Certification and Time-to-Market: The eVTOL Battery Balancing Act
Urban Air Mobility is the aerial passenger or cargo transport over short- to-medium distances. In addition to numerous companies building smaller unmanned air systems, more than one hundred companies are focused on the development and production of larger eVTOL (electrical vertical take-off and landing) vehicles.

There are three main use cases envisioned for the near future:

- Last mile delivery of goods
- Air Metro
- Air Taxis

Last mile services will typically include delivery of smaller packages currently transported by the delivery companies (FedEx, UPS, etc.) to end customers. Both Air Metro as well as Air Taxi services will transport passengers. Air Metro is doing that on a fixed and regular route e.g., from John F. Kennedy International Airport in New York City to lower Manhattan for example — Air Taxi services are intended to operate on demand like a taxi or ridesharing operator today, although restricted to take-off and landing infrastructure.

Apart from regular transport services, special applications are also planned. The German ADAC, which is similar to the AAA in the US, has announced plans to work with Volocopter, a German eVTOL startup, to evaluate eVTOLs for their medical transport missions currently conducted through a combination of helicopter and ground-based ambulance vehicles.1
The three mentioned use cases have specific demands on the energy storage setup, which is a central component for fully electric vehicles, especially with highly weight-sensitive aircrafts. The use case in which the specific vehicle will be used has a significant impact on the definition of the energy storage system. The biggest differentiators are the mission profile, e.g. regarding flight altitude and turnaround times, and the ground infrastructure present at the landing spots.

To win the urban air mobility race, eVTOL companies have to strike a balance between time to market, technological advancements like battery technology and aerospace certification. As of today, no vehicle has entered the commercial application phase. There are three high-level business requirements driving the development of eVTOL energy storage:

1. eVTOL operations benefit from long flight times, which in turn necessitates low weight and high energy densities.

2. Safety, specifically fire safety, is paramount as an in-air fire is one of the worst-case scenarios in commercial aviation; however, additional safety measures typically increases system weight.

3. Different flight phases (vertical take-off, horizontal flight) require high peak, but comparably low average power. Even though peak power is not used for most of the flight, this requirement again increases energy storage weight.

As typical in engineering, there is no easy answer to implement all of these requirements at the same time. Final system design usually is the result of careful optimization and is a balancing act. For example, the different flight phase requirements could be fulfilled by increasing the peak power ability of the primary energy storage system which increases weight. It might also be implemented by using multiple energy storage systems or battery cell types each optimized for a specific flight phase – which might help to keep weight down but increases system complexity.

All of these engineering requirements need to be considered simultaneously along with the critical time to market implementations. Due to competition, market pressure and the comparatively long certification timelines, an early specification freeze needs to be achieved, which hinders the full potential of modern battery technology.
Development

Development Cycle

Aircraft development in general usually follows the classical V-model, due to the structure of the management process and therefore good basis for certification (see Figure 1).

This starts on the vehicle level with defining business and regulatory requirements. Business requirements could be expressed in terms of a mission profile including range, speed, load capacities etc. Requirements for the powertrain, energy storage, and typically battery systems are derived from these business requirements. In the next level to cell specifications and potentially even the electrode level are created from system-level requirements. An eVTOL company could definitely take this detailed approach as this is one of the most critical components.

Following those thoughts, looking at the right side of the V-Model, the next steps are testing and validation (two critical steps in which umlaut has extensive expertise). Specifications will be adjusted iteratively if necessary. This approach would result in the optimal cell for the application and an optimized energy storage system. However, an optimal system might need to be customized and not be able to be purchased "from the shelf" and hence might incur higher costs. Additionally, due to the constraints in development time, it might be necessary to stop the optimization cycle at a certain point. However, it will be extremely valuable for further vehicle generations to document any optimizations that could not be included to provide technological superiority in the next generation. Even if certification requirements lead to a design freeze with a suboptimal design, subsequent modifications of the certified design are much easier to achieve than the initial certification.

