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# Opening Autonomous Airspace–a Prologue

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Integrating Unmanned Aerial Systems (UAS) safely with conventionally piloted, manned aircraft presents long-term challenges, especially during the lengthy transition period when UAS will be mixed with manned aircraft. Integration of dissimilar systems is not an easy, straight-forward task. In today's active sensor/radar-based airspace system, finding small UAS (sUAS) is complicated by their diminutive size and typically low altitudes. Simply knowing they are present in the airspace and knowing their true location can be extremely challenging.

The purpose of this paper is to discuss and encourage industry dialog around the significant operational implications and issues with the integration of manned and unmanned air vehicles. As acknowledged in Pappas, Tomlin, Lygeros, Godbole, and Sastry, (1997); Ravich (2009); and in Weibel and Hansman (2005), moving beyond today's voice-controlled network will require another method of integrating and sharing airspace. One possible view of future airspace design is presented—this view can be a prologue of how airspace could operate autonomously, without strain. Care has been taken in the discussion to balance operational flexibility with safety; this is most critical at lower altitudes, in the near term, where the vast bulk of sUAS activity is expected to require assured separation from manned aircraft.

A fundamental presumption in this discussion of an unstrained air traffic future is a fully networked, autonomous environment in which all air vehicle participants are nodes on the network; and, in the long-range view would operate without human intervention. Accomplishing these objectives moves the Air Traffic Control (ATC) system of today to an Air Traffic Management (ATM) system requiring significantly less direct human control. A conceptual air traffic management philosophy of autonomous self-separation of all nodes on the network underpins this future.

Correspondingly, in a networked airspace with a requirement for active participation, if a user is choosing to not participate on the network this action would connote either that the user is experiencing an emergency preventing network participation, or a purposeful choice to deceive. The latter scenario could be interpreted to be an intruder and a threat to the integrity of the network, a threat to the other network participants, or a threat to the populace on the ground.

Rather than rooted in scientific exploration, the paper is an operational postulation based principally on the author's personal experience as a civil (Instructor and Air Transport) pilot, a user of the airspace and air traffic control system, and former corporate air traffic management executive program manager.

The methodology used in this operational postulation was strongly influenced by a blend of Creswell's (2007) description of case study and grounded theory coupled with the University of Southern California's (USC) (2017) description of exploratory design. The paper concentrates conceptually on *what* a future airspace design must have to safely absorb the anticipated diversity of air vehicles, especially the significant infusion and integration of sUAS. The paper does not delve deeply or authoritatively into the details of *how* a future airspace would specifically operate.

Recognizing the global air transportation system has already entered what will likely be a lengthy transition period from manned aviation to unmanned aviation, safety must remain as the ultimate benchmark. In addition to the future airspace structure presented in this paper, a brief discussion of the required technology issues and obstacles to transition to this future includes topics such as self-separation logic, air-vehicle self-healing, cybersecurity, intruder detection/mitigation, neural network, societal trust, policy reform, and employment implications. Each subject is described at a macro operations analysis level versus a more detailed, systems engineering level. A similar review of these subjects were offered by DeGarmo (2004). Like DeGarmo's (2004) overall objective, the potential value of such a discussion is to encourage industry dialog about possibilities and, more importantly, a focus toward workable, future, air traffic solutions.

## Method

An exploratory design methodology like that espoused by the USC (2017) blended with elements of Creswell's (2007) description of case study and grounded theory qualitative research design significantly influenced the author in capturing a vision of a possible future airspace design from a logical extension of the present.

The paper is exploratory in that it attempts to predict what may occur, offers an alternative explanation for how the future airspace could be structured differently from today and states direct, causal relationships that must happen to enact this future. These are characteristics that USC (2017) offer as evidence of an experimental design but apply strongly to an exploratory design methodology where "…there are few or no earlier studies to refer to or rely upon to predict an outcome. The focus is on gaining insights and familiarity for later investigation or undertaken when research problems are in a preliminary stage of the investigation. Exploratory designs are often used to establish an understanding of how best to proceed in studying an issue or what methodology would effectively apply to gathering information about the issue." (USC, 2017). It is the latter phrase "how to best proceed" that drives the motivation for this paper. The espoused airspace design is one possibility. By exploring and discussing its merits and challenges, it is possible that paths with a higher probability of success may be identified over those which would be much less preferable.

Current International Civil Aviation Organization (ICAO) airspace design was used as a launching point for the exploration. Modifications to the ICAO structure by layer, starting with the airspace closest to the surface of the earth, are suggested with specific technological additions to incorporate the influx of sUAS and UAS. Weather criteria, the impacts of technology need on both manned and unmanned operations within the airspace, and transition considerations from today's airspace to the proposed airspace are presented and illuminated as issues requiring resolution. These explorations are intended to contribute to the industry discussion of future airspace operational principles, requirements, and solutions to integration of both sUAS, and UAS with manned aircraft.

Creswell (2007) states that grounded theory is designed, "…to move beyond description and to generate or discover a theory, an abstract analytical schema of a process. Participants in the study would all have experienced the process, and the development of the theory might help explain practice or provide a framework for further research" (p. 62-63). While no data was expressly gathered to support the espoused future airspace design it is anticipated that the readership will also have personal exposure to and hands-on experience with the current ATC system, and thus the readership then becomes surrogate participants in the discussion. Furthermore, using the current ICAO airspace structure makes it easier to move from something which is familiar to what is proposed.

Lastly, Creswell (2007) describes case study as that focused on, "…an issue explored through one or more cases within a bounded system, i.e., a setting, a context." (p. 73). The examination offered here is focused on one instance, the integration of UAS and manned aircraft, how they must cooperate, and how they will continue to operate in a bounded/closed system, the future ATM system.

Characteristics of the three methodological approaches are blended and significantly influenced the author's experiential views to propose the future airspace structure and discuss the issues necessary to support that airspace structure.

## Predications

Before a more detailed conceptual discussion, there are seven predications upon which the proposed airspace design was made:

1. Every air vehicle is a node on the future air traffic network
2. An overall operating philosophy of self-separation
3. The vast bulk of sUAS, at least for the near term, are at low altitudes
4. The careers of ATC and piloting as we know them today sunset

5. sUAS maneuverability exceeds that of piloted aircraft
6. Trust in autonomous air transport technology is implicit
7. Current ATC service provisions do not change

## Network Participation

**Predication 1.** Each air vehicle will be a node on the air traffic network.

Any air vehicle desiring to access commercial airspace will be required to be a continuously active air traffic network participant. Recreationally manned aircraft, commercially manned aircraft, remotely controlled UAS (those controlled typically from the ground), semi-autonomous UAS (those that share human input with automation), fully autonomous UAS (no human control), and a significant infusion of small, lighter weight sUAS (which can either be manually controlled, semi-autonomous, or fully autonomous) will be simultaneously competing for unimpeded transit in the airspace.

It is also presumed there will be a significant transition period from a historically human-controlled flight in a voice-based network to a long-range future where all but the most specialized of flight is autonomously controlled on the air traffic network; this transition period has already started.

