Improving Conflict Prevention in Constrained Very Low-Level Urban Airspace, U-Space

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***Abstract*—The rate of urbanization is expected to continue increasing [1]. This has led to an interest in using drones and air taxis for urban transportation in place of the current methods, which often lead to road congestion. In most places urban air operations will happen above buildings. However, in many cities with large skyscrapers it may not be efficient to fly above buildings as it would add travel distance. For these cases, aircraft will have to operate in constrained airspace (above roads and between buildings). There is still a knowledge gap for operating in constrained very low-level urban airspace [2]. Most studies attempt to improve the safety in constrained airspace with strategic or tactical conflict resolution. But this may not be enough to ensure safety in highly-dense urban environments. The restriction of heading manoeuvres by buildings substantially limits the solution space for conflict resolution. Therefore, conflict prevention with airspace design can be an important tool for improving airspace safety. In a layered airspace, turn layers can be used so that turning aircraft do not create bottlenecks for cruising aircraft that may be behind it. However, merging conflicts can occur when these turning aircraft attempt to re-enter cruising layers. These are typical in both orthogonal (New York) and non-orthogonal (Paris) street networks. Non-orthogonal street networks can also create merging conflicts because it is not always possible to segment cruising aircraft at intersections. This work will propose two conflict prevention doctoral research experiments that aim to reduce merging conflicts. The first will use three different layering techniques to reduce merging conflicts created by turn layers. The second will focus on merging conflicts that are typical of non-orthogonal networks.**

***Keywords*—Conflict Prevention, U-Space, Unmanned Traffic Management (UTM), BlueSky ATC Simulator, Urban Airspace, Urban Air Mobility**

I. INTRODUCTION

As of 2020, 56.2% of the world population live in cities and by 2050 it is expected to increase to 68.4 % [1]. This increasing degree of urbanisation is one of the triggers of interest in air taxis and drone deliveries in cities. However, the traffic expected for these missions far exceeds the typical densities seen in present air traffic management [3]. This has led to efforts like Unmanned Aircraft System Traffic Management (UTM) by the National Aeronautics and Space Administration (NASA) and U-Space by SESAR Joint Undertaking.

Although in most places it may be possible to avoid buildings by flying above them, it may not be desirable for noise and/or privacy considerations. Moreover, this will not be possible in cities with skyscrapers (e.g., New York and Hong Kong). This study will consider operations that are restricted to flight above streets and between buildings (constrained airspace). Also, only aircraft with hovering capabilities will be used in the simulations. Moreover, two types of aircraft with different cruising speeds will be modeled based on a DJI Matrice 600 Pro hexacopter. Although traffic can be highly heterogeneous, constrained airspace may impose speed limits similar to road traffic or other limitations if the overall safety and efficiency improves. For this reason, the type of mission, parcel delivery or air taxi is not a focus of the doctoral work.

There are several studies [2], [4]–[6] that have looked at operations in constrained airspace. However, there is still a lot of room for development. This doctoral paper is inspired by the limitations of constrained airspace outlined in [2]. One of the main outcomes was that conflict prevention in constrained airspace can be improved by focusing on merging conflicts. Therefore, this doctoral paper describes two experiments that test different airspace structures at different traffic densities in constrained airspace. The goal is to understand how the optimal structure is affected by the capacity of the airspace.

Section II describes constrained airspace and merging conflicts. Section III describes an experiment that attempts to mitigate vertical merging conflicts. Section IV describes an experiment that aims to reduce horizontal merging conflicts.

II. CONSTRAINED AIRSPACE AND MERGING CONFLICTS

A loss of separation occurs when an aircraft intrudes the protected zone of another aircraft. A conflict is a predicted loss of separation. In [2], state-based conflict detection was used, which means that the current state of all aircraft is linearly extrapolated with a given look-ahead time. If within this look-ahead time aircraft are expected to fall inside the protected zone, a conflict is detected. Conflicts can be solved with Conflict Resolution (CR) algorithms, such as the Modified Voltage Potential (MVP) algorithm [7], even when limiting the solutions to the speed or vertical dimension. However, in highly-dense scenarios the conflicts become harder to solve with CR algorithms alone. Therefore, conflict prevention strategies via airspace structure are needed so that CR algorithms can be exploited to their fullest capabilities.

