Does [a test site] really have a 3D radar?", "Did [a test site] really just fly a UAS without a manned follow plane?"
  - While test sites report incidents to the FAA, there is no database available to test sites which provide lessons learned share outs.
    - A database such as ASRA could be used for incident reporting. It could then be de-identified and available to all the test sites/public.

- Improvements to the technologies needed to fly UAS in the NAS is coming.
  - Ground based radar fidelity is improving, software interfaces are being revised, and airborne radar systems are getting smaller, lighter, and more energy efficient.
  - Requirements will need to be developed to support these technologies and use cases involving higher traffic areas with combinations of cooperative and non-cooperative aircraft.

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