## Overall Operating Philosophy

**Predication 2.** The airspace and the air traffic system of the future will not be based on control of individual air vehicles as they are today; rather, both will be very similar to current, two-dimensional automobile driving. They will be based on *self-separation management of air vehicles and flow* in four dimensions (4-D); the classic 3-D position and time.

Two analogies are offered to help envision the future airspace and air traffic system. The first requires a slight relaxation in the laws of physics, but once that is recognized, the analogy should be helpful in conceptualizing the future.

First, to envision the self-separation of air vehicles, imagine a handful of dissimilar-sized, self-repelling magnets thrown into the air[1]. Instead of rotating and sticking together, imagine the magnets will seek to separate themselves as far apart from each other as possible in nature's most efficient spherical packing method, a 3-D, hexagonal, closest-packed distribution (Neser, Bechinger, Leiderer & Palberg,

[1] This concept is accredited to Mr. Rick Palace, Boeing Air Traffic Management, Herndon, VA, (2003)


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1997). This vision could also appear like a school of dissimilar-sized fish or a flock of dissimilar-sized birds.

Second, to envision the future air traffic flows, imagine airports are connected by a network of arteries and veins similar to organs in the human body. The heart is analogous to one major hub airport while the organs represent the satellite-destination airports served from that hub.

Combining these two visions yields the self-repelling magnets as the individual air vehicles moving about in organized, ordered traffic flows. The air traffic flows diverge from hub airports towards the satellite airports, similar to the divergence of arteries from the human heart, and the air traffic flows would simultaneously converge from the satellite airports towards the hub airports, similar to the convergence of veins toward the human heart.

**Location of the Vast Bulk of the sUAS**

**Predication 3.** The bulk of the sUAS will be at low altitudes, below 500 ft. Above Ground Level (AGL).

Given their light weight and limited endurance, sUAS will initially be concentrated at low altitudes, typically below 500 ft. AGL. The recently enacted Federal Aviation Regulations (FAR) Part 107 deals specifically with sUAS, those weighing less than 55 pounds, and regulates/restricts their operation to below 400 ft. AGL. As improved battery technology directly correlates with and enables increased sUAS range/endurance, realistically accessible sUAS flight profiles and altitudes will increase.

According to FlightRadar24 (2016), during daylight hours, approximately 6,000 aircraft are airborne over the continental United States (U.S.). Except for take-off and landing and selected vocational uses such as agricultural aerial application, manned aircraft do not operate below 500 ft. AGL. The Federal Aviation Administration (FAA) (2015a) predicts marginal to no growth in total manned air traffic in the next five to ten years.

In the unmanned arena, however, the growth projections are much different. The FAA (2015a) anticipates that by 2020, “490,500 lower-end UAS” (those costing less than $2,500) to be in the fleet in the U.S. alone. If this prediction is accurate, there very well may be a comparatively large number of sUAS competing for low-altitude airspace.

## Effect on Manned Careers

**Predication 4.** Presumed in this exploration of a future airspace design is that the longstanding, aviation careers of both Piloting and Air Traffic Control will be "sunset careers," meaning these careers, as defined today, will eventually disappear.

Piloting will transition in limited application to systems monitoring, and ATC will transition from a control function to a management function. Automation resident on each air vehicle will be necessary for safe separation and to supplant direct pilot control or the control currently directed by ATC.

To achieve the current air traffic system safety levels enjoyed in North America, Europe, and the Middle East with autonomy will require substantial, long-term safety-of-life-technology investment, testing, and new certification standards. New career fields in software development, validation and verification, air traffic system safety monitoring, management, and cyber security must emerge to compensate for the loss of direct, human control.

## Air Vehicle Maneuverability

**Predication 5.** All UAS must react and then adjust their trajectories, yielding way to manned aircraft actions.

Currently, FAR 107.37 requires that sUAS yield right of way to manned aircraft. This regulation, however, does not apply to UAS. When dissimilar air vehicles of size, speed, control, or capability are mixed, care must be exercised to ensure safe separation between the air vehicles.

Due to their small size and light weight, sUAS can maneuver in ways that manned vehicles cannot. Take for example that many commercially available ~1 lbs. sUAS can do a complete loop, a summersault of 6-inch radius, in 0.1 sec. The radial (turning) acceleration they experience is equivalent to their velocity$^2$ divided by their radius of turn. When the acceleration is divided by acceleration due to gravity, this equates to a G-loading of nearly 62 Gs as follows:

$$a = (v^2/\text{radius})/32 \text{ ft./sec}^2 \tag{1a}$$

$$a = ((\text{circumference of 1 ft. diameter circle}/0.1 \text{ sec})^2/0.5 \text{ ft.})/32 \text{ ft./sec}^2 \tag{1b}$$

$$a = ((\Pi * 1\text{ft}/0.1 \text{ sec})^2/0.5 \text{ ft.})/32 \text{ ft./sec}^2 \tag{1c}$$

$$a = 61.9 \text{ g} \tag{1d}$$


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G-loadings that humans can tolerate is predicated on how long the humans have exposed and the magnitude of the loading. A maximum lateral acceleration design goal of 20 g for 0.1 sec was offered by Zimmerman and Merritt (1989, p. 26), and this was with proper seat support and body restraint. Without supplemental systems, such as a G-suit, most humans can withstand 3-5 Gs for modest periods of time. Survivable instantaneous G-loadings can be much higher. However, as soon as a G-loading of 10 Gs is extended to one minute, this is usually considered lethal.

To ensure a survivable, sustained G-loading, manned air vehicles are less able to make quick, erratic, or violent trajectory changes compared with sUAS which have no human-based restrictions on their maneuverability. These differences become critical when closure rates are high and the distance between conflicting air vehicles is small, less than approximately current, nominal 2-5 NMs (Nautical Miles) that the FAA uses to separate aircraft. A potential solution to the performance diversity issue would require that all UAS are subordinated to manned aircraft; meaning all UAS must react and adjust their trajectories by yielding way to manned aircraft actions.

## Trust in Technology

**Predication 6.** Humans must implicitly trust the technology that will be autonomously transporting them.

The author extensively evaluated confidence in technology, specifically in autonomous airliners and found trust must also extend into the larger system in which the airliners operate, i.e., the ATC system (Vance & Malik, 2015). Specific factors that heavily influence a human's ability to trust technology were identified as (a) prior behavioral history; (b) breaches of expected behaviors; (c) the service provider's moral integrity, technology investment, and prior history of fiduciary obligation satisfaction; (d) automation sophistication; and (e) the reputation of those who represent the novel technology. Weibel and Hansman (2005) found nearly identical results in their literature review with a human's ability to accept technology risk.

As society continues to grow more dependent on multimedia, real-time data communications, and the free sharing of data, cybersecurity compromises correspondingly grow as potent and legitimate threats. Trusting in autonomous transportation technology will also implicitly trust that the vehicle can stay properly connected to a node on the network. Data integrity compromises can negatively affect normal, routine operations as well as sensitive, personal, corporate, or national security operations. Sophisticated, malicious, virus software breaches are not required to inflict harm; compromise can occur with simply invalid data.

It is inconceivable that control of human life, with any form of automation, would be relinquished without exhaustive verification and validation of the entrusted system's integrity and invulnerability to cyber compromise or corruption. Earning humans' trust in an autonomous air transport future will be a monumental achievement predicated not only on trust in the air vehicles themselves but also confidence in the airspace system in which the air vehicles operate.

