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Unmanned Aircraft System traffic management: Concept of operation and system architecture

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ABSTRACT

Within the past few years, civilian demand for small unmanned aircraft systems (sUAS), commonly referred to as drones, has skyrocketed. The passage of the Federal Aviation Administration (FAA) Modernization and Reform Act in 2012 acknowledged this fact, and has since prompted expedited research and development for civilian sUAS. As proposed at a recent National Aeronautics and Space Administration (NASA) Convention, central to the safe and efficient operations of sUAS will be an unmanned aircraft system traffic management (UTM) system. Such a UTM system will borrow fundamental ideas from large-scale air-traffic control, albeit with several key differences that provide for sUAS which vary in method of control, maneuverability, function, range, and operational constraints. Ultimately, an expansion of UTM infrastructure, a decentralization of governing authority over sUAS operations, and the establishment of a web-interface for pilots to submit flight plans and access crucial data will allow for sUAS operations to shift from being a science-fiction gimmick to an element of daily life. The major objectives of this paper are to: (1) define what a UTM system is; (2) review current UTM practice from industry partners; (3) describe how sUAS pilots would use a typical UTM system, and who has authority over UTM; and (4) determine what physical architecture is required in a UTM system which handles a large variety of sUAS.

Abbreviations: AACS, Automated Airspace Computer System; ADS-B, automatic dependent surveillance-broadcast; ASPs, airspace service providers; ATC, air traffic controller; ATM, air traffic management; BVLOS, beyond visual line-of-sight; CA, certificate authority; COA, certificates of waiver or authorization; DAG-TM, distributed air-ground traffic management; DOT, department of transportation; DSRC, dedicated short-range communication; EASA, European Aviation Safety Agency; FAA, Federal Aviation Administration; GPS, global position system; NAS, National Airspace System; NASA, National Aeronautics and Space Administration; NextGen ATM, next generation air traffic management; NTIA, national telecommunications and information administration; NTSB, National Transportation Safety Board; NUSTAR, national UAS standardized testing and rating; PBN, performance-based navigation; PKI, public key infrastructure; RA, registration authority; RTT, research transition team; SAA, sense-and-avoid; sUAS, small unmanned aircraft system; TCAS, traffic alert and collision avoidance system; TCLs, technical capability levels; TSAFE, Tactical Separation Assisted Flight Environment; TSS, terminal sequencing and spacing; UASIS, unmanned aircraft system information security system; UTM, unmanned aircraft system traffic management; VLOS, visual line-of-sight.

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Introduction

Unmanned aircraft systems (UAS) have long been considered for a variety of tasks, including infrastructure monitoring, precision agriculture, package delivery services, search and rescue operations, photography, and more. Previously, UAS were only used for military reconnaissance and later for the U.S. military's controversial drone strike program (Spinetta, 2016). The introduction of small unmanned aircraft systems (sUAS) for civilian purposes has caused quite a stir for lawmakers and federal regulatory agencies, like the Federal Aviation Administration (FAA). Initially, there was a legal gray area for early adopters of civilian drone technology, as rules and regulations regarding the operations of these vehicles were largely nonexistent, especially on federal and state levels. The passage of the FAA Modernization and Reform Act in 2012 identified the need to prioritize drone safety and efficiency as important goals for the near-term future (West, 2015). The act requires the creation of a plan to safely integrate civil UAS into the National Airspace System (NAS) by September 30, 2015.

In 2015, the FAA published a Notice of Proposed Rulemaking (NPRM) to allow routine use of certain small UAS. The final rule, which creates a new "Part 107" in Title 14 of the United States Code of Federal regulations, was published on 28 June 2016 and took effect on 29 August 2016 (Table 1) (Federal Aviation Administration (FAA), 2016). The European Aviation Safety Agency (EASA) also published a Concept of Operations for Drones, which focused on the integration and acceptance of drones into the existing aviation system in a safe and proportionate manner (European Aviation Safety Agency (EASA), 2015a,b,c). Following this, an Introduction of a regulatory framework for the operation of drones was published on 31 July 2015, then opinion of a technical nature was published on 18 December 2015 with 27 concrete proposals for a regulatory framework and risk-control (European Aviation Safety Agency (EASA), 2015a,b,c). In the year of 2016, a "Prototype" Commission Regulation on Unmanned Aircraft Operations was published on August 22. It combined the efforts made last year and presents a formal regulation guide book with respect to the operation of UAS (European Aviation Safety Agency (EASA), 2016). Hopefully a finalized official regulation would be published by the end of 2016.

While these proposed rules are extremely limiting, they are expected to be temporary. An effective unmanned aircraft system traffic management (UTM) system must allow for both manually controlled and autonomous sUAS to be operated BVLOS, even if only in Class-G airspace (uncontrolled airspace typically below 1200 feet above ground level and a safe distance away from tower-controlled airports). Implementing sUAS activities into the NAS (beyond Class G) or into airspace with heavy manned aircraft traffic is beyond the scope of this paper. Interesting reader is encouraged to refer to the book "On Integrating Unmanned Aircraft Systems into the National Airspace Systems", which is written by K. Dalamagkidis (Konstantinos, 2012). This book presents, in a comprehensive way, current unmanned aviation regulation, airworthiness certification, operation rules, etc. This paper will focus more on what kind of UTM system should be expected by a goal of 2019.

The proposed solution for UTM agreed upon by both academia and government agencies includes elements of airspace design, corridors, dynamic geo-fencing, severe weather and wind avoidance, congestion management, terrain avoidance, route planning, re-routing, separation management, sequencing and spacing, and contingency management (NASA UTM, 2015). This solution is essentially a combination of automobile traffic management (rules of the road) and air traffic control. The challenge arises from having many more arrival and departure points than air traffic control systems as sUAS are not limited to a finite number of airports with their own air traffic control towers. The potential for significant congestion in a three-dimensional area of travel also needs to be considered. Therefore, there needs to be a national standard for UTM systems, individual zones where all sUAS operations must be approved on a case-by-case basis.

Table 1
The FAA's proposed operational constraints for sUAS.

