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EDITORIAL

Reviews and Responses for Very-low-level U-space Conflict Detection and Resolution: Current Developments and Future Prospects

Authors: Calin Andrei Badea, Andres Morfin Veytia, Andrija Vidosavljević, Joost Ellerbroek, and Jacco Hoekstra

Reviewers: Shulu Chen, Christopher Conrad, and Yutong Chen

Editor: Peng Wei

1. Original paper

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2. Review - round 1

2.1 Reviewer 1

This manuscript provides a comprehensive analysis of air traffic management and conflict detection and resolution (CD&R) methods for Very-Low-Level (VLL) U-Space operations. The authors have made a contribution by critically evaluating current approaches, highlighting challenges, and offering recommendations for future research. Their integration of simulation-based methodologies and proposals for dynamic capacity management and tactical deconfliction is a commendable step toward enhancing the safety and efficiency of U-Space operations.

While the paper is well-structured and provides valuable insights, I have a few suggestions for improvement:

1. Clarify the Scope: The paper mentions methods seems applicable to both Urban Air Mobility (UAM) vehicles, such as eVTOLs, and smaller UAS (drones). The authors should explicitly differentiate between these two scopes, as their safety metrics and operational methodologies often differ. In addition, I suggest elaborating on why certain methods might be more suited to one category over the other, or discussing tailored approaches to accommodate these distinctions. This clarification will help readers understand the distinct requirements and applicability of the proposed solutions.

2. Visualization of Integration Framework: To enhance reader comprehension, I recommend including a diagram that integrates all the methods discussed in the paper. This visual aid would illustrate how the proposed strategies align within a unified framework and their interdependencies.

3. Correct Reference Details: In the references, the last name of the first author of citation [36] should be corrected to "Tang."

These revisions will strengthen the clarity and impact of the manuscript and further its contribution to the field. I look forward to seeing how the authors address these points in their revised submission.

2.2 Reviewer 2

The paper offers a good overview of the research conducted by the authors surrounding very-low-level (VLL) conflict detection and resolution (CD&R) in U-space and highlights the need for a unified approach to airspace design, strategic deconfliction, dynamic capacity management (DCB), and tactical deconfliction. The authors present a concise summary of their research in each of these four areas, consolidated within a harmonised simulation environment for VLL traffic. They summarise the results obtained when testing their algorithms against other approaches in the literature, emphasising current limitations and important directions for future research. While suitable for this journal, the following areas need attention:

Title:

The title is somewhat misleading. It suggests a comprehensive review of the subject matter but primarily summarises the authors' prior work, with limited discussion of other relevant research. To align with its title, the manuscript should better present and compare external literature. Alternatively, if the focus is solely on consolidating the authors' own contributions, the title should be revised to better reflect this narrower scope.

Airspace Structure Design:

The discussion of airspace structure design focuses on the authors' own work without providing an adequate discussion of other proposals in the field. Moreover, the authors should quantitatively compare the performance of different airspace structures, including their own, in terms of their impact on CD&R, to better reflect the aims of this review. While Section 3.1 references some results, a clear and summarised comparison of airspace structure performances would make the discussion more cohesive.

Strategic Planning:

The section on strategic planning lacks sufficient context within existing research. While the authors summarise their own contributions, they provide limited insight into how their approach compares to or builds upon other strategies in the field. Additionally, some technical aspects need clarification:

- The phrase, "The set of routes that can be assigned to aircraft is created by generating alternatives avoiding parts of the nominal flight path," is unclear and should be rewritten.

- Variables $x_{p,n,\theta}$ and $z_{p,y}$ should be adjusted to $x_{f,p,n,\theta}$ and $z_{f,p,y}$ to emphasise that a unique variable exists for each flight f.

- Constraint (1) implies that all flights are accepted, but this assumption is not explicitly stated. The authors should clarify this point and discuss the scalability of their approach in high-density scenarios where rejecting some flight requests may be necessary.

- The definition of the time windows T should be better explained.

DCB:

The discussion of DCB similarly lacks a thorough overview of existing research. Additionally, the metrics referenced in the phrase, "By comparing the effects of various traffic metrics (position, conflicts, intrusions)," should be clearly explained. These metrics should then be used to analyse algorithm performance in Section 3.

Tactical Deconfliction:

The proposed tactical CD&R approach is not clearly explained, and several assumptions need to be explicitly stated. The proposed halting manoeuvre, for example, appears unsuitable for fixed-wing

aircraft which cannot hover. If this limitation applies, it should be clearly stated and discussed. Additionally, the need to handle uncooperative aerial entities in tactical CD&R is not addressed, which is a significant concern in urban airspace.

Simulation and Results:

While the simulation framework is well-outlined, the results should better reflect the stated aims of the paper. Firstly, no results are provided on airspace structuring or tactical deconfliction, even though these are key aspects of the paper. Second, the authors' algorithms are benchmarked against few other approaches from the literature, limiting the depth of the comparative analysis. Lastly, the results do not clearly link back to the paper's central message advocating for a unified approach to airspace structuring, DCB, and strategic/tactical deconfliction. This connection should be more explicitly drawn in the discussion, beyond analysing the algorithms independently.