### Unchanging Foundations of ATC Service Provision

**Predication 7.** ATC will always be responsible for the separation of participating, piloted vehicles from each other and known obstructions.

The ability to remain clear of other air vehicle traffic and all obstructions are the two foundational tenets of ATC service provision to piloted aircraft; these two essential tenets are timeless and will not change, no matter how the service is provided. The ability to affect both tenets with automation for manned and unmanned vehicles is yet unproven but necessary if other air vehicles, terrain, weather, flight restrictions, and man-made obstacles are to be autonomously avoided. With these seven predications intact, the conceptual discussion can more effectively proceed.

## Discussion

This section presents a conceptual overview of the future airspace design, a more detailed explanation of each future airspace layer, how the layers differ from today's structure, the technology impacts of the new airspace design, and considerations in overall airspace transition to this new design.

### Conceptual Overview

Figure 1 shows a schematic of the autonomous airspace of the future with a diversity of air vehicles sharing the airspace in a free navigational flow. In this depiction of the future, the air vehicles must be capable of self-separation and trajectory de-confliction with each other and obstacles. For simplicity, the graphic suggests a predominately bi-directional flow of opposing traffic with a significantly reduced volume of orthogonal, crossing flow. The future system, however, must be able to simultaneously accommodate any air vehicle direction and velocity.


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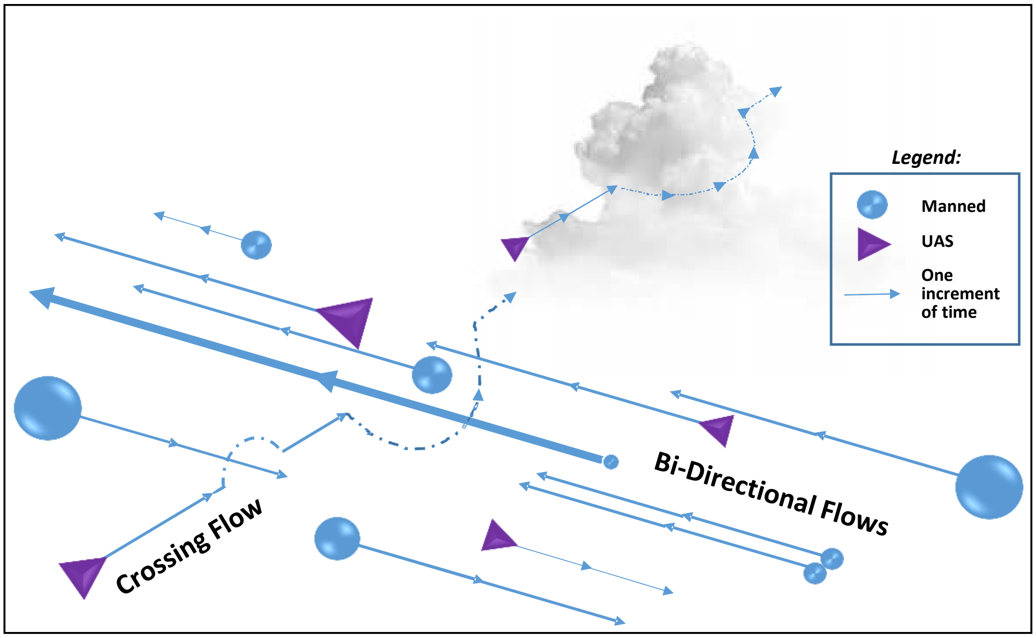


*Figure 1*. The future autonomous airspace must be equitably shared by a diversity of manned and unmanned air vehicles differentiated in size and speed but significantly not in capability. Each must communicate their precise location and trajectory intent, have the same ability to sense a conflict with other network participants and obstructions, as well as compute and execute de-confliction actions. Bi-directional/opposing and crossing/conflicting traffic flows are shown in this schematic. The spheres represent manned aircraft, and the triangles represent UAS. The size of the sphere or triangle connotes the air vehicle's mass. Each vehicle communicates their trajectory in equal time increments, represented by the dissimilar length arrows projecting ahead of the vehicles. A minimum of two, equal time increments are shown by two, collinear arrows for each vehicle. The direction of the arrows shows intended travel while the magnitude of the arrows shows speed. Note there are differing size manned and unmanned air vehicles with different velocities sharing the airspace. In the center of the figure, immersed in the bi-directional/opposing flow among numerous manned and unmanned air vehicles traveling at similar rates of speed, is a small manned aircraft traveling at a high rate of speed, shown by the thicker, longer time increment arrows? A slower, manned, formation flight is following behind and slightly to the left. The UAS in the lower left crossing flow is shown de-conflicting its trajectory/yielding the right-of-way to the manned air vehicles obstructing its path. The UAS in the upper center of the figure is shown circumnavigating threatening weather. All network participants must be able to autonomously execute the same, predictable de-confliction actions.

Functionality such as Automatic Dependent Surveillance-Broadcast (ADS-B), coupled with a TCAS (Terminal Collision Avoidance System) capability, would be the foundational building blocks that allow each air vehicle to communicate their current, precise, 3-D location, their intended location, plus receive the same information from other air vehicles. The intended location adds the necessary and significant enabler of a 4$^{th}$ dimension (4-D), time to the data block. Knowing where each air vehicle will be at defined increments of future time is the enabler that allows them, with commensurate decision logic, to self-separate. The now 4-D data block must include 3-D position plus trajectory into the future (time) with sufficient accuracy to allow self-de-confliction with other air vehicles, and self-de-confliction with all digitally data-based obstructions. Mapped terrain, man-made structures, transmitted weather, and air traffic system flight restrictions are examples of digitally data-based obstructions.

With standardized, trajectory-optimization, decision logic, all air vehicles as network participants could also organize into flows. To enable the maximum utility of airspace, the required ADS-B Out/In and TCAS functionality must be miniaturized in size, especially weight so that it is compatible with the smallest air vehicles comprising the flows. Flows must be predicated on established criteria which regulate the speed at selected distances from the point of intended landing, or for vertical take-off and land (VTOL)-capable air vehicles, the point of intended alignment. Self-separation and speed-control will facilitate matching demand and capacity at points in space, or the destination airports where flows are converging.

Significantly complicating the future airspace will be the diversity and mix of manned and unmanned air vehicles of grossly different sizes, thus inertia. The combination of air vehicles should co-mingle without impacting each other's trajectories or terrain, weather, flight restrictions, and man-made obstacles. To ensure that no two air vehicles touch is a challenging physics, a 3-D optimization problem that must in real-time accommodate the flow and capacity demands made of each route and each airport. What is being optimized is the number and types of air vehicles that can be safely and reliably mixed in the airspace.

The key, system success metric will be time; the minimization of time required to transit between two points. Any deviation from this minimum will be considered as decreasing efficiency. This time deviation metric is easily additive and can be observed for a single air vehicle of interest, a fleet of air vehicles (defined as those which share an organized commonality), segments of the future system such as individual flows or geographic areas of interest, or the system in its entirety. Large-scale, flow management functions currently performed in the U.S. Air Traffic Control System Command Center will have to be absorbed by each air vehicle. Every air vehicle participant in the future will need the ability to re-route around obstructions in their originally desired trajectory, adhere to adjustments in the flow in which they are immersed, and then, if necessary, re-integrate themselves into a revised flow.