Category	Summary of proposed requirements
Operational limitations	• Must weigh less than 55 lbs. (25 kg) • Must operate within visual line-of-sight only • May not operate above any persons not directly involved in the operation • Must only operate during the day, no nighttime operations • Maximum airspeed of 100 mph (161 km/h) • Maximum altitude of 500 feet (152 m) above ground level • Must not operate carelessly or recklessly • Establishment of a micro-manned aircraft system (UAS) category (4.4 lbs. or less) (2.0 kg or less) • Must yield right-of-way to other aircraft, manned or unmanned
Operator certification and responsibilities	• Must either hold a remote pilot airman certificate or under direct supervision of a person who does • Must pass a knowledge test initially and every 24 months • Must be vetted by the Transportation Security Administration (TSA) • Must obtain an unmanned-aircraft operator's certificate with a small UAS rating
Aircraft requirements	• FAA airworthiness certification not required, but operator must conduct a preflight check of the sUAS to ensure safe condition for operation
Model aircraft	• Would not apply to model aircraft that satisfy all of the criteria specified in Section 336 of Public Law 112-95 • Would codify the FAA's enforcement authority by prohibiting model aircraft operators from endangering the safety of the national airspace system

Objective

The motivation behind this paper is to assist with the research and development of sUAS for civilian use. The objectives of this paper are to: (1) define what an unmanned aircraft traffic management (UTM) system is, (2) review current UTM practice from industry partners; (3) explain how pilots would use a typical UTM system and identify who has authority over UTM systems, and (4) determine what physical architecture is required of a UTM system which handles a large variety of sUAS. In addition to these four main objectives, this paper will also address privacy concerns and the evolution from today's sUAS organization to the UTM systems proposed in the following text.

Literature synthesis

From ATM to UTM

The need for an air traffic management (ATM) system in the United States emerged from a mid-air collision of two commercial flights over the Grand Canyon in 1956. All passengers and flight crew died in that catastrophic accident. Prior to that disaster, limited services were provided to manage the capacity and traffic flow in the NAS. Generally speaking, the NAS was in an uncontrolled situation, and pilots relied on see-and-avoid to enable safe operation (Kopardekar et al., 2016).

Since then government agencies, experts from industry and academic field spared no effort on the development of ATM to enable safe and efficient operation of NAS. Initially, the ATM prototype consists of ground-based radar, ATC, etc. All the flights were scheduled to avoid conflicts en route, and most of the work load were taken by the ATC. Therefore, the key to achieve a larger increase in the capacity of airspace is to reduce the workload of ATC. In the 1990s, National Aeronautics and Space Administration (NASA) developed a concept called DAG-TM, which distributes information, decision-making authority, and responsibility among flight crews, the air traffic service provider, and aeronautical operational control organizations (Ballin et al., 2002). After that, researchers from Ames Center put forward the concept of NextGen Air Traffic Control System, which is designed to safely and efficiently scalable to contend with the factor of 2 or more increase in the demand expected by the year 2020 (Erzberger, 2004). Controller-in-the-loop simulations in the Airspace Operations Laboratory at the NASA Ames Research Center in 2010 have shown promising results for air traffic control with respect to automatic separation assurance, weather avoidance and schedule conformance (Prevot et al., 2011). TSS is the recent research outcome which increases the use of PBN arrival procedures during periods of high traffic demand (Robinson et al., 2015).

Upon entering the 21st century, UAS, especially sUAS become common in civilian applications. According to the FAA's registration data on May 12 2016 there were already 469,950 users registered in the US (FAA, 2016). Actually long before the stories of UAS, NASA and FAA recognized the need for a way to safely manage UAS flying at low altitude. NASA is leading the researches of prototype technologies to accommodate a large-scale mix of BVLOS and VLOS operation of UAS and manned operations. In order to achieve the goal, NASA and FAA has established a RTT, where NASA and FAA work jointly to conduct research to identify airspace operations requirements that enable large-scale BVLOS and VLOS operation of UAS. They use build-a-little-test-a-little strategy to ensure UTM RTT approach offers path towards scalability (UTM Convention, 2016). And all the UTM test is under NUSTAR system. On 05 November 2015, NASA published a guideline for air traffic management for low-altitude drones. In NASA's plan, the UTM research was divided into four TCLs, in which the technology, test sites, testing scale gradually become advanced and complex throughout each level (NASA, 2015). In August 2015, TCL1 has been tested successfully with VLOS condition at all six FAA test sites (Northern Plains UAS Test Site, Reno-Stead Airport, Alaska Center for unmanned aircraft systems Integration, Texas A&M University Corpus Christi, Virginia Tech Mid-Atlantic Aviation, and Griffiss International Airport) over unpopulated areas (Kopardekar et al., 2016). TCL2 test has been done at Nevada test site in October 2016 under BVLOS condition over sparsely populated areas, which demonstrate the possible of longer range applications (Lozano, 2016). The UTM TCL3 test is scheduled to be in January 2018, which will leverage level 2 test results and focus on the technologies that maintain safe operation between cooperative and non-cooperative UAS over moderately populated areas (NASA, 2015). The next step of NASA's UTM research would be: (1) exercise with all FAA test sites for expanded/BVLOS operations; (2) build up prototype for flight information management and overall UTM architecture; (3) conduct vehicle research on geo-fence conformance, track and locate, hazard avoidance, etc., (4) towards complex and heterogeneous operations to fulfill air/ground integration (UTM UTM Convention, 2016).

Current UTM practice

As we mentioned above, NASA is leading the research in UTM, while experts from industry and academic fields also work closely with NASA and FAA towards to goal of integration of UAS into NAS. The following part will put effort on evaluating the current UTM practice conducted by partners from industry field.

Case 1: Amazon

Amazon proposed an idea of "Determining Safe Access with a Best-equipped, Best-served Model for sUAS", which classifies the sUAS into categories based on vehicle equipment and technology, often referred to as equipage. In addition, a formula for access to airspace is defined. As there is no one-size-fits-all model for the safe operation of sUAS due to its complexity, it is paramount that all sUAS operators understand where they can and cannot safely operate. Based on this, four classes of safe operations were developed, which are referred to as Basic, Good, Better and Best. The first three class has limited airspace access with VLOS flight over less populated areas during daytime only, accordingly the vehicle equipage is of lower level. The ''Best'' class would allow BVLOS flight over relatively populated areas during either daytime or nighttime (Amazon Prime Air, 2015a,b).

