WHITE PAPER

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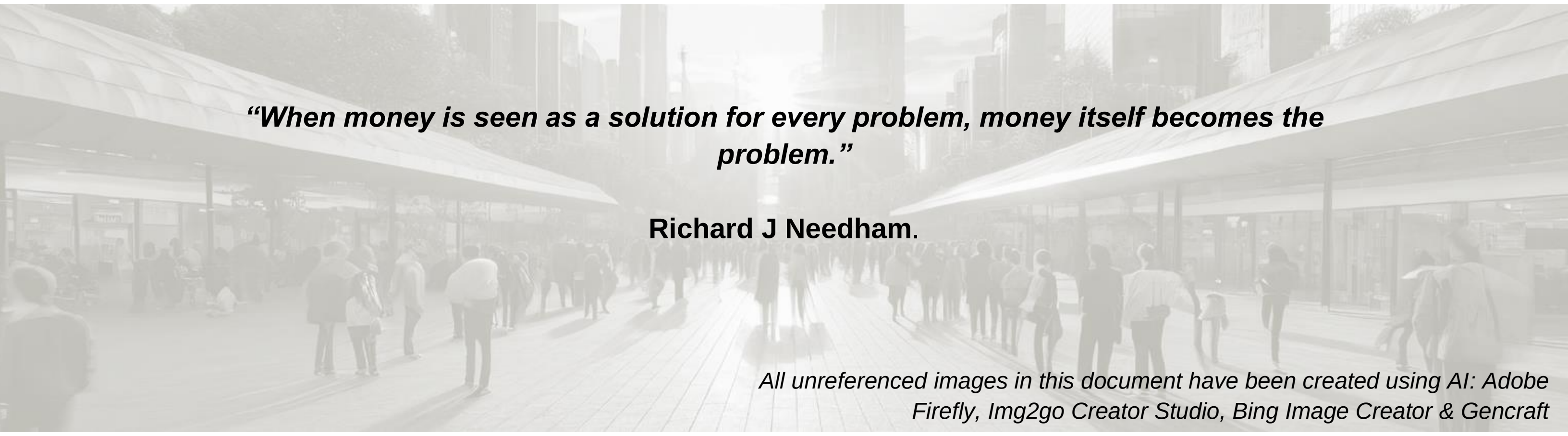
eVTOL: A problem that money can't solve.



"When money is seen as a solution for every problem, money itself becomes the problem."

Richard J Needham.

All unreferenced images in this document have been created using AI: Adobe Firefly, Img2go Creator Studio, Bing Image Creator & Gencraft

Introduction

Throwing money at a problem can be an effective strategy if you're willing to accept the short-term unavailability of your money.

This approach is often applied to a problem when the cost is difficult to predict and is often an alternative to rational cost and risk estimation. Money is used to maintain forward momentum when the path to resolution is not clearly defined.

In aerospace, this financial brute force policy has been applied with government money in almost every large military and civil aircraft project since we started making military and large civil aircraft.
General aviation or small aircraft programs are generally not supported by government money - other than the normal tax credits, incentives, and grants that any business might qualify for.

It is important to acknowledge that eVTOL aircraft are general aviation aircraft. (https://www.iaopa.eu/what-is-general-aviation), despite what the new marketing lexicon may want to tell us.

To estimate the cost of solving a problem the full extent of the problem must be understood. More importantly, there must be a desire to understand the full extent of the problem.

Leading EVTOL programs have chosen to throw money at their problems. They are largely using private equity funding in the pursuit of their goals.[1,2] That strategy has evolved into throwing shareholders money at their problems via SPAC-induced IPOs.

This is a unique situation in aircraft development. This amount of money is rarely spent on general aviation development; when it has been tried in the past it has not resulted in success.

There appears to be a slow awakening of "*conscientiam emptor scriptor*". It is only recently that the chance of success, and the risk of failure of these endeavours have begun to be critically assessed.

The lack of objective assessment by investors is curious for those with experience in general aviation. It is normal for investors to make these types of assessments before investments are made, not after. In advance of investing the chances of success or failure, the likely cost to get to market, and the effect of program cost on the business case are assessed.
In this case, either due to an intoxicating rush of futurism or an optimistic faith in unverified data, critical assessments have been deferred.

To understand the chance of success and risk of failure of these projects, all the likely risks must be defined, and their magnitude assessed.

The problems can be broken into three families of risks: Technical, Commercial, and Compliance.

Each of these areas can impact any of the other two areas and any problem or issue can exist in more than one area. However, to keep things simple these are the risk definitions used.

[1] https://www.urbanairmobilitynews.com/air-taxis/paris-2023-evtol-funding-rises-but-manufacturer-cash-reserves-limited-mckinsey/
[2] https://www.mckinsey.com/industries/aerospace-and-defense/our-insights/future-air-mobility-blog/fam-funding-capital-flows-regain-momentum-despite-challenges

Contents

Technical

Almost every eVTOL aircraft is based on an electrical distributed propulsion architecture. It is the major design aspect that marks them apart from normal general aviation or small part 27 rotorcraft. This propulsion architecture is usually in the form of multiple propellers or rotors driven by multiple electric motors[3]. This configuration is only possible with electric drive systems. Turbine or piston engines generally must be 'inline' with the propeller or thrust vector (this is not the case for helicopters where heavy, expensive, and complex gearboxes are required). Turbine and propeller engines do not scale efficiently below a certain level and require complex mounting and fuel system arrangements. This makes piston and turbine engines inherently unsuitable for a distributed propulsion architecture that requires many small motors driving multiple rotors or propellers.