Analysis and Conclusions:

The recommendations provided in the conclusion are sound but would be more compelling if supported by a more comprehensive review and analysis of existing work. While the authors effectively critique their own contributions, they do not sufficiently contextualise their findings within broader research trends. For example, the paper emphasises the need for a unified approach but fails to substantiate how its proposed methods holistically address airspace structuring, DCB, and deconfliction within a harmonised solution. A clearer demonstration of the need for this integration would strengthen the conclusions significantly.

Grammar and Syntax:

The manuscript is clear but would benefit from grammatical and stylistic revisions. Phrases such as "in our past work, [missing 'we'] developed" and "are not accounted [missing 'for'] within" should be corrected. Similarly, phrases like "as the deployment of U-space operations approaching" need rephrasing for proper syntax. The authors should also avoid vague expressions such as "with relatively high accuracy" and instead use specific, quantifiable comparisons to improve clarity and rigor.

Acronyms:

Acronyms (ex. VLL) should be used consistently throughout the manuscript after their first use.

References:

The references should be carefully reviewed, as some links are currently broken or inaccessible.

In summary, the paper should either revise its title to reflect its focus on summarising the authors' work or, preferably, expand its scope to include a comprehensive review and analysis of ongoing research in the four pillars of CD&R. This should involve a detailed comparison of different methodologies and algorithms, supported by quantitative analyses where possible, to justify the proposed directions for future research. By addressing these gaps, the review paper could make a much more substantial contribution to the field.

2.3 Reviewer 3

The authors, building on their previous methodological research, explore the current developments and future prospects of Very-Low-Level (VLL) U-space Conflict Detection and Resolution (CD&R). I appreciate the systematic research and contributions made by the authors on this topic. However, this paper appears to be positioned as a review paper, yet most of its content discusses the authors' own studies, which limits the scope and conclusions of the paper. Significant improvements are needed in the depth of discussion, experimental rigour, accuracy of conclusions, and overall readability. Although I believe the paper requires more than a single major revision to meet the publi-

cation standards, I would still recommend allowing the authors to address these challenges. Below are my comments for the editor's and authors' reference:

- 'The CD&R system itself is generally described as a set of three key components [4]: pre-departure strategic planning, dynamic capacity management, and tactical deconfliction.' (lines 30-31). While I agree with describing these as components of conflict management, stating that they are components of CD&R may be imprecise, as CD&R refers to more specific technologies or operations. Additionally, I could not find a similar statement in Reference [4] (although I may have missed it).
- Regarding 'navigation' in line 45, do the authors actually mean 'guidance'? Please note the distinctions and connections among the three core components of aviation: navigation, guidance, and control.
- 'While the complexity of open airspace operations is lower' (line 64). Can the authors provide references for this statement? Complexity depends on multiple factors. Open airspace can also reduce complexity through well-designed routes. A more appropriate statement might be: 'Open airspace may have fewer operational constraints.'
- For Figure 1, if VLL U-space is simply modelled as a road network and does not account for altitude changes, how is this fundamentally different from ground traffic? Can techniques from ground traffic management be directly applied? The logic underlying the methods in Figure 5 appears similar to roundabout systems in road traffic (also based on priority operations), which raises further concerns.
- 'Any node is reachable from any other node' (lines 84-85). Is there any theoretical evidence to ensure this claim?
- 'However, the results of our work [16] indicate that such methods are not resilient towards uncertainties that lead to aircraft deviating from their flight plan due to traffic over-optimisation (i.e., the reduction of safety margins as a result of increasing efficiency) [17]' (lines 95-98). This statement seems debatable. Resilience depends on the design of trajectory planning methods, which can balance efficiency and safety through parameter settings (e.g., separation distances or probabilistic considerations).
- For Section 2.2.5, based on the given set of alternative trajectories, it seems Constraint (2) cannot always be satisfied. How is this addressed in unsolvable cases?
- In the proposed 'Dynamic Capacity Management', what exactly constitutes the 'Dynamic' aspect?
- In Section 2, the authors mention multiple previously developed techniques without sufficient introductions. This may force readers to refer to other papers to understand this study. Even then, several described methods remain unclear. I suggest adding descriptions of these methods' main characteristics and including framework diagrams to explain their logic and implementation timing.
- Section 2.6 lacks necessary descriptions of the experimental methods and disclosures of key experimental parameters.
- In Section 2.6.1, based on the limited content and references provided, the optimisation objectives and constraints of the two comparative methods seem different, which challenges the fairness of the experiments.
- The 4DT planning method in Reference [19] may fail to meet the initial conflict-free constraint and is affected by the given set of alternative trajectories.
- Regarding the experimental metric 'The number of intrusion events', what specifically does this refer to?