In order to enable safe integration of sUAS, amazon proposed a concept of airspace design and management. Basically, the class G airspace is divided into three classes vertically with a ''predefined low risk location'' laterally. The three vertical classes are: ''low-speed localized traffic'' zone of airspace below 200 feet, ''high-speed transit'' zone of airspace between 200 and 400 feet, and ''no-fly'' zone between 400 and 500 feet. With such a separation, we could envision a set of sky-highways separated by altitude in class G airspace (Fig. 1).

Beyond the airspace separation, amazon also puts forward a concept of one-operator-to-many-vehicle model, which distributes the decision-making authority to operators greatly. This is somewhat similar to the concept of NextGen ATM, which aims at solving the problem of over-load workload of ATC which is the key constraints of today's airspace capacity (Amazon Prime Air, 2015a,b).

Case2: Google

In Google's architecture of UAS Airspace System, the airspace is also partitioned into several classes in accordance with FAA's definition and the UAS is assumed to operate with class G at first stage. All the UAS should be equipped with communication, SAA technology to perform cooperative flight when encounter with other UAS or manned aircraft occasionally. The separation and planning service is provided by ASPs (Fig. 2).

Within this art of work, Google elaborates the identification and security process of the system. Users are broadly divided into two groups, namely existing identity precedent and identity tomorrow (a system of trust on existing precedent with safety through Good Citizenship). First, the airspace participant need to establish a Secure Identity using existing and proven PKI, in which the process involves RA and CA. Then the user secure identity in operation throughout the Airspace Ecosystem, which would make the flight submission process much more efficient and greatly reduce workload from human aspect.

The next step would be to allow the ASPs to be open and collaborative with each other and with ATC. In addition, enable ultra-low cost and low power ADS-B to allow fully cooperative traffic between both UAS and manned aircraft is in the to-do list (Google, Inc, 2015).

Proposed: UTM concept of operation and system architecture

A UTM system consists of its own airspace and manager(s) (NASA UTM, 2015). This is similar to the way in which current Terminal Radar Approach Control (TRACON) zones each consist of designated airspace and air traffic controllers. The following section will discuss who has regulatory authority over UTM systems, what physical infrastructure is conducive to sUAS operations within the airspace, and how pilots will effectively fly sUAS within the airspace.

The overall structure of the UTM system

Concept of operations

The FAA will continue to be the highest authority in regards to UTM systems. The agency will establish policies and regulations involving airspace safety, vehicle registration, vehicle authorization, and pilot licensing. Individual UTM Systems will require one or more managers to oversee day to day operations, to ensure that pilots follow protocols, to communicate with law enforcement and the public, and to ensure that UTM automated services are functioning properly. UTM clients, which are web-based software applications, will allow pilots and managers to access crucial airspace data and to plan and review flight plans. Ground-based radar, GPS, local weather stations, and relevant agencies will provide all flight related information to UTM clients. UTM automated services, referred to as AACS and TSAFE, will plan routes for autonomous

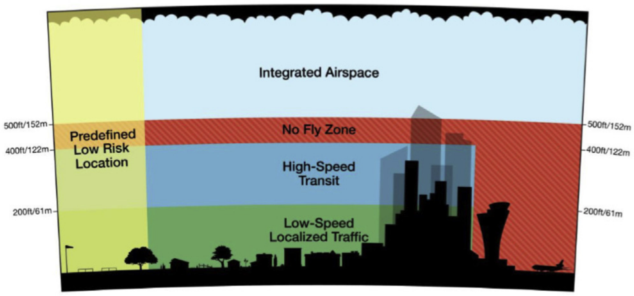


Fig. 1. Airspace design for small drone operations proposed by amazon.

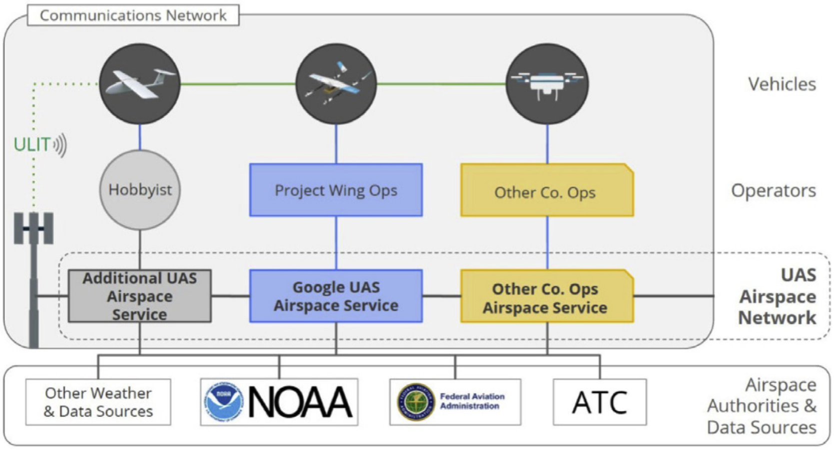
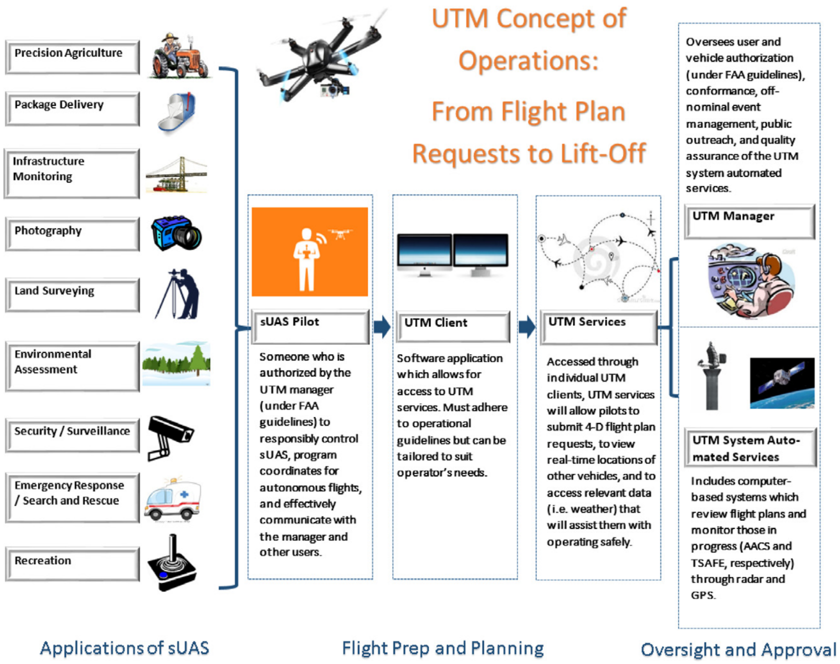


