The Future is…
Automated & Integrated

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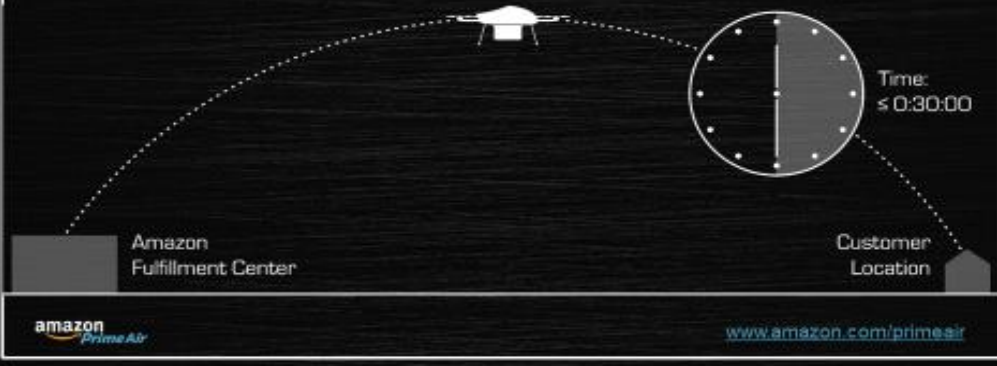
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Current Realities

UAS/Robotics Industry growth is dramatic

New use cases daily

Public Safety, Security, Privacy concerns

Governments, National Aviation Authorities struggling to keep up with pace of industry
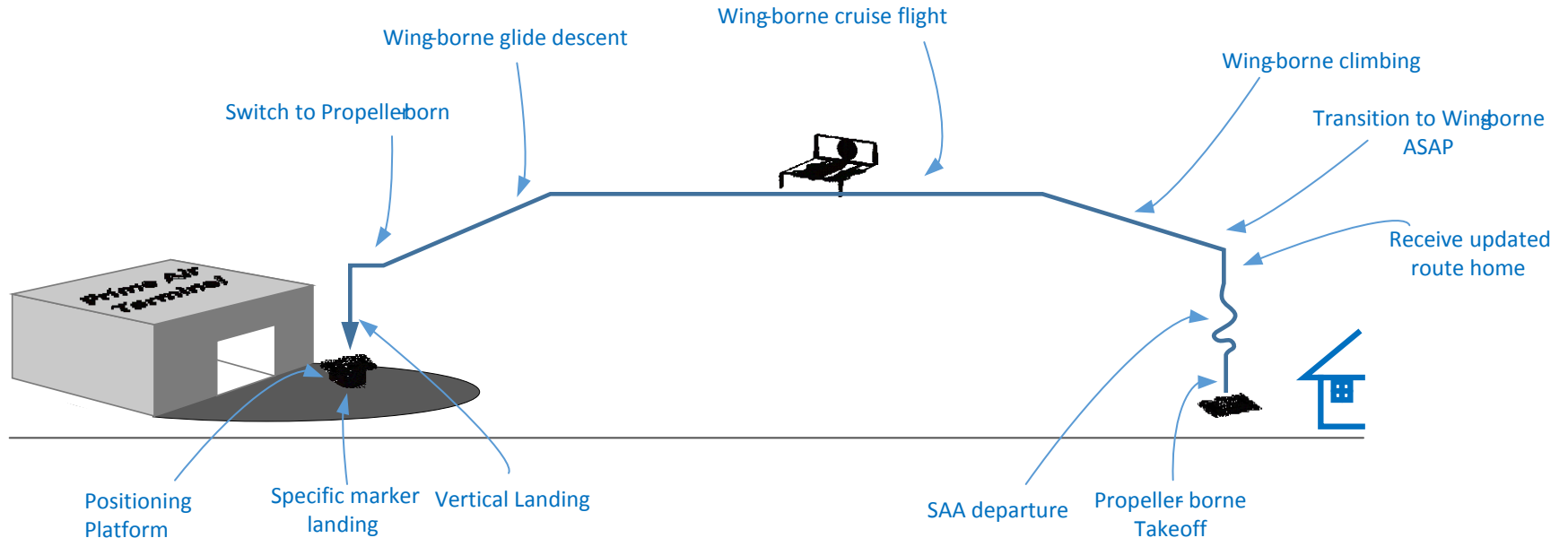
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Recipe for Commercial Ops

- BVLOS capabilities and approval
  - SMS, Operational Safety Case
  - Certification/Authorization
- Highly automated (Autonomous) functionality
  - Greater than 1:1 operator to vehicle ratios
- Use of land mobile networks (plus space based options)
  - Spectrum Access
- Airspace & Ground Access

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Sample Concept of Operations

