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**POSSIBLE SOLUTIONS FOR THE FLIGHT OF SEVERAL UNMANNED AIRCRAFT SYSTEMS IN URBAN AREAS**

**Summary.** The development and use of unmanned airborne systems are currently undergoing a huge transformation. This allows the development of computer technology, new materials for their construction. Reducing airborne funds would enable them to be widely used. This applies to not only military use but also mainly civil use, industrial and commercial use as well. This new use brings new challenges, including security, legislative, technical, social, and so forth. This paper focused on the possibility of having several Unmanned Aircraft Systems movement in urban areas. It contains the description of a philosophical proposal of flight corridors and flight trajectories in urban areas with the example of a small town.

**Keywords:** Unmanned Aircraft System, urban area, pilot-operator, flight corridor, flight trajectory

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## 1. INTRODUCTION

The use of several Unmanned Aircraft Systems (UAS) in urban areas has proven to be one possible solution for parcel delivery to customers in the future, however, it is forbidden according to the current European and worldwide legislation. Quick delivery of goods to the customer is the current trend in business and this is what new devices like Unmanned Aircraft Systems seek. Presently used as one way of delivery for individual goods, it is being explored for mass delivery of goods in the future.

It is concerned mainly with light package weighing up to 20 kg, delivered to customers through Unmanned Aircraft Systems with maximal take-off weight up to 27 kg.

The aim of this paper is to analyse possible conditions and propose possibilities under which several Unmanned Aircraft Systems would fly in urban areas in the future.

## 2. PRINCIPAL CONDITIONS FOR FLIGHT OF SEVERAL UAS

The philosophy of movement of several UAS ( $n$  UAS) requests to introduce into the system of such conditions, which assure:

- a) Flight safety – not only safe mission fulfilment;
- b) The solving of a psychological problem – the introduction of such operations into the lives of people without any apprehension resulting from potential risk.  
Until now, no survey of peoples' reaction on the flight of one or several UAS in the town was conducted. The simple survey focused on the use of auto aircraft in the Czech Republic turned out in the negative (40% of people voted in favour of, while 60% of people counter voted against);
- c) UAS technical solution;
- d) Flights in solid legislative conditions.

The above-mentioned conditions are linked together. Safety is interconnected with technical and legislative problems. We will deal more with the technical and partially with safety and psychological problems. These conditions are as follows (Figure 1):

- exact and reliable UAS control, also without direct visibility,
- necessity of autonomous control,
- necessity of coordination with other UAS,
- solution of safety – collisions,
- automatic landing at take-off place,
- automatic emergency landing,
- requirements on safety design and meeting of all requirements resulting from legislation, etc.

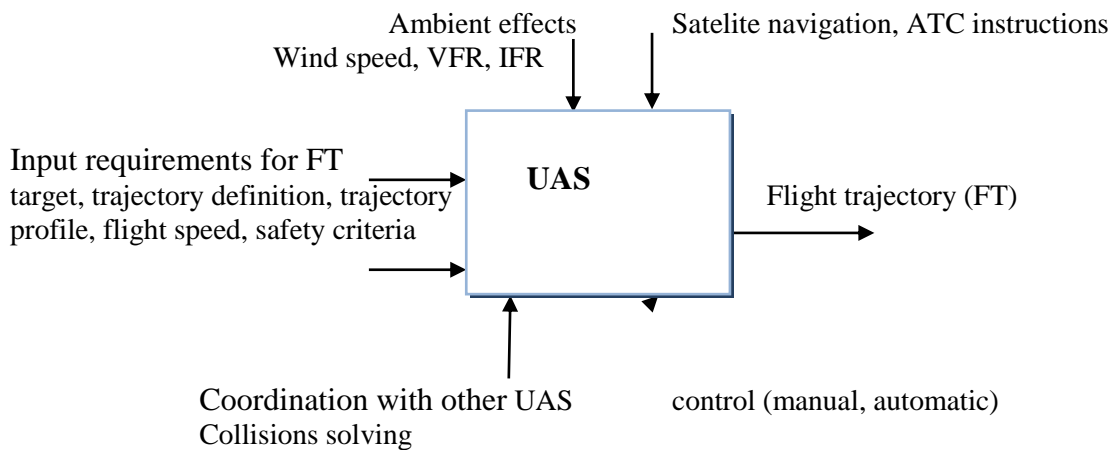


Fig. 1. Model philosophy of more - n UAS movement

Above conditions must be met by all UAS with strict compliance.

### 3. INITIAL AMBIENT CONDITIONS FOR FLIGHT OF SEVERAL UAS

An ambient condition is another important determining factor for flight movement of several UAS, especially in urban areas.