The networked future will need to accommodate participants who desire to complete their transit manually, semi-autonomously, and fully autonomously from the first movement of the air vehicle from its starting point at its origin to the last movement at its destination. Sequencing of participants may be simpler if the current, FAA "first come/first served" model (FAA, 2015b, paragraph 2-1-4) were retained; however, an alternative, proposed model that should make flow integration more efficient is "on-time/first-served", meaning those participants that accurately estimate when they will be ready to enter the system, or meet waypoints in the system, will be queued ahead of those with less precise time estimates (Boeing, 2004). Current, FAA time-based, flow-management, while very similar conceptually to on-time/first-served, does not assign air traffic priority based on ability to meet scheduled times of arrival (FAA, 2009).

In a system predicated on self-separation, the safety distance required between participants will require accurate, 4-D positions. Where the need for maneuver exists to avoid conflict, an accurate, 4-D position allows each participant the ability to adjust their flight path by either absorbing or dissipating momentum. Small, light, agile, sUAS can withstand maneuver limits that are incompatible with human flight thus can be safely separated at much closer distances than large, heavy, air vehicles that have slower response times to flight control commands.

Each participating air vehicle will need to possess the same, self-separation decision-logic. As popular destinations are approached and converged upon, graduated flow restrictions will be placed upon all vehicles desiring access to the same location. The closer to the destination, the more stringent the restrictions will be in meeting time estimates. Participants will enter homogeneous flows of similar air vehicle size and momentum to minimize their speed difference/separation distances and, more importantly, the wake turbulence effects of the preceding air vehicles on the air vehicle(s) immediately following.

If at any time a choke point in the system develops in the air or with ground infrastructure (runways, taxiways, gates, receiving areas), participants must choose either a non-interfering wait posture similar to today's holding pattern or re-route to alternate destinations. These choices are not materially different than what is done manually in today's ATC system protocol to accommodate contingency flow operations.

As with unmanned operations in the future, manned or piloted operations will also transfer the current, ATC traffic separation responsibility to the air vehicle. Both the future pilots and the remaining air traffic controllers will be respective system monitors for safety-of-flight integrity. Pilots will have complete awareness of all the air vehicles around them and notification of trajectories requiring conflict resolution.

The described conceptual future airspace design has these characteristics: it is chaotic in appearance, but at the same time orderly, accommodating, responsive, efficient, safe, cyber-secure, and autonomous. The following airspace structure, technology impact, and system transition discussions illustrate, starting with airspace layers, how these characteristics interleave.

## Proposed Future Airspace Structure

**Tenets.** The future airspace design presented in Figure 2 is a simplification of the basic, ICAO-based design presently employed in the U.S. with the addition of one new and unused layer, Class F.

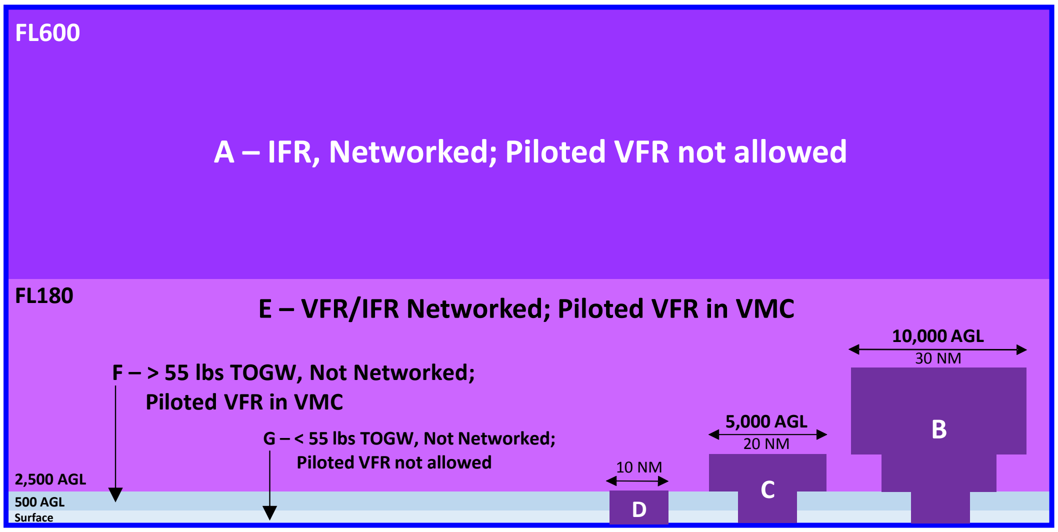


*Figure 2.* The ICAO-based, future airspace design closely resembles that of today with the significant differences being simplicity and uniformity at each airspace classification, and the use of Class F airspace. The proposal for Class G airspace starting at the surface and universally extending to 500ft AGL is to only permit non-networked sUAS operations. Class F, currently not incorporated or utilized in the U.S., is proposed primarily for non-networked, visual flight rules (VFR) operations of recreational, single-piston engine, manned aircraft between 500ft and 2,500ft AGL. Class E is proposed as primarily commercial airspace for lower altitude operations of both manned and unmanned air vehicles from 2,500ft AGL to Flight Level (FL) 180. FL180 is 18,000ft above Mean Sea Level (MSL). Class A remains unchanged for manned, commercial IFR operations but can include appropriately equipped UAS. Class D, C, and B remain to handle manned aircraft at successively larger airports and excludes all UAS VFR operations but will include UAS instrument flight rules (IFR) operations. For simplicity in the national airspace system, each Class D, C and B airspace retain the identical horizontal and vertical dimensions independent of their geographic location.

These tenants, or guiding assumptions, were used in the reconstruction of which activities are permissible in the various airspace layers and volumes:

- All airspace would be available for commercial purposes including Class G—the airspace closest to the earth's surface.

- Except for manned aircraft taking off, landing or aerial applicators (FAR 137), Glass G airspace would be segregated to sUAS operations only. All other airspace would be open to properly IFR-equipped UAS thus integrating them with manned aircraft. This philosophy is a significant departure from the current segregation approach to any UAS operations in controlled airspace or within 5 NM of towered airports.
- All unmanned operations outside of Class G must be IFR.
- Class F airspace will allow manned, recreational, single-piston engine, non-networked Visual Flight Rules (VFR) operations in Visual Meteorological Conditions (VMC).
- Manned aircraft operating under VFR in Class E must operate in VMC and will be required to be active participants in the air traffic network.
- All operations in Class A, B, C, D and E airspace, and all operations in Class F and G airspace when operating under IFR, will be conducted as an observable participant on the air traffic network.
- To ease user understanding and respect for Class D, C, and B airspace dimensions, all are cumulative; meaning Class C is identical in shape to Class D but with the second layer on top, and Class B is identical in shape to Class C but with a third layer on top.
- Each respective Class D, C and B airspace would be universally consistent in volume and independent of airport geographic location.
- For consistency and simplicity with navigation convention in NM, all weather-related visibilities are quoted in NM; no longer will weather-related visibilities be quoted in Statue Miles (SM).
- VFR weather minima would be defined identically with VMC (greater than 2,500ft AGL ceilings, and greater than 5 NM visibility).
- Marginal Visual Meteorological Conditions (MVMC) will be defined as ceilings greater than 500ft AGL, but less than 2,500ft AGL, and visibility greater than 3 NM, but less than 5 NM. MVMC will require flight under IFR in all airspace, except below 2,500ft AGL in Class D, C, and B where manned flight in MVMC under VFR would be permitted.
- IFR weather minima would be defined identically with Instrument Meteorological Conditions (IMC); which will be defined as less than 500ft AGL ceilings, and less than 3 NM visibility). These last three definitions for VMC, MVMC, and IMC would couple the regulatory requirements for VFR/IFR flight with the VMC/IMC weather minima, respectively.