Wing-borne glide descent

Wing-borne cruise flight

Wing-borne climbing

Switch to Propeller-born

Transition to Wing-borne ASAP

Receive updated route home

Positioning Platform

Specific marker landing

Vertical Landing

SAA departure

Propeller borne Takeoff

Where We Are Going

Current Model - EVLOS

SO
LHR19
OiC GSO
GSE OM
VO
VO
SO

FULL BVLOS

LHR19
GSE

LHR13
GSO
OM
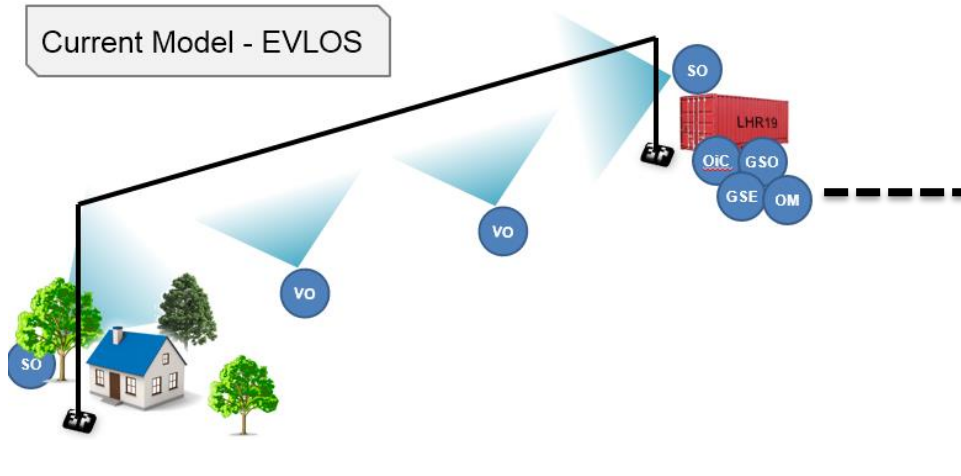
Goal: to have an environment that will enable BVLOS capabilities for customer delivery trials

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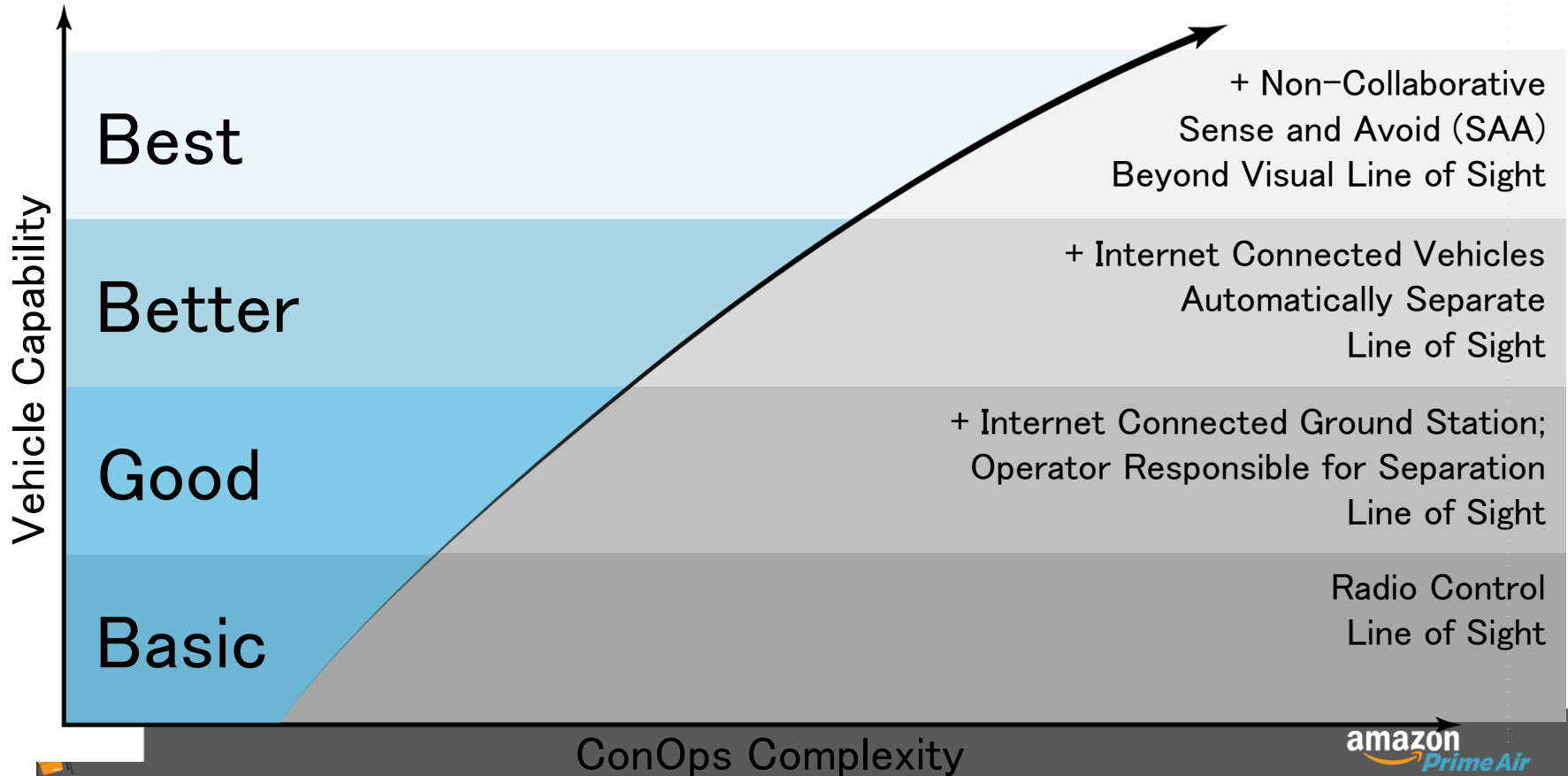*Prime Air*

