1. Introduction

Urban mobility is getting more and more into the focus of industry and public bodies, but is also attracting attention of investors in a promising market, where a rising number of start-up enterprises is preparing the launch of their individual concepts. Main driver is the changing traffic situation in large and highly populated areas, especially in the so-called mega-cities. Air taxis were first discussed in the context of potential markets for areas like Dubai, Singapore or Mexico City. But there will be no limitation to those regions. For example, the European Commission described the situation of urban transport from their point of view as follows [1]: “European cities increasingly face problems caused by transport and traffic. The question of how to enhance mobility while at the same time reducing congestion, accidents and pollution is a common challenge to all major cities in Europe.” The basic idea behind urban
air taxi technology comes from the need to “rearrange” the growing individual traffic by operating a certain portion away from roads and rails into urban air airborne transport.

Driven by the trend to develop electrically powered unmanned aerial vehicles (UAV) or “drones” for urban surveillance, delivery etc., the idea of establishing air borne taxi services or shuttles is forming a logic step which is already followed by a dozen or more companies around the globe.

While appreciating the zero emission effect regarding air pollution, those vehicles will still have a certain, and in some cases significant noise signature. Electrical flight does only mean no relevant engine or exhaust noise emitted towards the ground. But each propeller, rotor or fan will generate aerodynamic noise sources. And even if the individual vehicle’s noise levels may be reduced by using a specific design or low noise measures [2], the number of the air taxis may give reason for additional community noise impacts [3], or new noise issues, where communities have not yet been exposed to air traffic noise so far. At the same time, taking the air taxi industry’s time tables serious, commercial urban air mobility will start within the next 5 or 6 years [4]. Taking also into account that approvals for the required, and environmental relevant infrastructure (e.g. air taxi ports or hubs) will consume time at the authorities to establish surveys and expertise, the sensitisation for this topic has to begin today.

Following this logic, the study described in this paper is trying to give a first assumption on how the noise impact from this specific type of urban mobility may develop. It clearly shows that there will be noise on the ground, which has to be acknowledged by the makers of regulations, but also accepted by the public. The aim of this study is not about to give absolute values for the single air taxi concepts (it is even to avoid ranking of different concepts or products), but it will provide a first understanding, that there should be a new focus on community noise which will be generated by future urban air taxis.

2. Generic scenario modeling

2.1 Air taxi concepts

Meanwhile, there is a variety of different concepts which are proposed and followed by several potential manufacturers. Among them are large companies, some already well established in the aerospace and even automotive industry. But there are also smaller or medium enterprises, many of them appearing as start-up companies.

The technical concepts are also covering a broad variety of engineering solutions, currently available on different technical levels. There are some concepts which are existing only as blueprints, some are already available as demonstrators, and some others are flying as prototypes [5-9].

The concepts may be roughly classified as follows:
- propeller driven (like small or light aircraft, but the use of several propellers is possible)
- rotor driven (like small helicopter or multi-copter architecture using more than one rotor)
- fan/jet driven (distributed small fans)
- fixed or tilt-wing technology.

Most of the know concepts can further be regarded to use so-called distributed electric propulsion, which consists of a certain number of “propulsion packets”. The concepts may additionally be distinguished by the number of passengers, which in general does affect the propulsion regarding its required
electrical power - and thus usually higher noise generation - due to higher payload and therefore higher take-off weight.

As a consequence, the different concepts will be accompanied by a different noise contour, originating from different noise levels and spectral shapes. This will automatically lead to different results of the noise impact, as it will be shown later in this study. In the following section the principle noise characteristics will be explained in more detail.

2.2 Main noise sources and their characteristics

All air taxis have in common that their rotors, propellers or fans will be the main, primary noise sources of the propulsion systems. In some cases, secondary noise sources may appear e.g. from the specific installation situation which can take additional and significant influence on the noise footprint of the vehicle. Those details are not included here because this would be equivalent to assess different products, which is not the wish of this paper. Here the focus is set on generalised noise sources.

During a first step, these main sources will have to be characterised. This is usually the most ambitious part of the modelling, but it is even more difficult now because there are not sufficient or no data at all available for the most promising air taxi concepts, except some general technical data such as projected propeller diameter, altitude for later operation and targeted speed. This is the reason why for a very first assessment the use of generic air taxi models appeared to be the best approach from an engineering point of view. A future market share of propeller driven air taxis can be expected to be much higher due to the number of vehicle concepts using this technology, but there are also concepts using “fan packets” or “fan-like” propulsion.

Fig. 1 shows the used sound power spectra for the two noise sources propeller and fan. The propeller spectrum was computed for a 5-blade propeller [10] and the fan spectrum was taken from literature [11].