For Class A, B, C, D and E airspace, network participation, and correspondingly observing the lack of network participation, are fundamental to this future. To accommodate the diversity of air vehicles co-occupying airspace, the accurate and instantaneous communication of 4-D trajectories requires network participation. Participation in the network is also the enabling ability for air vehicles to self-separate. For any air vehicle operating in Class A, B, C, D and E airspace that possesses one or more of the following characteristics (a) greater that 55 lb TOGW, (b) more than one piston engine, or (c) turbine-engine(s) a lack of network participation will constitute a threat.

**Airspace structural differences from today.** The significant differences from today's manned, piloted airspace design are highlighted below with a proposed, "plain English" title for each type of airspace following the ICAO designation.

***Class G–uncontrolled.*** [Below 500ft AGL] This airspace is reserved exclusively for sUAS operations, either recreational or commercial, and is not controlled by ATC. All air vehicles must weigh less than 55 lbs. Take-Off Gross Weight (TOGW). Other than the ability to self-separate, no restrictions or specific requirements would be placed on private or commercial operations, air vehicle certification/licenses, or avionics/communications. Class G airspace would be the only airspace in which less than 55 lbs. uncertified/unlicensed sUAS operations would be permitted. Other than for take-off, landing or aerial applicators, no operations would be allowed in Class G for any air vehicles greater than 55 lb.

The 55-lb TOGW threshold has been adopted by the FAA from the Academy of Model Aeronautics (AMA) who use it to distinguish a "large model airplane" where additional training and specifications apply to hobbyists at an AMA airfield (AMA, 2015). In consideration of unrestricted, low-altitude, sUAS operations, there is an intuitive safety concern that the 55 lbs. limit seems high. An objective, third-party, operations analysis study which balances utility with safety could be helpful in suggesting a lower alternative, possibly in the 15-20 lbs. range, similar to current, British UAS regulation. However, it should be appreciated that if golf balls are lethal to humans (Pfankuch, 2010), then sUAS much less than 15 lbs. can also be lethal—this weight limit deserves dedicated to research, public vetting, and careful regulatory promulgation.

***Class F–low-altitude recreational/commercial.***[2] [Above 500ft AGL, but below 2,500 ft. AGL] This airspace is designed primarily for the piloted, single-piston engine, a recreational user who owns either a vintage aircraft without an electrical system or a simple, low-cost aircraft for pleasure VFR flying. This airspace can also accommodate low-altitude commercial IFR operations. All air vehicles must weigh greater than 55 lbs. TOGW. Piloted VFR requires VMC. There are no restrictions nor requirements for aircraft avionics/communications for private, non-commercial, piloted VFR operations; although, it is encouraged that

[2] Currently, there is no Class F in the United States.

minimal equipage to self-separate and join the network be installed. Piloted IFR will be required in either MVMC or IMC. All commercial air vehicles and commercial operations must be certified/licensed, equipped with self-separation capability, ability to communicate with the air traffic network and operate under IFR. Recreational, piloted IFR operations must be identically equipped as commercial air vehicles.

Unless ATC radar is painting the non-participating aircraft – and – it has been determined to be a non-threat – and – this info can be broadcast on the future network so that all participating aircraft can avoid the non-networked recreational user, the UAS in this airspace will require a sense-and-avoid system to operate in Class F. Recreational, non-networked users should only be operating VMC in Class F, so manned aircraft would still bear a see-and-avoid separation responsibility.

***Class E–low-altitude controlled.*** [Above 2,500ft AGL, but below 18,000ft MSL] This airspace is designed for low-altitude, commercial IFR operations but can also accommodate low-altitude recreational VFR and IFR operations. All air vehicles must weigh greater than 55 lbs. TOGW, be certified/ licensed, equipped with self-separation capability, and ability to communicate with the air traffic network. Piloted VFR requires VMC; whereas, piloted IFR will be required in either MVMC or IMC.

***Class D–controlled; towered.*** [Within 5 NM of the Control-Towered airport below 2,500ft AGL] This positive ATC-controlled airspace primarily serves local operations and typically will not include scheduled air service. All air vehicles must weigh greater than 55 lbs. TOGW, be certified/ licensed, equipped with self-separation capability, and ability to communicate with the air traffic network. Piloted VFR will be permissible in VMC and MVMC; whereas piloted IFR will be required in IMC. All manned and unmanned air vehicles require communication with and permission from towered ATC.

***Class C–controlled; towered; restrictions.*** [Within 5 NM of the Control-Towered airport below 2,500ft AGL, and within 10 NM above 2,500ft AGL, but below 5,000ft AGL] This positive ATC-controlled airspace primarily serves regional operations and typically will include scheduled regional air service. All air vehicles must weigh greater than 55 lbs. TOGW, be certified/ licensed, equipped with self-separation capability, and ability to communicate with the air traffic network. Piloted VFR will be permissible in VMC and MVMC below 2,500ft AGL; whereas, piloted IFR will be required in IMC. Above 2,500ft AGL, piloted VFR requires VMC and piloted IFR will be required in either MVMC or IMC. All manned and unmanned air vehicles require communication with and permission from towered ATC.

***Class B–large; controlled; towered; restricted.*** [Within 5 NM of the Control-Towered airport below 2,500ft AGL, within 10 NM above 2,500ft AGL, but below 5,000ft AGL, and within 15 NM above 5,000ft AGL, but below 10,000ft AGL]–This positive, ATC-controlled airspace primarily serves national operations and will include regional, national and international scheduled air service. All air vehicles must weigh 55 lbs. TOGW, be certified/ licensed, equipped with self-separation capability, and ability to communicate with the air traffic network. Piloted VFR will be permissible in VMC and MVMC below 2,500ft AGL; whereas, piloted IFR will be required in IMC. Above 2,500ft AGL, piloted VFR requires VMC and piloted IFR will be required in either MVMC or IMC. All manned and unmanned air vehicles require communication with and permission from towered ATC.

***Class A–high-altitude controlled.*** [Above 18,000ft MSL (FL180)] This airspace is designed for high-altitude, commercial IFR operations. All air vehicles must weigh greater than 55 lbs. TOGW, be certified/ licensed, equipped with self-separation capability, and ability to communicate with the air traffic network. Piloted IFR in any weather conditions will be required. Piloted VFR not permitted.

