A Preliminary Study in Managing Safe and Efficient Low-Altitude Unmanned Aircraft System Operations in a Densely Built-up Urban Environment

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Abstract

The Unmanned Aircraft System (UAS) has emerged as a commercial operating technology that shows great promise in the evolution of civil aviation. The concept of UAS integration for operations in urban environments shows great potential to be economical and sustainable in the long run. The present paper presents a preliminary study aimed to develop a robust traffic management that ensures safe and efficient low altitude UAS operation in an urban environment.

This research can be considered as a stepping stone towards establishing potential Conceptual Operations (ConOps), which will require further research and evaluation through modelling and simulations. This will ensure that a sustainable strategy can be employed to enable safe and efficient UAS operations in an urban environment.

1. Introduction

Popularity and interest in Unmanned Aircraft Systems (UASs) have been increasing in recent years, especially for commercial, professional or recreational use. Therefore, more variants of UAS have been developed in the consumer market at affordable costs. However, dangerous behavior could be developed as end users may not be aware of the safety implications for UAS operations, especially in an urban environment. This could lead to potential risks of injury to people and damage to public properties, if not well managed through the use of technologies and regulations.

Situated in the Indian Ocean off the southern tip of the Malay Peninsula, Singapore has an area of approximately 700 square kilometers, with a total population of more than 5 million. Not only did Singapore develop into a modern and cosmopolitan city with high rise buildings, it has also developed into one of the world's best garden cities, transforming its landscapes with the greenery of trees. Singapore is also a business-friendly country, with a defined strategy to

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1 This paper is a conceptual & research paper solely in the view of the authors. It is by no means a proposal discussed with any other organization.
capitalize on the latest technology to improve productivity and efficiency to generate economic growth. Therefore, it can be foreseen that low-altitude UAS operations will have a high potential for growth in Singapore. However, being a dense urban country with a huge population and limited airspace, special considerations and detailed plans must be developed for UAS operations to be realized in Singapore. Therefore, there is a need for in-depth research and the formulation of effective measures to ensure safe UAS operations in an urban environment. Furthermore, regulatory guidelines from ICAO Circular 328 (ICAO, 2011) and CAP 722 (CAA, 2015) should be taken into consideration to ensure airspace safety within an urban environment. Particularly, as stated in ICAO Circular 328 for General Concept of Operations, 'In order for UAS to integrate into non-segregated airspace and at non-segregated aerodromes, there shall be a pilot responsible for the UAS operation'.

1.1 Present Status for UAS Traffic Management
Various organizations such as the National Aeronautics and Space Administration (NASA) and the Netherlands Aerospace Centre (NLR) are developing traffic management for UAS operations. Using Technology Capability Levels (TCL), which are series of activities that increases in complexity at each level, NASA has been working on possible UAS Traffic Management (UTM) strategies that will enable low-altitude UAS operations (NASA, 2016). On the other hand, NLR is looking at the application of a virtual tube airspace concept at different altitudes and transit points which will ensure safe separation and reduce conflicts (Schneider et al., 2014).

2. Preliminary Proposal for Low-Altitude UAS Operations in a Densely Built-up Urban Environment (Singapore Context)
UAS operation is expected to grow as its potential applications continue to rise due to technological advancement and increasing interest on commercial operations. Even with a crowded and urbanized environment, Singapore still possesses great potential for UAS operations. As such, Singapore needs a sound and structured UTM to ensure seamless and safe UAS operations. This leads to the need to carry out research being carried out, with goal to realize safe UAS operations and without causing any negative impacts to civilian or military aircraft operations.

2.1 Model of Operations
As a business-friendly country, Singapore looks to technologies that can generate economic benefits and provide world-class service efficiently. Therefore, it is highly possible that UASs will eventually be deployed for commercial activities and in the service industry. The proposed model of operations, including the enforcement of regulations, is depicted in Figure 1.
The model of operations consists of the conceptualization of UAS operations that requires in-depth research and will be discussed in the following sections. In particular, relationships between the stakeholders in UAS, which will be discussed in Section 2.2, should be established to ensure safe and seamless UAS operations.

2.2 Working Relationship between Various Stakeholders

The manned aircraft and automobile industry, regulators, manufacturers and end users must work closely with each other to ensure safe and efficient UAS operations as shown in Figure 2. The manufacturer or operator must ensure that technologies and operating systems are reliable, and operators are well trained. Both the operator and the system should also be certified by an appointed regulator. Federal Aviation Administration (FAA) for example, is a suitable candidate to hold the position of the regulatory board to ensure that the rules and guidelines are enforced. The manufacturer or operator, such as Boeing or Airbus for example, must also follow the regulatory framework to develop future technologies, operations and commercial applications.
The end user, such as Amazon or Google, has to work collaboratively with manufacturers/operator to ensure that the regulations are strictly adhered to during UAS operations. The working relationship between the end user and the manufacturer or operator must be well defined, especially for cases where any accident or incident that can occur during flight. It must be determined who will be responsible for the unforeseen accident or incident. It is possible that the manufacturer or the operator holds full responsibility for the occurrence of any unexpected incident if they are engaged to perform flight operations.