<table>
<thead>
<tr>
<th>Development Cycle</th>
<th>V-Cycle development</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Concept/Design</strong></td>
<td><strong>Definition/Detailed Design</strong></td>
</tr>
<tr>
<td>Start of „certification lock-in“</td>
<td>Specifications for each system component to fulfill &quot;mission&quot; e.g. weights, volume, cell configuration, cooling system, material restrictions. Specifications for Cell(s) e.g. voltage, internal resistance, homogeneity and other components e.g. BMS, Cooling System. Specifications for Electrode, e.g. Thickness of active material, copper and aluminum Parts of BMS et al., e.g. reliability of chips/capacitors etc.</td>
</tr>
</tbody>
</table>

Fig. 01
To satisfy aerospace regulators both the Design Organization and the Production Organization have to be certified by the authorities, e.g. the FAA in the USA or EASA for Europe, respectively. Only a certified design organization according to EASA / FAA Part 21.J may design an aircraft. The need is to begin the certification process in communication with the certification body early in the design phase; the process is finished along-side with the finalization of the design. As always, there are exceptions like eVTOL flown under FAA “experimental” class rules which are more flexible. However, no higher risk commercial applications like in-city transport may be offered with aircraft flown under those rules.

This early involvement of the authorities, the certification basis preparation in the conceptual design phase, leads to some aspects of the design being determined equally early on. Those aspects cannot be easily changed later, which leads to a certification lock-in phenomenon that requires the use of fully understood systems. These might not be fully optimized for performance.

This is how the authorities have operated until recently, which is not necessarily what benefits the rapid developments made in the eVTOL space. Nevertheless, both the authorities and the eVTOL companies are working on changing this, e.g. through the release of the SC (special condition) VTOL by the EASA accompanying close and active communication between the EASA and European eVTOL startups3.

During the certification basis preparation, the design organization has to determine and claim with which certification specifications (CS) they plan to be compliant. Traditionally, those have been the CS23, 25 and 27 for (small) aircraft and helicopters, respectively. Through the SC more targeted certification specifications will be gradually introduced. After the design and the certification basis has been finalized, the production organization takes over and produces what has been designed. There, of course, further certification aspects come into play which will not be detailed here.
As the electrification of automotive vehicles is accelerating, the aviation industry can and should assess the automotive roadmap to see where this market is going at scale (see Figure 4). Technologies that are currently being developed for ground usage can be used in aviation later, after their safety has been proven, the technology has been optimized further, and certification specifications have become clearer.

The automotive market shows clear trends in terms of battery cell and the battery system design. Mid-term, we will see changes in the cathode design towards higher energy materials, a change of the electrolyte from liquids to solids, and high-capacity anodes using silicon or lithium metal. Also a trend towards higher battery system voltages can be observed in some cases.

At the same time, an interesting trend arises that could support usage in aviation but will surely introduce new challenges. Historically, battery cells have been packed into battery modules which are integrated into the vehicle. Modern methods like cell-to-pack design directly integrate battery cells into the battery pack or even the chassis of the vehicle, which optimizes the design space utilization and the energy density of the battery. However, looking at the aviation industry this might necessitate huge engineering efforts to ensure safe containment in case of accidents and to verify that the system loads are still within acceptable limits. This might prove especially challenging when the battery cells are an integral part of the structure.

**Market Trends**

**Automotive Industry**

**Automotive Battery Systems**

**Technology Roadmap**

- **Battery cells**
  - 2018: NMC-622
  - 2019: NMC-622, NMC-811
  - 2020: NMC 811, NCA, LFP
  - 2021: NMC 811, NCA, LFP
  - 2022: NMC 811, NCA, LFP
  - 2023: NMC 811, NCA, LFP
  - 2024: NMC 811, NCA, LFP
  - 2025+: NMC 811, NCA, LFP

- **Battery systems**
  - 2018: Cell-to-module-to-pack
  - 2019: Cell-to-pack
  - 2020: Cell-to-pack
  - 2021: Cell-to-pack
  - 2022: Cell-to-chassis
  - 2023: Cell-to-chassis
  - 2024: Cell-to-chassis
  - 2025+: Cell-to-chassis

**Fig. 04**
Market Trends

Global Battery Demand

Looking at the forecasts for eVTOL vehicle demand, which is said to top 100k vehicles in 2030, the demand for eVTOL-specific batteries will rise dramatically. We see that funding in eVTOL companies is still bullish despite the current economic caution due to the effects of COVID-19.

The forecasted vehicle demand would lead to an estimated battery manufacturing capacity demand of 10 GWh. This number might sound large, but is still insignificant compared to the demand of the automotive industry. The electrification of cars will not stop and their demand for battery cells is rising fast, leading to an expected manufacturing demand of 2,300 gigawatt hours in 2030* (see Figure 5).

Comparing the eVTOL demand to current battery capacities shows that it might be sufficient to justify a Gigafactory, which focuses on producing batteries for the eVTOL sector only. This presents an opportunity for battery cell manufacturers.