The most important ambient conditions are:

- a) day time,
- b) Weather,
- c) Environment,
- d) building obstacles,
- e) energy obstacles,
- f) emergency landing possibility.

a) *Day time* is an important parameter because during the day it is easy to make a visual sighting of the controlled UAS, as such normal people can react to its presence, accordingly. However, it is difficult to sight a UAS at night owing to the ensued darkness.

b) *Weather*: 1) Under visibility – in wind speed (WS) up to 20 km/h - IFR  
2) During the night and in reduced visibility in the course of automatic control assurance in meeting landing safety in wind speed of up to 20km/h - VFR

Therefore, functional dependency for flight trajectory (FT) can be formulated thus:

$$FT = f(IFR, VFR, WS) \quad (1)$$

c) *Environment*: These are the towns and villages divided according to habitation structure from the security point of view. Different requirements are observed in different sections of these localities, that is, populated area, park, square or field, meadows and forest. Presently, some enthusiasts have been observed flying UAS around the residential houses without observing safety standards. From a safety viewpoint, it might be impossible to avoid collision with humans and UAS in the future.



Side target trajectories

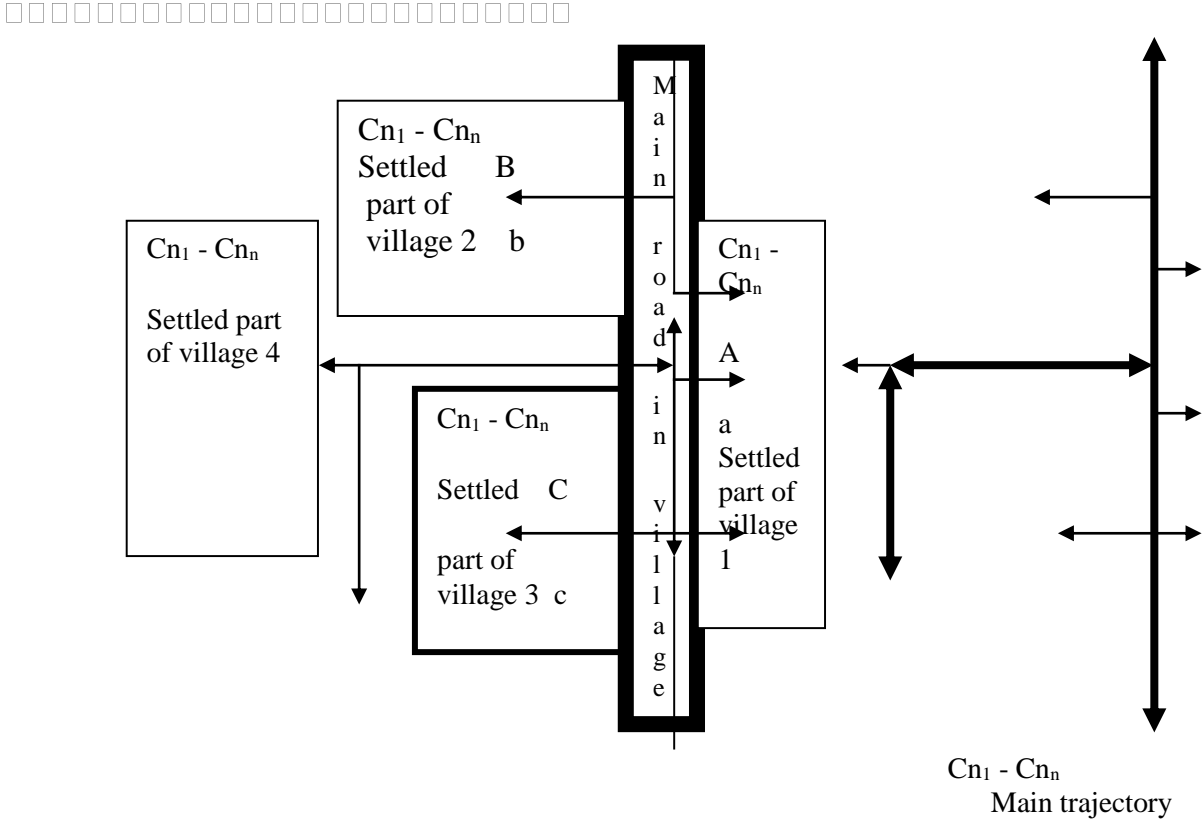


Fig. 2. Principal village divided into individual parts

For a smaller town, it is possible to come out from its principal structure and propose closed settled agglomerations and among these introduce and select suitable safe flight trajectories as shown in Figure 3 and Figure 4, respectively.

**5. PHILOSOPHY OF FLIGHT CORRIDORS AND FLIGHT TRAJECTORIES**

It is necessary to define the needed data for a flight in the flight space (flight corridor) – “tunnel” with the exact defined and approved flight trajectory (defined course, flight altitude and speed range), with the defined control points and potential crossing of flight corridors and flight trajectories. Division of corridors can be according to local organisation and operation intensity in several flight trajectories. The flight corridor illustrated in Figure 5; it is divided into four flight trajectories in Figure 5a and six flight trajectories in Figure 5b.