How Do We Get There?

- ✓ Extensive data collection (vehicle systems) under approved operating cases approved by regulator
- ✓ Use of currently approved airspace
- ✓ Operational enhancements;
    - ▪ Consolidation of pilot/ground support functions with operato
    - ▪ Simultaneous & remote operations
    - ▪ Removal or relocation of visual observers
- ✓ Engineering BVLOS Capabilities Development (SAA, etc.)
- ✓ BVLOS operating safety case approval

Conceptual representation of one possible route plan

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Four Equipage Classes

Vehicle Capability (vertical axis) vs **ConOps Complexity** (horizontal axis)

Best
+ Non-Collaborative
Sense and Avoid (SAA)
Beyond Visual Line of Sight

Better
+ Internet Connected Vehicles
Automatically Separate
Line of Sight

Good
+ Internet Connected Ground Station;
Operator Responsible for Separation
Line of Sight

Basic
Radio Control
Line of Sight

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Air Traffic Operations & Management Solutions for sUAS

ATC/Air Navigation Service Provider (ANSP): Authority must be delegated to federated, highly-automated services (e.g.NASA UTM)

Managed by Exception: With increased automation levels, operators need to be informed, intervene only in significant off-nominal cases

Vehicles and Systems: Standard, interoperable protocols. Connected vehicles with appropriate automation levels.

# Federated/ Interoperable Unmanned Traffic Management (UTM)

- Unmanned vehicle operations coordination through agreed upon data/information exchanges about each other's operations and with ATC systems