Global Battery Demand in GWh and EVOL market in 2025 and 2030

Drivers: • Falling price of li-ion batteries • CO2 fleet emission rights • Governmental incentives

Sources: EU, World Economic Forum 2019, Interact Analysis

EVOL Market 2025 2030

<table>
<thead>
<tr>
<th>Demand vehicles</th>
<th>10,000</th>
<th>100,000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Battery size (in kWh)</td>
<td>48</td>
<td>96</td>
</tr>
<tr>
<td>Demand for batteries in GWh</td>
<td>0.48</td>
<td>9.6</td>
</tr>
<tr>
<td>Global Demand</td>
<td>971</td>
<td>2620</td>
</tr>
<tr>
<td>Percentage</td>
<td>0.05%</td>
<td>0.37%</td>
</tr>
</tbody>
</table>
When it comes to designing the battery pack, there are many different options that depend on the overall strategy of the operation and mission. A classical morphological box might demonstrate that well and can also be used in the design process. We will share three different design examples (Figure 6).

Clearly, some combinations are not really feasible, and some choices in one feature or strategy almost require important choices in another feature or strategy. For instance, if in the first example which starts with no fast charging and no swap, the choice of redundancy instead of reserve allows the operating window of 8–92%, but then might require at least 3, if not 9 cell strings. In a second version with a lower operating window, the reserve with 3 strings might be sufficient. Also, the strings might lead to the choice in cell size, depending on the overall requirement. Two types of chemistries mean at least one string being high-power, the others a high–energy cell. The third system might be the long-term optimal, which would require more customized solutions on the cell, but could be the technically superior choice to fulfill the overall vehicle requirements, being optimized for each phase of the mission, have the least weight, a quick turnaround at the landing port—all with meeting critical safety requirements.

Designing the System with Morphological Box

When it comes to designing the battery pack, there are many different options that depend on the overall strategy of the operation and mission. A classical morphological box might demonstrate that well and can also be used in the design process. We will share three different design examples (Figure 6).

Clearly, some combinations are not really feasible, and some choices in one feature or strategy almost require important choices in another feature or strategy. For instance, if in the first example which starts with no fast charging and no swap, the choice of redundancy instead of reserve allows the operating window of 8–92%, but then might require at least 3, if not 9 cell strings. In a second version with a lower operating window, the reserve with 3 strings might be sufficient. Also, the strings might lead to the choice in cell size, depending on the overall requirement. Two types of chemistries mean at least one string being high-power, the others a high–energy cell. The third system might be the long-term optimal, which would require more customized solutions on the cell, but could be the technically superior choice to fulfill the overall vehicle requirements, being optimized for each phase of the mission, have the least weight, a quick turnaround at the landing port—all with meeting critical safety requirements.
Design

Advantages and Disadvantages of Cell Design

The choice of the battery cell format is almost religious in some circles, but the key point is that optimization cannot happen only at the cell level; it must happen throughout the entire system.

In addition to the technical considerations, there is also a strong business aspect to the choice of the cell format. Cylindrical cells are commonly available and large cell manufacturers might not be very interested in small volume special cells adapted to electric flight. One solution might be small battery cell manufacturers looking for a niche. The cell might come with a high cost at first, but considering the costs of change, due to certification and non-optimized packs later, this might tip the scale toward these solutions. With the rising demand, as seen before, these companies might also be able to scale up and provide a low-cost, specialty cell in the mid-term when investing in a large production facility.
Design

Design Modification

A minor modification has a negligible, or no appreciable, effect on the mass, balance, structural strength, reliability, operational characteristics, or other characteristics affecting the airworthiness of the product. By definition, a major modification absolutely has a significant impact on the airworthiness of an aeronautical product.

There are three subcategories defined as "Major," "Not Significant," "Significant" and "Substantial" and the re-certification effort depends on the category, from component testing up to a complete recertification of the vehicle. With battery prototypes going up to $5M, this could become rather costly, let alone time-consuming.

A risk in being only a small volume customer when purchasing battery cells is that the certified cell might be sacrificed by the cell manufacturer in the mid-term, due to optimization. The big question will be which changes will lead to which category. If eVTOL companies buy basically "off-the-shelf" solutions, and the big cell OEM companies decide to change the cell design, whether anode, electrolyte, cathode, this could have a significant impact on eVTOL companies.

So, the big uncertainty will be how the changes and updates to the battery management software will be categorized and this might be interpreted differently by the FAA in the U.S. as by the EASA in Europe or the CAAC in China. Looking into the history with the Dreamliner, we expect high awareness and high standards to be applied.