Fig. 2. ASPs connect data and ATC to UAS operations and vehicles over communications.

vehicles and review pilot flight plans. All sUAS will be equipped with sense-and-avoid technology in the event that pilots and automated services fail to avoid danger. One such technology is ADS-B, which is a precise satellite-based surveillance system. The aircraft's location, airspeed and other data would be determined using GPS technology, and broadcasted to a network of ground stations (Kunzi and Hansman, 2011). Another collision avoidance system is TCAS, which is a mandatory system all large transport aircraft (Kuchar and Drumm, 2007). The MIT Lincoln Lab has done research on a comprehensive aircraft encounter model to simulate aircrafts operations in complex situations (Kochenderfer et al., 2008). Besides the safety related technologies for regular operation of sUAS, emergency rescue system is necessary as well. The ability of landing area detection would enable sUAS a safe, non-destructive landing at a desired landing location at abnormal operation condition (Kakillioglu, 2016).

For a normal flight request, the following flowchart explains the process of flight authorization beginning with the demand for using sUAS (Fig. 3).



Oversees user and vehicle authorization (under FAA guidelines), conformance, off-nominal event management, public outreach, and quality assurance of the UTM system automated services.

Someone who is authorized by the UTM manager (under FAA guidelines) to responsibly control sUAS, program coordinates for autonomous flights, and effectively communicate with the manager and other users.

Software application which allows for access to UTM services. Must adhere to operational guidelines but can be tailored to suit operator's needs.

Accessed through individual UTM clients, UTM services will allow pilots to submit 4-D flight plan requests, to view real-time locations of other vehicles, and to access relevant data (i.e. weather) that will assist them with operating safely.

Includes computer-based systems which review flight plans and monitor those in progress (AACS and TSAFE, respectively) through radar and GPS.

Fig. 3. UTM system concept of operations flow chart.

UTM physical architecture

The physical architecture for UTM consists of four classes: sUAS pilots, control centers, vehicles (sUAS), and airspace infrastructure. Within the classes are subsystems, which can be physical entities that support the UTM system or functions related to physical entities of the system. Each subsystem is interconnected by some type of communication system. For UTM systems, there are three methods of communication: wide-area wireless, wireline, and vehicle-to-vehicle. Wide-area wireless consists of wireless internet connections, satellite connections, and cellular connections. Wireline consists of telephone networks, cable television or internet access, and fiber-optic connections. Vehicle-to-vehicle connections could use DSCR technology, GPS, automated services, or a combination of all to synchronize vehicles sharing airspace. The following diagram details the UTM physical architecture (Fig. 4).

The role of the Federal Aviation Administration (FAA)

Rules and regulations for sUAS and UTM systems

The FAA should always remain at the forefront of policymaking for sUAS as to uphold the safety of UTM systems as well as the privacy of those who live below airspace where sUAS operations occur. Like for manned aircraft, the FAA should oversee administrative procedures, such as aircraft model certification, vehicle registration, and pilot training and licensing, and operational procedures. The regulation named "Part 107" mentioned in the introduction was a solid first step in standardizing rules and regulations for sUAS operators. In addition to administrative and general flight policies, there should be minimum technological requirements allowed to operate in UTM system airspace, like basic sense-and-avoid technology. Though state DOTs are not expected to play a huge role in sUAS operations, they may introduce additional standards, policies, or procedures if they so desire. Take the EASA standards as example, there are three categories with different safety requirements, proportionate to risk: "Open" (low), "Specific" (medium) and "Certified" (high) (European Aviation Safety Agency (EASA), 2015a,b,c). Related policies, standards or procedures about sUAS operation with risk level proportional to "Open" category could be managed by state DOTs, e.g., the plants surveillance and pesticide spray of a cranberry farm.

UTM manager certification

Another important job of the FAA will be approving UTM managers (whose roles are mentioned in length below). UTM managers can be municipal employees, state employees, private employees, or even FAA employees, depending on who is funding the UTM system. Regardless, all UTM managers should be approved by the FAA. The FAA may require training and testing for managers to earn certification, much like is the case for air traffic controllers. The agency might also require regular knowledge testing over certain time intervals so that managers are constantly updated with the latest policies, procedures, and technological advancements to be implemented within UTM systems. Ultimately, these are merely recommendations and the FAA will make the final decisions regarding local sUAS oversight.