There are three main groups that can be defined as an end user. They are:

- **Commercial user**: Comprises of private companies and retail shops that deliver goods or items to customers. Teams that conduct Maintenance, Repair and Overhaul (MRO) might also use Unmanned Aerial Vehicles (UAVs) to deliver essential components that are urgently needed for servicing. The UAS operations for this group have a great impact to economical benefits.

- **Service provider**: Comprises of law enforcement agencies such as the police force to conduct coast or land surveillance to detect any unlawful activities. Government agencies such as National Environment Agency may also use UAVs to detect mosquito breeding sites that are unreachable by humans while hospitals might use them to deliver medication urgently required during offsite treatment. Civil agencies and the construction industry may also use UAVs for surveying and mapping of certain areas and properties. UAS operations in this category mainly focus on security, servicing and emergency.

- **Hobbyists or leisure flyers**: UAVs, flown by the public as a hobby or for leisure purposes, must be well managed to prevent any accident or incident from occurring. Designated areas (example see Section 2.4) in sparsely populated zones must be established for such purposes, if desired. In general, UAS activities operated by this group are for personal purposes and do not contribute significantly to economical and society benefits.

### 2.3 Future Scenarios, Applications and Proposed Flight Profile

In order to study the traffic management required for low-altitude UAS operations in an urban environment, scenarios involving various government and commercial applications are simulated. Examples of these applications are environmental and traffic monitoring, emergency services, surveillance, and delivery of goods or essential aircraft parts to the airport. These simulated applications will also be assessed for their economical benefits and sustainability, especially with the finite airspace that is available.

Meanwhile, these applications could be performed simultaneously in various compounds within a vicinity, which might consist of high rise buildings or residential areas. To ensure safe operations, an Unmanned Aerial Vehicle (UAV) lane incorporated with Geo-fencing technology is proposed to establish a robust traffic management system. Since an important determinant to ensure safety is the vertical and horizontal separation between UAVs, flight simulations will be carried out to determine the required separation distance between various UAVs based on their
size, weight and technologies incorporated into them. Suggested flight profiles include a two way traffic lanes that are horizontally or vertically separated (Figure 3).

![Figure 3 Possible flight profiles for UAS operations; safe distance separation in all directions (lateral/horizontal, back and front) must be ensured. Source: (Google Earth, 2016)](image)

2.4 Usage of Existing Infrastructure

To establish safe low-altitude UAS operations in an urban environment, new UAV lanes need to be carefully defined. As the Singapore airspace is very finite and the establishment of these lanes might intrude the airspace reserved for military and civil purposes, it is highly possible that UAS operations would leverage on the existing transportation infrastructure, such as the Mass Rapid Transit (MRT) tracks, traffic and light poles, rooftop etc.

As shown in Figure 4. In order to reach its destination during a task-specific flying, the UAV will make use of existing infrastructure while performing flight operations in the flying lane. The UAV will first divert its flight away from the populated area at Transit Point 1 and proceed to climb at Transit Point 2 to reach the top of a high rise building. After which, the UAV will stop ascending at Transit Point 3 and continue to fly above existing high rise buildings that are less populated to reach its destination.
3. Safety Management

With new operations being introduced, any risks and unsafe conditions must be identified, managed, and reduced to acceptable levels that are in accordance to Doc 9859, ICAO Safety Management Manual (ICAO, 2013). There are various factors that should be considered to ensure that the traffic management system is sufficiently robust to provide safe and effective low-altitude UAS operations in urban environments. Research and simulations will be conducted to study the following factors:

- **Operating environment**: Rain, haze, and the wind effects on UAS, especially in an urban environment with high rise buildings where UAS are likely to be exposed to strong winds or possible wind shear. UAS operations above trees and plants are also factors should be considered;

- **Technologies**: Detect and avoid, stable communication links, localization (with/without GPS) and remotely piloted flight need to be developed to ensure the reliability and safety of UAS flight operations. Flying distance separation of the UAVs could be improved with the use of detect and avoid technology. Flying speed of the UAVs will also be determined to ensure safe and efficient UAS operations;

- **Emergencies**: The procedure that an UAS will perform during any emergency such as link loss, communication loss or loss of control, for example, will be determined. The emergency procedures developed should not affect the continuity of UAS operations and...
deteriorate the efficiencies of UAS operations. Various emergency landing sites or tracker systems will be proposed to be positioned in various existing infrastructure or buildings;

- **Human factors:** Operational roles ranging from operators to service providers must be determined and staff must be well trained due to the complexity of UAS operations. Systems or procedures must be determined to reduce undesirable human errors, which in turn increase the efficiency of the operators and UAS operations;
- **Security:** Control measures must be determined to prevent any unwanted cyber attacks or to prevent fly drones above sensitive zone;
- **Privacy:** Should operators never fly drones above private property? While this is a valid question concerning of privacy, one must not overlook the vast benefits of this technology.