Flight in the flight corridor “tunnel” must be well defined and must have defined space for entrance and exit of UAS from the flight corridor. Regarding the current division of flight corridors, it turns out to be a suitable corridor up to altitude maximum 300 m. It is valid without the definition of safety separation. The developed legislative documents accept maximum UAS flight altitude of up to 150 m. Due to this fact, the flight corridor begins from the minimum UAS flight altitude, that is, 10 m and maximum altitude up to 150 m. High-altitude distance of flight corridor will be 50 m. Width distance would arise from the safety condition defined in the given locality. Practical experience demonstrates that this distance would be in the range 5-20 m.

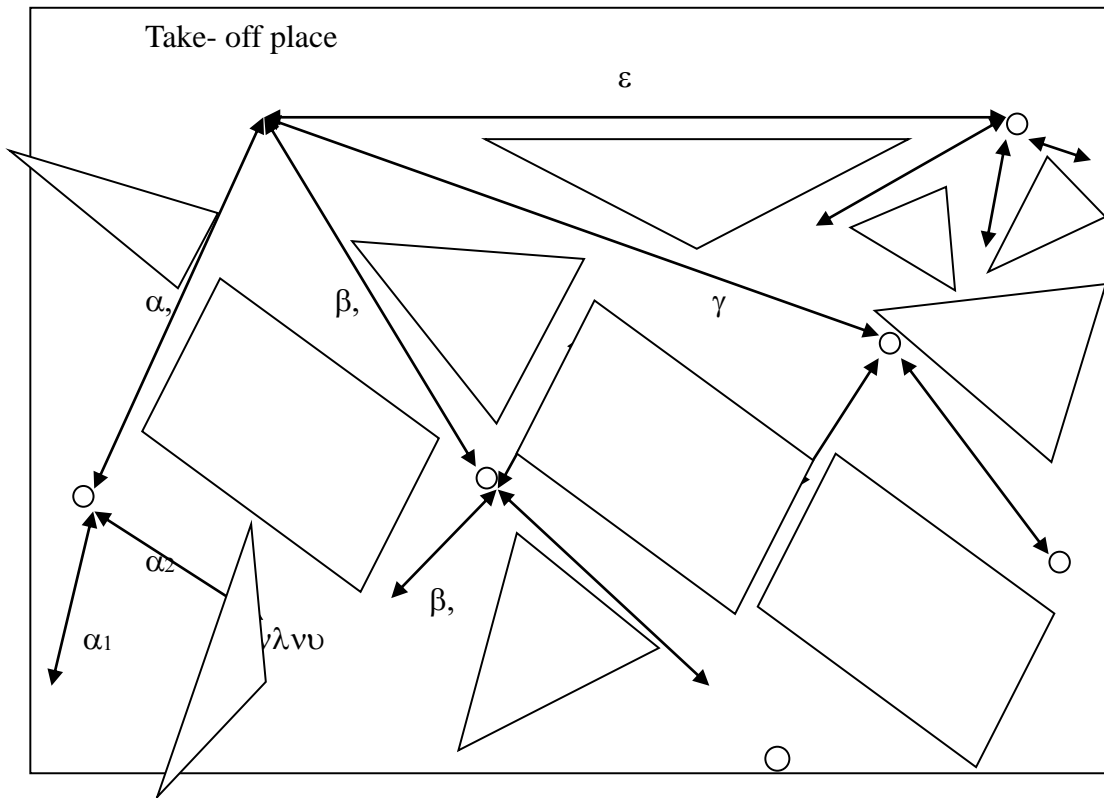


Fig. 3. Philosophy of town divided into individual parts