- In Section 2.6.1, beyond the fixed parameters, the experimental results are influenced by the safety separation distance and flight speeds used in the 4DT methods. Changes in these parameters could alter the experimental results and conclusions, significantly challenging the validity of the findings.
- 'This suggests that the latter set of methods can provide similar safety performance as established strategies while also enhancing airspace stability by not requiring strict flight plan compliance' (lines 241-243). This comment seems subjective, as there is no benchmark. The current results appear only suitable for internal comparison among the control groups to determine which methods are more robust and analyse the reasons behind this.
- 'This suggests that the latter set of methods can provide similar safety performance as established strategies while also enhancing airspace stability by not requiring strict flight plan compliance' (lines 241-243). This conclusion and its rationale are unclear. Could the authors provide further clarification?
- In Section 2.6.1, how is departure delay applied in the experiments? This remains unclear to me.
- In Section 2.6.2, what are the differences 'including and excluding the dynamic capacity management module'? There is a lack of clear experimental method descriptions.
- In Section 3, most discussions validate existing knowledge from traffic engineering or conventional ATM fields, lacking new insights in the authors' specific scenarios. For instance, the content in Section 3.2 reflects the philosophy of layered management (strategic, pre-tactical, tactical) in traditional ATM. Ideally, the most direct method is conflict-free 4DT planning before departure, but due to problem complexity and uncertainties, layered management based on time and space becomes necessary.
- In lines 341 and 345, Reference [36] corresponds to 'Tang', not 'Yang'.
- In Section 4, I recommend discussing Conclusions 2, 3 and 4 in a more dialectical manner. For example, assuming the authors' conclusions are valid, even if decentralised or automated tactical CD&R manoeuvring can lower system complexity, interdependency, and controller/supervisor workload, this approach might sacrifice optimisation and stability while requiring higher equipment performance (e.g., CNS systems). A better approach might be discussing which method balances key performance metrics better in more specific scenarios.

3. Response - round 1

3.1 Response to reviewer 1

This manuscript provides a comprehensive analysis of air traffic management and conflict detection and resolution (CD&R) methods for Very-Low-Level (VLL) U-Space operations. The authors have made a contribution by critically evaluating current approaches, highlighting challenges, and offering recommendations for future research. Their integration of simulation-based methodologies and proposals for dynamic capacity management and tactical deconfliction is a commendable step toward enhancing the safety and efficiency of U-Space operations. While the paper is well-structured and provides valuable insights, I have a few suggestions for improvement.

1. **Clarify the Scope:** The paper mentions methods seems applicable to both Urban Air Mobility (UAM) vehicles, such as eVTOLs, and smaller UAS (drones). The authors should explicitly differentiate between these two scopes, as their safety metrics and operational methodologies often differ. In addition, I suggest elaborating on why certain methods might be more suited to one category over the other, or discussing tailored approaches to accommodate these distinctions. This clarification will help readers understand the distinct requirements and applicability of the

proposed solutions.

Response

We have clarified that our work mainly concerns VTOL operations using small UAS.

2. **Visualization of Integration Framework:** To enhance reader comprehension, I recommend including a diagram that integrates all the methods discussed in the paper. This visual aid would illustrate how the proposed strategies align within a unified framework and their interdependencies.

Response

A system architecture diagram was added in section 2.7.

3. **Correct Reference Details:** In the references, the last name of the first author of citation [36] should be corrected to "Tang."

Response

This has been fixed.

These revisions will strengthen the clarity and impact of the manuscript and further its contribution to the field. I look forward to seeing how the authors address these points in their revised submission.

Response

Thank you for your feedback and for helping us improve our work.

3.2 Response to reviewer 2

The paper offers a good overview of the research conducted by the authors surrounding very-low-level (VLL) conflict detection and resolution (CD&R) in U-space and highlights the need for a unified approach to airspace design, strategic deconfliction, dynamic capacity management (DCB), and tactical deconfliction. The authors present a concise summary of their research in each of these four areas, consolidated within a harmonised simulation environment for VLL traffic. They summarise the results obtained when testing their algorithms against other approaches in the literature, emphasising current limitations and important directions for future research. While suitable for this journal, the following areas need attention.

1. **Title:** The title is somewhat misleading. It suggests a comprehensive review of the subject matter but primarily summarises the authors' prior work, with limited discussion of other relevant research. To align with its title, the manuscript should better present and compare external literature. Alternatively, if the focus is solely on consolidating the authors' own contributions, the title should be revised to better reflect this narrower scope.

Response

We have altered the title to better reflect the scope of the article.

2. **Airspace Structure Design:** The discussion of airspace structure design focuses on the authors' own work without providing an adequate discussion of other proposals in the field. Moreover, the authors should quantitatively compare the performance of different airspace structures, including

their own, in terms of their impact on CD&R, to better reflect the aims of this review. While Section 3.1 references some results, a clear and summarised comparison of airspace structure performances would make the discussion more cohesive.

Response

While we do acknowledge that airspace structuring is an important consideration of U-space system design. In this article, we chose to mainly focus on the CD&R aspect, with the airspace structuring method serving as a way to set up a general testing environment. Thus, in Section 3.1, we acknowledge the limitations of our method and propose it to be improved in the future.
We have thus expanded the discussion on the influence that the airspace structure can have on the performance of CD&R methods in Section 3.1.

3. **Strategic Planning:** The section on strategic planning lacks sufficient context within existing research. While the authors summarise their own contributions, they provide limited insight into how their approach compares to or builds upon other strategies in the field. Additionally, some technical aspects need clarification:
   - The phrase, "The set of routes that can be assigned to aircraft is created by generating alternatives avoiding parts of the nominal flight path," is unclear and should be rewritten.
   - Variables $x_{p,n,theta}$ and $z_{p,y}$ should be adjusted to $x_{f,p,n,theta}$ and $z_{f,p,y}$ to emphasise that a unique variable exists for each flight f.
   - Constraint (1) implies that all flights are accepted, but this assumption is not explicitly stated. The authors should clarify this point and discuss the scalability of their approach in high-density scenarios where rejecting some flight requests may be necessary.
   - The definition of the time windows T should be better explained.

