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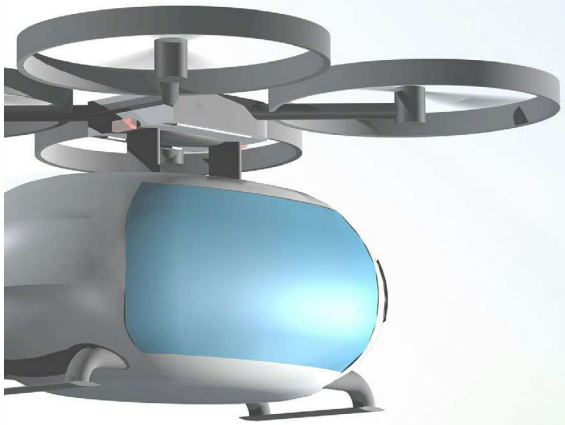

eVTOL & Urban Air Mobility: Business & Technology Choices

A PTC WHITEPAPER

April 2024
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PTC and eVTOL/UAM

The eVTOL (Electric Vertical Takeoff and Landing) and UAM (Urban Air Mobility) industry is a rapidly evolving sector of the air transport industry that promises to revolutionize how we move people and products. The development of this industry has been driven by advancements in technology, particularly in electric propulsion and autonomous systems, and the growing need for efficient, congestion-free, and eco-friendly transportation.

The eVTOL/UAM industry has attracted significant capital investment. In 2020, Avionics International announced that urban air mobility technology companies raised a total of $1.3 billion in private investment, an increase of 80 percent from the pre-COVID year of 2019. McKinsey & Company later reported that three short years later, by mid-2022, cumulative disclosed industry investment exceeded $15 billion. This influx of capital has enabled companies to invest in research and development, infrastructure, and regulatory compliance.

Regulatory approval is a critical milestone for the eVTOL/UAM industry. Before eVTOL and other Advanced Air Mobility (AAM) aircraft can be deployed commercially on any scale, regulators need to work through the novel issues presented by these aircraft, including certification processes, collaboration across jurisdictions, and critical infrastructure such as vertiports and energy supply. Leading regulators such as the FAA and EASA have been working for several years now toward certifying eVTOLs, but safety is paramount, and it will take time to work through these new technology criteria and business models. PTC estimates that the first eVTOL companies will achieve sufficient regulatory certification to launch scaled commercial operations by early 2026.

Despite this multi-year regulatory process, companies need to act quickly and build aircraft at a fast pace to maintain a competitive edge and to seize business case opportunities. The eVTOL landscape is highly competitive, with over 500 concepts in the works as of mid- 2022. Companies including Archer Aviation and Joby Aviation are leading the pack, announcing plans for end-of-2024 certification for their eVTOL aircraft. To stay competitive, companies need to balance team, technology, and capital, and align their scaling plans with market needs.

The eVTOL/UAM industry is at the forefront of a transportation revolution. With significant capital investment, rapid technological advancements, and a multi-year regulatory path well underway, companies in this industry are poised to transform the way we commute and transfer goods. However, they must navigate a complex landscape of technical, regulatory, and market challenges to achieve commercial success and maintain a competitive edge. There are fundamental business and technology choices that players in the space must make for success. There are few “right answers” to these questions and PTC doesn’t, in this paper, attempt to judge the choices being made – rather we believe it is important to understand the technology and business landscape so supporters of eVTOL/UAM can continue to supply best in breed solutions.

PTC is a pre-eminent supplier of Digital Thread software solutions to the industry. As a publicly traded company with a deep and growing bench of Aerospace customers, we provide digital solutions to companies to help them truly transform the physical. PTC is a major supplier of digital thread software solutions to eVTOL/UAM companies including computer-aided design and product lifecycle management systems, and we aim to increase our share of support to this important sector. Importantly, major technology investors in this market include automotive and aviation players which we have supported for decades with leading software innovation.

This paper will identify key business and/or technology choices confronting this sector and begin to identify the implications of one choice over another. This is an exciting industry that will experience substantial growth and consolidation over the coming decade and we at PTC are proud to contribute to this success.

CHALLENGE: Piloted or Un-Piloted?

Companies are faced with a critical early design decision: should they operate their eVTOLs with a pilot, or should they push for fully autonomous, unmanned operations? This decision is far from straightforward and involves a complex interplay of technological, regulatory, and societal factors.

Let's explore the advantages of operating an eVTOL aircraft with a human pilot on board.