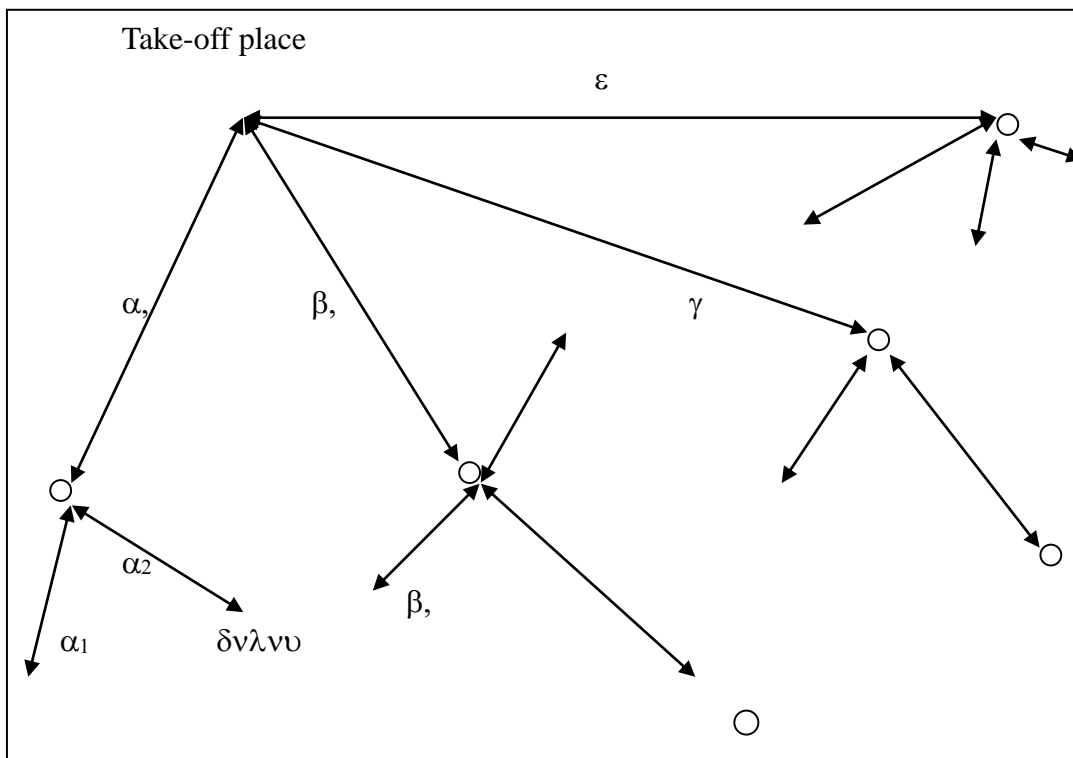


Fig. 4. Philosophy of selected and exactly defined town flight trajectories in individual parts

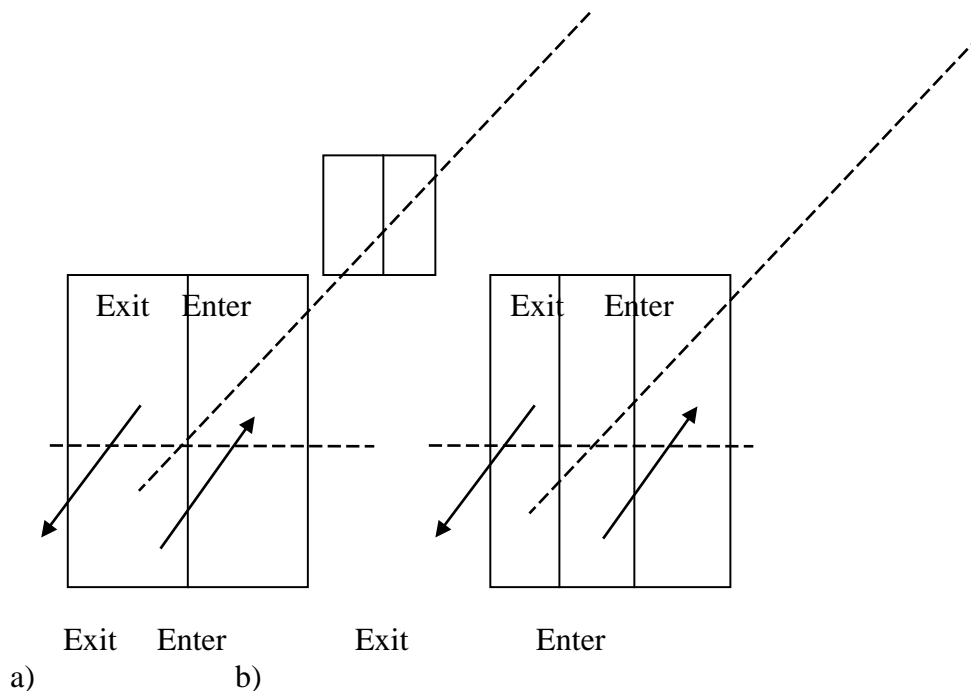


Fig. 5. Philosophy of flight corridors and flight trajectories,  
 a) corridor with four flight trajectories, b) corridor with six flight trajectories

## 6. FLIGHT CORRIDORS ELABORATION PROCEDURE FOR UAS OPERATION

Flight corridors (FC) are designated only for UAS operation. In the framework of our considerations, we assume the UAS is used, for example, by the distribution companies, for the realisation of the delivery of parcels from the company warehouse to the target destination. The target destination is subsequently the place selected in advance by the customer (buyer). Selection of target destinations corresponds with the FC network outside the town. Customer selects parcel delivery place during order.