Response

More explanation was added about the way the alternative routes are generated.
The mentioned variable names were amended.
Our approach to ensure problem feasibility was added as a stand-alone section.
A new section was added to better explain the time windows.

4. **DCB:** The discussion of DCB similarly lacks a thorough overview of existing research. Additionally, the metrics referenced in the phrase, "By comparing the effects of various traffic metrics (position, conflicts, intrusions)," should be clearly explained. These metrics should then be used to analyse algorithm performance in Section 3.

Response

We have added a paragraph discussing previous research on dynamic capacity management in Section 2.3. Regarding the metrics, this work only presents the results of the position of conflicts for identifying the clustered areas. We have removed the references to position and intrusions in the text.

5. **Tactical Deconfliction:** The proposed tactical CD&R approach is not clearly explained, and several assumptions need to be explicitly stated. The proposed halting manoeuvre, for example, appears unsuitable for fixed-wing aircraft which cannot hover. If this limitation applies, it should be clearly stated and discussed. Additionally, the need to handle uncooperative aerial entities in tactical CD&R is not addressed, which is a significant concern in urban airspace.

Response

We better clarified the scope of our article to include that the focus is on VTOL-capable aircraft. Within very-low-level constrained airspace (i.e., when flying in-between buildings), it is still unclear whether fixed-wing aircraft with no VTOL capabilities will be allowed to fly.
Furthermore, while it is an important investigation, we indeed did not consider the handling of uncooperative aerial entities. We consider that the procedures for such situations would be implemented within a detect and avoid (DAA) system similar to TCAS in classical aviation. We thus indeed assume that all aircraft are cooperative. We have added an explanation of this within the tactical CD&R section.

6. **Simulation and Results:** While the simulation framework is well-outlined, the results should better reflect the stated aims of the paper. Firstly, no results are provided on airspace structuring or tactical deconfliction, even though these are key aspects of the paper. Second, the authors' algorithms are benchmarked against few other approaches from the literature, limiting the depth of the comparative analysis. Lastly, the results do not clearly link back to the paper's central message advocating for a unified approach to airspace structuring, DCB, and strategic/tactical deconfliction. This connection should be more explicitly drawn in the discussion, beyond analysing the algorithms independently.

Response

It is indeed true that results on the airspace structuring and tactical CD&R were not included in order to maintain a focused and manageable scope for the paper. However, we did include more information about previous work that shows the comparison between the worst-case CD&R method and other methods from literature. We thus expanded the discussion in Section 2.4.
We have also expanded the discussion on our recommendation for a unified approach towards CD&R concept development and testing.

7. **Analysis and Conclusions:** The recommendations provided in the conclusion are sound but would be more compelling if supported by a more comprehensive review and analysis of existing work. While the authors effectively critique their own contributions, they do not sufficiently contextualise their findings within broader research trends. For example, the paper emphasises the need for a unified approach but fails to substantiate how its proposed methods holistically address airspace structuring, DCB, and deconfliction within a harmonised solution. A clearer demonstration of the need for this integration would strengthen the conclusions significantly.

Response

We have expanded the discussion on our recommendation for the use of a unified approach for the design of CD&R methods for U-space operations in a newly created section (3.6).

8. **Grammar and Syntax:** The manuscript is clear but would benefit from grammatical and stylistic revisions. Phrases such as "in our past work, [missing 'we'] developed" and "are not accounted [missing 'for'] within" should be corrected. Similarly, phrases like "as the deployment of U-space operations approaching" need rephrasing for proper syntax. The authors should also avoid vague expressions such as "with relatively high accuracy" and instead use specific, quantifiable comparisons to improve clarity and rigour.

Response

The grammar and syntax has been revised and checked again.

9. **Acronyms:** Acronyms (ex. VLL) should be used consistently throughout the manuscript after their first use.

> Response
>
> The consistency of acronym use was improved.

10. **References:** The references should be carefully reviewed, as some links are currently broken or inaccessible.

> Response
>
> The references were reviewed and the links were fixed.

In summary, the paper should either revise its title to reflect its focus on summarising the authors' work or, preferably, expand its scope to include a comprehensive review and analysis of ongoing research in the four pillars of CD&R. This should involve a detailed comparison of different methodologies and algorithms, supported by quantitative analyses where possible, to justify the proposed directions for future research. By addressing these gaps, the review paper could make a much more substantial contribution to the field.

> Response
>
> Thank you for your feedback and for helping us improve our work.

3.3 Response to reviewer 3

The authors, building on their previous methodological research, explore the **current developments and future prospects of Very-Low-Level (VLL) U-space Conflict Detection and Resolution (CD&R)**. I appreciate the systematic research and contributions made by the authors on this topic. However, this paper appears to be positioned as a review paper, yet most of its content discusses the authors' own studies, which limits the scope and conclusions of the paper. Significant improvements are needed in the depth of discussion, experimental rigour, accuracy of conclusions, and overall readability. Although I believe the paper requires more than a single major revision to meet the publication standards, I would still recommend allowing the authors to address these challenges. Below are my comments for the editor's and authors' reference.