## Required Technologies

There are at least five significant components of this proposed future airspace design that are still immature technology (a) autonomous, self-separation logic, (b) the ability of autonomous air vehicles to survive catastrophic system and/or mechanical failures and self-heal with graceful degradation, (c) complete cyber security of the network, (d) detection and mitigation of intruders, and (e) full deployment of healing, neural networks. The first two immature technologies, self-separation, and self-healing, must be resident on each air vehicle while the remaining three immature technologies would need to be shared between the air vehicles and the overall network.

**Self-separation logic.** Self-separation can be accomplished either actively or passively. Active self-separation has historically required an expensive, heavy, indigenous-to-the-vehicle ability to sense-and-avoid conflicts. Typically, this active sensor has been a sophisticated, air-to-air radar and limited to military aircraft. Ultra-lightweight avionics will be required to truly open the Class G airspace to unrestricted sUAS operations. The avionics size, power, and space requirements for active sense-and-avoid, while a logical vehicle requirement, will still be a significant stretch for 55 lbs. class sUAS and possibly incompatible with significantly lighter sUAS. Substantial progress in miniaturization of active sense-and-avoid systems has been made as evidenced by MIT Lincoln Labs (Duffy, 2014) but the overall capabilities remain embryonic (Carey, 2016; Exelis, 2013). It may be a significant overstatement to assume that shortly, ultra-lightweight air vehicles


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will have active sense-and-avoid capability (Erwin, 2015). With avionics miniaturization, passive sense-and-avoid, such as ADS-B Out/In functionality, is feasible and is required to effect self-separation capability.

The very nature of the hobby, or recreational, less than 55 lbs. sUAS, is ad hoc operations, those operations that are not necessarily planned. For the future airspace to accommodate all manner of ad hoc operations, management of the airspace will likely not be centralized. Given the current, restrained proliferation of sUAS, the sheer volume of unrestrained sUAS operations in the future airspace strongly suggests the need for self-separation, not positive control from a centralized, ground facility.

In the immediate future, self-separation would most likely occur passively and must occur automatically between manually controlled UAVs, those on autonomous flight profiles, and manned aircraft. Minimum, passive self-separation, common-equipage requirements for any vehicle in the airspace of the future could facilitate this capability. This basic safety obligation to keep air vehicles separated points away from centralized, positive-controlled air traffic to a self-separated, distributed air traffic network model. The key point, however, is the air vehicle then must assume self-separation responsibility and possess the technology to affect this responsibility.

The ADS-B Out/In and TCAS functionality introduced previously to safely self-separate two air vehicles are known as a pair-wise, *one-on-one* calculation. In order to separate from more than one air vehicle at a time, the trajectories of the other conflicting vehicles would have to be considered. Trajectory optimization then becomes a computed extension of the pair-wise ADS-B Out/In and TCAS functionality which includes other nearby vehicles; this is known as a *one-on-many* calculation. A layered approach based on time-to-conflict seems logical so that the highest priority conflicts, those that will occur first, are mitigated, then followed by later predicted conflicts. When all air vehicles are equipped with the same decision logic, it should be very reasonable to predict safe, de-conflicted trajectories for more than two, converging air vehicles (Gardi Sabatini, Ramasamy & Kistan, 2014).

In an extreme scenario where many air vehicles are converging on the same point (known as a *many-on-many* calculation), nature provides a potential solution—a swarm (Findler, Narayanan, & Hill, 2006). All air vehicles would be required to either become a member of the swarm or execute a diverging route away from the swarm. A swarm requires both simultaneous speed and trajectory compliance from all participants until a different flight path is selected and the participant leaves the swarm. A significant, self-separation hurdle will be perfecting the autonomous many-on-many optimization logic and then deploying this logic in lightweight avionics.

**Air vehicle self-healing**. The air vehicles themselves, especially those carrying passengers, must possess the ability to heal in a controlled and survivable manner from degradation. Vehicle maladies that must be survivable include minor-to-catastrophic loss from system malfunction, physical loss of an airframe component(s), or an environmentally induced calamity such as ice, electrical energy, volcanic ash, or violent, atmospheric air movements.

As an extreme example, systems failures and airframe component loss as improbable as United Airlines Flight 232 experienced in July 1989 will have to be survivable simply because the air vehicle itself possesses the ability to absorb the damage and recover for a safe landing. In this accident, the DC-10 aircraft catastrophically shed its #2 engine fan disk which severed and completely compromised the three hydraulic systems. All flight controls, high-lift devices, trim surfaces, brakes, and nose-wheel steering were instantly rendered inoperative. The only controls the pilots had were the remaining two engine throttles. This was a billion-to-one probability of occurrence event and deemed unsurvivable. However, due to the heroic efforts of the flight crew, 175 of the 285 occupants survived (Haynes, 1991; NTSB 1990).

Numerous researchers and authors have offered the year 1995 as the approximate tipping point where humans became the largest contributory cause to transport-category aviation accidents (Hilkevitch, 2012; Lowy 2011; Patterson, 2012; Veillette and Decker, 1995; Wood, 2004). Flight Safety Foundation President, Bill Voss, during the April 2012, San Antonia Corporate Aviation Safety Seminar was quoted by Wright (2013), “Five years ago we passed the point where automation was there to back up pilots. Clearly, today, the pilot is there to back up the automation.”

In contrast to how the pilots accomplished saving United Airlines Flight 232 nearly 30 years ago, it is fully appreciated that current air vehicles’ ability to heal in-flight are still at grossly insufficient levels of maturity and reliability to facilitate the envisioned networked future airspace design. Vehicle self-healing maturity and reliability are recognized and respected as steep technological requirements and are actively being researched at Georgia Tech, the University of Michigan, and Stanford (Atkins, 2010; see also Asadi, Sabzehparvar, Atkins & Talebi, 2014; Balchandran & Atkins, 2016; Choi & Atkins, 2009; Donato & Atkins, 2016).

**Cybersecurity**. The network components that must be cyber-secured include all navigation, communication, and safety-of-flight electronic functionality required to facilitate operations in the future airspace design. Neither the network nor the air vehicles can be susceptible to foreign, uninvited intrusion or compromise. The primary cybersecurity concern is the free flow and data integrity of the air vehicle-to-air vehicle automatic communications that must occur to ensure safe self-separation. To facilitate the unimpeded flow of information, all air vehicles would have to have the same omnidirectional/spherical transmission capability. Unimpeded, spherical transmission from air vehicles cannot be accomplished from a single transmission point on the air vehicle, an antenna is required; this challenge is exacerbated by increasing the physical size of the air vehicle.

Any compromise in an air vehicle's ability to transmit, and receive, valid trajectory data from surrounding air vehicles will require the degraded vehicle increase its self-separation distances. A vehicle with a total power loss would be one example of an extreme, worst-case situation since no other vehicle could sense its presence passively. Another extreme, very challenging scenario would be identifying vehicles that are transmitting corrupted data. In either scenario, the affected vehicles would need to remove themselves from the airspace immediately and land at the nearest suitable point. Either scenario could be a vehicle anomaly, or induced by external malicious intent such as jamming.