![Figure 1: Normalised sound power spectra for propeller and fan, revealing the clear different characteristics.](image)

For a better comparison of the two different propulsion systems, both spectra were normalised to a sound power level of $L_W = 128 \text{ dB}$, which comes close to the value of sound power for a light sports aircraft at ~2,000 propeller rpm [12]. Of course, the real sound power of the air taxi’s propulsion will strongly
depend on the specific design and its operational conditions. Shrouded propellers could be less noisy, other configurations may develop higher noise levels due to already mentioned installation effects [13].

While the noise source levels in this study are set to the same value, propeller and fan are radiating the noise significantly different. This is described by their directivities, which are shown in Fig. 2 and which were used for the computations.

![Figure 2: Typical directivities for propeller [14] and fan [15].](image)

### 2.3 Air taxi scenarios

For the computation different scenarios have to be established. These scenarios should at least describe the locations of the air taxi hubs or ports with the routing of the connecting flight paths. Information about the number of vehicle movements per flight path and information about the rate of - in this study - propeller and fan taxis must also be provided. Covering all of this information, artificial scenarios in the proximity around the city of Munich, Germany, were created on the basis of the following assumptions:

- The region will consist of 4 hubs, located according their relevance especially for the automotive and aerospace industry of the region. One of these hubs is located close to the international airport of Munich.
- All hubs are mutual connected.
- Roughly 10 % of the traffic will be expected in the evening (in reality might be more, related to business travellers).
- No air taxi operations during night time.
- It is expected that a higher portion of propeller driven taxis will be operated, but computations for a higher fan portion were carried out, too.
- All air taxis are using the same flight level. Nevertheless, altitude variation is also computed for parameter study.
- All taxis of the same type are flying with the same speed, which is selected to be 69 m/s for fan propulsion [7] and 33 m/s for the propeller driven taxis [9]. A variation of the speed may be performed as well, but in this study the influence of vehicle numbers seemed to be of higher importance.

The first assessments will be done by using the common CNEL (Community Noise Equivalent Level), which is the noise level for all hourly $L_{eq}$ measurements, averaged over 24 hours and including a 10 dB penalty for all night-time levels between 10:00 pm and 7:00 am, and a 5 dB penalty for the evening levels
between 7:00 pm and 10:00 pm. This is the definition of the well-known “level day-evening-night”, $L_{den}$ [16].

3. Computations and results

3.1 Computation area and flight paths

The basic idea was to inter-connect technology centres and to establish a direct bound shuttle the international airport of the region. Thus, the computations were carried out for a region in southern Bavaria/Germany where high-tech industry, especially automotive and aerospace, is situated. The area and the selected hubs with connecting flight paths is shown in Fig. 3 and has an extension over about 9,200 km². The air taxi noise was computed on a grid of around 147,000 points which corresponds to a distance of 250 m from neighbour to neighbour. This may appear still large but regarding the size of the computation area it seems to be sufficient for this first generic survey. Finally, the path lengths and the flight times of the air taxis are provided by Table 1.

![Figure 3: Computation area [17], air taxi flight paths (1 - 6) and hubs (MUC, A, IN, GIL) for the scenario study.](image)

The paths were selected under certain aspects, such as avoiding flying over larger cities (e.g. path no.2) or trying to align to already existing roads (e.g. path no.6). Flying over densely populated central Munich city was avoided, too (path no.5).

3.2 Scenario parametrisation

This section provides a brief summary of the parameters to describe the air taxi movements on the 6 flight paths.

<table>
<thead>
<tr>
<th>Path</th>
<th>Length [km]</th>
<th>Flight time “prop taxi” [min]</th>
<th>Flight time “fan taxi” [min]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Path 1</td>
<td>64</td>
<td>31</td>
<td>15</td>
</tr>
<tr>
<td>Path 2</td>
<td>70</td>
<td>35</td>
<td>17</td>
</tr>
<tr>
<td>Path 3</td>
<td>69</td>
<td>34</td>
<td>16</td>
</tr>
<tr>
<td>Path 4</td>
<td>43</td>
<td>22</td>
<td>10</td>
</tr>
<tr>
<td>Path 5</td>
<td>52</td>
<td>26</td>
<td>12</td>
</tr>
<tr>
<td>Path 6</td>
<td>79</td>
<td>40</td>
<td>19</td>
</tr>
</tbody>
</table>
As mentioned earlier, the most relevant parameter may be the number of vehicles and their individual propulsion concept. Therefore, the primary parameter for the simulations was the absolute number of air taxis, secondary the composition of this number with respect to the air taxi type (propeller or fan driven) was varied. Table 2 is showing the different scenarios - overall 13 different situations were simulated - and their main parameters.