1. **'The CD&R system itself is generally described as a set of three key components [4]: pre-departure strategic planning, dynamic capacity management, and tactical deconfliction.'** (lines 30-31). While I agree with describing these as components of conflict management, stating that they are components of CD&R may be imprecise, as CD&R refers to more specific technologies or operations. Additionally, I could not find a similar statement in Reference [4] (although I may have missed it).

> Response
>
> Please refer to Table 1 in Section 2.2 of Reference [4] (Page 20), *The phases in the life of a flight.* This table shows three relevant U-space services that we attribute to CD&R. In the table these are: (1) Strategic – pre-fligh, (2) Pre-tactical (with demand capacity balancing), and (3) tactical.

2. Regarding **'navigation'** in line 45, do the authors actually mean **'guidance'**? Please note the distinctions and connections among the three core components of aviation: **navigation, guidance, and control.**

Response

The text has been clarified and now states **'guidance'**.

3. **'While the complexity of open airspace operations is lower'** (line 64). Can the authors provide references for this statement? Complexity depends on multiple factors. Open airspace can also reduce complexity through well-designed routes. A more appropriate statement might be: **'Open airspace may have fewer operational constraints.'**

Response

The text has been updated to reflect that open airspace has fewer operational constraints.

4. For **Figure 1**, if VLL U-space is simply modelled as a road network and does not account for altitude changes, how is this fundamentally different from ground traffic? Can techniques from ground traffic management be directly applied? The logic underlying the methods in Figure 5 appears similar to roundabout systems in road traffic (also based on priority operations), which raises further concerns.

Response

In our work, we assume that there are no altitude changes en-route, as we observed that these increase conflicts in urban airspace (reference 7). This has been expanded upon in section 2.1. Since this work focuses specifically on constrained urban environments, where it is not possible to fly straight to the destination, aircraft are limited to operate in a network (similar to ground traffic). However, some important differences are that (1) the required separation threshold is significantly larger than for ground-based vehicles, affecting the way in which operations can be conducted (e.g., two drones cannot fly in parallel on the same street) (2) wind significantly affects cruise velocity, and (3) the turning dynamics of aircraft differ from those of turning vehicles, as explained in section 2.5.

5. **'Any node is reachable from any other node'** (lines 84-85). Is there any theoretical evidence to ensure this claim?

Response

Indeed, the graph configuration was checked and designed in order to ensure that it is strongly connected (i.e., any node is reachable from any other node). This check is performed using the NetworkX Python library within our code.

6. **'However, the results of our work [16] indicate that such methods are not resilient towards uncertainties that lead to aircraft deviating from their flight plan due to traffic over-optimisation (i.e., the reduction of safety margins as a result of increasing efficiency) [17]'** (lines 95-98). This statement seems debatable. Resilience depends on the design of trajectory planning methods, which can balance efficiency and safety through parameter settings (e.g., separation distances or probabilistic considerations).

Response

We have rephrased this part, as well as expanded upon our reasoning.
A system that balances efficiency and safety would need to select a balance based on current conditions, a task which could be difficult given the lack of availability of live-weather data that can

accurately represent the environmental conditions within constrained urban environments (e.g., hyper-local winds, gusts, unexpected delays). The approach we studied achieves resilience without needing to balance efficiency and safety in function of environmental or operational conditions, or better said, by implicitly balancing efficiency and safety through the use of traffic flow as an optimisation objective.

7. For Section 2.2.5, based on the given set of alternative trajectories, it seems Constraint (2) cannot always be satisfied. How is this addressed in unsolvable cases?

Response

We have added another section detailing upon how we deal with this issue. It was indeed only described in our other work. We thus ensure problem feasibility by relaxing constraint number 2 according to the method described now in Section 2.2.8.

8. In the proposed **'Dynamic Capacity Management'**, what exactly constitutes the **'Dynamic'** aspect?

Response

We call this a dynamic method because the identification of high-complexity cluster areas only depends on a current snapshot of the airspace. These cluster areas are continuously updated, therefore, the decision to choose a new route changes depending only on the current situation of the airspace. We have clarified in Section 2.3 that the clusters are created considering the current position, conflicts, or intrusions of aircraft.

9. In Section 2, the authors mention multiple previously developed techniques without sufficient introductions. This may force readers to refer to other papers to understand this study. Even then, several described methods remain unclear. I suggest adding descriptions of these methods' main characteristics and including framework diagrams to explain their logic and implementation timing.

Response

We added more description in section 2 about the methodology to reduce the dependency on reading other works.

10. Section 2.6 lacks necessary descriptions of the experimental methods and disclosures of key experimental parameters.

Response

In order to keep the article at a reasonable length, we chose to focus on the results and conclusions of the previous works. Please refer For a more in depth explanation of the experimental set-up please refer to the referenced works.

11. In Section 2.6.1, based on the limited content and references provided, the optimisation objectives and constraints of the two comparative methods seem different, which challenges the fairness of the experiments.

Response

That is indeed the case. However, the difference in optimisation objective is a large part of the outcome and recommendations, as we suggest shifting the focus from an efficiency-oriented optimisation to a flow-oriented optimisation, that should prioritise traffic flow over prediction-based efficiency and safety trajectory design. Safety and efficiency would then be achieved through the use of tactical manoeuvring. We thus believe that fairness is not a factor to be considered here, as we mainly recommend an alternative for high traffic density situations.