Aircraft operating in constrained airspace must avoid buildings as well as other aircraft. It is also probable that they will need to avoid flying over parks and side walks to limit third-party risk. This naturally leads to aircraft flying above a road network like the one in Fig. 1. The presence of buildings does not allow for aircraft to alter heading for conflict resolution. They are limited to speed or altitude changes.

Figure 1. Street layout of the experimental area in Vienna from [2] with traffic flow directions.

The layers concept from the Metropolis [8] project showed that in an unconstrained airspace, aligning aircraft with similar headings and segmenting those with different headings into separate travel layers lead to a large decrease in the number of conflicts. In constrained airspace, aircraft are aligned because they follow the direction of the streets. Several studies in constrained airspace have tried to adapt this layering technique to constrained airspace [2], [4]–[6]. This layering technique can be seen in Fig. 2. It shows that East/West streets are vertically segmented from North/South streets.

Although not unique to it, merging conflicts are typical of layered constrained airspace. In [2], the airspace was divided into North/South and East/West streets with a turn layer in between (Fig. 2). This vertically segments traffic with different directions at intersections. Turning layers are added so aircraft can make turns at slower speeds and because there is typically no straight-line path to the destination. Prior to a turn, aircraft vertically manoeuvre to the turn layer, slow down, and turn. After turning, the aircraft should accelerate to cruising speeds and then move back to the cruise layer. This vertical manoeuvre to re-enter the cruising layer is what creates merging conflicts. These were also seen in [2], [4]–[6].

Most of those studies (except for [2]) assumed an orthogonal street network, in which it is always possible to vertically segment traffic at intersections. Some cities, like Vienna, have a non-orthogonal street network (e.g., Fig. 1) that creates additional complications for conflict prevention. Fig. 3 shows different types of intersections. Assuming, that the streets in Fig. 3 (a) both contain cruising layers at the same height there would be a horizontal merging conflict if aircraft meet at the intersection. Note that, depending on the specifics of the geometry of the intersections, it is not always possible to vertically segment all intersections in non-orthogonal networks because there is only limited vertical space. The airspace can become saturated and inefficient if a segmentation is added for all merging intersections.

III. PREVENTION OF VERTICAL MERGING CONFLICTS

In the layered airspace from [2], [4], [5], vertical merging conflicts occur as a result of the stacking of turn layers and cruising layers. Thus, the first research goal of this doctoral project will be to investigate how to prevent these conflicts with airspace structuring techniques, which we denominate *Merging Conflict Prevention with Layers in Constrained Very Low-Level Urban Airspace*.
The independent variables are:

- Vertical Layering Structure (1-to-1, 2-to-1, fully-segmented).
- Traffic Density (Very Low, Low, Medium, High, Ultra).

The dependent variables are:

- Number of conflicts.
- Number of losses of separation.
- 3D travel distance/time.

There are three layering structures considered for the experiment. The first is similar to the structure from Fig. 2 and is shown in Fig. 4a. The difference is that it will be a stack of 6 cruising layers with alternating direction with a turn layer in between. This is named the 1-to-1 structure since the stack is made by stacking one travel layer and one turn layer. The second, shown in Fig. 4b, is the 2-to-1 structure. This structure has two travel layers per turning layer. Both travel layers can be used for cruising or vertical deconfliction. The third structure, shown in Fig. 4c, is the fully-segmented structure. The top half of this airspace is for East/West traffic and the bottom half is for North/South traffic with two turn layers dividing them. The travel layers near the turn layer

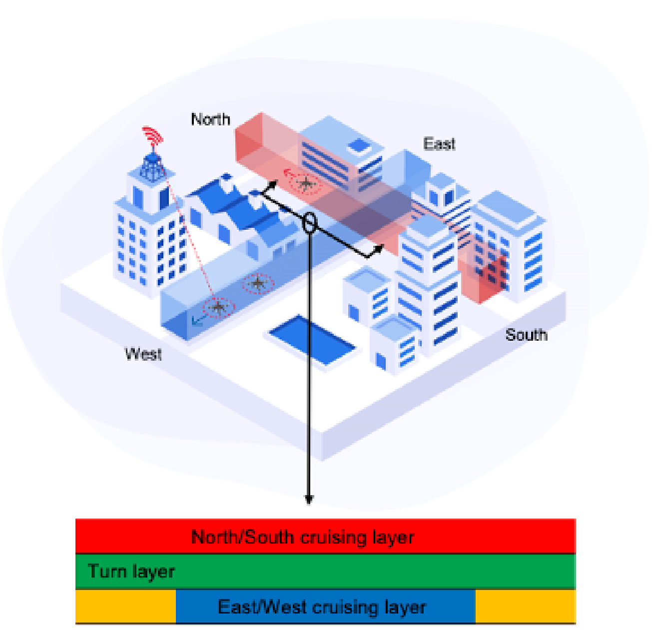


Figure 2. Airspace Layering at an Intersection for [2].

