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A METHODOLOGY AND FIRST RESULTS TO ASSESS THE POTENTIAL OF URBAN AIR MOBILITY CONCEPTS

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ABSTRACT:

This article is about a methodology to conceptually design and comprehensively assess the technical and operational feasibility of urban air mobility as well as the potential added value.
At the beginning a wide analysis of the scene for Urban Air Mobility is given. Furthermore, initial design proposals for the setup of various system elements are derived. For this purpose, the structured approach itself is presented. In a second step, the model based workflow is described.
The last part gives a first insight into the results, which will be elaborated with the workflow environment.

1. INTRODUCTION

Urban air mobility is a highly notified trend in mobility and especially in aviation. Therefore, the Institute of Air Transportation Systems of the Hamburg University of Technology in collaboration with DLR Air Transportation Systems started to perform a study to investigate the potential of mobility concepts based on such vehicles, [1].
Much more than one hundred air vehicle concepts are worldwide under development, [2], [3].

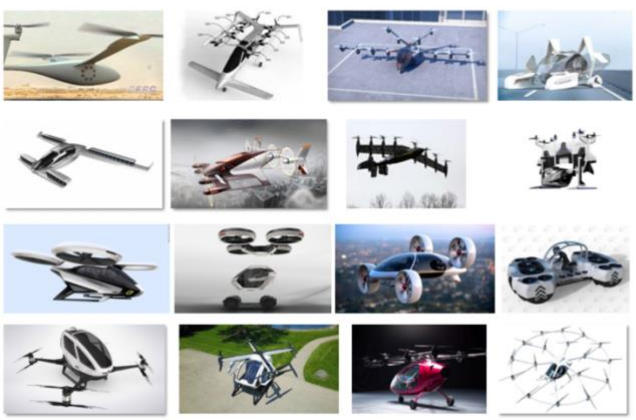

Figure 1. Examples of Urban Air Taxis, [2]

The level of maturity of these concepts varies fairly wide from conceptual ideas up to demonstrator, prototype and pre series level, like Lilium, UBER, VOLOCOPTER, [2]. Also Boeing (KittyHawk) and Airbus (VAHANA) and Airbus Helicopters Germany (City Airbus) develop such vehicles to investigate the potentials of the concepts itself but also single technologies like VTOL drive concepts, [2].

The upcoming of these concepts is mainly driven by significant advances in automation and the drone market. But also high performance communication and navigation technologies enable the operation of such vehicles in confined urban areas.

Further after various big and cost intensive development programmes like Airbus A350, or Boeing B787 “Dreamliner” and various others the aeronautical industry is consolidating and focussing on efficient production and return on investment of the new products.

There is also a strong yearning among aerospace engineers to develop new air vehicle, which look different and innovative. These emotional and irrational aspects drive the development of urban air mobility, too.

Highly congested urban ground transport in many regions cries for alternatives to enhance capacities.

There are also some indications like the daily operation of about 500 helicopters with about 700 flights in Sao Paolo to overcome the highly congested ground transport, which support the hypothesis, that there is some drive behind this new type of mobility, [10].

Also, industry leaders like Tom Enders, the former executive of Airbus, state, that they expect the establishment of Urban Air Mobility within 10 years from now, [11].

Therefore, we are currently facing the development of a new type of mobility, which is not only driven by real market needs but more by the aforementioned trends.

However, operational concepts are not yet mature while blueprints from e.g. DLR, A3 and SESAR already exist, e.g. [13].

This resumes to the need to investigate the overall technical and operational feasibility of urban air mobility concepts from a more “top down” perspective to find out whether there is a reasonable and feasible

overall architecture and market.
Because of the complexity of interdependent systems, it is not possible to investigate right from the beginning all details in all relevant areas. To find some resilient answers about the feasibility and added value of such a concept a holistic system of systems approach is required.

We follow an approach to enable an analysis of principle feasibility on a conceptual but holistic basis. Especially interdependencies and impacts of various disciplines in width are important to identify and assess at very early stages.

With this initiated research study following key questions shall be addressed:

– Which *method* provides a resilient feasibility proof of urban air mobility concepts?
– What kind of *demand* can be expected?
– How may principle *air traffic architectures* look like in urban environments?
– Which *infrastructures* in terms of *landing areas* but also *guidance, navigation, command and control systems* are needed to operate such urban air vehicles?
– How may *flight routes* and *networks* look like?
– What is the *societal impact* or under which conditions such concepts could be accepted?
– What are the *added value and potential cost*?

These questions are the focus of the study being performed at the institute.

2. SOME BASICS AND DEFINITIONS

Urban Air Mobility today is not clearly defined. Therefore in the following the urban area but also the considered vehicles will be defined.