- **Expertise in Control:** A trained pilot can handle unexpected situations and make decisions based on training and experience. This can be particularly important in emergency situations or complex flight conditions where human judgment and adaptability can outperform automated systems.
- **Passenger Confidence:** Passengers may feel more secure knowing there's a human pilot in control. The presence of a pilot can provide reassurance and a sense of safety, especially during the early stages of eVTOL adoption.
- **Regulatory Approval:** Currently, aviation regulations are more favorable towards piloted aircraft. Regulatory bodies like the FAA have established protocols for piloted aircraft, making it easier to gain approval for piloted eVTOLs.

Now, a look into the cons of operating an eVTOL aircraft with a human pilot on board.

- **Cost:** Employing pilots can be expensive and requires regular training. This can significantly increase the operational costs of eVTOL services.
- **Limited Operation:** Pilots can only fly for a certain number of hours before they need to rest. This will limit the operational efficiency and availability of eVTOL aircraft.
- **Human Error:** Despite training, human error can still occur. Mistakes made by pilots can lead to accidents, potentially undermining the public confidence in eVTOL technology.

Similarly, there are both advantages and disadvantages to fully autonomous, unmanned operations. A look at the pros.

- **Cost-Effective:** Autonomous eVTOLs can potentially avoid the need for expensive pilots. This can significantly reduce operational costs and make eVTOL services more affordable.
- **Scalability:** Autonomous systems can operate continuously, which is beneficial for scaling operations. Without the need for pilot rest periods, eVTOL services can potentially operate around the clock.
- **Hazardous Environments.** For cargo-only operations, not having a human pilot on board potentially opens up significant and attractive business opportunities for aerial support in hazardous environments.

Fully autonomous, unmanned operations come with cons as well.

- **Public Acceptance:** The public may be hesitant to accept autonomous aircraft due to safety concerns. Trust in autonomous systems is still developing, and early (and isolated) incidents involving autonomous automobiles undermine public confidence.
- **Regulatory Hurdles:** Current aviation regulations do not fully accommodate autonomous aircraft. Gaining regulatory approval for autonomous eVTOLs can be a complex and time-consuming process.
- **Technical Challenges:** Developing a reliable and safe autonomous system is technically challenging. Ensuring that autonomous eVTOLs can safely handle all potential flight scenarios requires advanced technology and rigorous testing.

CHALLENGE: Humans or Cargo?

Should eVTOL manufacturers design their aircraft primarily for human passengers or cargo transport? This decision has far-reaching implications for the design, operation, and business model of eVTOL services.

Let's explore the pros of designing eVTOL aircraft with the end goal of transporting humans.

- **Increased Accessibility:** eVTOLs could make it easier for people to get around, especially those who are unable to drive or don't want to take public transportation. For example, eVTOLs could be used to transport people with disabilities or the elderly to medical appointments. This could significantly improve their quality of life and independence.
- **Efficiency:** eVTOLs are more environmentally friendly and, for the most part, more convenient. They can land in tighter spaces, operate quietly, and significantly reduce commute times in urban settings. This makes them a very attractive solution for urban mobility.

- **Financial:** A primary advantage often emphasized in the utilization of eVTOLs for human transportation is the potential for substantial economic returns. There is an untapped and lucrative market of time-conscious businesspeople who will pay a premium for urban transport as a trade-off to avoid congestion delays. This is why we anticipate that early eVTOL networks will flourish where helicopter networks exist today.

A look into the cons of designing an eVTOL aircraft with the end goal of transporting humans.

- **Regulatory Hurdles:** eVTOLs will need certifying regulations before they can start to transport passengers in built-up areas. This requires safety, so laws will have to catch up, and fast. Companies will ultimately have to prove to regulators that these aircraft can operate safely. Some of the certifying regulations do not yet exist.
- **Limited Range:** The limited range of eVTOLs compared to other aircraft, along with reduced carrying capacities, don't lend themselves to things like search and rescue or making long-haul deliveries that helicopters and airplanes are so good at. Passenger service further limits the effective technological range of eVTOL aircraft, thereby constricting the business case.

Some eVTOL companies are primarily interested in carrying cargo and here is why.

- **Safety:** Since cargo eVTOLs don't carry passengers (and are likely remotely-piloted as well), the risk to human life in the event of an accident is reduced. This could potentially lead to lower insurance costs and less stringent safety requirements, allowing for more design flexibility.
- **Regulations:** Cargo eVTOLs may face fewer regulations compared to passenger eVTOLs. Passenger eVTOLs need to meet certain very high safety standards designed to protect passengers, which will be costly and time-consuming to design. By focusing on cargo transport, companies can potentially bring their eVTOLs to market more quickly with substantially lower costs.
- **Flexibility:** Cargo eVTOLs can operate at all hours and in a wider range of weather conditions than passenger eVTOLs. This can provide a significant advantage in terms of logistics and efficiency, as cargo can be transported exactly when and where it's needed.