- Exceptions handling – entry into controlled airspace

- Beyond visual light of sight

- Manned and unmanned vehicle operations coordination

- Higher density operations

Longer-term: Changing the paradigm of airspace operations

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UTM Architecture
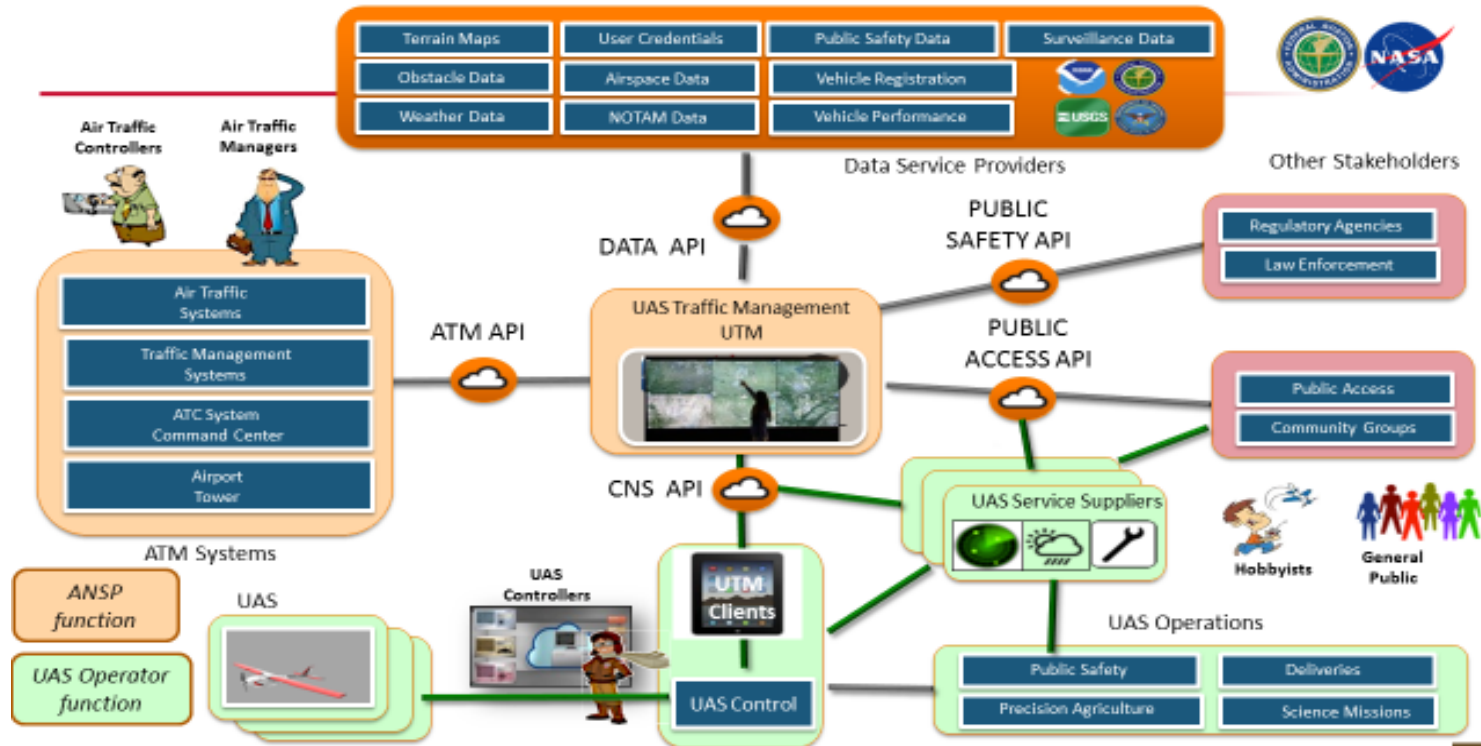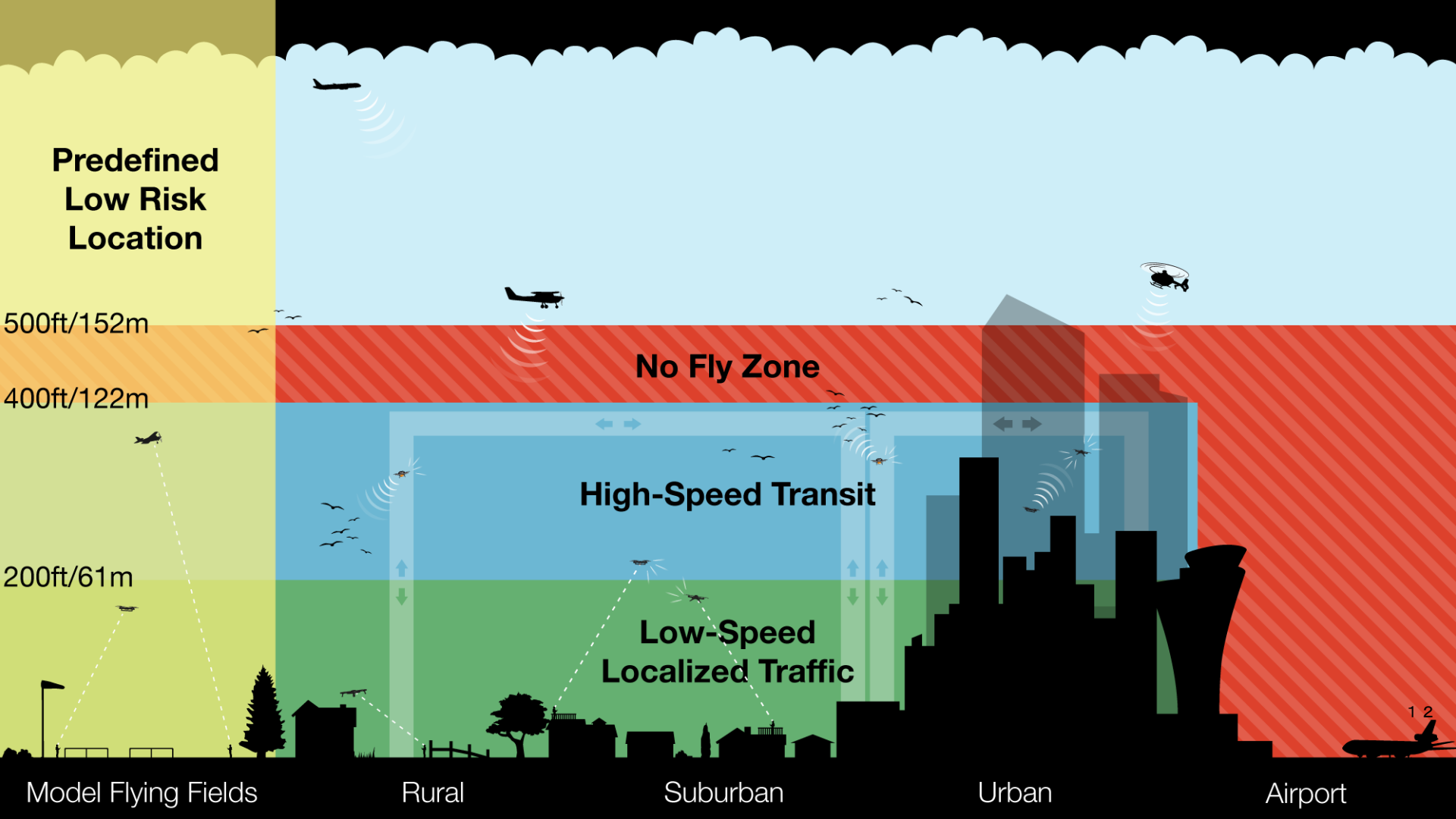
Predefined Low Risk Location