The technology to simultaneously and continuously guard or shield against cyber threats across a diverse terrestrial, airborne and spaceborne network is a monumental undertaking. While components of this cyber-secure network exist today, the current reliability of that protection would likely be judged as insufficient for the widespread, autonomous air traffic network application envisioned.

**Intruder detection/mitigation**. Intruders are, at the minimum, disruptions to the normal flow of air traffic. Determination of an intruder is a binary problem, either the air vehicle is an intruder or not. Determination of whether or not the intruder is also a threat is much more complicated, but in the end is also a binary decision. In order to handle disruptions, both the logic deployed on every participating air vehicle and the logic resident in whichever distributed ATC facilities remain will have to be able to (a) efficiently remove the threat of non-participants (b) remove participants whose integrity of network connectivity falls below levels that permit predictable and safe, self-separation behaviors, and (c) assist in the response to flow disruptions. These are complicated scenarios that must be reduced to acceptable, binary outcomes.

In addition to either air vehicle-induced or weather-induced flow disruptions, an air vehicle which is a non-network participant also challenges the safe and efficient operation of the air traffic system. Given all air vehicles in this future airspace design operating in Class A, B, C, D, E, and F and G airspace, when operating IFR, are required to be active net participants, intruders must be detectable by their absence of participation on the net. Active, most likely ground-based sensors need to be strategically positioned to be a final protection against threats in high-density traffic areas or around national assets. In these locations, an intruder's location can be determined and communicated to the air traffic network instantaneously. When active sensors have the reliable ability to detect bird-sized sUAS, network participation could be corroborated with the sensor-provided location. Correspondingly, a detected air vehicle which lacks network participation data will connote non-participation and be classified as an intruder.

For any net participant without active sensors to avoid non-network air vehicles, an off-board sensor to detect the non-network air vehicles and provide that information back to the air traffic network will be required. In the past and present, the air traffic industry has relied on ground-based radar to perform this function; however, it must be appreciated that ground-based active sensors are expensive and infrastructure-intense. When outside of active sensor ranges, it will be a significant challenge, if even possible, to locate intruders and more significantly, to confirm the intent of intruders—these are issues without easy answers but nonetheless necessary to be solved for network integrity.

Non-air-traffic-network participants in any airspace outside of active sensor range (hence undetected) are, at the minimum, problematic—and without resolution could be disastrous to the viability of this future, air traffic network concept. Exotic technologies such as gravity gradiometers, multi-static radar, and satellite-based atmospheric wake/emissions/thermal detection may be necessary to overcome this obstacle. For consideration, one brute-force, calloused technology and policy approach could be, once the ability to eliminate intruders upon detection is possessed, advertise that ability and reason that any intruder bold enough to challenge that ability must be of ill-intent and justifiably eliminated. This approach has significant societal and global ethical implications that would have to have universal agreement to enact.

**Neural network**. An additional and necessary component of each air vehicle being a participant in the air traffic network is sufficient communications bandwidth. Beyond what is required for the communication of precise position and trajectory, all air vehicles' bandwidth must also support the simultaneous requirement to be a consumer and pass-through for three data streams (a) weather reports, observations, advisories, and predictions; b) current, emergent and expected regulatory flight restrictions such as Flight Data Center (FDC) Notices to Airmen (NOTAMS) or Temporary Flight Restrictions (TFRs); and c) safety-of-flight advisories such as security/navigation or emergency actions. Each participant must use, to their individual-air-vehicle-advantage, the information they are also passing through to the network. When summed, the participants are acting like nerves in a network; they have a position, they sense, and then pass information—these are the fundamental elements of a *neural network*.

Neural networks function like our brain's network. "Neural networks have the ability to adapt to changing input, so the network produces the best possible result without the need to redesign the output criteria." (Investopedia, 2017). This is an important characteristic that allows neural networks to grow, shrink or heal while not compromising their purpose; in the future airspace application, the output criteria is the free flow of the air vehicle's precise position, trajectory and the three data streams noted above.

The significant advantage of a neural network approach to data flows is, the more participants in each volume (i.e., the closer they are spaced), the more actively and easily information will flow about the network. Adding participants strengthens the network, and deleting a participant will not negatively impact the network integrity unless there are no other communications routes within the compatible range of the transmitting air vehicle. In the absence of a participant, and if the remaining participant spacing supports these now longer transmission ranges, the network can heal. Where participant spacing is too large to facilitate atmospheric transmission, a backup mode must exist for the transmission of these message streams. Each message stream could be pushed to an overhead satellite network and redistributed. This back-up, the overhead-communications mode would be necessary for lightly trafficked areas.

The information passed on this network should complement and could influence the computed, air vehicle trajectory for any participant. Any of the data passed over the network may be treated as an obstruction when appropriate to do so; for example, air traffic flows will be automatically able to ebb and adjust to severe weather/flight restrictions passed over the network. If functioning as discussed in the preceding paragraphs, the future air traffic network will be a large, living, neural network.

Assuming cybersecurity, self-healing technology for both the air vehicles and the air traffic neural network, self-separation, and intruder detection are technologically mature, this future airspace design's impacts to safety and security are significant. The human-induced variability in either the piloting of the air vehicles or in the control of the air vehicles currently exercised by ATC would default to the vehicles' inherent ability to self-separate and organize into homogeneous flows, no matter whether the air vehicles and the network were in a fully-operational or degraded, self-healing state. Theoretically, if these conditions can be met, the error caused by human variability could be significantly reduced and possibly eliminated.

## System Transition

The significant challenge facing transition is the co-mingling of manned and unmanned air traffic. A system comprised of one or the other type of air traffic would be much simpler to operate. In the long run, this paper is postulating aviation will very likely transition to a completely automated structure. It is the intervening transition decades which present the significant challenge (Vance & Malik, 2015). Investing in, deploying, and perfecting passive, self-separation technology facilitates an initial integration between unmanned and manned air vehicles with the previously suggested caveat that manned aircraft retain maneuver priority over UAVs. Segregation is another approach to integration where blocks of airspace are sectioned/cordoned for only one type of air vehicle; however, wide-scale segregation does not tackle the much more difficult, long-range view of mixed-use airspace where manned and unmanned air vehicles safely complete their sorties in the same airspace, independent of their flight control mechanism.

An autonomous air traffic future aids transition in providing an internet protocol like foundation on which capacity can be managed with minimal infrastructure impact. Since the network is comprised of a self-governing collection of nodes (air vehicles), nodes can be added to and subtracted from the network at will.

The transition should conservatively occur in layers from the surface up. Class G containing only less than 55 lbs. sUAS could be the first beta test to examine and verify that the airspace within 5 NM around airports with control towers (either Class B, C, or D) remains free of sUAS from the surface to 500 ft. AGL. Class F would follow to ensure that unless they are operating IFR, all UAS remain clear of Class B, C, or D airspace from 500 ft. AGL to 2,500 ft. AGL. For the remainder of class F airspace, all UAS will be required to operate IFR and must be able to avoid all other traffic including private (non-commercial), non-network participants. Finally, advancing then to Class E and A airspace, traffic separation protocols should be easier if the previous integration challenges have been successfully negotiated at the lower airspace levels.

