Enabling Safe Operations of Unmanned Aircraft Systems in an Urban Environment: A Preliminary Study

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Abstract
There is an increasing demand for Unmanned Aerial Vehicles (UAVs) to be used for commercial purposes. This paper is a primary study on what needs to be done in an urban scenario to enable safe and secure operations of Unmanned Aircraft System (UAS). With regard to the potential research areas on UAS in metropolitan area, the paper discusses proposals to manage dynamic airspace and to develop operational concepts and technologies such as possibilities of UAS tunnels and Geo-fencing methodology for safe operations. The idea of establishing traffic management stations for UAS operations is also discussed in this paper. The paper also presents the simulation of three different concepts of UAS operations demonstrated in an indoor flying facility. These three concepts are: ‘Detect and Avoid’ between flying UAS, Geo-fencing methodology for security purposes and UAS Take over control by UAS Traffic Controller (UTC) sitting in a UAS traffic management station, when the UAS tries to intrude into flight restricted zone. The user interface developed for this demonstration by the team portrays the movement of UAVs in a virtual tunnel/lanes.

1. Introduction
In recent years the interest in Unmanned Aircraft Systems (UAS) has increased among commercial entities and recreational flyers. Potential areas of applications have been expanding rapidly as well. Hence there is a need to ensure safety for people, properties and also to other airspace users like manned aircraft and helicopters during UAS operations.

1.1 Rapid Development of UAS Operations
Across the world, the interest in UAV (Unmanned Aerial Vehicle) is growing. Various countries have taken efforts to integrate UAS commercial operations safely and routinely into civil airspace (ICAO, 2015), (RPAS CASA, 2015). At present, for safety reasons, the restrictive authorization program limits UAS operations by restricting their access or confining them to a special-use airspace.

The most important challenge faced today is the safe integration of UAS operations in an airspace shared with other manned aircraft. At present, UAVs are used for many purposes such as survey operations, agriculture, search and rescue missions, security activities, etc. However in many countries, there are also restrictions that limit the use of small UAVs and confine its flight to below 500 ft. above ground level. (Flying of unmanned aircraft Australia, 2015), (France UAV Regulation, 2015), (Civil Aviation Authority UK, 2015), (Federal Aviation Administration, 2014). The purpose of this paper is to identify challenges for safe UAS operations in “Urban environment” for commercial purposes and possible methodologies and technologies that could be adapted to enhance the safety and reliability of the system.

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This paper is meant to initiate exchange of views and explore various research and development areas which enable safe and reliable operation of UAS in low-altitude urban airspace. Interested readers are encouraged to give feedback on the perspective of this paper.
1.2 The Need for Establishing UAS Operations in Urban Environment
The global movement to expand the regulatory parameters for UAVs is playing an influential role in the future regulations of unmanned systems in ‘Urban’ airspace and environment. Without a proper regulatory framework, UAV operations in urban areas could become extremely chaotic. The proposed concepts in this paper do not affect present civilian and military operations. The height limit for UAV operations in urban airspace has to be evaluated with the available technology enablers, categories of UAVs and its purpose of application.

One of the concepts for safe UAV operation in urban areas is the establishment of UAV lanes/tunnels or routes which are similar to the safe helicopter routes in an urban airspace. However, more studies have to be done to understand the safe separation of UAVs within the specified route. NASA has already done studies on dynamic airspace management for both midterm and long-term airspace configuration concepts (Parimal et.al. 2007). The paper describes that one of the primary areas to focus on is long-term airspace configuration. NASA also went on to discuss the ‘super density and Metroplex operations airspace’ where the need for structured routes was emphasized for an urban landscape.

In order to support the safety and security requirements the introduction of Geo-fencing is possible for commercial UAV usage in urban airspace. The “Geo-fencing” technology prevents UAVs from flying into the safety perimeter of an aerodrome, military installations or other restricted areas such as the government buildings etc. If a UAV tries to enter these areas, it will be forced to land or to turn around.

