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Conflict Prevention, Detection, and Resolution in Constrained Very Low-Level Urban Airspace

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***Abstract*—The interest for using small aircraft for missions in urban airspace is growing for applications like parcel deliveries. Research shows that conventional airspace structure and conflict detection and resolution techniques are not suitable for maintaining a high level of safety in constrained urban environments, especially when aircraft are restricted to flying within the limits of the road network. The problem at hand becomes even more complex when factoring in cities with topologically organic street networks, thus increasing the probability of crossing and merging traffic flows. Preliminary results show that such networks induce the detection of false-positive conflicts when using classical state-based conflict detection, decreasing the effectiveness of conflict resolution. Velocity-obstacle based conflict resolution methods were able to improve airspace safety, but require further development in order to handle conflicts in such an unpredictable and constrained environment. Thus, the doctoral project at hand seeks to develop and research improved methods for conflict prevention, detection and resolution in constrained, urban, very low-level urban airspace.**

***Keywords*—Conflict Detection and Resolution (CD&R), Velocity Obstacle (VO), U-Space, Unmanned Traffic Management (UTM), BlueSky ATC Simulator, Urban Airspace**

I. Introduction

With the increasing population densities of cities, traffic congestion is becoming a growing threat to the quality of life in such urban centres. As the market for home deliveries expands (e.g., parcels, food), vehicles used to fulfil the demand contribute to increased road travel times and decreased safety. A potential solution for this problem could come from the aviation domain in the form of small aerial vehicles, which is currently being investigated by commercial operators and investors.

As a result, future urban air traffic is predicted to reach magnitudes of billions of flights per year[1]. There is a need for the research and development of concepts of operation in order to create a safe and efficient set of governing rules for very low-level (VLL) urban airspace.

There are three possibilities that are currently being studied pertaining to the navigation of urban airspace by drones:

1) **Above-building navigation**, implying aircraft would follow more direct flight paths to their destinations by flying above urban obstacles, suitable for areas with low building heights;
2) **Between-building navigation**, where aircraft follow the existing transport infrastructure ways (streets, train tracks, etc.) in order to avoid higher altitude flight, suitable for cities with high buildings and skyscrapers;
3) **Mixed navigation**, where both constrained and open airspace areas are defined in function of the urban topology.

In either of these navigation possibilities, airspace structure and detect and avoid strategies need to be developed in order to ensure deconfliction and safe separation of aircraft. Previous research has investigated these in the context of above-building navigation [2], [3], [4], as well as between-building navigation in urban environments with orthogonal street networks (e.g., New York) [5], [6], [7]. However, limited research has been performed on cities with more organically developed, non-orthogonal street networks, as often encountered in Europe (e.g., Paris, Vienna).

The doctoral project at hand focuses on studying and developing operation strategies for urban environments with organic infrastructure layouts, with emphasis on conflict prevention, detection, and resolution methods. These types of street networks pose additional problems when compared to orthogonal networks or open airspace, such as less reliable conflict detection, more false conflicts and topologically diverse intersections [8].

II. Methods

The following section presents the methods and techniques used to research, develop and simulate conflict prevention, detection and resolution concepts within constrained urban airspace. Much of the presented insights were gained from research we performed within the SESAR Metropolis II project [9].

A. Airspace topology and structuring

While not being a main point of focus of the doctoral project at hand, the airspace structure plays an important role in the mitigation of unsafe situations. The first Metropolis project has shown that a layered airspace leads to fewer conflicts and thus fewer losses of separation between aircraft in a highly dense urban environment [4] compared to other configurations.

Furthermore, a layered airspace structure was applied within constrained urban airspace with orthogonal street networks [6], resulting in fewer conflicts and losses of separation when streets are uni-directional, and turning aircraft are assigned to a specialised turn layer. For the investigation of conflict detection and resolution methods within the research project at hand, a layered airspace that uses a sequence of cruise layers and turn layers will be used, as depicted in Fig. 1, with the possibility of changing their configuration as research into airspace structure advances.

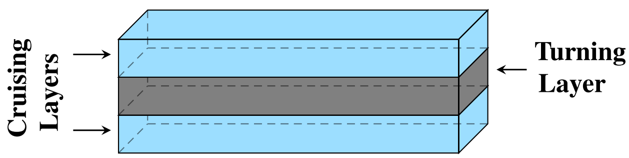

Fig. 1: Planned airspace structure to be used during future investigations of conflict detection and resolution techniques in urban airspace [8].