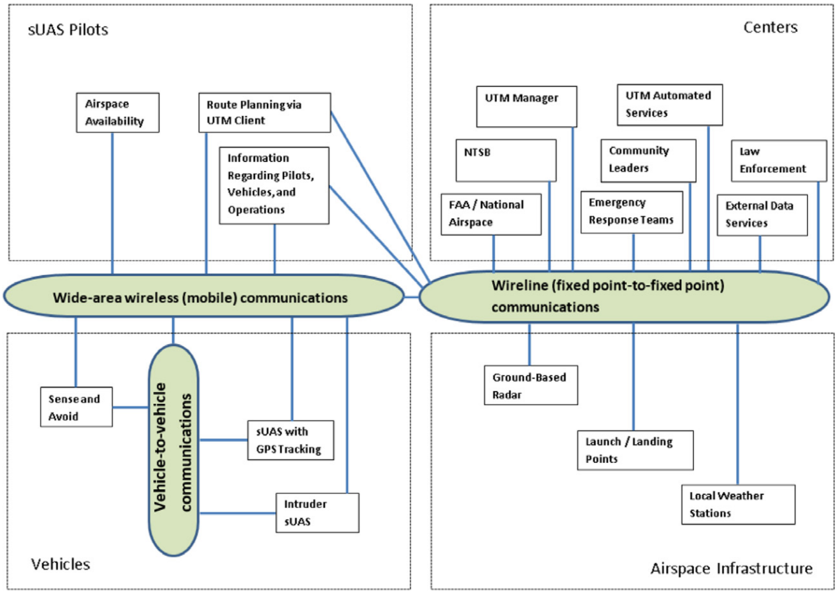


Fig. 4. Unmanned aircraft traffic management (UTM) physical architecture.

Current methods for flight authorization

Currently, certification for operators occurs in one of three ways. These include COA, which allow for specific activities for two years for public entities, Experimental Certificates, which provide for research and development, training, and demonstrations for civil entities, and Section 333 Exemptions (from the FAA Modernization and Reform Act), in which the Secretary of Transportation decides which UAS may operate safely in the NAS prior to the completion of UAS rulemakings. However, this authorization process is extremely limiting, as there are stringent requirements to gain approval, not to mention a large backlog of requests within the FAA waiting to be reviewed.

Future methods for flight authorization

Recently, however, the FAA has rolled back the requirements for authorization. New COA now allow test sites to fly various types of sUAS anywhere up to 200 feet (away from airports and restricted airspace) under daytime Visual Flight Rules. In addition, operators now only need a recreational or sport pilot certificate to conduct test site operations, rather than a private pilot certificate. Also, Section 333 Exemptions can now be processed more quickly since similar exemptions can be used to justify a new request (George, 2015a,b). One recommendation to further streamline the process is for the FAA to still establish authorization policies for operators (i.e. businesses), pilots, and vehicles, but relinquish control of the reviewing of requests to either UTM managers or state DOTs. Managerial authority, though, would most greatly simplify authorization from the operator's perspective and allow for more efficient communications.

Rules and regulations for areas with limited sUAS

The FAA would also need to develop rules for operating outside normal UTM systems. This would be similar to the way in which commercial aircraft operate in areas without radar, such as oceanic airspace. For example, it would not be economically feasible to set up UTM systems complete with a manager and physical infrastructure in very scarcely populated areas. For example, alongside highway area for transportation emergency investigation or logistics. Instead, large rural areas could have a different, less-advanced UTM system suitable for user needs. A possible solution is to have one UTM manager, appointed by the FAA, cover several rural counties. The FAA could then establish lenient guidelines, such as blanket authorization for a certain model of sUAS, an operator. There would be no need for route planning as each sUAS would be expected to remain in the airspace above the property which the operator owns. If, for some reason, a sUAS intrudes on another property, sense-and-avoid technology equipped could help prevent a collision.

Other topics the FAA should investigate

Further down the line, the FAA would also need to establish a way to safely separate manned and unmanned vehicles before sUAS are successfully integrated into the NAS. According to the "Part 107" for sUAS proposed by the FAA, sUAS pilots must gain permission to fly outside Class-G airspace from an air traffic control center (and are banned from Class-A airspace altogether). The FAA needs to develop a better way to organize sUAS in the presence of manned aircraft. However, such an organization is beyond the scope of this paper, and it would be encouraged for academia or government to investigate this issue.

The role of the National Aeronautics and Space Administration (NASA)

Initiator and carrier

The research of UTM was initiated by NASA, and still the bulk of the UTM work is being carried out by NASA. Specifically, NASA's Ames Research Center with its extensive experience in autonomous flight control system and air traffic management, is leading the UTM research in close collaboration with several other NASA's research centers, namely Armstrong Flight Research Center, Glenn Research Center and Langley Research Center. NASA will continue to be the main carrier of research with respect to various aspects of UTM to safely enabling large scale of UAS into NAS.

The role of the National Transportation Safety Board (NTSB)

A new division that deals with sUAS

The NTSB should establish a new division to research sUAS safety and to investigate sUAS crashes, as which exists for large commercial airliners. Each sUAS should be equipped with a miniature black box as to record speed, altitude, etc. before the event of a crash to determine whether the error was made by the pilot, or whether there was engine failure or a technological error. Findings which support systematic failure, such as too liberal spacing requirements or a defect with a vehicle model, could prompt new policies by the FAA or large scale vehicle recall campaigns.

The role of the UTM manager

Vehicle and pilot authorization

One primary responsibility of the UTM manager will be vehicle and pilot authorizations, which include certification and registration for vehicles and permission for licensed pilots to operate, for a particular UTM system airspace. This, however, is if the FAA does decide to relinquish the actual authorization authority to individual managers. As stated before, the FAA would still decide the criteria for authorizations. Managerial authority to decide authorizations would make the process more efficient. A decentralized authorization process would also make it easier to ensure that only responsible pilots with the right credentials, as well as reliable vehicles with the correct level of technology, can operate in the airspace.

Flight plan review and approval

In basic UTM systems, the UTM manager will need to review flight proposals put forth by pilots and approve, reject, or amend them. The FAA or NTSB should select the safety criteria (i.e. spacing and headway requirements) for which the UTM manager should consider when either approving or rejecting flight plans. In a basic system, the UTM manager should also establish the time frame for flight proposals. For example, he or she could require all plans to be submitted by 2 p.m. the day before a flight is planned. This will depend on the resources available to the manager as well as his/her hours. The manager should rarely attempt to reject plans unless the UTM system airspace has already reached capacity based on other proposals. If possible, the manager should be able to suggest to pilots alternate times or routes for flights. However, if a UTM system employs AACS and TSAFE (UTM automated services) as in more advanced systems, this function of the manager would not be necessary.