Table 2: Air taxi numbers, ratios, and altitudes used for computations. Each line of the table represents scenario.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Total number of air taxi movements</th>
<th>Number of taxis during daytime (0700 – 2200)</th>
<th>Number of taxis per path per hour</th>
<th>Ratio prop/fan [%]</th>
<th>Altitude [m]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>50</td>
<td>44</td>
<td>3.7</td>
<td>50 / 50</td>
<td>800</td>
</tr>
<tr>
<td>2</td>
<td>100</td>
<td>90</td>
<td>7.5</td>
<td>10 / 90</td>
<td>800</td>
</tr>
<tr>
<td>3</td>
<td>100</td>
<td>90</td>
<td>7.5</td>
<td>30 / 70</td>
<td>800</td>
</tr>
<tr>
<td>4</td>
<td>100</td>
<td>90</td>
<td>7.5</td>
<td>50 / 50</td>
<td>400</td>
</tr>
<tr>
<td>5</td>
<td>100</td>
<td>90</td>
<td>7.5</td>
<td>50 / 50</td>
<td>800</td>
</tr>
<tr>
<td>6</td>
<td>100</td>
<td>90</td>
<td>7.5</td>
<td>50 / 50</td>
<td>1200</td>
</tr>
<tr>
<td>7</td>
<td>100</td>
<td>90</td>
<td>7.5</td>
<td>70 / 30</td>
<td>800</td>
</tr>
<tr>
<td>8</td>
<td>100</td>
<td>90</td>
<td>7.5</td>
<td>90 / 10</td>
<td>800</td>
</tr>
<tr>
<td>9</td>
<td>100</td>
<td>90</td>
<td>7.5</td>
<td>100 / 0</td>
<td>800</td>
</tr>
<tr>
<td>10</td>
<td>100</td>
<td>90</td>
<td>7.5</td>
<td>0 / 100</td>
<td>800</td>
</tr>
<tr>
<td>11</td>
<td>250</td>
<td>226</td>
<td>18.8</td>
<td>50 / 50</td>
<td>800</td>
</tr>
<tr>
<td>12</td>
<td>500</td>
<td>450</td>
<td>37.5</td>
<td>50 / 50</td>
<td>800</td>
</tr>
<tr>
<td>13</td>
<td>1000</td>
<td>900</td>
<td>75</td>
<td>50 / 50</td>
<td>800</td>
</tr>
</tbody>
</table>

A total number of 100 air taxi movements in the region of interest was chosen arbitrarily as the reference for propeller/fan comparison and altitude variation, knowing that it may appear relatively small. But it still represents more than 7 taxi movements per hour during the day, which seems to be realistic at least in an early experimental stage of this new technology of urban transportation. If the technology is successful, the counts may increase rapidly.

It has to be mentioned that all vehicles were distributed uniformly over the 6 flight paths. An additional variation of taxi numbers on the different routes would require a detailed market or case study.

### 3.3 Simulation results

The relevant noise metrics e.g. $L_{eq}$ per flight path, SEL (sound exposure level) per air taxi etc. have been calculated at all grid points for each scenario from Table 2. The procedure was performed by following common guidelines, e.g. by segmenting the flight paths [18,19]. For the noise mapping, the $L_{den}$ as the most significant metric according to the “European Environmental Noise Directive” was computed and the simulation results for selected scenarios are shown in the noise maps of Figure 4 to Figure 6. All noise maps are representing the same dynamic range from 0 dB(A) to 50 dB(A).
Figure 4: $L_{den}$ scenario 5 (100 air taxis, left) and scenario 13 (1000 air taxis, right), indicating maximum $L_{den}$.

Figure 5: $L_{den}$ scenario 4 (altitude 400 m, left) and scenario 6 (altitude 1200 m, right), indicating max. $L_{den}$.

Figure 6: $L_{den}$ scenario 8 (90 % prop taxi, left) and scenario 3 (30 % prop taxi, right), indicating max. $L_{den}$. 
4. Conclusions

The study about air taxi noise, presented in this paper, is based on generic numbers since currently no sufficient and authentic data about noise emission and taxi operations are available from the industry. But it could be shown from an engineering point of view that in any case there will be en-route and community noise, generated by those novel urban traffic systems.

First of all, but not surprising the number of vehicles is the dominating parameter for the prediction of future air taxi noise immission. It was also shown that - by nature of the noise spectrum - propeller driven air taxis can be expected to be more perceptible on the ground. Of course, in any case a detailed knowledge of the individual taxi concept is required for the acoustical description of the individual noise sources. Beside the air taxis’ numbers, the flight levels in which they will operate may also play an important role, especially when thinking about taxi services over populated city areas.

The peculiar public perception of new urban air mobility systems is almost focused on the technological fascination, and the emphasis on its future fully environmentally friendly traffic. But this is related to the electric propulsion and its zero emission of greenhouse gases. The study of this paper showed that with significant numbers of electric air taxi movements, direct and probably additional (to existing) noise impacts on the population in the vicinity of the future air taxi hubs, but also along the trajectories will be created. It will become inevitable to establish realistic scenarios which have to be supported by reliable market studies or surveys like [4].

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