500ft/152m

No Fly Zone

400ft/122m

High-Speed Transit

200ft/61m

Low-Speed Localized Traffic

Model Flying Fields   Rural   Suburban   Urban   Airport

First Customer Delivery (Dec 2016)

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thank you

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Revising the Airspace Model for the Safe Integration of Small Unmanned Aircraft Systems

This paper describes Amazon's position on the design, management and operations of the airspace for the safe and efficient integration of low-altitude small unmanned aircraft systems. Amazon anticipates this model will be refined over time, and will work in close collaboration with public and private industry on the development of an approach that is safe and efficient for all types of operations.

Airspace Design

The development of an air traffic system that fully enables the safe operations of small unmanned aircraft systems (sUAS) in civil airspace, particularly highly-automated vehicles operating beyond line of sight (BLOS), is essential for realizing the enormous benefits of this technology in a safe and responsible manner. A good place to start in creating such a system is to clarify the use of the airspace.

The majority of airspace integration efforts over the past decade have focused on integrating medium or large unmanned aircraft systems into non-segregated civil airspace, i.e. airspace above 500 feet where most civil and military aviation activities occur. However, given the rapidly growing small unmanned aircraft industry, Amazon believes the safest and most efficient environment for sUAS operations—from basic recreational users to sophisticated BLOS fleets—is in *segregated* civil airspace[1] below 500 feet. Segregating the airspace will buffer sUAS operations from current aviation operations. It will also buffer lesser-equipped vehicles from highly-equipped vehicles able to safely perform BLOS missions.

In this proposed model:
- Airspace below 200 feet, or the 'Low-Speed Localized Traffic' area, will be reserved for (1) terminal non-transit operations such as surveying, videography and inspection, and (2) operations for lesser-equipped vehicles, e.g. ones without sophisticated sense-and-avoid (SAA) technology. Those lesser-equipped vehicles will not have access to certain airspace in this zone, such as over heavily-populated areas.

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[1] Segregated airspace is defined as airspace which is restricted to the exclusive use of specific users.

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- A 'High-Speed Transit' space, between 200 and 400 feet, will be designated for well-equipped vehicles as determined by the relevant performance standards and rules.
- The airspace between 400 and 500 feet will serve as a permanent 'No Fly Zone' in which sUAS operators will not be permitted to fly, except in emergencies.
- Finally, this airspace model will also encompass 'Predefined Low Risk Locations.' Altitude and equipage restrictions in these locations will be established in advance by aviation authorities. These Predefined Low Risk Locations will include areas like designated Academy of Model Aeronautics airfields, where members will meet pre-established parameters for altitude and equipage.

Amazon believes this segregated airspace model will enable safer overall operations by providing a framework where airspace access is tied to vehicle capability, and by buffering sUAS operations from current aviation operations.

Below is a visual representation of this proposed airspace design model.