Communication and public outreach

Of course, there needs to be some kind of interaction between the UTM system and law enforcement, emergency response teams, and the general public. This is another area where the UTM manager or some other UTM system employee will come into play. If law enforcement receives complaints of sUAS flying too low or invading someone's privacy, these reports must be forwarded to the UTM manager. The manager can then conduct an investigation to determine whether or not a pilot intentionally disobeyed flight plans. If that is the case, the manager can enforce suspensions and/or inform law enforcement of wrongdoing and allow them to determine legal charges and fines. However, if available, the UTM automated services should be advanced enough to report sUAS vehicles that have deviated from flight plans immediately. The UTM manager should be able to send a warning to the operator before he/she is subject to punishment.

Privacy concerns

Other times, citizens or businesses might complain of noise or sight pollution because of sUAS, even if they are adhering to original approved flight plans. If that is the case, the manager might see the need to prevent vehicles from operating in certain areas, like cemeteries, golf courses, or other areas which require privacy. The manager could indicate a no-fly zone on the UTM client's map interface to inform operators that any flight plans proposed in that airspace will automatically be cancelled. The manager could also geo-fence an area, which provides that virtual fencing would not allow autonomous vehicles to fly in those areas, and that pilots would be sent notifications or warnings upon approach. To assist pilots with avoiding so-called privacy zones, the manager could establish corridors to funnel traffic around sensitive areas. Traffic through these corridors would be subject to FAA defined spacing and headway requirements. To the latest update, on 24 February 2016, the NTIA held a meeting with multi-stakeholders with respect to craft a best practice of privacy and transparency for both private and commercial use of UAS (Federal Register, 2016).

Security concerns

Aside from physical privacy stated above, the UTM system also incorporates an UASIS, due to the nature that sUAS rely heavily on its on-board autopilot to function. The sUAS is vulnerable to several kinds of attacks as indicated by FAA and the

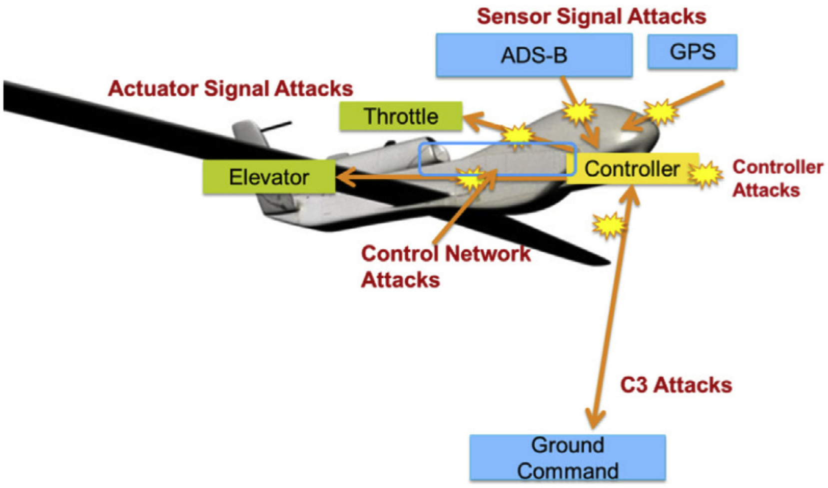


Fig. 5. Diverse attack vectors.

potential consequences would be catastrophic if not handled properly (Fig. 5) (George, 2015a,b). In order to develop a cyber-secure autopilot architecture, researchers from AIAA conducted a thorough analysis of general cyber-attacks and the post-attack behavior of the autopilot system through simulation (Kim et al., 2012).

Emergencies and prioritizations

Lastly, if emergency response teams rely on sUAS vehicles for search and rescue or medical supply delivery to accident sites, the manager should have the ability to assist with the safe navigation of such vehicles by grounding non-essential vehicles along the path which the emergency response vehicle needs to traverse. Like on surface transportation, emergency vehicles should always be given the right-of-way. In addition, the manager can, based on reasonable consideration, prioritize some operations over others. For example, sUAS used to investigate brush fires should be approved over package delivery sUAS if routes are planned in the same area. Other decisions that the UTM manager must make not specifically mentioned in his or her responsibilities will be given to his or her discretion. This could include special immediate authorizations for multiple sUAS from different news agencies to cover a breaking news story. Of course, many other scenarios will emerge in which the manager must use his or her better judgement, which will be typical of the job.

UTM client and UTM services: proposing flights plans and receiving relevant information

What is a UTM manager?

A UTM client is a web-based software application which allows pilots to access UTM services (NASA UTM, 2015). Such an application could be accessed via computer, tablet, or smartphone, so that pilots can access UTM services from the field or from an office setting. Third parties should be allowed to develop personalized UTM clients, however; they must be able to communicate with the UTM services via some widespread standard so that all pilots have access to accurate and reliable data. Hobbyists, independent pilots, and small businesses would probably have access to some basic UTM client, developed by a third-party for widespread use.

Flight planning

To begin with, pilots must plan routes through the UTM client's map interface. There will be several ways of doing this. For pilots who will be manually controlling a vehicle (either within visual line-of-sight or not), they have the options (1) to reserve a 3-D airspace for operations with unpredictable flight plans which are based on instantaneous necessity, (2) to propose a rough geo-fenced path with some buffer space for deviation, or (3) request available flight paths from the UTM automated services based on providing an origin and destination. For pilots setting up plans for autonomous vehicles, they must allow the UTM automated services to provide and amend the flight path (if necessary) for autonomous sUAS.

Automated computer systems to review flight plans in advanced UTM systems

Depending on the level of technology which exists when the rudimentary UTM systems debut, either the manager will have to sift through all flight plans, or the UTM system automated services will organize and plan routes using advanced software. As sUAS traffic increases, the automated services would be a necessity as to not overburden the manager. Useful technology like AACS and TSAFE, borrowed from next-generation air traffic control, could make the airspace nearly foolproof (7). AACS, as applied to UAS, would consider all of the pre-confirmed routes and plan new trajectories that both satisfy the needs of the operator and established safe clearance between other sUAS. This plan would be communicated to the pilot via the UTM client, and the pilot would have the option to roughly plan an alternative route and have the system amend it based on its safety algorithms. TSAFE, as applied to UAS, would double-check routes proposed by AACS as well as monitor operations in progress, especially manually controlled ones, to ensure that pilots are following protocol. Most recently, Mosaic ATM has performed a two-year NASA project to development a mission safety assessment and contingency tool called Aviate. The Aviate system provide a set of tools and algorithms for checking the safety of UAS flight paths and for finding and safety checking contingency routes to local landing locations. Now the Mosaic ATM has completed two releases of functionality under the NASA project (DiFelici and Wargo, 2016). As a triple failsafe, the manager would also have the ability to monitor the performance of these systems as well as all sUAS vehicles in the air.