A glance at the cons of carrying cargo as opposed to humans.

- **Limited Market:** The market for cargo transport may be smaller than the passenger transport market. While there is certainly a demand for fast, efficient cargo transport, it may not be as large or as profitable as the market for passenger transport. This could potentially limit the profitability of cargo eVTOLs. A potential exception to this might be the military cargo market, where the advantage of unmanned eVTOL cargo carriers appears to be of considerable interest.

- **Technical Challenges:** Designing eVTOLs that can carry heavy cargo loads over long distances is technically challenging. It requires powerful, efficient engines and large, sturdy airframes.
- **Infrastructure:** Cargo eVTOLs require a different kind of infrastructure compared to passenger eVTOLs. They need larger landing pads to accommodate the size and weight of the cargo, as well as cargo handling facilities. Building this infrastructure can be costly and time-consuming.

CHALLENGE: Fully Electric or Hybrid?

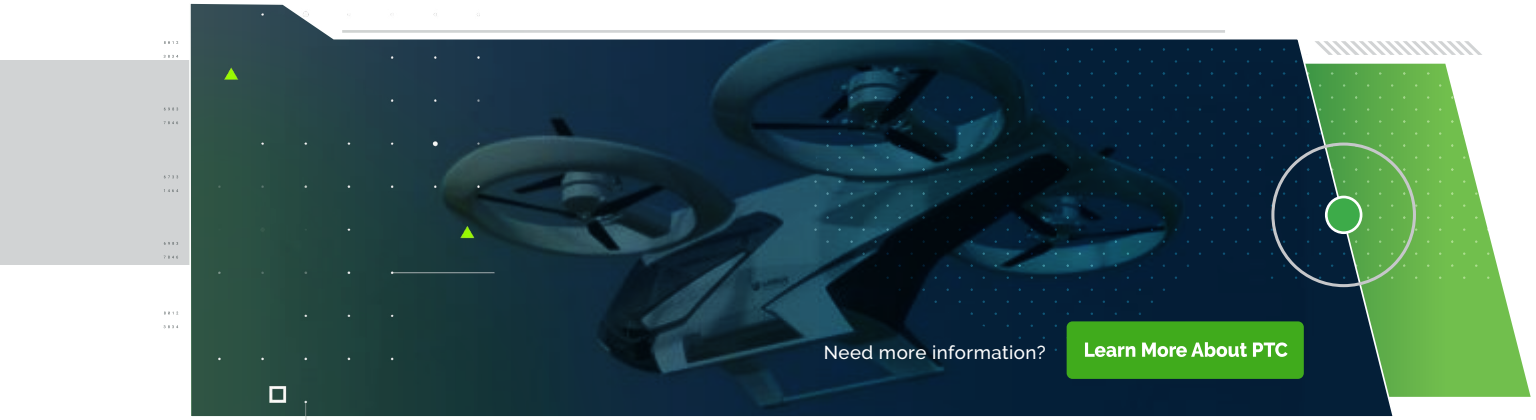
Another key decision, should eVTOLs be fully electric or hybrid? Each option carries its own set of advantages and challenges, shaping not only the technical design but also the environmental impact, operational costs, and regulatory considerations.

Let's delve into the advantages of fully electric eVTOL aircraft.

- **Environmental Impact:** All-electric eVTOLs are powered by batteries, making them more eco-friendly as they produce zero emissions during flight. This is a significant advantage in today's world where there is a growing emphasis on reducing carbon emissions. Furthermore, the use of renewable energy sources to charge the batteries can further reduce the overall environmental impact.
- **Noise Reduction:** Electric propulsion systems are typically much quieter than their combustion engine counterparts, which is a significant advantage in urban areas (indeed perhaps an urban authority requirement). This can potentially lead to less noise pollution, making eVTOLs more suitable for operations in densely populated areas.
- **Simplicity and Cost-Effectiveness:** Electric systems are simpler and more cost-effective than hybrid systems. They allow for smaller aircraft designs, which can lead to lower manufacturing and maintenance costs.

Conversely, let's explore the cons of eVTOL aircraft that are completely electric.

- **Limited Range:** The range of all-electric eVTOLs is currently limited by battery technology. This means that they may not be suitable for long-distance flights or longer loiter times in the event of unforeseen flight issues. This will significantly affect business cases.
- **Long Refueling Time:** Charging batteries takes longer than refueling a conventional or hybrid aircraft. This can lead to longer downtime between flights, which can impact the operational efficiency of eVTOL services.
- **Infrastructure Requirements:** All-electric eVTOLs require considerable charging and energy generation infrastructure, which is still under development in many areas. This includes charging stations and power grids capable of handling the high energy demands of eVTOLs.