2.1. Urban Air Vehicles

Mostly urban air vehicles are commonly understood as urban air taxis. However, also drones are considered for various operations such as surveillance or package deliveries.
Some address passenger transport in urban environment with on board piloted or remotely piloted vehicles.

Others consider the use of unmanned air vehicles in urban areas as urban air mobility. In the context of this study urban air systems are considered as air vehicles, which fulfil the following major characteristics:

	Passenger-transport	Cargo-transport	Special Operations
Manned (Pilot)	X	X	X
Unmanned	X	X	X

Table 1. Definition of Urban Air Vehicles

In addition to this very basic definition also the associated ground services and infrastructures are considered with these systems.
Regarding the payload size an orientation towards individual ground transport is useful, [2], [3]; leading to payload sizes of 2 – 4 (eventually 10) passengers. Also, the most accepted concept paper of UBER defines the passenger payload in this range, [4].
This means a considerable payload range is between 200 kg – 400 kg (1000 kg) roughly.
Overall, takeoff masses are estimated in a range of 350 – 900 kg (2500 kg) approximately, [2].

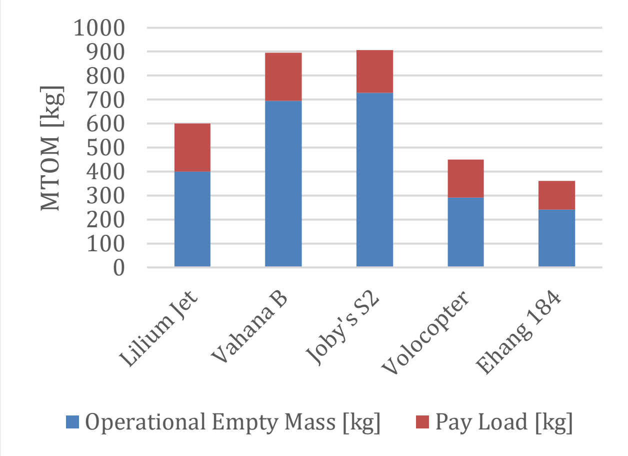

Figure 2. Approximate take off masses of air taxis, [2]

It must be noted at this point, that not all these mass breakdowns contain information about the systems mass, like avionics, sensors etc.. These will have a significant impact on the feasibility of those vehicles as well as the power drive mass decides about the feasibility.

On the other hand most of the vehicle concepts are based on full electric drives, which defines currently the achievable range, speed and payload.

As a conclusion of the study the payload definition will be performed depending on the demand and operational concept within this range. Regarding the overall take off mass, two approaches will be followed.

First, vehicles are taken as they are announced and proven with their characteristics. Based on that it will be elaborated what kind of operational concept is possible and which market can be realised.

Second reasonable operational urban air mobility concepts will be developed based on given demand and other boundary conditions for scheduled and unscheduled operations and the required vehicle characteristics including equipment will be derived from here.

2.2. Urban Area

A further basic definition is required to specify the “Urban Area”, which leads to the required ranges and route networks.

Here highly populated areas are of particular interest, where ground traffic capacity congestion and other barriers limit societal life, [5].

Instead of creating something generic, it was decided to select one typical but real representation for the investigation of urban air mobility concepts. This decision was mainly driven by the idea to support the understanding and acceptance of the research results.

Looking at some potential areas of operation like Los Angeles in the U.S. and Hamburg Metropolitan Region and the "Ruhr"- Area in Germany one can see at a first glance they are fairly different it its structure but always there is a capture area of about 150 km from the (city) center.

	Metropolitan Region Los Angeles	Metropolitan Region Hamburg	Metropolitan Region "Ruhr" Area
Inhabitants: City area/region	3.976.322/ 13.310.447	5,3 Mio	5 Mio.
People density:	3.273 people/km^2	192 people/km^2	1136 people/km^2
Area:	1.290,6 km^2 with 1.214,9 km^2 land	ca. 28.500 km^2	4.400 km^2
Districts/loca countries	15 districts	4 states	4 counties/ 11 cities

Table 2. Characteristics of Urban/Metropolitan Areas, [1]

Further for the operational considerations it has to be noted, that different governmental structures in terms of districts, cities or counties and states are typical for such regions.
For the research study the Hamburg Metropolitan region is used as an exemplary use case, because it shows all major general characteristics, [1].

Figure 3. Topology of Hamburg Metropolitan region

The metropolitan region has an extension of about 300 km each in North-South and East-West direction. It covers 3 states and various counties, which represent various regional administrations as shown in Fig.3.

Looking at exemplary vehicle concepts there are two clusters of envisaged ranges, one somewhere around 300 km and one around 50 – 100 km, Fig.4.