1.3 Essential Technologies for Safe UAS Operation
The technologies that ensure the safety of UAV flight and their performance are rapidly developing. The safety and reliability of the control and data link between the pilot on the ground and the UAV are of paramount importance, since it will be some time before UAVs will become fully autonomous machines. (Gambold, 2011)

Also, the security and reliability of the communication channels are essential for any integration of UAVs into non-segregated and segregated airspace as well as to convince the insurers, regulators, and the general public that UAV operations are safe (Hesselink and Schmitt 2011). Collision avoidance systems are another technological area to focus on. The development of robust and sophisticated sensors and avoidance systems has been a key focus for the civil UAV sector. There are a large number of companies involved, particularly in Europe and the US, in developing all these technologies required for the safe operation of commercial UAVs. They will need to obtain appropriate certifications and meet the same level of airworthiness as manned aircraft in order to fly in non-segregated airspace.

The major areas of focus in this paper are, firstly, identifying various applications of UAS in urban environment. Secondly, presenting the development of various concepts for safe UAS operation in urban areas. Knowing the airspace will aid in the development of previously mentioned concepts of operation. Thirdly, discusses about the indoor simulation done on the basic concept of operations.

2. Applications of UAS in an Urban Environment
Observing that commercial UAV industry is gaining a supportive image globally, urban areas has increased its attention in this area. However, it is difficult to quantify the present usage of UAV in urban areas. To fortify public and political acceptance of commercial UAV applications, it is vital that the UAV industry in urban
areas underpin communication on its advantages and its social contribution for sustainable socioeconomic development.

2.1 Possible Application Examples for UAVs
A few application scenarios for UAVs, including both governmental and private applications in urban environment are described below.

- Environmental monitoring – UAVs with sensors on board could be used to measure atmospheric parameters. The National Environment Agency in Singapore is assessing proposals to use UAVs to conduct more efficient searches for environmental issues on the island (Government agencies turn to drones, 2015).
- Emergency services – to search and locate, or firefighting are some of the areas where UAVs can be deployed for action.
- Surveillance – security surveillance near the borders, police patrolling over certain areas are other important activities where UAVs could be used.
- Aerial mapping – infrastructure inspection (traffic monitoring by Transport Authority, port inspection, oil & gas sector inspection, etc.) is a potential area where UAVs can play a major role in evaluating the setup.
- Delivery of goods – in future there are possibilities of UAVs delivering goods to particular locations around the urban areas.
- Photography/filming – these days there is a wide interest in using UAVs for photo-taking/filming during public and private events. Also, this includes using aerial filming for research and commercial (TV, Cinema) purposes.

As we can see there are many potential applications of UAS in urban environment. These usages of UAV for different commercial applications need to be assessed with their economic benefits. With the increase in potential applications of UAVs, there arise potential risks, which are narrated in the next section.

2.2 Potential Risk and Management Strategies
With the advancements in technology, the potential applications of UAS will increase. The operation of these UAS appears to generate new risks to other users of airspace and people and property on the ground. Therefore, strategies need to be developed to ensure that the risks associated are managed to acceptable levels.

Since UAS are different from conventional aircraft, there are some unique aspects to be considered for the development of a risk management framework for them in urban airspace.

Some of them are:
- Technology: Complex systems, C2 link loss, and reliability of autonomous systems.
- Operation environment: Special operations, for example, flying in unfavorable weather conditions, like rain, strong wind or high altitude missions; or flying in highly urbanized and congested areas with high rise buildings, etc.
- Performance: Determining the performance and capability of airborne systems, like climbing speed, endurance, turning rates, etc.
- Human Factors: Complexity of operational roles, human machine interface issues, and personal attitudes on safety and procedures.
- Security: UAS is vulnerable to external hacking or interference from unwanted elements. Threat could be a cyber or physical attack.
Developing an authorized risk analysis framework would be a handy tool that provides the necessary information to guide decision making to facilitate UAS operations in urban airspace. A possible risk assessment and management procedure is discussed in figure 1.