Now, let's navigate the advantages that hybrid eVTOL aircraft offer.

- **Extended Range:** Hybrid eVTOLs can switch to conventional fuel when the battery is depleted, extending their range. This makes them more versatile and capable of serving a wider range of missions.
- **Quick Refueling:** Hybrid systems can be refueled more quickly than batteries can be recharged. This can lead to shorter downtime between flights, improving the operational efficiency of eVTOL services.
- **Transitional Technology:** Hybrid systems can serve as a transitional technology while all-electric systems continue to develop. This allows for the early adoption and deployment of eVTOLs, effectively seizing the early mover advantage, while benefiting from advancements in electric propulsion technology

The negatives of hybrid eVTOL aircraft are not inconsiderable.

- **Environmental Impact:** While hybrid eVTOLs are more efficient than fully fuel-powered aircraft, they still produce emissions when the conventional engine is in use. This can have a negative impact on the environment, particularly in terms of air quality and greenhouse gas emissions.
- **Complexity:** Hybrid systems are more complex than all-electric systems, potentially leading to higher maintenance costs and reliability issues. The need to maintain and operate both an electric motor and a conventional engine can add to the operational complexity (and weight).
- **Noise:** Hybrid eVTOLs will be louder than their all-electric counterparts due to the use of conventional engines. This can lead to higher levels of noise pollution, which can be a concern in urban areas.

CHALLENGE: Rural Service or Urban Areas?

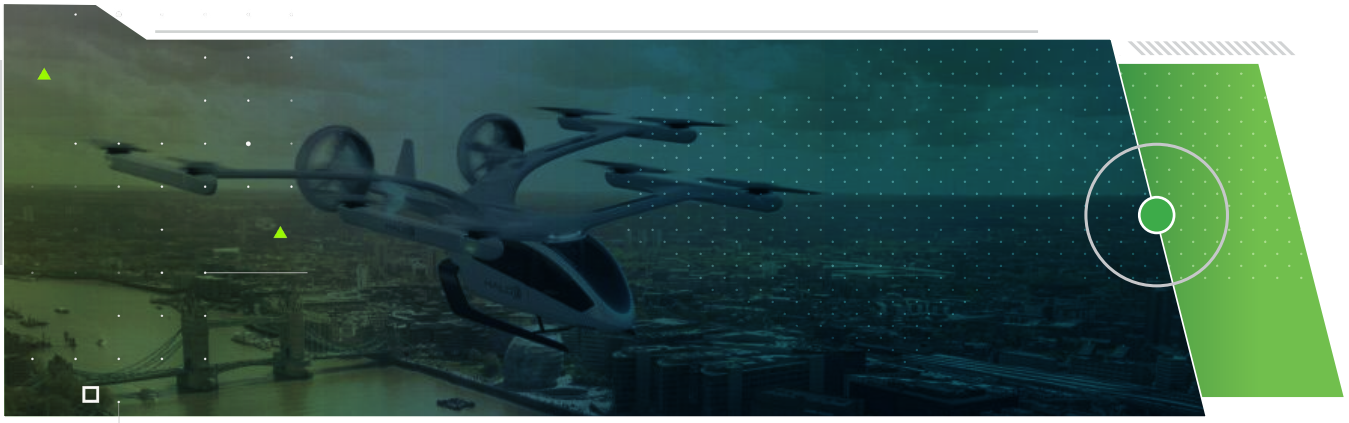
This section looks into the pros and cons of operating eVTOLs in rural areas versus downtown urban areas. The Urban "case" for eVTOL/UAM is well understood so here we will only look at the pros and cons of rural service.

Let's investigate the positive aspects of operating eVTOLs in rural areas.

- **Better Coverage and Reduced Response Times:** eVTOLs can provide better coverage in rural areas where road infrastructure may be lacking or inefficient. They can quickly reach remote locations, reducing response times, especially in emergency situations. For instance, they can be used for emergency medical services (EMS), where the response time is critical. They can also overcome geographical challenges such as rivers, mountains, and congested roads that may delay ground vehicles.
- **Less Infrastructure Needed:** Unlike electric or combustion road vehicles, eVTOLs do not require extensive transport infrastructure. They can take off and land vertically, eliminating the need for runways. This makes them suitable for rural areas where the development of such infrastructure may be challenging or costly. eVTOLs can take off and land in very small spaces. This means they can operate from various locations within a city, not just airports or specific landing pads.