B. Conflict detection

State-based conflict detection in air traffic management has been researched and proven to be suitable for open airspace [10]. An extrapolation of the current state of aircraft within a certain look-ahead time is used to predict future losses of separation. The simplicity of this method provides the necessary robustness and predictability for cooperative conflict resolution algorithms.

However, in a constrained urban airspace, state-based detection methods might be insufficient in identifying conflicts in a timely manner, as aircraft perform turns more often, resulting in frequent and large changes of state. Furthermore, due to the topology of the street network, some conflicts are detected regardless of whether the trajectories of the aircraft actually intersect, resulting in unnecessary conflict resolution manoeuvres that disrupt traffic [8]. Therefore, improved conflict detection methods which maintain the robustness and scalability of conflict resolution algorithms need to be developed for use in constrained urban environments.

C. Conflict resolution

Extensive research has previously been conducted on cooperative conflict resolution methods in open airspace, such as the Modified Voltage Potential (MVP) [11] or the Optimal Reciprocal Collision Avoidance (ORCA) [12]. However, these have proven to be less feasible in constrained urban airspace due to their reliance on combined speed and heading resolutions.

This means that conflict resolution manoeuvres in constrained urban environments should be performed using vertical and speed-based manoeuvres if aircraft must follow streets. Such methods have not been extensively explored, especially when considering topologically organic street networks. Furthermore, such networks introduce merging and diverging situations that are not handled properly by current conflict resolution algorithms [8].

Therefore, this doctoral project will seek to produce conflict resolution strategies for situations encountered in topologically organic urban airspace, including investigations into the use of prioritisation, merging and diverging intersection deconfliction, and selection of vertical and speed-based manoeuvres depending on conflict characteristics.

D. Air traffic flow control

During the first Metropolis 2 trial simulations, it was noticed that flow control algorithms that use geovectoring [13] for traffic management can potentially decrease the number of conflicts that occur in high-density air traffic situations. In our constrained environment, this is obtained by decreasing the maximum allowable velocity in the area and thereby lowering the relative velocities between aircraft. However, this also affects the solution space for conflict resolution, limiting the choices for a resolution manoeuvre. This concept will be further explored within the doctoral project at hand.

E. Simulation environment and performance metrics

The developed conflict prevention, detection, and resolution techniques will then be tested within experiments performed using the BlueSky Open Air Traffic Simulator [14], an open-source software developed within the Control and Simulation department at the Faculty of Aerospace Engineering of TU Delft. The simulator offers the possibility to use conflict detection and resolution plugins, enabling the testing of different such methods under controlled conditions.

Air traffic scenarios containing high numbers of aircraft will be analysed using fast-time simulations, and in this way different operational concepts can be compared in terms of performance metrics. The prime focus of the doctoral thesis at hand will be the safety of operations, followed by efficiency, and will especially consider the following metrics, among others:

- **Number of detected conflicts per aircraft**
  A conflict is defined as a predicted loss of separation within a certain look-ahead period of time. Detected conflicts will depend on the used detection method.
- **Losses of separation per aircraft**
  A loss of separation is defined as the situation in which the distance between two aircraft falls below a minimum threshold.

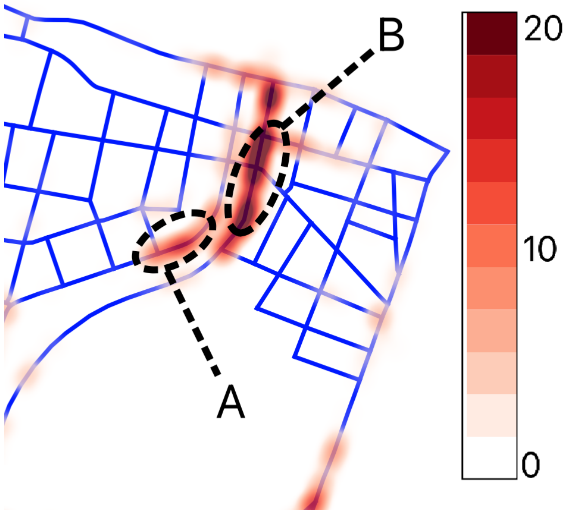

Fig. 2: Area in the street network of Vienna prone to detection of false conflicts if state-based methods are used. Colour gradient represents the number of conflicts that were detected.

- **Average flight time and distance**
  Metrics of overall airspace and flight efficiency. When using conflict resolution manoeuvres, flight time and travelled distance tend to increase.

III. Preliminary Experiments and Results

We performed preliminary research towards the scope of the doctoral project at hand [8] within the SESAR Metropolis II project. Small-scale simulations have been performed in constrained urban airspace based on the street network of Vienna in order to explore the limitations and challenges that need to be overcome to enable such operations. More information about the setup of the experiments can be found in [8].