Protocols or procedures will be devised with contributions from relevant departments and results from the simulations conducted. This will greatly reduce the likelihood of any unwanted accidents or incidents from occurring that will affect the efficiency of UAS operations. Some procedures or protocols, such as path and rule planning that could be proposed are:

- **UAS lane:** Defined lanes should avoid areas with dense population or high human traffic to prevent any unsafe incident from occurring;
- **Operation time:** UAV flying in certain areas could only be allowed during specific timings such as non-peak hours;
- **Rules for UAS lane usage during operations:** UAS lanes should utilize existing infrastructure such as MRT, rooftop and traffic lights. UAVs using these lanes will be ranked according to their purpose so that UAVs that are used for emergency purposes will be given priority to perform flight operations first. This will be in accordance to flying protocol that will be proposed based on orders, altitude and lanes;
- **Ground to roof:** Designated area for UAVs to perform climb to roof of high rise building will be determined;
- **Roof to roof:** UAVs are desired to perform flight operations from roof to roof above high rise buildings in order to avoid highly populated areas;
- **Travelling distance between the UAV:** As multi-UAV operations will be anticipated, travelling distance between the UAVs will be determined to ensure safe and efficient operations. Protocol and performance guidelines such as flying speed and turning radius, should be indicated by up-and-down movement, forward-and-backward movement, turning, hovering, and emergency landing;
- **Zone classification:** Flying can be classified into different zone, such as No Flying Zone (NFZ), Business Zone (BZ) and Residential Zone (RZ), for UAS operations as shown in Figure 5. UAS control stations will be stationed, with operators to remotely perform UAS operations at each zone. This is to reduce unnecessary long distance operations that could increase risks factors and to promote more efficient operations. In fact, UAV flying for commercial deliveries would be expected: (1) at a designated corner of a high-rise building from the ground to a designated storey, (2) from the rooftop of one building to another rooftop. Such a delivery could be quite time consuming if it’s provided manually. UAS traffic control stations (UTMS), whose function is the same as ATC to manage, control and monitor UAS operations of all zones, will be defined. It is possible for UAS
operations to occur between different zones but transferring control of the UAV must be carried out by the UAS control station deployed at each zone;

- **Multi-modal and multi-mode operation**: For effective task-/mission-specified execution, UAS flying are expected to operated together with other land and/or sea vehicles in a complex multi-mode mission;

- **Ground procedure**: As a safety measure, signage of UAS operations must be placed at all UAS operating sites as an indication for people to exercise caution when travelling within them. For safety, UAS flying above the areas of human paths, traffic and trees should be avoided as much as possible;

- **Emergency flight procedure**: Navigation lights on the UAV must be blinking during emergencies as an indication for people to exercise caution. Different colors or patterns of lights can be clearly defined and shown for different flying stages and heights during the flight at all times.

![Figure 5 Possible zone classifications for UAS operations in Singapore.](image)

*Source*: (Google Earth, 2016)

**4. Potential Conceptual Operations**

Potential Conceptual Operations (ConOps), such as multi-UAV operations, will be developed for UAS to operate efficiently and safely in areas that are of high priority to Singapore's needs. However, all ConOps will be evaluated through modellings, simulations and test flights. The following ConOps: detect and avoid between flying UAVs, geo-fencing methodology for security purposes, and UAS take-over control by an UAS Traffic Controller (UTC), was initiated and evaluated through modelling and simulations.
The preliminary tests for these ConOps produced satisfactory results shown in Figure 6. Predetermined flight tubes are developed for the UAVs to perform flight operations. With the capability to detect and avoid, UAVs are able maneuvers safely around still and moving objects, throughout the flight. Three different UAVs, which had different flight profiles, were being used throughout the simulations. Several test runs were performed to examine the stability and performance of the UAS operations, with modifications made to attain better results.

![Figure 6 Concept simulation of Multi-UAV flight in urban environment with Air Traffic Management.](image)

5. Concluding Remarks

As a commercial-centric and technology driven country, Singapore is very likely to deploy UAS operations due to its potential applications. However, implementing low-altitude UAS operations in an urban environment is highly complex. Therefore, a robust traffic management system is required to ensure safe and effective UAS operations. In order to achieve this, potential ConOps with various factors that have high correlation to safe UAS operations must be researched and evaluated. Other than establishing necessary ConOps to ensure success in air traffic management, there is a need to develop required protocols and procedures for all potential operators and service providers to understand the structure of UAS operations.

With a well-developed safety management system, a robust traffic management, and clearly demarcated zones, UAS flight operations can be conducted safely and efficiently in an urban environment. Although Singapore is used as a case study for this paper, this initial study can also be potentially relevant to other urban cities such as Beijing, Tokyo, New York, etc.
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