The idea of FC in the selection of spaces should be assured the following conditions:

- 1) Adequate safety.
- 2) Adequate place service.
- 3) Possible connection of published sectors.

These general conditions are subsequently applied to the concrete decision-making process for FC selection. FC is first selected in a horizontal plane with the help of an internet map. Herein, the selection is controlled by undermentioned requirements for the fulfilment of initial conditions.

Subsequently, the vertical plane was proposed. It contents describe the accrued FC only. Operation of FC depends on equipping of unmanned aircraft only. It assumes mostly autonomous flights (over advance planned routes outsider FC) without visual control of pilots-operators, which is in discrepancy with the actual formulation of regulations almost all around the world. FC eventually consists of three more aviation routes (depending on the width of the road, water surface and railway) within them in a UAS operation. FC placed above the earlier selected spaces in that manner pose no safety risk.

### 6.1. Horizontal selection of flight corridors

Suitable spaces (trajectories) for flight corridors (FC) creation were selected through the use of internet maps. These spaces are:

- 1) Existing transport lines - roads, railways, cycle paths.
- 2) Watercourses- lakes.
- 3) Energy routes – electric, oil, gas
- 4) Free surfaces – meadows, forests, mountain ranges.

Due to the selection of these spaces, the safety of the flight trajectories is increased. Possible incidents on roads, watercourses or railways would not have fatal results. In addition, they ensure the possibility of satisfactory UAS separation from persons, because increased movement of persons in these areas is not expected. These usable trajectories were marked on the map. The main and additional routes were selected by the valuation of the company domicile location and selected trajectories. These routes are also marked and differentiated.

### 6.2. Vertical segmentation of flight corridors

The inspiration for the vertical division of flight corridors was gotten from the dividing of air space for transport aircraft operation. A lone corridor is situated 100 m above ground level and it is up to altitude an of 150 m above ground level. This ensures the impossibility of likely collision with ambient traffic because minimal flight altitude above densely built-up areas according to VFR rule is 300 m. Taking into account the different sizes of possible operating UAS, it is suitable to divide this space vertically as well. Dividing ensures sufficient spaces for the operation of any UAS. During denser traffic, however, there would be need for this segment to be further divided horizontally in order to increase route capacity.

Flight in “tunnel” with space dividing according to altitude and speed is introduced in Figure 6.

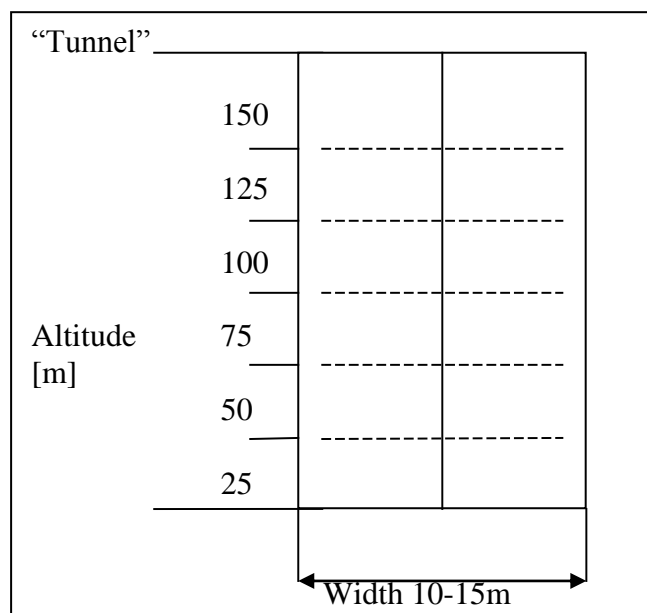


Fig. 6. Philosophy of flight corridors and flight trajectories



### 6.3. Functional dependence on movement proposal

Flight trajectory is an important parameter from all points of view on which probably depends also the overall mass deployment of UAS into urban agglomerations.

The basic definition of flight trajectory (FT) is designated as follow:

- ZLT – engaged flight trajectory,
- SNS – satellite navigation system,
- $H_b$  – altitude barometric,
- $H_{SNS}$  – altitude,
- $H_{ra}$  – radio altitude,
- $v$  – flying speed against the ground,
- OP – orientation points,
- OI – operation intensity.

$$FT = f(SNS, H_b, H_{SNS}, H_{ra}, v, OP, OI) \quad (2)$$

Achievement of this functional dependence will fundamentally determine the use of UAS in urban agglomerations in the future.

## 7. AN EXAMPLE OF FLIGHT CORRIDORS AND FLIGHT TRAJECTORIES SELECTION

An example of flight corridors and flight trajectories selection with labelling of applicable trajectories for flight routes creation is illustrated in Frýdlant nad Ostravicí town in the Moravian-Silesian Region.