are for aircraft that are near a turn. Aircraft may use any of their available layers in their direction of travel for vertical deconfliction. Note that the 1-to-1 and 2-to-1 structures will take the same amount of vertical space as the fully-segmented structure.

The initial hypotheses are as follows:

- At higher densities, the 2-to-1 structure will have the least number of conflicts and losses of separation because it provides space for vertical deconfliction as unlike the 1-to-1 structure. It also contains more turn layers than the fully-segmented structure, so any potential hotspot at a turn will be divided amongst several turn layers.
- At lower densities, the fully-segmented layer will have the least number of conflicts and losses of separations because it allows for more efficient use of the airspace.
- At higher densities, the fully-segmented structure will have the largest number of conflicts and losses of separation because the limited number of turn layers will concentrate traffic at turns.

The experiment area for the simulations will be in an orthogonal street network so that the effects of horizontal merges can be removed. The goal of the experiment will be to understand how the availability of airspace relates to the optimal structuring technique. These structures will be implemented with BlueSky, an open air traffic simulator [9].

It is notable to state that the merging strategy is reactive for the proposed experiment. This means that aircraft merge from a turn layer to a cruise layer without checking if it will cause a conflict. The main difference with past studies ([2], [4]–[6]) is that vertical resolution manoeuvres are possible in the 2-to-1 and fully-segmented structures. The experiment may be extended to include higher-level merging rules. One possibility is for merging aircraft to check if there are any aircraft in the cruising layer and delay their merging. This strategy has been explored in a yet to be published study [10]. Alternatively, cruising aircraft could check for any potential merging aircraft and move to another layer (2-to-1 or fully-segmented). The choice may depend on some priority rules between aircraft themselves or between the layers.

In Metropolis [8] it was shown that a difference in relative speeds increases the conflict probability. Therefore, two aircraft types with different cruising speeds will be used in the simulation (20 and 30 knots) - as in [11] - to create conflicts and see if the airspace structure is successful in preventing them. The trajectories will be generated based on the parcel demand and other demographic factors [3], [11] of the simulation area.

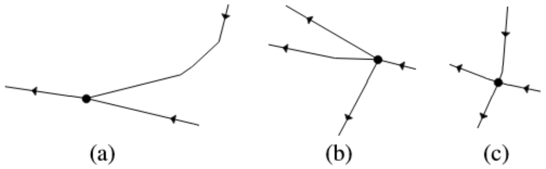


Figure 3. Examples of intersections in the city of Vienna: (a) merging intersection, (b) diverging intersection, and (c) classical four-way intersection [2].

IV. PREVENTION OF HORIZONTAL MERGING CONFLICTS

Vertical merging conflicts are present in orthogonal and non-orthogonal street networks. However, in non-orthogonal networks like the one in Fig. 1, horizontal conflicts may occur. In this figure there are several places where two East/West streets merge into one (see Fig. 3). Since there is limited vertical space, it is not always possible to segment all intersections. Therefore, these horizontal merges must be accounted for. The second topic of this doctorate work will be *Merging Conflict Prevention at Intersections in Constrained Very Low-Level Layered Urban Airspace*.

The same dependent and independent variables as before will be used, but with fewer densities and structures:

- Vertical Layering Structure (1-to-1, 2-to-1).
- Traffic Density (Low, Medium, High).

The dependent variables are:

- Number of conflicts.
- Number of losses of separation.
- 3D travel distance/time.

The merging rules for the 1-to-1 structure, Fig. 4a, are based on street priority. Rather than giving aircraft priority, streets have priority for merging. When an aircraft is traveling in the lower priority street it will descend to the turn layer before merging and then return to its cruising layer. The merging rules for the 2-to-1 structure (Fig. 4b) are similar. The difference is that the aircraft in the lower priority street must make a vertical manoeuvre to another cruise or turn layer.