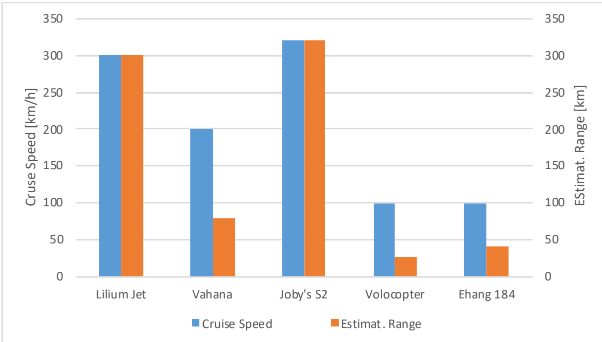

Figure 4. Ranges and speed of urban air taxis, [2]

These ranges are either derived from the expected electrical storage capacity (lower range) or in a minor sense by an operational demand (higher range).

This operational environment defines 2 major requirements related to the vehicles to be considered. For passenger and cargo transport the design range shall be about 300 km. The associated cruise speed shall be 300 km/h to ensure a maximum travel time of 1h to cross the region.
For vehicles used for special operations not carrying any passenger no specific range and speed can be defined because the types of operations are varying too much.
However they will be considered in the urban operational scenario as entities, which contribute to the upcoming urban air traffic.

2.3. Special Conditions

The Elbe river as a natural barrier is a major characteristic of Hamburg, which in principle may justify the introduction of airborne transport systems to cross it.

Also, Hamburg is one of the metropolitan regions, which owns an airport very close to the city center. On the one hand this makes flying competitive to other transport systems.

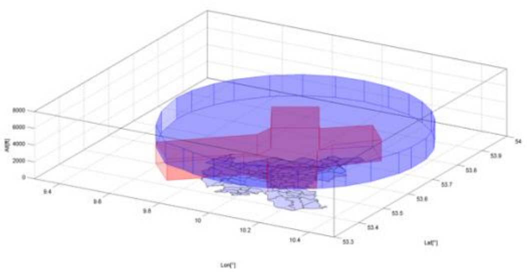

Figure 5. Spatial representation of Hamburg airport controlled airspace area

On the other hand, the airport heavily affects the potential operational area for urban air mobility. As shown in Fig.5 the airspace control areas cover approximately 80% of the Hamburg city area, while looking at the real flight tracks the city center is not very much affected by commercial aviation.

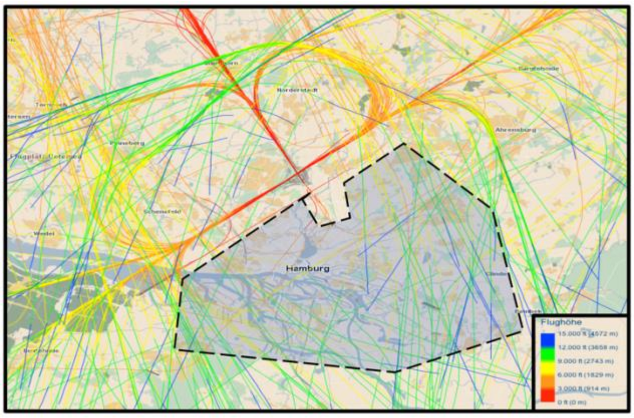

Figure 6. Commercial aviation flight track distribution over Hamburg.

The shaded area in Fig.6 covering the harbour and the city center provides some separated space for potential urban air mobility, since only a very few flight tracks towards Fuhlsbüttel airport cross this area.
This feature of potential conflict with commercial aviation makes Hamburg representative for urban air mobility feasibility investigations, too.

Since the design of the air operations concept is one essential part of a feasible and market relevant urban air transport system, such influences or restrictions are of major importance, to see potential influences and to resolve inconsistencies.

3. SOCIETAL EXPECTATIONS

The success of new technology or mobility concepts is mainly depending on customer and societal expectations and acceptance. Actually only a very few studies exist, which may give an inside into these attitude.
In the following some findings are resumed as a basis for further investigations.
The German Aerospace Center (DLR), Institute of Aerospace Medicine and Institute of Flight Guidance have performed an empirical study to find out, which applications people may consider for an acceptable use of civil drones in Germany, [6].
One outcome of this study is, that people preferably see drones in surveillance or reconnaissance missions. Parcel transport or unmanned air taxi operations are at lower priority, Fig.7.