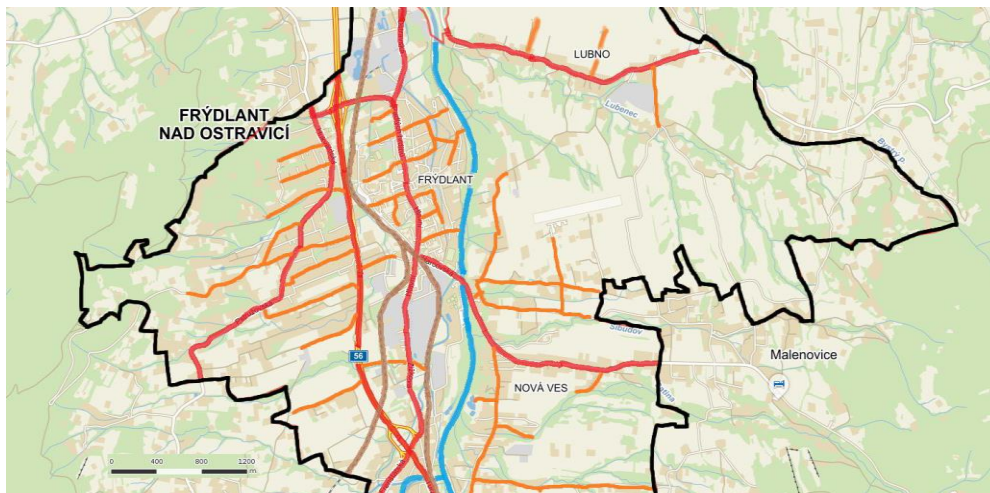


Fig. 7. Labelling of applicable trajectories for flight routes creation in the framework of Frýdlant nad Ostravicí town

For this purpose, we used the accessible map (mapy.cz) with the possibility of routes network labelling. This is easy to use as an example for illustration and creation of flight corridors and flight trajectories. For simplicity, we assumed that flight corridors must not be directly above roads, but beside roads, where there is sufficient space. Selection of flight corridors must be approached with sound knowledge of places and safety compliance.

Labelling of applicable trajectories for flight routes creation in the framework of Frýdlant nad Ostravicí town is illustrated in Figure 8. This figure represents the selected flight routes network for the UAS operation. By the red and orange colours are images of the main and minor flight routes above the roads. By the brown colour is the image of the flight routes above the railways and by the blue colour is the image above the watercourses. The black line determines the borders of Frýdlant nad Ostravicí town.

The network of selected flight routes is dense in the centre of the town, less dense in the surroundings parts of the town, Lubno and Nová Ves (Figure 8). There is no intersection of flight routes and sectors designated for UAS operation. The utility of these places is likely to increase faster UAS overflights.