Airspace Design for Small Drone Operations
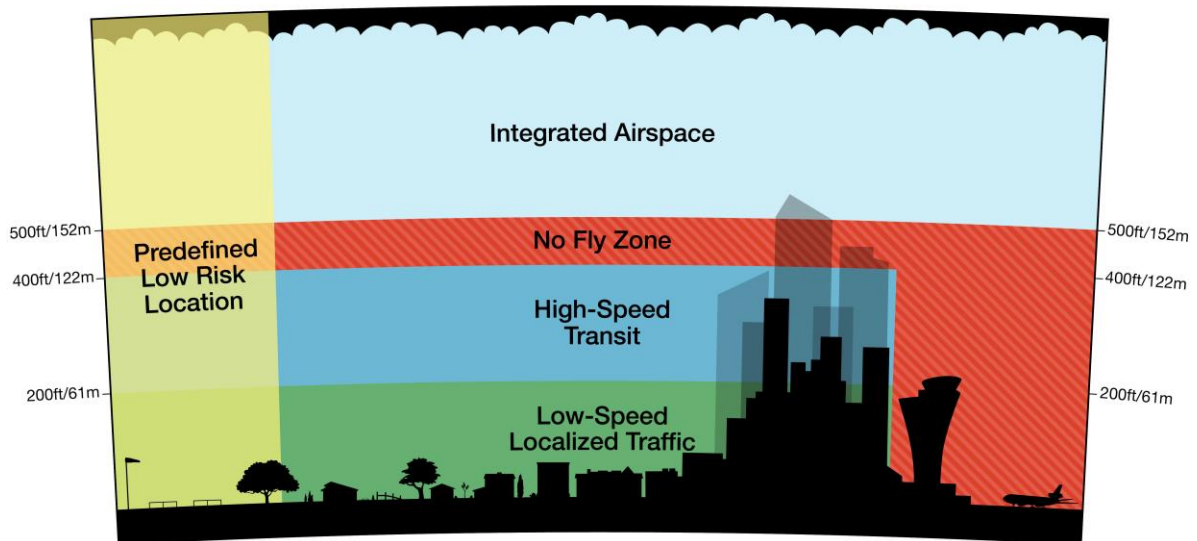
Airspace Management & Operations

Revising the way airspace is managed is also a key factor in the development of a system that will meet future sUAS demands. Today, most of the world's airspace systems and related

training are designed for a single pilot or flight crew per-vehicle concept. More so, in the United States and Europe, air traffic controller workload is the single-greatest functional limitation on airspace capacity [2] [3] [4]. Workload is largely driven by airspace complexity, and controller workload increases linearly as the ratio of UAS to manned aircraft increases[5]. In the United States, for example, there are approximately 85,000 commercial, cargo, military, and general aviation flights every day. This number is likely to be dwarfed by low-altitude sUAS operations in the next 10 years.

As a result of these factors, Amazon believes the current model of airspace management will not meet future sUAS demands, particularly highly-automated, low-altitude commercial operations. A paradigm shift in airspace management and operations is necessary to safely accommodate the one-operator-to-many-vehicle model required by large-scale commercial fleets.

While more research is needed to identify exactly how an air navigation service provider (ANSP) will evolve to support high-volume sUAS operations, it is Amazon's position that the projected industry growth also requires the delegation of responsibility for many traditional air navigation services, such as navigation and air traffic control and communication. There should be a controlling entity that serves a central, offline coordination and auditing function, however, many of these services will be handled in a more distributed and federated fashion where multiple operators cover overlapping areas, each managing their own fleet. Those operators would coordinate by following established protocols, using vehicle-to-vehicle, vehicle-to-service and service-to-service data communication and automation, to safely and efficiently manage the shared airspace.

Highly-equipped sUAS will be capable of navigation, merging and sequencing, communication, maintaining safe self-separation, collision avoidance and deconfliction in congested airspace without operator assistance. Again, while many of the traditional ANSP responsibilities may be delegated, the underlying authority will still reside with the ANSP and/or the civil aviation authority. To help move this model forward, Amazon will collaborate with civil aviation authorities like the Federal Aviation Administration, as well as NASA and others, on research related to delegation and federation.

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[2] Lishuai, L., Hansman, R.J. (2009), Experimental Studies of Cognitively Based Air Traffic Control Complexity Metrics For Future Operational Concepts, MIT International Center for Air Transportation, Cambridge, MA.
[3] Hilburn, B. (2004), Cognitive Complexity in Air Traffic Control: A Literature Review, Eurocontrol Experimental Centre, Brussels, Belgium.
[4] Majumdar, A., Polak, J. (2001), Estimating Capacity of Europe's Airspace Using a Simulation Model of Air Traffic Controller Workload, Transportation Research Record: Journal of the Transportation Research Board, 1744:30-43.
[5] Helleberg, J., Maroney, D. (2010), UAS Operations in the National Airspace System: Human-in-the-Loop Simulation and Experimentation, The MITRE Corporation, Mclean, VA.

Additionally, it is Amazon's view that air traffic management operations should follow a 'managed by exception' approach. This means operators are always aware of what the fleet is doing, yet they only intervene in significant off-nominal cases, e.g. emergencies and national security directives. Automation on the vehicles, e.g. vehicle-to-vehicle communications and SAA, and automation on the control structure, e.g. routing, separation management and optimization, will handle nominal and minor off-nominal cases. This approach will entail a distributed network comprised of local/regional air operations centers and remote vehicle operators. This new system is essential given the highly-automated nature of future sUAS, and it will result in a decrease in operator workload and an increase in both safety and capacity.