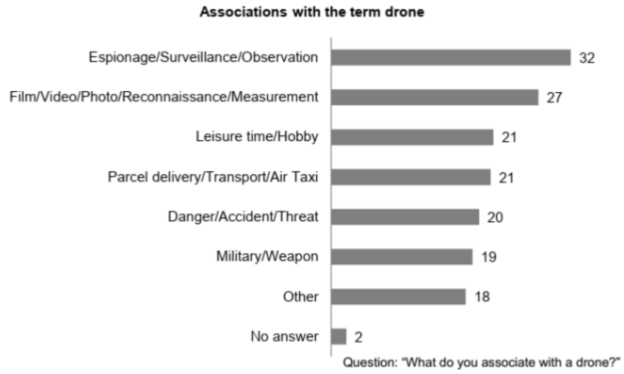

Figure 7. People´s associations with drone missions, [6]

On the other hand major concerns are raised about potential misuse and violated privacy, while noise is not considered as a major issue, Fig.8.

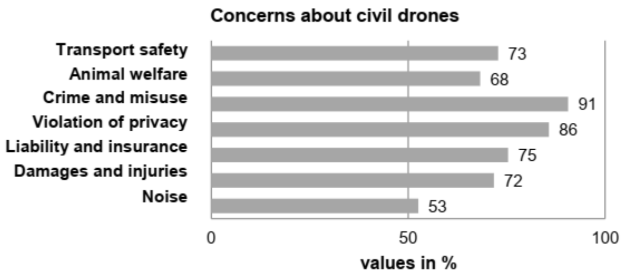

Figure 8. People´s concerns about drones, [6]

Another, more spotcheck like study discusses the people´s experience with the first in flight demonstration of Volocopter in Stuttgart in September 2019, [7]. The survey was performed among about 1100 visitors of the event. Here nearly 67% of the people supported the use of air taxis.
Regarding the reasons for acceptance the innovative character leads the scoring, as shown in Fig.9. The new mobility offer is following, while the noise impact is assumed to be of lower impact. Such a mindset is not surprising, because such demonstrations will be typically visited by supporters rather than criticisers.

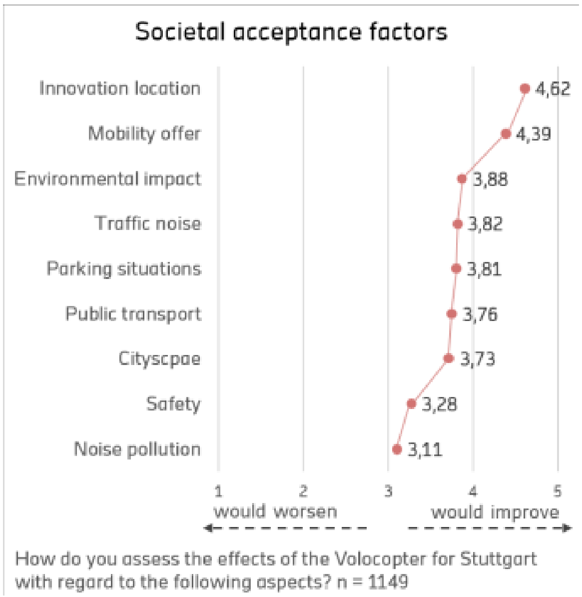

Figure 9. Societal acceptance of air taxis, [7]

Further in this survey people requested air taxi travel especially for transport to airports (86%) and railway stations (75%), Park&Ride stations (58%) and city center(54%), [7]. This demand is not unexpected but logical and will drive the analysis and design activities in this study.
Also, resuming the results of these studies it seems, that noise is of less relevance than expected. Further unpiloted air taxis are not really accepted by potential customers.
Regarding drones, there seems to be an ambivalent situation where surveillance and observation missions are well accepted, while misuse and violation of privacy are major concerns.
Since these studies are only very first ones further investigations are necessary to verify these spot check results.
Resuming these initial and preliminary findings, concerns exist against urban air mobility regarding misuse and violation of privacy, while they found to be attractive for urban transportation. Noise and operational safety are at least in Germany not a limiting issue at a first glance. Medical or humanity missions are not addressed by the people! These first findings need to be quickly verified to get profound baseline for future research.

4. METHODOLOGY

Based on these principle considerations in the following a methodology has been developed, which allows for a flexible and iterative design and analysis of various urban air mobility concepts on a broad interdisciplinary and conceptual level. The implemented urban air mobility model connects individual system-models which allow the analysis of concrete traffic examples in Hamburg.
Such a resilient approach requires both an integrating less detailed modeling level and also detailed descriptions of relevant specific research topics.

In a first step, the team identified major elements and their interdependencies in workshops using cognitive techniques like mind mapping and n-2 charts, [1].

Some major model elements for the methodology being identified are:

- Urban data (topology, population distribution, income distribution, e.al.)
- Airspace concepts and architectures
- Operating concepts
- Vertiport concepts and integration
- Trajectory simulation and traffic routes

These elements interact as shown in Fig.10.