12. The 4DT planning method in Reference [19] may fail to meet the initial conflict-free constraint and is affected by the given set of alternative trajectories.

Response

This can indeed be the case. However, a constraint relaxation method is used to ensure feasibility. We have added an explanation of this procedure (used in our work as well) within the strategic flight planning section.

13. Regarding the experimental metric **'The number of intrusion events'**, what specifically does this refer to?

Response

The meaning of an intrusion event has been explained in the newly added Figure 2.

14. In Section 2.6.1, beyond the fixed parameters, the experimental results are influenced by the safety separation distance and flight speeds used in the 4DT methods. Changes in these parameters could alter the experimental results and conclusions, significantly challenging the validity of the findings.

Response

This is indeed the case, the separation distance and flight speeds could affect the experimental results. However, when selecting the values for these, we aimed to portray the most current vision of how U-space operations will take place within constrained airspace. We furthermore emphasise that the main aim of the results is not to compare the absolute values, but to portray that the 4DT method is more affected by uncertainties than the flow-based methods.

15. **'This suggests that the latter set of methods can provide similar safety performance as established strategies while also enhancing airspace stability by not requiring strict flight plan compliance'** (lines 241-243). This comment seems subjective, as there is no benchmark. The current results appear only suitable for internal comparison among the control groups to determine which methods are more robust and analyse the reasons behind this.

Response

Our aim was indeed to analyse which methods are more robust and analyse the reasons behind this. We have clarified this within the results section. The aim is not to compare the methods in terms of absolute performance, but to study the influence of various factors on the methods, as well as the interactions between them.

16. **'This suggests that the latter set of methods can provide similar safety performance as established strategies while also enhancing airspace stability by not requiring strict**

flight plan compliance' (lines 241-243). This conclusion and its rationale are unclear. Could the authors provide further clarification?

Response

We have expanded upon the discussion and conclusions of the article.

17. In Section 2.6.1, how is departure delay applied in the experiments? This remains unclear to me.

Response

We improved the explanation of the departure delay in section 2.5.

18. In Section 2.6.2, what are the differences **'including and excluding the dynamic capacity management module'?** There is a lack of clear experimental method descriptions.

Response

Aircraft always use the shortest route to their destination and do not consider any route changes in the case where the dynamic capacity management module is excluded. This has been added to the text.

19. In Section 3, most discussions validate existing knowledge from traffic engineering or conventional ATM fields, lacking new insights in the authors' specific scenarios. For instance, the content in Section 3.2 reflects the philosophy of layered management (strategic, pre-tactical, tactical) in traditional ATM. Ideally, the most direct method is conflict-free 4DT planning before departure, but due to problem complexity and uncertainties, layered management based on time and space becomes necessary.

Response

This is indeed the case. Our aim is to reinforce and recommend good practices using results and analysis applied to constrained U-space airspace. We believe the presence of similar knowledge in existing fields serves as validation for our results.

20. In lines 341 and 345, Reference [36] corresponds to **'Tang'**, not **'Yang'**.

Response

This has been corrected.

21. In Section 4, I recommend discussing **Conclusions 2, 3 and 4** in a more dialectical manner. For example, assuming the authors' conclusions are valid, even if **decentralised or automated tactical CD&R manoeuvring can lower system complexity, interdependency, and controller/supervisor workload**, this approach might sacrifice optimisation and stability while requiring higher equipment performance (e.g., CNS systems). A better approach might be discussing which method balances key performance metrics better in more specific scenarios.

Response

We have modified the mentioned conclusions to better reflect our intended recommendations, as well as explained that these should indeed be considered and applied in function of the U-space operational environment characteristics and requirements.

Response

Thank you for your feedback and for helping us improve our work.

4. Review - round 2

4.1 Reviewer 1

The authors have addressed all my comments and I am satisfied with the response.

4.2 Reviewer 2

The authors have substantially improved the manuscript and have addressed many of the initial concerns. The revised paper now presents a clearer and more valuable analysis of CD&R within the context of U-space/UTM. Below are some additional comments based on the updated submission:

(1) Scope: The manuscript now provides a more appropriate contextualisation of related work and better clarifies the scope and intent of the study.

(2) Airspace Structure: The expanded discussion on the impact of airspace structure on CD&R is appreciated and aligns better with the goals of the paper. However, the statement: "Two main approaches towards this exist: open airspace above most buildings, similar to traditional aviation, and constrained airspace, limited to the space above streets" is overly reductive. Several other proposals for urban airspace design exist in the literature. It is recommended to either rephrase this statement for clarity or briefly acknowledge alternative approaches.

(3) Strategic Planning: This section has been improved and is now easier to follow. However: - An additional paragraph in Section 2.2 would be beneficial to briefly outline alternative strategic planning approaches proposed in the literature. - Further discussion is needed regarding the relaxation of the operational flow constraint. Specifically, the rationale for relaxing this constraint instead of the number of accepted missions should be elaborated. Could this choice lead to safety concerns in high-density scenarios? How could the constraint on accepted flights be relaxed, if necessary to preserve system safety and feasibility?

(4) Tactical Deconfliction: This section has been clarified, and the focus on VTOL-capable aircraft is now appropriately stated. Nonetheless, including a comparison or at least referencing established proposals such as ACAS Xu (or sXu) would be beneficial.