It is anticipated that in the transition period initially there will be an inversely proportional relationship between altitude and the concentration of UAS. Given the future airspace design espoused in this paper restricts sUAS to Class G and less than 500ft AGL, the inversely proportional relationship implies that the threat of manned-UAV conflicts reduces as altitude is gained. This inversely proportional relationship also presumes that the bulk of greater than 55-lb UAS operations will be at lower altitudes in Class F and E airspace. As the functions performed by manned aircraft yield to unmanned, the density of unmanned air traffic will increase, and the spread of UAS across Class F, E and A airspace will likely become more uniform. For those few remaining manned aircraft operating in Class F, E or A airspace, the conflict threat would correspondingly grow more uniform and not be altitude dependent.

**Societal obstacles to transition.** Three principle categories of societal challenges lie ahead and will, if unresolved, inhibit or prevent transition (a) human trust in autonomy, (b) policy reform to accommodate sUAS and UAS, and (c) employment.

***Trust.*** Human trust in autonomy that involves safety-of-life transportation systems will likely be tested on the ground first with autonomous automobiles, and with trains (Folsom, 2011; Kelly, 2012). The lessons learned in these transportation modes about capacity versus demand management, accommodation, usage, and economics should provide a reasonable foundation for translation to air travel for either personal air taxis or more traditional, transport-category aircraft. It would be more logical if air cargo completed this transition first, followed by the autonomous air transport of humans (Patterson, 2012; Vance & Malik, 2015).

***Policy reform***. Regulation, certification, privacy, and liability are all policy areas that will need reform. Aviation regulation and certification to standards are time-tested processes with careful, meticulous, functioning change mechanisms. Aviation regulation and certification to standards are well understood and likely easier obstacles to overcome than either privacy or liability. If Class G airspace operates as suggested, the public will have to absolve their government from liability protection against sUAS damage to their property. This responsibility will transfer completely to the sUAS owner/operator. Responsibility for damage caused by all other manned or UAVs greater than 55 lbs. would be shared by the federal government and the owner/operators based on the proportion of the vehicle's flight which was conducted autonomously. The government should only be liable for the portion which was human controlled by government ATC employees.

Privacy laws would need explicit clarification on what type overflight of any air vehicle would constitute a breach. The current definitions of navigable airspace extending from the surface of the earth may no longer be sufficient when sUAS can precisely maneuver at minimal altitudes (Vance, Newburg, & Patankar, 2014). The current U.S. aviation regulatory structure makes any overflight of the populace at less than 1,000 ft. AGL illegal. The applicable FAR 91.119 Minimum Safe Altitudes would be realistically impossible to enforce with widespread proliferation of sUAS. A loiter, the time-based policy is possible to define privacy; but, while seemingly attractive, with advanced digital photography, infrared, noise, and scent collection/detection, it does not guarantee privacy. To accommodate the sensitive policy issue of privacy, this specific aspect of sUAS operations deserves its regulatory part in the U.S. Code structure.

There are other policy issues that also share a strong technology relationship such as revisionary or backup modes for both air vehicle navigation and communication failures. Revisionary modes for either type of failure will have to be universally adaptable to all net participants.

***Employment***. The last, societal obstacle is the natural resistance to the changing job market. The challenge will be to convince current, as well as, matriculating, professional aviation employees that when one job classification/function sets another must rise. While traditional piloting and air traffic controlling will decrease, the need for aviation automation specialists, system safety monitor/management/cybersecurity specialists, and certification/validation specialists will rise, possibly outpacing the aviation positions which will be lost.

## Conclusion

The rapid proliferation of UAS, particularly sUAS, will have significant operational implications for the ATC system of the future. During the lengthy transition period, which has already started, when unmanned air vehicles will be mixed with conventionally piloted vehicles, integrating unmanned air vehicles safely presents significant technological and sociological challenges. The sheer number of future manned and unmanned air vehicles suggests the current, voice-based ATC system cannot scale to meet demand—another approach to managing air traffic must be considered. The future of air traffic will likely be a fully networked environment where the absence of participation on the network could connote a potential intruder and a threat.

If the satisfactory and complete integration of UAS is to occur, the overarching current U.S. air traffic management philosophy of first-come/first served will need to migrate to on-time/first-served. This transition will require a networked future where all participants have the ability to be recognized, contribute, share and pass information on the network, self-separate from other participants, de-conflict their trajectories with other air vehicles, and re-route and re-organize into alternate trajectories and flows when unforeseen obstacles are present.

To achieve these objectives, a potential airspace design was introduced and explored along with the conceptual air traffic management philosophy of self-separation. In this future, all sUAS traffic would be contained in the lowest atmospheric layer, below 500ft AGL (Class G). Manned, recreational, VFR, single-piston engine, non-networked aircraft would be restricted to the next lowest layer, that above 500ft AGL but below 2,500ft AGL (Class F). Dedicated, commercial (for profit) airspace would start at 2,500ft AGL. All manned and unmanned air vehicles above 2,500ft AGL would need to be recognized nodes on the network. All unmanned operations outside of Class G will be required to be active air traffic network participants and operate under IFR.

The macro purpose of this paper is to entice and encourage professional dialog on future airspace options which would accommodate the blend of conventionally piloted, semi-autonomous and autonomous air vehicle network participants. Acknowledging and discussing the significant, future airspace designs' technological, cybersecurity, societal-trust, policy, liability, and employment implications are responsible steps to better understand the challenges ahead.

## Acronyms and Associated Definitions

| | |
|---|---|
| ADS-B Out/In – | Automatic Dependent Surveillance-Broadcast; 'Out' transmits information to the air traffic network; 'In' receives information from the air traffic network |
| Air vehicle – | Physical flying vehicle, either manned or unmanned |
| AGL – | Above Ground Level |
| ATC – | Air Traffic Control |
| FAR – | Federal Aviation Regulations |
| FDC – | Flight Data Center |
| FL – | Flight Level; 1,000s of feet above mean sea level, predicated on a standard altimeter setting of 29.92 inches mercury |
| ft. – | Feet |
| lbs. – | Pounds weight |
| ICAO – | International Civil Aviation Organization |
| IFR – | Instrument Flight Rules - permits operations in MVMC and IMC |
| IMC – | Instrument Meteorological Conditions (less than 500ft AGL ceilings and less than 3 NM flight visibility) |
| MSL – | Mean Sea Level |
| MVMC – | Marginal Visual Meteorological Conditions (greater than IMC but less than VMC) |
| NAS – | National Airspace System |
| NM – | Nautical mile (6,076 ft.) |
| NOTAMS – | Notices to Airmen |
| Participant – | Air vehicle that is an active node on the future air traffic network |
| SM – | Statue Mile (5,280 ft.) |
| sUAS – | Small Unmanned Aerial Systems, those weighing less than 55 lbs. |
| TCAS – | Terminal Collision Avoidance System (currently, a pair-wise de-confliction) |
| TOGW – | Take-Off Gross Weight |
| UAS – | Unmanned Aerial Systems, those weighing 55 lbs., or more |
| VFR – | Visual Flight Rules - requires VMC |
| VMC – | Visual Meteorological Conditions (greater than 2,500ft AGL ceilings, and greater than 5 NM flight visibility) |
| VTOL – | Vertical Take-Off and Land |

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