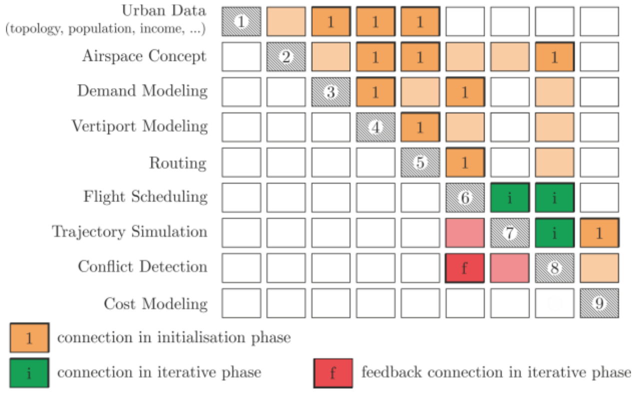

Figure 10. Interdependencies in the Urban Air Mobility System (N-2 Chart)

In various steps major relations were identified. These relations will drive the setup of the modelling architecture, as shown in Fig.11. As an example, urban basic data like population density distribution, income distribution but also the topology of the city or metropolitan region are important input data which will have an impact e.g. on the demand structure, the airspace concept, the type of vehicle and also the vertiport integration. Further, the operating concept model will iteratively drive the vehicle selection, the vertiport integration, routing, the flight scheduling and the cost for example.
Based on these findings a model architecture was developed to reflect the system characteristics.

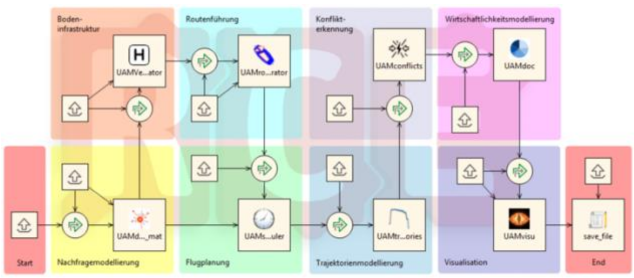

Figure 11. Model architecture of Urban Air Mobility System in RCE based on the described N-2 Chart

Here models for local airports, routing and network, flight planning, conflict detection and trajectory calculation have been integrated based on the prementioned dependencies.
The entire model architecture is realized in the DLR´s Remote Component Environment (RCE), [9]. RCE is a workflow driven software integration environment, which allows the integration of distributed heterogenous models. Associated to RCE, the DLR interface specification CPACS (Common Parametric Air Transport Systems Configuration Scheme) is used to link the models, [8]. The different domain-specific modules are integrated into one overall UAM system by data interfaces and control flows. For the first setup of the overall UAM system, a basic toolkit of low-fidelity analysis modules has been developed. With this model system some first analysis has been performed.

5. DEMAND FOR URBAN AIR MOBILITY

To estimate the potential and amount of Urban Air Mobility as a market concept it is necessary to find out how much air vehicles may be operated in the related area.

In a first study a rough investigation of the demand in various districts in Hamburg was performed. 104 districts are building Hamburg city, of which 16 were selected for demand investigation. Further as an example Fig. 12 shows the demand distribution between the district *Sülldorf* in the west of the city and *Fuhlsbüttel*, where the airport is located. The selection of OD pairs is here derived from the expected time savings compared to other transport possibilities. The rough UAM demand estimation is based on the population distribution of the departure district, [1].

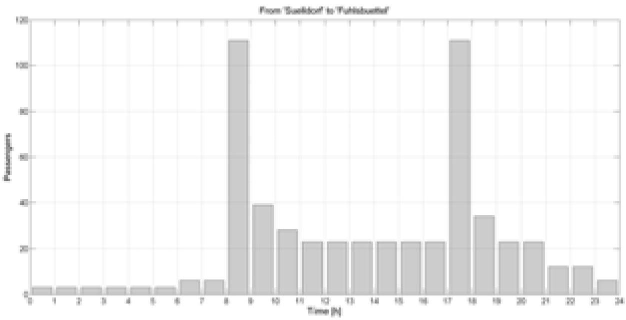

Figure 12. First estimation of the demand between Sülldorf and Fuhlsbüttel (Airport)

The distribution is typical for normal business traffic, but there is also a big difference between the main business travel times and the rest of the day. Since there is not much demand given after 21:00 and before 8:00, this expectation fits well to the societal wish not to have significant urban air travel in the evening and over night, [7].

For the most relevant demand Origin-Destination (OD) pairs in a next step vertiports were placed in the center of the related districts. After that, thanks to the support of real area data from the Hamburg Agency for Geoinformation and Surveying (LGV) the vertiports were manually positioned, where suitable free areas are available, also considering take-off and landing paths.