A Path Forward

Modifying the way airspace is used will require close collaboration with multiple stakeholders—aviation authorities, academia, the commercial and recreational sUAS industry, as well as the manned aviation industry. It will also require investment in advanced technologies, like the types of automation discussed above. Amazon believes NASA already has a solid understanding of these technologies through decades of experience in airspace automation, as well as a firm grasp on how they will be used for sUAS through its Unmanned Aerial System Traffic Management, or UTM, program. Amazon applauds NASA's efforts as the technological investment will result in a safer and more efficient use of the airspace, enabling innovation across a wide range of missions and scenarios. To help realize this new airspace model and bring the industry forward, Amazon will actively cooperate with other sUAS stakeholders—large and small, commercial and recreational—in developing equipage and performance standards for sUAS.

In summary, Amazon believes the safest and most efficient model for sUAS with mixed equipage and capabilities is in segregated airspace with a defined structure for operations below 500 feet, alongside federated, highly-automated, highly-available and secure air navigation services. The public and private sUAS industry should work together to realize this new concept of airspace operations if we are to bring the remarkable innovations of sUAS to bear in a safe and responsible way.

Determining Safe Access with a Best-Equipped, Best-Served Model for Small Unmanned Aircraft Systems

This paper describes Amazon's proposed approach for determining airspace access for low-altitude small unmanned aircraft systems. Amazon anticipates this model will be refined over time, and will work in close collaboration with public and private industry on the development of the safest system of access for a wide range of applications, not limited to package delivery.

Best-Equipped, Best-Served

Best-Equipped, Best-Served means that the vehicle equipment, often referred to as equipage, network functionality and concept of operations (ConOps) determine whether or not the required level of safety—as determined by the relevant performance standards and rules—is achieved, and therefore, whether access to the airspace is granted.

Amazon envisions the safe operation of small unmanned aircraft systems (sUAS) as a combination of real-time planning and on-board vehicle automation. With this approach, required degrees of planning and automation vary based on vehicle capabilities, web-service-based command and control, and ConOps. These capabilities are expected to be online, with the network able to adapt in real time to varying situations, such as changes in weather and emergency access needs.

When looking at equipage, there are a number of critical technologies currently being explored in areas like vehicle-to-vehicle communications (V2V), command and control networks, and sense-and-avoid (SAA) technology. It is important to note the two distinct types of SAA in relation to vehicle equipage: collaborative and non-collaborative. V2V capabilities enable collaborative SAA, providing vehicles with a way to communicate directly with each other to create awareness and maintain separation. Sensor-based SAA capabilities, however, enable non-collaborative separation between vehicles and non-equipped entities, which can range from birds to balloons.

A Formula for Access

Airspace access for manned aircraft is determined by capabilities. For example, communication and navigation equipage is required for transit through controlled airspace and to gain access to certain airports. Amazon believes a similar model of determining access—one focused on

segregated blocks of airspace below 500 feet and away from most manned aviation operations—is the best pathway for safe and scalable sUAS operations.

Evaluating the vehicle's equipage and network capability in order to determine performance is the first step. Once performance levels have been established, the operator's ConOps requirements will determine whether or not the operator is granted airspace access and can safely perform the designated mission.

The variety of ConOps and vehicle capabilities means there is no one-size-fits-all model. For example, an operator with a lesser-equipped vehicle may be able to achieve the required level of safety if they are flying in a remote area. On the other hand, an operator seeking to fly in an urban environment would have to meet a highly sophisticated equipage standard, with both robust communications and the ability to avoid other airborne entities and people on the ground.

Four Classes for Safe Operations

Operators seeking broad airspace access in multiple environments will need to have highly-equipped vehicles. They will also need to minimize interaction with lesser-equipped small unmanned aerial vehicles, as well as the occasional manned aircraft flying at low altitude. To ensure the safety and integrity of the overall system, it is paramount that all sUAS operators understand where they can and cannot safely operate.

It is with this in mind that Amazon envisions four separate sUAS equipage classes: Basic, Good, Better, and Best. These classes optimize for safe and efficient airspace operations by creating categories of access based on capability. For example, a vehicle with an equipage classification of 'Good' does not meet the vehicle capability requirements, such as automated collaborative deconfliction (via V2V) and non-collaborative SAA, that are needed to perform a complex mission in an urban environment. On the other end of the spectrum, operators requesting access to execute missions with high complexity must equip in the 'Best' class and possess five equipage elements: (1) geospatial data for safe separation from known hazards, (2) online flight planning and management, (3) reliable Internet connection, (4) collaborative V2V SAA, and (5) non-collaborative sensor-based SAA. It is Amazon's position that these five 'Best' equipage elements are essential for safe, highly-automated operations.

The following table identifies Amazon's proposed classes, equipage capability examples, and the resulting airspace access.