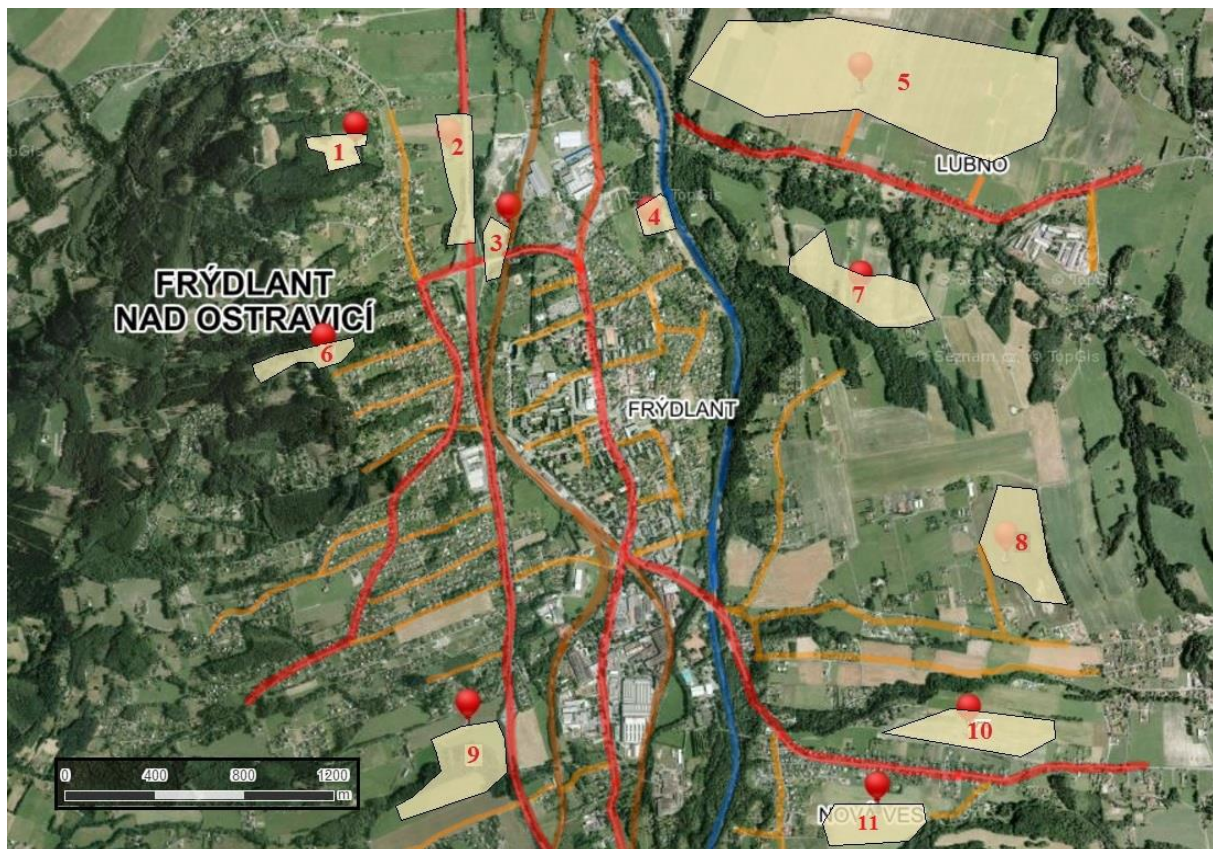


Fig. 8. Labelling of flight corridors in the framework of Frýdlant nad Ostravicí town in conjunction with overview of proposed corridors locations for UAS operation

Sample visualisation of flight corridors is illustrated in Figure 9. Operation directions are opposite on all minor routes: A, B and C. In the course of turning from middle route B are UAS avoiding the horizontal plane with AIS inside routes A or C. These measures alone increase the safety of the proposal.

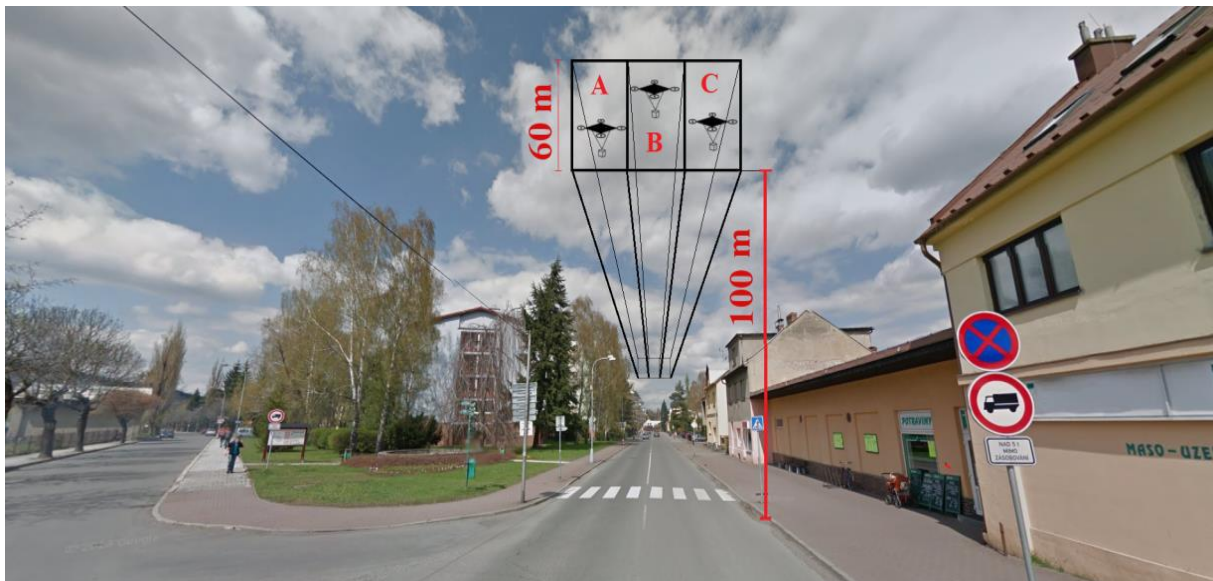


Fig. 9. Visualisation of flight corridors in the framework of Frýdlant nad Ostravicí town in conjunction with overview of proposed corridors locations for UAS operation

## 8. SAFETY RISKS OF UAS OPERATION IN AGGLOMERATIONS

For proposals finalisation of the possibility of UAS operation in agglomerations, the safety of these systems needs to be taken into consideration. A lot of potential risks originate during the use of UAS, hence the need for safety assurance. In spite of this, we were able to identify and anticipate in a great measure, eventual incidents or accidents.