(5) Simulation and Results: The structure of this section has improved. However, it still falls short of fully addressing the manuscript's stated aim "to mainly study the interactions between the different components of a CD&R system." Currently, the most compelling results are those illustrating system performance with and without DCB. It would significantly strengthen the contribution to include similar comparative results for other components—i.e., with and without strategic deconfliction, tactical deconfliction, etc.—to better demonstrate the individual and collective impacts of each layer within the CD&R framework.

(6) Discussion and Conclusions: The conclusions are clearer and now better reflect the findings. However, the statement: "Furthermore, the manner in which U-space operations are conducted within VLL constrained airspace is dependent on unique characteristics of the urban environment itself, which can greatly vary even within a single city" should be more clearly elaborated, with examples or clarification of what specific characteristics are being referred to. Additionally, Section 3.6 would benefit from a more thorough discussion, particularly if the suggestion in point 5 is addressed.

(7) Grammar and Syntax: Most language issues have been addressed, but a few minor errors remain. For example, "an dynamic capacity management" should be corrected to "a dynamic capacity management" in Section 2.3. A final careful proofreading is recommended.

Overall, the authors have effectively addressed the majority of earlier concerns, and the quality of the manuscript has improved considerably. Some minor comments should be addressed prior to publication. Once these are resolved, the manuscript will be well-suited for acceptance.

4.3 Reviewer 3

I would like to thank the authors for their constructive response and for actively addressing my previous concerns. The overall quality of the paper has been significantly improved, and the authors have managed to resolve most of the issues I raised. From the perspective of sharing research progress, the current version of the manuscript is acceptable.

For potential further enhancement of the paper, I would like to offer the following optional suggestions. Please note that none of these are mandatory, but I hope they may help improve clarity and rigor:

Comment 1 Response:

The revised manuscript still appears to differ in expression from the description in reference [4]. Moreover, in general, Dynamic Capacity Management refers to the management of controllers and sectors, whereas CD&R typically relate to flights. Considering the authors' reply to Comment 8, I suspect that the term intended here may be Dynamic Demand Management instead of Dynamic Capacity Management.

Comment 4 Response:

Among the three points proposed by the authors to differentiate air traffic from ground traffic systems, I find the first and third points debatable, while the second point could be valid. My reasoning is as follows:

(1) The idea of a single-lane system is not unique to air traffic, as similar constraints exist in ground traffic systems as well, such as single-lane roads. (2) While the influence of wind on velocity may be less relevant in ground traffic, it is still one of many sources of uncertainty. Therefore, what is the essential difference between uncertainty caused by wind in air traffic and uncertainties in ground traffic? If the authors believe that this factor fundamentally distinguishes their problem setting, a more in-depth discussion is needed. (3) Vehicles also have a turning radius, so the third distinction might not hold strongly.

Comment 6 Response:

The authors' logic in responding to my concern seems potentially vulnerable. The proposed method appears to manage uncertainty primarily by increasing the spacing in the initial separation management step (the proposed traffic flow management in this paper), which in essence creates a larger buffer. Similar effects can be easily achieved in general trajectory planning models—for example, if a conflict is defined as separation less than 200 meters, one could simply set the separation constraint in the optimisation model to 500 meters to achieve increased robustness.

This is why I initially requested a justification of the fairness in the comparative experiments.

Comment 11 Response:

It is still unclear what 'flow-oriented optimisation' means exactly. If this is a core methodological distinction, then the experimental design should include comparisons with other flow-oriented

methods using flow-related performance metrics.

Comment 14 Response:

I respectfully disagree with the authors' claim that 'the main aim of the results is not to compare the absolute values, but to portray that the 4DT method is more affected by uncertainties than the flow-based methods.' As discussed in my response to Comment 6, the presented results may not convincingly support this objective.

5. Response - round 2

5.1 Response to reviewer 2

The authors have substantially improved the manuscript and have addressed many of the initial concerns. The revised paper now presents a clearer and more valuable analysis of CD&R within the context of U-space/UTM. Below are some additional comments based on the updated submission:

1. **Scope**: The manuscript now provides a more appropriate contextualisation of related work and better clarifies the scope and intent of the study.
2. **Airspace Structure**: The expanded discussion on the impact of airspace structure on CD&R is appreciated and aligns better with the goals of the paper. However, the statement: "Two main approaches towards this exist: open airspace above most buildings, similar to traditional aviation, and constrained airspace, limited to the space above streets" is overly reductive. Several other proposals for urban airspace design exist in the literature. It is recommended to either rephrase this statement for clarity or briefly acknowledge alternative approaches.

   Response

   We have reworded the sentence to state that we are talking about the degree of constraints that the urban infrastructure imposes on the airspace. We now refer to it as a spectrum to imply that there can be a mix of both constrainedand open airspace.

3. **Strategic Planning** This section has been improved and is now easier to follow. However:
   - An additional paragraph in Section 2.2 would be beneficial to briefly outline alternative strategic planning approaches proposed in the literature.
   - Further discussion is needed regarding the relaxation of the operational flow constraint. Specifically, the rationale for relaxing this constraint instead of the number of accepted missions should be elaborated. Could this choice lead to safety concerns in high-density scenarios? How could the constraint on accepted flights be relaxed, if necessary to preserve system safety and feasibility?