The design and organization of UTM clients

All third-party UTM clients or a generic one should include a map of the UTM system airspace as the primary view upon first logging into the UTM client. There should be multiple options to plan routes using one of the ways mentioned previously. In addition to route planning, the map interface would be used to inform pilots of other sUAS close to their own operation, to show pilots the location of intruders, to show pilots the location of their own sUAS, and for automated services or the manager to give instructions in the event of an emergency for a contingency procedure. In addition, the map interface will be surrounded by panes which provide relevant data provided by external sources, which are mentioned in detail in the next section titled "External Data Services." As long as these guidelines are followed, third-parties can further customize UTM clients as they please.

External data services

External data services provide pilots, the manager, and automated services with the necessary information to assist with approving flight plans. Some helpful information includes, but is not limited to, weather and wind data, topographic maps, structure data, intruders and obstacles, and vehicle and user information. The table below includes a summary of all data that should be provided by outside sources to pilots, managers, and automated computer systems to assist with operations (Table 2) (NASA UTM, 2015).

Weather data

Weather and wind information is hugely important for sUAS because heavy rain or hail could cause vehicles to malfunction, and wind could knock a vehicle off of its planned trajectory. Local weather stations should constantly be updating the UTM system. The manager and pilots should be able to easily locate weather notifications and warnings via their UTM clients. AACS and TSAFE, which provide the algorithms which plan flight paths for autonomous vehicles, should be able to change trajectories to account for the effect of wind and cancel flights if the weather or wind is too severe. Vehicle manufacturers should provide the limits for which vehicles can operate in, with a margin of safety. If automated services or the manager realize that current conditions exceed manufacturer specifications, the flight should be cancelled or delayed.

Topography, man-made structure, and vertical obstructions

Pilots and autonomous vehicle systems need to know the exact locations of buildings, power lines, trees, etc. and the topography of the area of operation. The UTM client should include 3-D models of the landscape and cityscape within the UTM system airspace. For computer-controlled systems, there should be a minimum height allowed at as many geographic coordinates as possible. For a wooded area where the highest tree is 40 feet, for example, the computer system should not allow autonomous vehicles with a predetermined origin and destination to fly below 70 feet to provide a margin of error. The 3-D maps would ultimately assist the manager or automated services with approving flight plans or generating safe plans for autonomous vehicles.

Intruder aircraft

Ground-based radar, surveillance cameras, and other equipment will help send intruder and obstacle data to the manager and pilots via the UTM client. If a rogue UAS (i.e. not registered or not authorized for a flight) is using UTM airspace, for example, the UTM client will display a warning message to operators, and computer-generated flight plans will be altered based on the projected trajectory of the rogue UAS. A similar process could be used for unexpected helicopters or other low-flying aircraft. Based on this information, the manager can decide if vehicles are safe to operate despite an intruding aircraft or if all pilots need to conduct emergency landings.

Vehicle and user information

Vehicle and user information should also be available via the UTM client. Some UTM system managers may require pilots to waive their right to privacy in the name of safety. This would help if one pilot noticed inappropriate or concerning behavior exhibited by another vehicle or pilot. The pilot who observes this should be able to access vehicle and pilot information on the UTM client's flight map to access the other pilot's name, vehicle, employer, and contact information. Then, he or she could report inappropriate behavior to the manager to be reviewed, or issue friendly reminders to the other pilot about violations or vehicle issues.

System evolution

This section will discuss how individuals will request permission to establish a UTM system from the FAA. In addition, some intermediary steps are examined to bridge the gap between today's sUAS test sites and the advanced UTM systems

Table 2
Examples of data provided to UTM clients by other sources.

Data provided	Source
Airspace data	FAA, department of defense (DoD)
Notices to airmen (NOTAMs)	FAA
Vertical obstruction data	FAA, private
Terrain maps	U.S. geological survey (USGS), private
Weather conditions and forecasts	National oceanic and atmospheric administration (NOAA), private
Detailed models of urban and suburban structures	Private
Flight plan and surveillance data	FAA, state and local governments, private
Community information	State and local governments
Hobbyist data	Academy of model aeronautics

Listed below is a summary of the more crucial data provided by outside sources to pilots, automated computer systems, and UTM managers.

described above. This will help UTM systems evolve from merely test sites to fully functioning airspaces conducive to economic prosperity, increased public safety, and privacy.

Establishing a UTM system

Municipalities (either on their own accord or as requested by private businesses) should be able to send a request to the FAA to set up a UTM system in their airspace. Depending on the range UAS vehicles will have or the most frequently traveled routes, UTM systems should be able to have boundaries separate from those of state/county/city borders. The FAA then must approve of an airspace design, and the municipalities which requested approval should then seek one or more UTM managers, based on the predicted traffic of the UAS airspace. The FAA should then decide whether each candidate proposed for UTM manager meets the correct qualifications to ensure responsible, reliable, and equitable control of the UTM airspace.

Early UTM systems in rural areas

The earliest UTM systems are expected to be able to only support visual line-of-sight operations with only people or property related to the sUAS operation on the ground directly below. In addition, operations should be separated from manned aircraft and each sUAS should have geo-fencing around its personal airspace. This system would follow the rules set forth in the FAA NPRM, which is expected to be approved by June of 2016. Since these systems would be in rural areas, they would be especially conducive to precision agriculture. Many farmers could use sUAS to inspect crops for damage, precisely apply water or chemicals to specific locations in need, and to monitor farmland for potential hazards. In the long run, this could save farmers water, especially in dry regions like the Imperial Valley, and money, on aircraft images and chemicals.