In opposition, a look into the negative factors of eVTOLs operating in rural areas.

- **Safety Concerns:** There are safety concerns about eVTOLs, such as the risk of crashes. Factors like adverse weather conditions can pose challenges. Additionally, there are potential risks associated with lithium-ion batteries used in eVTOLs, such as the risk of fires.
- **High Initial Cost:** eVTOLs are still in the early stages of development, and they are likely to be expensive when they first become available. The high initial cost could be a barrier to their widespread adoption in rural areas where business cases will be exceptionally tight.



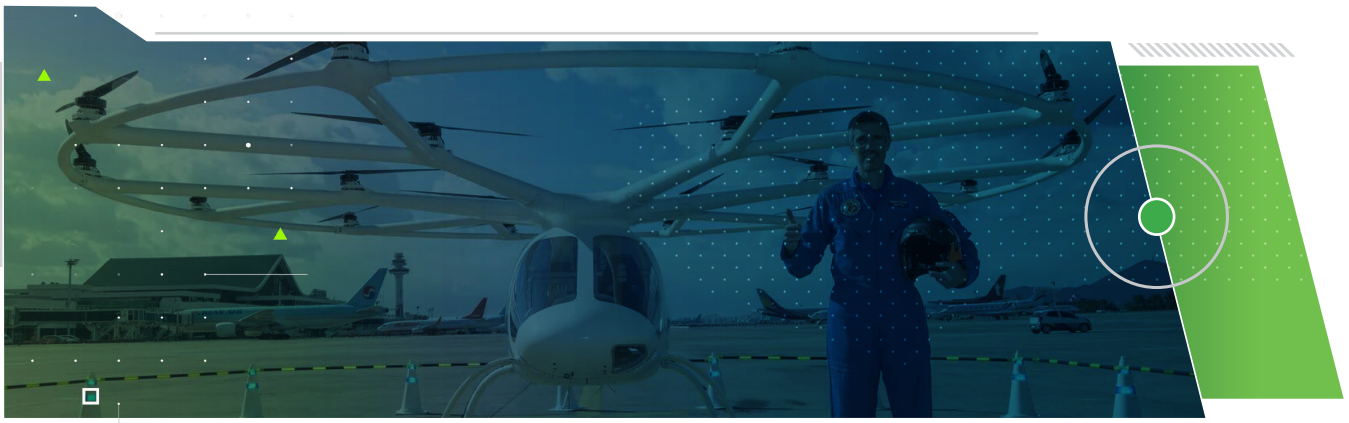
Charting a future course

The advent of Electric Vertical Take-Off and Landing vehicles (eVTOLs) marks a significant milestone in the evolution of transportation. The decision to operate piloted versus un-piloted eVTOLs, carry humans or cargo, and choose between fully electric or hybrid power systems, each presents its own unique sets of challenges and opportunities. Furthermore, the choice of operating environment, be it rural or urban, adds another layer of complexity to these considerations.

Piloted eVTOLs offer the advantage of human judgment and decision-making, while un-piloted one's leverage advancements in autonomous technology. The choice between carrying humans or cargo is largely dependent on the specific use case and safety considerations. Fully electric eVTOLs promise zero emissions, while hybrid systems offer extended range and versatility, thereby mitigating business case concerns. The decision to operate in rural or urban areas is influenced by factors such as infrastructure availability, regulatory landscape, and specific transportation needs. Rural areas offer the advantage of less crowded skies and potentially less stringent regulations, while urban areas present the opportunity to alleviate traffic congestion and provide rapid intra-city transportation.

The eVTOL market is dominated by fast-moving companies which fully understand the importance of the powerful capabilities available to them from software comprising the "digital thread". PTC is one of the largest suppliers to the industry (indeed we are the largest supplier of Product Lifecycle Management software to the United States Government and Defense Industrial Base) and we are delighted to support key industrial actors in the eVTOL sector with Computer-Aided Design, Augmented/Virtual Reality, Application Lifecycle Management, and other key digital thread solutions. No modern company can design, prototype, manufacture, manage, build, and sustain complex, heavily regulated equipment such as eVTOL without digital tools from PTC. We have an outsized influence in this sector and we intend to continue to grow our footprint among the key actors in the space.

As we navigate these decisions, it is crucial to consider not only the technological feasibility but also the societal, environmental, and economic impacts. The journey towards the widespread adoption of eVTOLs is a complex one, filled with both challenges and opportunities. As we continue to explore this exciting frontier, it is our responsibility to ensure that the decisions we make today pave the way for a sustainable, efficient, and inclusive future of transportation. PTC is committed to helping industry participants navigate this journey.



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