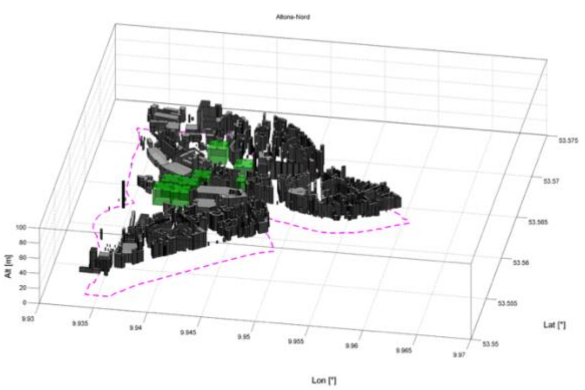

Figure 13. Example of vertiport positioning in the district Hamburg-Altona

Fig.13 shows one example, where such a vertiport could be placed in reality.

After that, exemplarily restricted areas were introduced as boundary conditions, for the trajectory calculation.

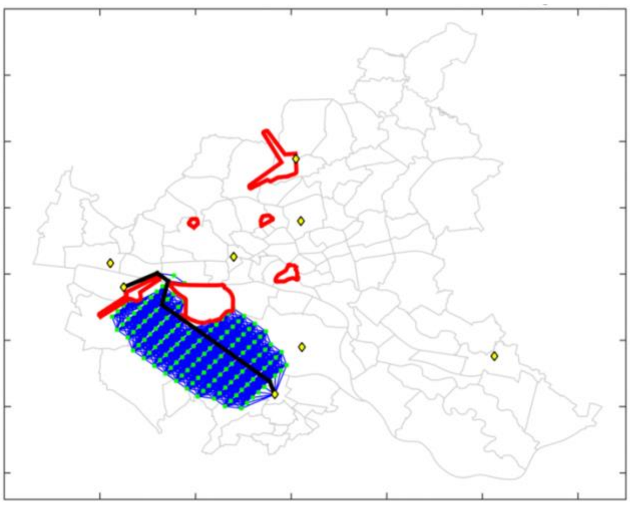

Figure 14. Illustration of the implemented route optimization algorithm considering generic restricted airspaces in Hamburg

Based on this scenario all principle model elements and basic data are available to calculate suitable routes between O-D.

6. AIRSPACE DESIGN AND TRAFFIC FLOW

The design of the urban air mobility airspace is mainly based on two pillars, which are the potential demand of air vehicle movements and the available capacity in the air.

Furthermore it is vital to discuss the role of the legal authorities to define the regulative principles for the introduction of this new mobility concepts.

6.1. Airspace Capacity and Demand

To get a first idea about the required and available airspace capacity a consideration of the potential use of urban air taxis might be a useful methodical approach.

Mainly, as mentioned in section 3, the quick transport to other transport modes like airport or railway stations but also city center and P&R stations are of interest.

In Hamburg about 500.000 commuter per day move to and from the city. On the other hand, roughly 450 "official" air vehicle movements are actually observed per day, [1].

The overall required air capacity CAP_{airHH} for Hamburg will result from

$$CAP_{airHH} = CAP_{airCom} + CAP_{airTaxi} + CAP_{airDrones} \quad (1)$$

Where CAP_{airCom} is the commercial air capacity, $CAP_{airTaxi}$ is the amount of air taxis and $CAP_{airDrones}$ covers the activities of drones.

Assuming 1% of the daily commuter may take the air

taxi service every day this will lead to approximately 5000 air vehicle movements per day, if each vehicle will carry only 1 passenger.
This will be 10 times more air vehicle movements, than today, which means 5450 instead of approximately 450.
Only this amount of increase may raise societal discussions.
Assuming an average of 2 persons may use an air taxi at one time, it will cause at least 2500 additional movements, which will result in $CAP_{airHH} = 2950$ movements per day.

This figure gives an order of magnitude about, what will happen if only air taxi services are considered. Any drones are not yet considered. The required capacity of drones in the regional airspace is hard to determine. It depends on how such drones will be operated and of which size will these drones be.

Drones in urban environment may be used for inspecting buildings, surveilling areas, performing medical services, carrying goods or moving cargo. Most of these activities have the principle character of on demand air movements. Today there is no analysis, how many movements will be caused from such missions. Studies like the one of Porsche assume on a global level about 21 Million flying units worldwide, but without any information about the size and the allocated amount for a metropolitan region, [3].
Therefore only a rough guess will be taken at this time, to consider the influence of drones. The figure of 2500 drone movements per day is assumed, just assuming it will be the same amount as air taxis.
This results in the end in roughly 5500 air vehicle movements in Hamburg per day, which are the starting point for the operational concept development.