First of all, the expected presence of false-positive conflicts was apparent when analysing the conflicts detected by a state-based algorithm that linearly extrapolated the current states of aircraft within a look-ahead time of 10 seconds. Fig. 2 presents an intersection that was a hot-spot for such detections. Aircraft in area **A** were travelling northward, while aircraft in area **B** were travelling southward. The detection method would often conclude that aircraft in these two areas would experience a loss of separation, which is impossible considering the aircraft followed the street network. These situations also unnecessarily interfered with other aircraft in this area, as they would attempt to solve these conflicts, and the traffic flow was disrupted by unnecessary velocity changes.

Another result of the preliminary simulations shows that, regardless of traffic density, using either airspace layering or a speed-based conflict resolution method reduced the number of losses of separation in the simulated constrained urban airspace section when compared to using no layering nor conflict resolution, as presented in Fig. 3. However, combining both layering and conflict resolution does not yet result in a further reduction. Apparently, these strategies and techniques still need to be developed further in order to improve airspace safety. This will also help to better understand the interaction between airspace structure and detection and deconfliction algorithms.

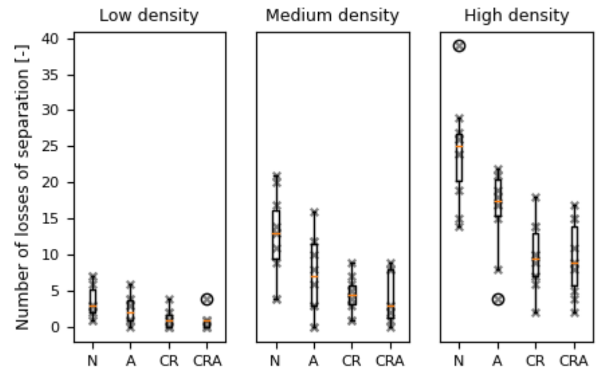

Fig. 3: Number of losses of separation recorded during preliminary simulations in function of deconfliction techniques and air traffic density. The x-axis values are as follows: **N**: no airspace layering or conflict resolution; **A**: airspace layering used, no conflict resolution; **CR**: conflict resolution enabled, no airspace layering; **CRA**: both airspace layering and conflict resolution methods used.

IV. Doctoral project

By considering the preliminary investigations presented in this paper, the doctoral project at hand will visit the following subjects:

1) **Decentralised concept of operations for air traffic control in dense urban airspace**
   A decentralised air traffic control system implies the handling of conflicts using tactical algorithms with minimal communication between agents. This part of the project will focus on aggregating the work done within the Metropolis 2 project, which compared such a system with a hybrid and a centralised one, and formulate conclusions on the advantages and disadvantages of such a system.

2) **A machine learning augmented hybrid approach for controlling traffic in dense urban airspace**
   A direct follow-up of the research performed with in the Metropolis 2 project, this part of the doctoral project will seek to solve some of the issues encountered in previous research through the use of centralised strategic planning

and artificial intelligence for conflict detection in urban environments.

3) **Merging and diverging at airspace transition points in urban airspace**
The research presented in this paper points towards the existence of at least two types of airspace in future concepts of operation for urban airspace: constrained airspace, where traffic must follow the street network due to infrastructure (e.g., high buildings, parks), and open airspace, where aircraft can fly freely. This part of the doctoral project will investigate ways to mitigate conflicts at the transition between these two types of airspace.

4) **Conflict resolution techniques in constrained urban airspace**
By constraining aircraft to fly within the boundaries of the street network, the possibilities for conflict resolution are restricted. Within conventional aviation, heading-based resolutions are preferred. However, this would no longer be possible in constrained airspace. The final part of the doctoral project will thus look into what types of conflicts emerge in such environments and what is the best way to solve them, either tactically or strategically.

V. Conclusion

Urban air traffic densities are projected to increase in the near future, and current airspace configurations and operational concepts are not suitable for maintaining a high level of safety, especially if flights are constrained to flying within the limits of the existing street network. The doctoral project described in this paper will attempt to develop and study improved methods for conflict prevention, detection and resolution. Preliminary results have revealed that conflict detection methods are a critical starting point, as current state-based methods are not suitable for topologically organic street networks. Furthermore, speed and altitude-based conflict resolution methods need to be improved and researched, as aircraft in urban airspace might be restricted to such manoeuvres in cities with tall buildings or limited airspace availability.

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