3. Potential Study Realm on Unmanned Aircraft Systems (UAS) for Urban Environment

Research in the domain of existing and new UAS technologies is required to reinforce the development of airworthiness and operational guidance in urban environment. As shown in Figure 2 the potential study areas in urban airspace can be classified into three major parts; airspace management, UAS technologies and other areas.

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3. Potential Study Realm on Unmanned Aircraft Systems (UAS) for Urban Environment
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Figure 1: Risk Management Procedure for safe UAS operations

Figure 2: Some of the Potential Research Areas on UAS methodologies & technologies in Urban Environment
3.1 Dynamic airspace management in urban environment
Dynamic airspace management and development of operational concepts for UAS in urban airspace needs foremost attention. A major factor that prevents the adoption of UAS operation in urban areas is the inadequacy of airspace management to prevent UAVs from colliding with each other, with manned aircraft or other flying objects, and with high rise buildings within our urban skyline. This states the necessity of studies on dynamic airspace management for urban environment.

In this context, any urban city could investigate the impact of airspace structure on capacity, complexity, safety, and efficiency for congested airspace for UAV operations. This research could focus on validating various concepts of operations through airspace modelling and simulation of different scenarios which are unique to its own terrain. These unique scenarios could be flying of UAVs in the city area and above high-rise residential/populated areas and verify the safety and reliability of these UAS.

Similarly, urban areas may foresee the development of a dynamic airspace which is flexible and adaptable for different factors of UAS operations such as traffic density, flight features and weather conditions. The utilization of the available Class G airspace in urban environment for integrating UAS operations is an area that can be explored.

3.2 Creation of UAV lanes/tunnels in urban environment
As an initial phase of enabling UAS operation in urbanized airspace, a structured operation with safe and efficient technology is very important. Hence new UAV lanes, tunnels, or routes could be developed and their impact on civilian and military restricted airspace has to be assessed.

One possible option for UAS passageways in urban environment is to follow along water canals/water bodies around the area or other less populated areas, such as nature reserves. Another alternative would be along the shoreline of urban area, if any, which is similar to heliroutes. Furthermore, establishment of UAV passageways should also not affect present helicopter operations, disrupt transportation services, nor intervene with industrial and maritime activities.

Most of the modern urban cities have a good land transportation infrastructures, with a good network of metro rail lanes and heavily accessed express roadways. Hence there is possibility to leverage on these existing infrastructures to define UAV tunnels. Introduction of UAV lanes/tunnels above or adjacent to these established infrastructures while keeping a safe distance from moving vehicles and nearby buildings is another potential area to explore. Figure 3 shows the concept of a UAV lane/tunnel over residential areas, avoiding the buildings and adjacent to roads. The routes or lane/tunnels for UAV operations over City Areas are depicted in Figure 4.
One of the methodologies that ensure the smooth operation of UAVs in these confined routes is Geo-fencing technology, which is detailed in the next section. Urban area’s study on the concept of UAS operation with structured routing needs to be developed considering the limited airspace. Other considerations for UAS operation include the vertical and horizontal separation of UAVs depending on their size, weight and supported technologies.

### 3.3 Geo-fencing technology for secure UAV operation

Geo-fencing methodology is one of the possible solutions that can provide a virtual boundary for the geographical areas which the UAVs are not supposed to fly over. This novel security strategy model is based on telematics and satellite positioning. This technology remotely oversees geographic areas surrounded by a virtual fence (Geo-fence), and involuntary detects the mobile objects that enter or exit these areas.
When this technology is applied, the geographic coordinates of the tracked object are automatically and consistently sent to a control center. Concurrently, a different set of geographic coordinates is used to establish a Geo-fence around a restricted area. This system identifies whether the tracked device is within or outside the geo-fenced area and an alert is created when it crosses this geo-fence (Reclus and Drouard, 2009).

As mentioned in the previous section, this technology could also help in creating a designated commercial UAV route within the defined airspace for its operation.