6.2. Airspace structure proposal

Since urban air mobility operations will be fairly different from commercial aviation in terms of speed, aircraft size, vehicle density in the air, operational environment and envelope it is recommended and taken as the basis for the study, that urban airspace will be completely separated from the usual airspace with dedicated control, interfaces and transfers. Associated to that, also the authority has to be discussed in section 6.3.
Therefore and in order to avoid any conflict with commercial aviation and airspace "C" conditions the upper limit of the urban airspace is set in our concept to 2500ft (600m), with a principle obstacle separation of 1250ft (300m). Indeed this will provide only a limited airspace for operations. Fig.15 provides an overview about the vertical perspective.

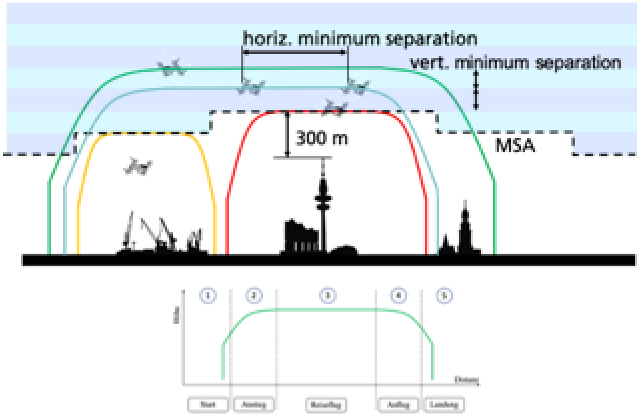

Figure 15. Principle urban airspace structure setup for Hamburg

Taking these limits, the available airspace capacity as shown in Tab.3 can be 9000 – 18000 movements per day, if the separation minima and the flight speeds are relaxed and adapted to the urban environment. For a cruise speed of 300 km/h a horizontal separation of 500 m provides 6 seconds overall reaction time. This is twice the time, which is considered in certification for pilot´s reaction and assumed to be realistic and reasonably safe.

		horizontal separation		
		3 nm	1000 m	500 m
vertical separation	300m	24	755	3020
	100m	72	2265	9060
	60m	144	4530	18120

Table 3. Initial analysis of theoretical airspace capacity depending on separation minima

For today´s instrument flight minima of 3 nm horizontal and 300 m vertical, 24 vehicles can operate equally distributed in the Hamburg airspace at one level. If the vertical separation is reduced to 100 m and the horizontal separation is 500 m, the capacity will increase to 9000 vehicles at 3 levels. This assumption is valid, when modern precision navigation and communication systems are taken into account with the aforementioned reaction time distance and automated deceleration controls.
A minimum vertical separation of 60 m will allow 18000 vehicles for simultaneous operation at 5 levels. For such environments appropriate flight conditions will be derived.

Concerning the operational conditions for such a vehicle density first the visual or instrument flight need to be addressed. For that "visual lines of sight" and safe area coverage are key for the flight rules concept.
Here a more detailed investigation about the type selection, installation and area coverage of the communication and navigation aids is essentially required and will be performed in the next step. Based on this capabilities and architectures of this

infrastructure in a next step, recommendations for applicable flight rules will be developed.

6.3. Legal Authority Concept

There is the very important and crucial point of consideration, which is about the authority about the regional airspace.
Since regional authorities are mainly driven by societal interest of the local inhabitants it is recommended to keep the authority on the regional metropolitan airspace in the hand of the local authorities.
This will require first a national, eventually a European rule framework, which shall be regionally applied. Such a regionally elaborated air navigation service is the baseline for the developed UAM concept.

Further urban air mobility is characterized as a highly dense air traffic in a limited air volume. This quite different type of operation shall be completely separated and controlled from conventional air traffic.
Urban air traffic controller need different support systems and need to control other airspace structures and type of movements.
Consequently it is recommended and taken as a basis for the feasibility study, that the urban airspace is a separated one. If vehicles have to transfer from urban to the other airspace, hand over procedures have to be developed.

6.4. Urban Air Traffic Flow

Based on the previous assumptions and design considerations, first for a limited set of O-D-pairs in the Hamburg area a network and traffic flow was built up.