   Response

   The main idea behind the constraint relaxation is to allow these remaining conflicts to be resolved by the tactical conflict detection and resolution module, as opposed to canceling missions. We have added this explanation in text.

4. **Tactical Deconfliction**: This section has been clarified, and the focus on VTOL-capable aircraft is now appropriately stated. Nonetheless, including a comparison or at least referencing established proposals such as ACAS Xu (or sXu) would be beneficial.

Response

Such references have been added.

5. **Simulation and Results**: The structure of this section has improved. However, it still falls short of fully addressing the manuscript's stated aim "to mainly study the interactions between the different components of a CD&R system." Currently, the most compelling results are those illustrating system performance with and without DCB. It would significantly strengthen the contribution to include similar comparative results for other components—i.e., with and without strategic deconfliction, tactical deconfliction, etc.—to better demonstrate the individual and collective impacts of each layer within the CD&R framework.

Response

We have indeed performed such investigations in previous work which we did not include in this article in order to limit the scope.

6. **Discussion and Conclusions**: The conclusions are clearer and now better reflect the findings. However, the statement: "Furthermore, the manner in which U-space operations are conducted within VLL constrained airspace is dependent on unique characteristics of the urban environment itself, which can greatly vary even within a single city" should be more clearly elaborated, with examples or clarification of what specific characteristics are being referred to. Additionally, Section 3.6 would benefit from a more thorough discussion, particularly if the suggestion in point 5 is addressed.

Response

We have clarified that an example refers to how structure of the street network may either be highly orthogonal or non-orthogonal.

7. **Grammar and Syntax**: Most language issues have been addressed, but a few minor errors remain. For example, "an dynamic capacity management" should be corrected to "a dynamic capacity management" in Section 2.3. A final careful proofreading is recommended.

Response

This has been corrected and we have done another proofreading.

Overall, the authors have effectively addressed the majority of earlier concerns, and the quality of the manuscript has improved considerably. Some minor comments should be addressed prior to publication. Once these are resolved, the manuscript will be well-suited for acceptance.

5.2 Response to reviewer 3

I would like to thank the authors for their constructive response and for actively addressing my previous concerns. The overall quality of the paper has been significantly improved, and the authors have managed to resolve most of the issues I raised. From the perspective of sharing research progress, the current version of the manuscript is acceptable. For potential further enhancement of the paper, I would like to offer the following optional suggestions. Please note that none of these are mandatory, but I hope they may help improve clarity and rigor:

1. **Comment 1 Response**: The revised manuscript still appears to differ in expression from the description in reference [4]. Moreover, in general, Dynamic Capacity Management refers to the

management of controllers and sectors, whereas CD&R typically relate to flights. Considering the authors' reply to Comment 8, I suspect that the term intended here may be Dynamic Demand Management instead of Dynamic Capacity Management.

Response

This a fair comment. However, the method works to locally manage the capacity of a certain area. The demand distributions for the missions is not modified. We have updated section 2.3 to state that we are lowering local traffic density and complexity.

2. **Comment 4 Response**: Among the three points proposed by the authors to differentiate air traffic from ground traffic systems, I find the first and third points debatable, while the second point could be valid. My reasoning is as follows:
   - The idea of a single-lane system is not unique to air traffic, as similar constraints exist in ground traffic systems as well, such as single-lane roads.
   - While the influence of wind on velocity may be less relevant in ground traffic, it is still one of many sources of uncertainty. Therefore, what is the essential difference between uncertainty caused by wind in air traffic and uncertainties in ground traffic? If the authors believe that this factor fundamentally distinguishes their problem setting, a more in-depth discussion is needed.
   - Vehicles also have a turning radius, so the third distinction might not hold strongly.

Response

This is fair argument. Perhaps it would be interesting to furher study different ground traffic strategies to apply them to constrained airspace design.

3. **Comment 6 Response**: The authors' logic in responding to my concern seems potentially vulnerable. The proposed method appears to manage uncertainty primarily by increasing the spacing in the initial separation management step (the proposed traffic flow management in this paper), which in essence creates a larger buffer. Similar effects can be easily achieved in general trajectory planning models—for example, if a conflict is defined as separation less than 200 meters, one could simply set the separation constraint in the optimisation model to 500 meters to achieve increased robustness. This is why I initially requested a justification of the fairness in the comparative experiments.

Response

We have added further explanations in section 2.2.3 to better explain the flow management concept. The proposed method differs from applying buffers due to the fact that, in theory, two aircraft can still arrive at an intersection at the same time. Thus, the planning would not necessarily ensure their separation, a task delegated to the tactical CD&R module. In Fig. 9 of the article, we test different combinations of time windows and node capacities. While increasing the node capacity does affect safety, the interesting find is that using this type of planning achieves robustness towards uncertainty.

4. Comment 11 Response: It is still unclear what 'flow-oriented optimisation' means exactly. If this is a core methodological distinction, then the experimental design should include comparisons with other flow-oriented methods using flow-related performance metrics.

Response

Please refer to the previous response.

5. **Comment 14 Response**: I respectfully disagree with the authors' claim that 'the main aim of the results is not to compare the absolute values, but to portray that the 4DT method is more affected by uncertainties than the flow-based methods.' As discussed in my response to Comment 6, the presented results may not convincingly support this objective.

Response

We added more explanations to support our stated aim.