However, this approach might still be valid for the first generation of eVTOL batteries with a small volume. The interesting part will be how soon the companies will work on the second and even third generation, in which other improvements might be in the same scope of a new certification, justifying the effort, investment and approach. Once the volume increases, the question becomes: which generation the eVTOL company will satisfy it with. "Forget about sunk cost" might become a valid strategy. Looking at current aviation OEMs, this would mean a major shift in operations, thinking, and culture as lifecycles shorten dramatically, especially in the first generations.
When automotive electric mobility with Li-Ion Batteries started about 15 years ago, there were no clear guidelines as to what needed to be tested. In 2021 there is much more clarity in the automotive industry. We have mechanical, thermal, chemical tests, tests to validate transport readiness and overall combined safety tests. This means that cells carried over from automotive into aviation could skip the component validation step, assuming the requirements are comparable. However, given Urban Air Mobility is still in its infancy stage, catalogue for validation is required. Most likely – and hopefully – these validation tests will be too harsh at first. Nobody wants to see an Air Taxi in flames, even if it lands safely.

Standards for the testing of batteries and systems in an aerospace context do exist, like the RTCA DO-311 “Minimum Operational Performance Standards for Rechargeable Lithium Batteries and Battery Systems” or the SAE AIR6897 “Battery Management Systems for Rechargeable Lithium Batteries Used in Aerospace Standards” which targets Battery Management Systems. How those standards will be applied, if they are supplemented with lessons learned from the automotive world and how the aviation authorities will adapt remains to be seen.
Further Technical & Business Considerations

Technical Considerations

Next to the certification, other key challenges are how to deal with the needed technical changes in a cell, and how the cell development can be aligned with the next generation vehicle or make one generation upgradable, considering the importance of the certification process.

There are also some interesting ideas such as using the rotor air to cool the battery pack. In addition, the parallel strings of the battery pack might actually be physically separated for safety reasons, but also to implement a quick release swap system or even fast charging with multiple inlets.

Business Considerations

A critical question from a business perspective to consider: how to ensure to receive high quality cells, especially if cells are bought from a big player. Also, it might be of interest to move into long-term strategic partnerships and/or manufacture battery cells in-house. The lifetime of the battery might be significantly shorter than in automotive applications, because the daily aircraft usage is higher. This will require adapted re-manufacturing and recycling concepts, and has to be part of the certification, maintenance and repair requirements and protocols.
On a very high level, we see three categories of eVTOL vehicle companies:

First, there are several start-ups that exclusively work on the design and production of eVTOL vehicles. A lot of them are very well-funded and some even have prominent backing, by Google or automotive companies, like Toyota and Daimler.

There are small aircraft companies, like Pipistrel and Karem, that pivoted or work on an eVTOL vehicle as an extension of their product line. There are also big OEMs like Embraer, Bell, Airbus, Aurora (a Boeing company) that are trying to establish themselves in this new, potentially lucrative market. Hyundai, an automotive company looking to break into this nascent industry through building air taxis, , is somewhere between all of those categories. They claim plans to invest $1.5 billion in the coming years6.

Currently, it is not clear if impossible to say who might have the upper hand at conquering this new market. Each company has inherent advantages and disadvantages for example when it comes to know-how-transfer.

For example – an OEM might be great at building a turbine or even rotor powered aircraft and lots of that knowledge will be helpful when building an eVTOL, especially the certification part. However, are they able to integrate knowledge from the automotive world? Due to their inherent appeal startups might have an advantage when hiring new talent. They might have an easier time with their specific approach on a greenfield, but might struggle more in working with the regulation bodies.
Future of eVTOL

In conclusion, we see that to win this race, a close alignment with certification bodies will be key. The answer to how modifications in the battery system will be categorized and need re-certification, will be critical for the development roadmap. Maybe it makes even sense to join forces with the competition to create standards to suppliers, bundle the voice towards cell manufacturers and certification bodies about change and modifications.

The demand might be high enough to create a Gigawatt Factory that solely produces cells for eVTOLs. Creating strategic partnerships might be the decisive factor to gain a competitive advantage here.

As with the automotive industry, if the battery is not treated as the key component and the vehicle is basically designed around it, the solution is likely not to be optimal.
References

[1] https://luftrettung.adac.de/volocopter/
[2] February 2021

Imprint

Authors
Martin Talke
Martin.Talke@umlaut.com
Nicolas Brieger
Nicolas.Brieger@umlaut.com
Delivered to you by umlaut SE
Am Kraftversorgungsturm 3
52070 Aachen
Germany

www.umlaut.com