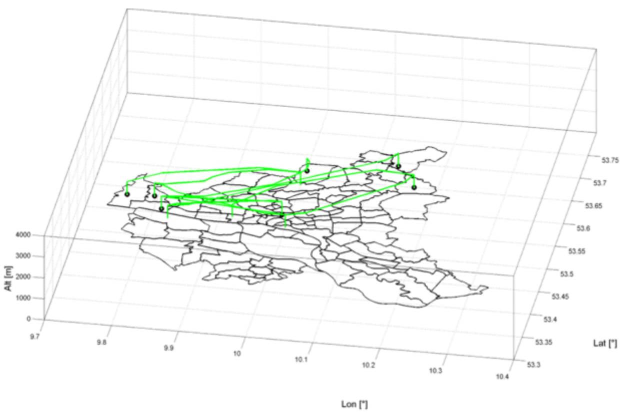

Figure 16. Sample OD-pairs for Hamburg area

Fig.16 shows the resulting sample network which mainly links the airport in vicinity to some districts. For all optimized routes, 4D trajectories are simulated, which become the basis for a first economical feasibility analysis.

7. Cost estimation

The cost estimation for urban air mobility is based on initial assumptions of:

- ATM
- Energy effort
- Insurance
- Staff
- Depreciation
- MRO
- Vertiport fees
- Interest

The details of this model will be published in [14]. We actually assume that most of the are caused by energy consumption and air navigation service fees. Also maintenance will play a major role as well as the vertiport fees. All the rest contributions are of lower relevance. Because most of the infrastructure has to be built up and also electric power drives are mainly considered we expect that the cost share among these elements will be more equally balanced, than for commercial transport aircraft. This is mainly caused by the principle, that VTOL-vehicle flights are mainly considered for operations, which have a quite high energy consumption. Other investigations assume here only a minor energy cost share of much less than 5%, [15].
The overall cost model is oriented to the pricing used for taxis and setup by 2 components:

$$Rev_{airTaxi} = Rev_{Fix} + Rev_{Dist} \quad (2)$$

Preliminary results show a high sensitivity of profitability on air fares.
With a basic charge of $2/flight and varying distance dependent air fares, at about $5 - 6/flight there is a threshold, where some routes become economically profitable.

These first calculations show, that about $50 are the cost for a 10 km travel. On the other hand such a direct track can save about 60-80% of the travelling time compared to taxis or public transport.

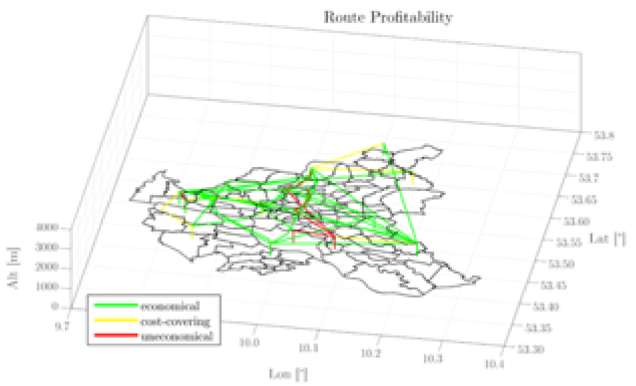

Figure 17. Profitability of various O-D pairs in Hamburg

This rough estimation is not too far away from actual taxi cost on such a distance. However air taxi flight will require much less time than taxis, but will cost more.
A lot of further modelling scenario analysis and data

formulation is necessary and is ongoing to verify this first impression and to lead it to validated knowledge.

8. CONCLUSIONS

Urban Air Mobility is a highly notified trend of new mobility, which requires a holistic analysis of its feasibility and added value. The Institute of Air Transportation Systems in collaboration with the DLR Lab of Air Transportation Systems is developing a modelling system, which allows a comprehensive analysis whether there is a realistic market with societal acceptance for this new mobility concept.
Starting from demand level a methodology has been developed which allows the direct derivation of a model architecture to design and asses various urban air mobility concepts.
Literature review indicates societal acceptance for urban air mobility based on drones and air taxis. Societal acceptance needs to be investigated much more in width.
Hamburg metropolitan region was derived as a representative use case to investigate the feasibility of urban air mobility. Within this study, an exemplary UAM network simulation is presented. Districts are connected by a network of vertiports and routes, and 4D-trajectories are calculated to show, how urban air mobility may be realized in Hamburg.
Urban air mobility based on air taxis and drones may increase the number of air movements above Hamburg city by a factor of ten and more. To investigate the possibility of integrating such a number of air vehicles into the airspace, the airspace capacity over Hamburg is estimated roughly for different separation minima. Much more detailed research is needed and performed to verify such first indications.
The impact of drones is actually not investigated but needs to be considered in detail.
The urban airspace authority is a crucial issue, which is recommended be allocated to the regional governments based on national or European rule frameworks. Local authorities by nature reflect better societal interests. This approach will be further investigated.
First results of the analysis show for the use case Hamburg, that there is a potential of profitable operational concepts for urban air mobility.
In the next phase more detailed modelling and analysis will be performed on broader project basis to verify these first results, which are understood as test results showing reasonable figures.

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