One big advantage in the safety area is legislation. It requires the installation of Fail-Safe systems on almost all UAS (apart from UAS with maximum take-off weight (MTOW) up to 0,91 kg in recreational or sports operation). Fail-Safe systems are bound to improve with the development of new technologies. It is assumed that they would become the backbone of UAS safety operation assurance. It is worth mentioning that presently, these systems, for the most part, guarantee the UAS come back to its pilot-operator. Assuredly, we will have more sophisticated versions in the future, which will be able to perform autonomous operations with automatic compliance with minimum distances in the case of heavier UAS.

Single safety of UAS is therefore satisfactory, especially from the technical point of view. It is bright, with the increase of MTOW, the potential risk rate of operation is increased as well.

### 8.1. UAS operation safety in the framework of setting sectors

The setting sectors proposals in this paper, in general, is to serve UAS operation. Introduced sectors are according to current legislative/instruction, requirements for UAS operation with MTOW up to 7 kg. Nevertheless, this fact does not exclude the possibilities of a lighter UAS operation.

The reasons for minimum distances, which must be complied with during a UAS flight are apparent. The highest risk is the likely collision of UAS with persons. Considering the speed and weight of a flying UAS, this collision could have fatal results. Due to this fact, the conditions for distance minimum compliance appear logical and obligatory, it is also valid for possible UAS collision with buildings or other objects in the framework of towns (high

voltage towers, antennas, trees). Probably, this does not present any direct threat to persons, however, the potential occasional financial damage is a high motivation for taking such relevant measurements. Setting of applicable corridors in compliance with the safety minimum distance is, therefore, a satisfactory prevention guarantee of the legislative/regulation standards.

The motivation for operation sectors setting was previously discussed in the paper. For now, it is needed to ensure the functioning of own sectors. Only publishing of borders and sectors size suitable for UAS operation does not ensure the continued serviceability of the sector. We must consider the possible accrued situations, which can threaten the serviceability of the sector. One of such possibilities is the movement of persons outside of the space. In this case, it is required to ensure minimum safety distance between a person and a UAS according to the instruction, which in this case represents 50 m and 100 m eventually. During movement of persons especially in the framework of smaller sectors, consequent considerable possible UAS operation may occur. Some sectors could become completely unusable. One of the possible solutions is the placing of operational central outside of the given sector. Suitable placing of central ensures satisfactory visibility over the whole sector. These sectors serve not only monitoring purposes except the sector is not in some way disrupted (that is, if restriction does not occur, leading to an impossible operation eventually), but also for UAS control. One operational central for monitoring operation and situation inside the sector is sufficient for nearby sectors. In the case of a large space, more operational central needs to be built. The advantages of this solution is that it solves other potentially limiting situations. These situations can be, for example, operation of other aircraft in the framework of the sector. Thanks to the operational central, it would be possible to ensure continual communication with close by operations, which would considerably increase the effectiveness of the proposed corridors.

## **8.2. Operation safety of UAS with weight up to 7 kg in the framework of a town**

For the UAS with MTOW up to 7 kg, the application of conditions concerning minimum distances is of no effect. In the current legislation, these minimum requirement is defined as “safe”. Thus, it depends first on the responsibility and experience of the UAS pilot. The obligatory UAS accounts are valid for all UAS in the profit, experimental or research operation and also for all systems with MTOW above 27 kg, where pilot registration is required too. For these cases, therefore, lies the responsibility of flight execution, pre-flight control and pilot preparation. According to the law, a pilot must use an unmanned system only for the purpose for which it was produced, designed and at the same time in such a way, that the technical parameters and UAS manner of use is in accordance with valid legislative requirements. In addition to this, the pilot-operator must record relevant flight information. Events of non-registered “UAS” pilots must not be reported. For this reason, it is impossible to elaborate on the statistics concerning operational safety of lighter UAS used for recreational and sport purposes.

## **8.3. Flight routes safety for UAS operation in the framework of a town**

Bottom limit of flight route is designated at 100 m altitude above the ground. This altitude meets minimum distance for take-off /landing and proper distance away from persons according to current legislation for UAS with MTOW up to 7 kg. The variation from actual regulation is in minimum distances between UAS, buildings and urban areas. This

discrepancy has been considered in draft only as a distinction between UAS flight altitude and height of the building.

UAS operation under the reduced minimum distance is of key importance for real use of UAS in towns. The proposed system takes into account the autonomous UAS operation according to advance planning trajectories. These trajectories are recorded into the navigation computer of the UAS.

Under the compliance with these conditions and assumptions, UAS could be in the framework of published routes to fly without pilot supervision and at night. The possibilities of cargo and package delivery are in these ways increased as well as overall ease of the proposed system.

## 9. CONCLUSIONS

Current conditions (technical, legislative) do not allow mass usage of UAS in urban areas. It is only a matter of years before they meet all required conditions for safety movement for first single flights, then mass flights in densely populated urban areas.

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