Figure 5 shows the Geo-fencing of some protected areas in an urban area such as the government building and airport area. UAVs are not allowed to go near or enter the airspace of these protected places. Even if any of them try to get into these restricted areas, this technology prevents their intrusion by forcing the UAVs to take a new path or to land outside these restricted areas as directed by a UAS traffic controller (UTC), who takes over the control of the aircraft. Another concept that could enable safe operation of UAS in urban airspace is the creation of designated traffic management stations, which is described in next section.

3.4 Traffic management stations for UAS operations in an Urban Environment

An urban area with congested airspace could benefit from the development of a unique and methodical ‘Traffic Management System for UAS (TMUAS)’ that enables safe operation of UAS. This TMUAS can be adapted from/in complement with NASA’s UTM (Parimal, 2014) concept, but it should also consider the limited airspace, along with other factors such as high-rise buildings, metro rail lines and other governmental restrictions.

As part of this TMUAS, UAS traffic control stations and a few landing/take off UAV stations can be developed. The UAS traffic control station can be defined as UTMS (UAV Traffic Management Stations), which is similar to the Air Traffic Control (ATC) Centre for the operation of manned aircraft. These UTMS houses the UTC (UAS traffic controller), who manages, monitors and controls UAS operations. UTC can perceive environmental data from his vision or information from other sources such as pilots, on-board sensors in a UAV, and the state metrology department.
UTC communicates with the pilot/operator of relevant UAVs using a robust communication link, and the study of which is necessary. Each flying UAV could also display its past trail along with its projected future path. Additionally, the UTMS data has to be updated each second to reflect the current state of entities within the assigned airspace. Environmental data can be perceived either by the pilot or observer's eyes for Visual Line of Sight (VLOS) operations or from the information collected from on-board sensors/camera in the case of Beyond Visual Line of Sight (B-VLOS) operations. Figure 6 shows the concept of TMUAS with its associated features and technological requirements.

![Figure 6: Concept of UAV ATM Station (UTMS) in a City area (Image source: Singapore skyline)](image)

An urban area can have 4 or 5 UTMS to control UAS operations in low altitude airspace across the land. A feasibility study has to be done to identify potential locations to construct UTMS, while considering factors such as the required signal coverage, convenience, and distance from civil and military airports, etc. Another possibility is to have a mobile UTMS that can be deployed at different UAS operation sites and be used for multiple scenarios. The UAS traffic management research could involve the academia as well as industry and commercial operators. There needs to be a collaborative approach for developing strategies that ensure safe UAS operation in an urban environment.

### 3.4 Demonstration of Safe Operations of Unmanned Aircraft Systems in an Indoor Simulated Urban Environment

This section discusses the demonstration of safe operations of UAS flight in an indoor simulated urban environment. The multi-UAVs flights are conducted to perform the three concepts of UAS Traffic Management, such as detect and avoid, geo-fencing as well as take over control in an emergency situation. The experimental setup includes simulated City area, airport tower and residential building in an indoor test facility. Demonstration shows how UAS fly in a flight lane/tunnel in urban environments. In the course the UAVs keep safe separation among themselves and also detect and avoid any obstacle in its path. The concept of geo-fencing is also demonstrated by shown by repelling a UAV trying to enter a restricted zone. UAV traffic controller warns this intruding UAV pilot and takes over control after no appropriate response from the pilot.
4. Concluding Remarks
Safe operation of UAS in an urban environment is a complex task and should ensure usage of reliable technologies. Along with technology, concept of operations considering various factors of environment is very important. Studies have to be done in order to analyze minimum separation distances and fly height limits for UAVs. There is a necessity to educate UAS operators and pilots about the airspace structure such as prohibited areas, the rules of the air, possible dangers of encountering manned aviation etc. It is important to enhance the safety culture among all the stakeholders (including UAS manufacturers, operators, pilots, UTCs etc.). The challenges in making them assume responsibility for their actions have to be overcome. The reporting of incidents must be made mandatory. These collected data can be valued as lessons learned and can be helpful in improving the future UAS operations risk management framework.

Therefore, this paper can be considered as an initial step in discussing possible areas of research and implementation strategies for enabling UAS operation in urban airspace with “safety and reliability” as the foremost feature.

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9