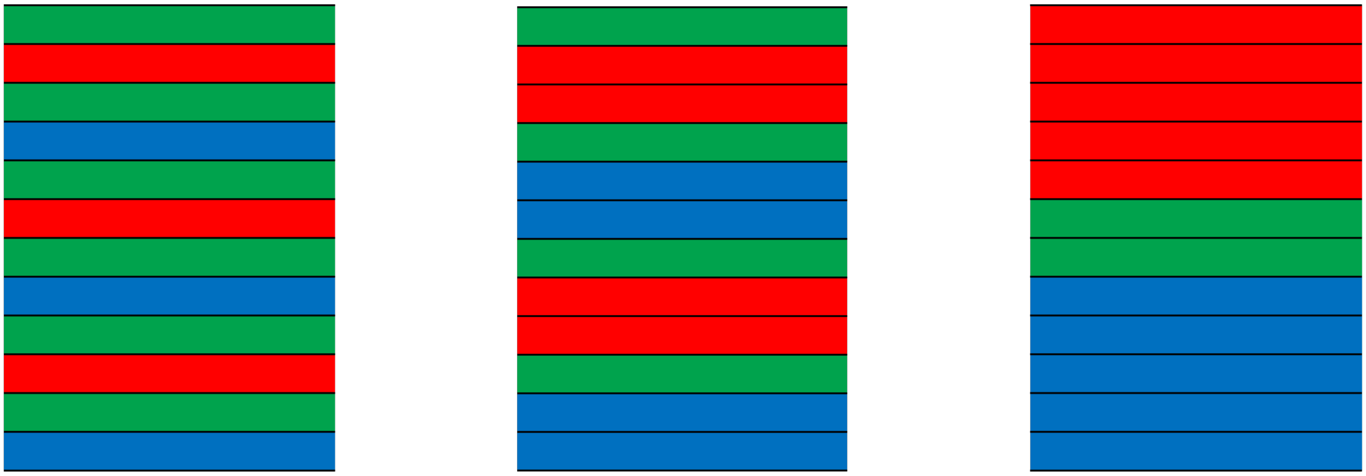
The initial hypothesis is as follows:

- At all traffic densities, the 2-to-1 structure will have fewer conflicts and losses of separation when merging than the 1-to-1 structure. Merging in the 1-to-1 structure will be more dangerous because there are less choices to merge. Aircraft can only use the turn layer in the 1-to-1.

Horizontal merging conflicts may not be as common as as vertical ones because not every intersection has this configuration. Therefore, a simulation area with many merging locations will be chosen to isolate the effects of these intersections. This will also be simulated with BlueSky [9]. It is also possible to extend this experiment, as suggested in Sec. III, by forcing aircraft to preemptively check for potential merging conflicts and manoeuvre before a conflict is created using priority rules. As in the previous experiment III, two cruising aircraft will be used with certain trajectories.

V. CONCLUSION

The goal of the doctoral research is to improve the safety by using conflict prevention in the design of the very low-level urban airspace. Some factors that will influence the future of urban air operations are not considered in this research but may be considered in future work. Among them are highly



(a) 1-to-1 structure. (b) 2-to-1 structure. (c) Fully-segmented.

Figure 4. The three proposed layered airspace structures. Blue is East/West layer, Red is North/South, and Green is the turn layer.

heterogeneous traffic, interactions with conventional aviation, and effects of take-off and landing operations.

Two research topics were outlined. The first will mitigate vertical merging conflicts that arise because of turn layers in constrained airspace. This will be done by simulating three layering techniques with five different traffic densities. It is hypothesized that the 2-to-1 structure (Fig. 4b) will have the least number of conflicts and losses of separation for higher densities. However, the fully-segmented structure (Fig 4c) should perform better at lower densities because it allows more freedom for aircraft manoeuvres. The second experiment is about reducing horizontal merging conflicts in non-orthogonal street networks. Two layering structures with three traffic densities will be tested. It is hypothesized that the 2-to-1 structure (Fig. 4b) will have the least number of conflicts and losses of separation for all densities. It is also possible to extend these two experiments by having aircraft preemptively act before a merging conflict is created considering some priority rules. The goal is not necessarily to prove which structure is better than the others. It is to gain insights into how the traffic capacity and street network layout affect the optimal layer structure in constrained airspace.

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