New methods of testing

Before achieving the level of architecture described in detail earlier on, sufficient testing must occur to determine the reliability and effectiveness of technologies like UTM clients, Automated Airspace Computer System (AACS), and Tactical Separation Assisted Flight Environment (TSAFE). Again, AACS, as applied to sUAS, would consider all of the already conformed routes and plan a new trajectory that both satisfies the need of the pilot and established safe clearance between other sUAS. TSAFE would double-check routes proposed by AACS and monitor options in progress, especially manually controlled ones, to ensure that pilots are following protocols. This technology could either be tested at actual test sites or in the rural UTM systems under close monitoring by the UTM system manager and its programmers. Once the technology is proven, UTM systems could expand into suburban and later urban areas.

Illustrative example: cranberry bog farming

Rural areas could be used to test the effectiveness of advanced UTM systems designed for more developed areas, with special FAA permission. Though such systems would not be necessary, they would provide for safe trials of technologies like UTM clients, geo-fencing, and automated services. One area where this could be tested is Southeastern Massachusetts, which includes many cranberry bogs whose owners have been itching to use sUAS. sUAS would make it much easier for bog farmers to investigate the bogs and to spray herbicides and pesticides in difficult to reach areas. As demand for sUAS testing increases for other applications in the area, there will be a need to establish an actual UTM system to organize all of the vehicles. All sUAS wannabe users could propose that local governments request an experimental UTM system from the FAA.

If the UTM system airspace is approved and a manager appointed by the FAA, the owner of the bog could contact the UTM manager to request "restricted airspace" above the bog. Say the maximum altitude which a UAS would need to climb to is 200 feet for surveillance and spraying. The manager and the UTM automated services would not allow other pilots to plan future routes within that airspace. Geo-fencing would notify hobbyists and pilots, who are planning routes or who deviate slightly from their planned route, of the reserved airspace. This could be indicated on the UTM client (the medium for which to plan routes using a map interface) by a dashed-red area. The manager would then need to decide whether this airspace is permanently reserved for the bog farmer or if the farmer must reserve the airspace using a UTM client in advance each time.

Since owning sUAS might be expensive for farmers, contractors could be used to perform UAS duties for a fee. This would help bog farmers avoid a steep down payment and share the cost with other farmers. Before a UTM system exists in an area, the contractor (if authorized with an Experimental Certificate) could haul portable radar on the bed of a truck to check for intruders in the airspace surrounding the operation. This would enable the radar system to be moved to each bog whose owner hires the contractor for spraying and surveillance services. Once a UTM system is in place, there would be no need to haul around radar, as each vehicle in the system would be tracked with permanent radar or GPS, and the contractor could reserve the airspace above each bog through the UTM manager, as mentioned in detail before. This UTM system trial would ultimately help to test the effectiveness and safety of UTM systems before allowing operations in more populated areas.

Summary and conclusions

Once the technology required to establish safe and efficient UTM systems is proven at the six test sites which already exist or others, UTM systems could expand from rural areas to developed ones. At least a suburban UTM system is expected to be operating within the next five years (2019–2020). Beyond that, UTM systems will become more complex since vehicle capabilities and avoidance technologies will undoubtedly improve. In addition, unmanned vehicles will eventually share the same airspace with manned vehicles, as the FAA seeks an integration approach as opposed to a separation one.

For the target urban UTM system in which sUAS do not share airspace with manned aircraft, the FAA will be the highest authority in regards to rules and regulations, authorization and licensing procedures, and operational guidelines. If the FAA so desires, it could allow UTM managers, the authorities over individual UTM systems, to impose further limits or to oversee pilot licensing and vehicle inspections/authorizations. State DOTs could share some roles with the FAA as well; however, their expected role will be to funnel federal or state grants into establishing the necessary infrastructure for UTM systems, system maintenance, or upgrading.

In terms of planning flights within a UTM system, pilots will use a UTM client, a software program which allows him or her to access crucial UTM services. A pilot will have several options for flight planning: he or she can reserve a 3-D area with virtual boundaries, outline a 3-D trajectory, or have UTM automated services plan or control (for autonomous vehicles) the trajectory. Pilots will also be able to access airspace availability data as well as information from outside sources, including weather and geospatial constraints, through the UTM client. The UTM automated services, borrowed from next-gen air traffic control, include AACS and TSAFE. AACS will consider ongoing sUAS operations and those that have already been planned, as well as weather and obstacle data, to generate trajectories for autonomous vehicles or recommend routes for pilots operating in crowded airspace. TSAFE will monitor all routes proposed by AACS for conformance and safety both before and during flights.

GPS and ground-based radar will assist the automated computer systems with organizing and monitoring the airspace. For contingency purposes, each vehicle will be equipped with sense-and-avoid technology in the event that automated services fail to reorganize autonomous vehicles in a safe manner or if manually controlled vehicles pose a threat to others by deviating from original flight plans. This architecture and concept of operations for unmanned aircraft traffic management should be a realistic aspiration to reach within the five years, and will greatly contribute to economic growth, all while providing safety and privacy for those not involved with operations.

Future research areas

There are many areas of sUAS traffic management in which further research would be greatly beneficial in helping to advance sUAS for public and civil purposes. Firstly, there needs to be a better understanding of how the current test sites could evolve into full-fledged UTM systems. Currently the NASA just conducted first BVLOS drone tests on 19 October 2016 in Nevada What would the next stage be for tests in populated areas? Second, what are the safe separation requirements between two vehicles, and how well is clear to maintain safety and efficiency as well? Next, there is the issue of integrating sUAS into the NAS with manned aircraft. Then, there is all the technology required for such a UTM system to function. How would AACS and TSAFE actually work (or similar automated systems)? Lastly, there is public policy research that needs to be done. Currently, laws governing sUAS can vary by town, making it difficult to fly any type of unmanned vehicle (Ison et al., 2014). What can be done to ease regulations all while upholding safety and privacy? As shown, much work still needs to be done before sUAS become viable.

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