Class	Equipage *Examples*	Airspace Access
Basic	Radio control	Line of sight (LOS) flight in predefined low risk locations
Good	*Basic +* Ability to announce and log identity location and activity via V2V; ability to receive air traffic information, weather data, GPS and Wifi; Internet connected via ground control; proximity alerting to operator via collaborative V2V; basic geospatial data	*Basic +* Unrestricted daytime LOS flight less than 200 feet in rural operating areas; limited operations in suburban areas
Better	*Good +* Autopilot capable of auto-deconfliction via collaborative V2V; on-vehicle Internet connection; Automatic Dependent Surveillance-Broadcast (ADS-B) Out capability	*Good +* Daytime LOS flight less than 400 feet in suburban operating areas; limited operations in urban areas
Best	*Better +* Non-collaborative SAA and automated deconfliction; reliable on-vehicle Internet connection; 4D trajectory planning and performance management; geospatial data of all hazards to navigation over 200 feet; onboard vehicle condition monitoring system; alternate landing execution; long-range SAA able to detect and differentiate non-collaborative targets and safely deconflict; ADS-B In/Out	*Better +* Beyond line of sight flight less than 400 feet in all operating areas, including urban, with vehicle-to-operator ratios greater than 1:1, transiting between 200 feet and 400 feet; daytime and/or nighttime; good weather or all weather as determined by sensor-package performance capabilities

The proceeding graphic takes it ones step further and illustrates the relationship between vehicle capability, ConOps complexity and airspace access.
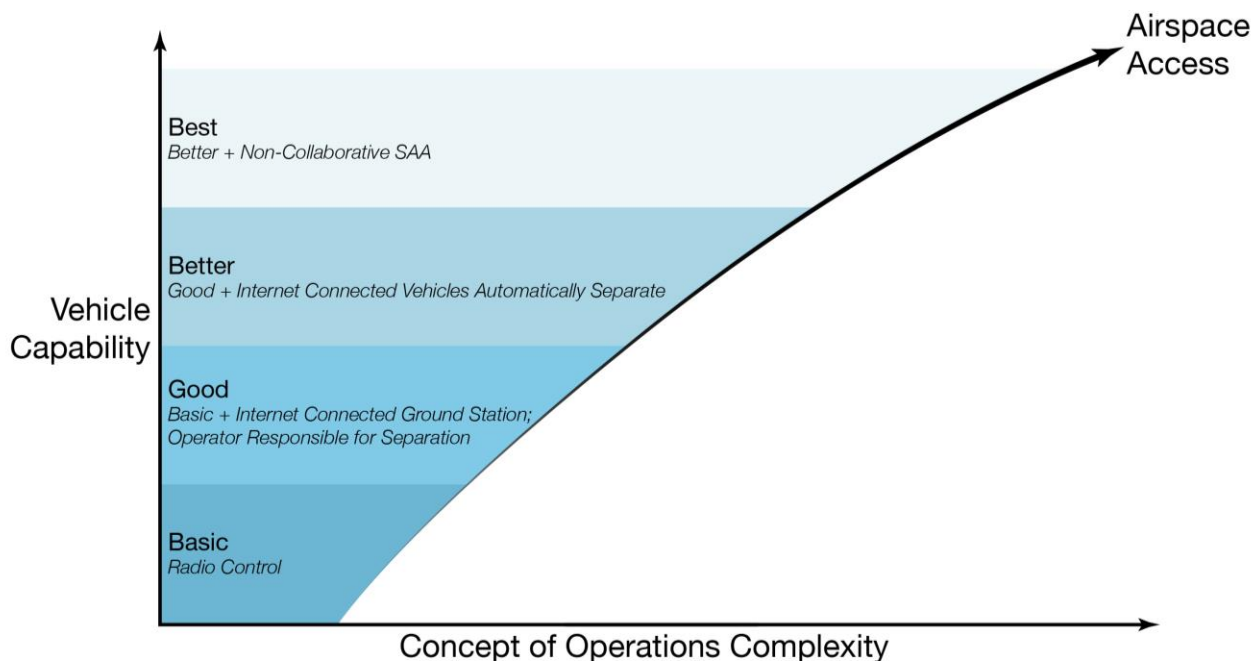
Creating Standards, Enabling Innovation

Aviation authorities, manufacturers and operators around the world have created high standards for equipment, operations, reliability, and safety. In order to maintain and enhance the level of safety achieved in aviation today for sUAS, aviation authorities should adopt performance-based equipage and operating standards. Such standards will allow for the safety of the system to improve as the technology improves, rather than locking into a specific set of technologies that quickly become outdated.

It is Amazon's position that a Best-Equipped, Best-Served model for determining airspace access, alongside the creation of four separate sUAS equipage classes, is the safest way to usher in this new era of aviation in scalable and sustainable way. Amazon is committed to collaborating with industry to help define standards in a way that will provide operators, manufacturers and policymakers with a clear understanding of what is needed to operate safely in the shared global airspace.