There is an old dictum in aircraft design - you design the aircraft around the engine. When your engine is new and unique the risk of technical failure is high. The aircraft is designed around a major system that is unique and there is no replacement.

If an electrical drive system is flawed for any reason, there are likely no suitable alternative powertrain systems. These air vehicles that use distributed propulsion cannot be converted to traditional drive systems. These air vehicles are rendered useless and worthless.

This is why almost all conventional aircraft programs have an 'A' primary powerplant choice and an alternative 'B' engine that they can use with some adaptation. If an engine supplier lets down an OEM, they have a way to continue with their program and recoup the investment.

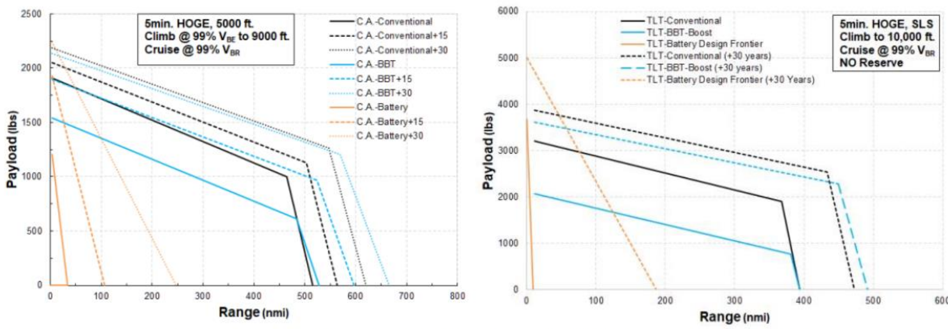
There are two major technical risks inherent in an electric powertrain.

Batteries

Batteries are a suitable energy storage medium in non-weight critical applications where low power output is required. Laptops, phones, flashlights, etc.

[3] https://www.mdpi.com/2226-4310/6/3/26

Batteries have low energy density compared to hydrocarbon liquid fuels[4]. This can be seen in the limited range and endurance numbers published for eVTOL and other electrical aircraft. The image below shows the effect of converting a helicopter to a battery-powered electric drive system[5].



C.A. Conventional = Conventionally powered Configuration A light helicopter with a design TOGW of 5,781 lbs
C.A. BBT = Configuration A–based battery-boosted gas turbine hybrid electric helicopter
C.A-Battery—All-electric, battery-powered variant of Configuration A.
TLT-Conventional—Conventionally powered tiltrotor vehicle calibrated to match the performance of the XV-15.
TLT-BBT-Boost —Hybrid variant of the tiltrotor configuration featuring downsized engines and a boost battery using a parallel hybrid propulsion architecture. The battery is sized to provide sufficient power for boosted hover, boosted climb, and OEI operations.
TLT-Battery Design—All-electric, battery-powered variant of the tiltrotor configuration.

With contemporary battery technology, the range of a conventional helicopter is reduced by a factor of more than ten. With projected battery technology in thirty years, the range is still less than half of a conventional helicopter today.

Modern lithium-based batteries have an irreversible thermal failure mode that results in temperatures about twice that of burning aviation fuel. These battery fires are effectively inextinguishable because burning batteries generate their own oxygen for the combustion process.[6]

This critical failure mode of batteries and the requirement for residual power for safe flight and landing after any failure creates additional system complexity and additional weight. Battery installations must be designed with a high degree of redundancy, separation, venting and thermal protection.[7]

The weight of these risk mitigations further degrades the already low performance of the aircraft.

Motor certification

It is a little-known fact that at the time of writing, there is no electric motor that is certified for commercial aircraft primary powertrain use. There is one motor that is certified for use in Light

[4] https://en.wikipedia.org/wiki/Energy_density
[5] https://ntrs.nasa.gov/api/citations/20205000636/downloads/2021-08-20-eVTOL-White-Paper-Final_V48.pdf
[6] https://www.sciencedirect.com/science/article/pii/S2542435118302800
[7] https://www.easa.europa.eu/downloads/136701/en

Sport Aircraft. This is the Pipistrel Velis powertrain[8]. Several projects may result in a certified aircraft electric drive system such as SAFRAN[9] which aims to have its motor certified by the first quarter of 2024, Rolls Royce[10] (who bought the business from Siemens[11]) which again targets 2024 certification and MagniX[12]. MagniX probably has the longest development program, having started in 2009 and they have not published a date for certification.

There will be a limited and uncertain choice of electric motors for eVTOL developers to choose from. However, vehicles have already been configured, developed, and flown and certification programs have begun.

This is similar to running the first leg of a relay race while your teammates are at the sports store looking for a pair of running shoes.

Certification of a new aircraft system does not guarantee the reliability of that system in service conditions. Almost all complex systems when they are first put into service suffer from lower than planned reliability. Electric aircraft powertrains will be no different.

Other Powertrain Systems

There is a plethora of positive messaging and targeted investments for hydrogen-powered aircraft. Hydrogen has a wide range of practical barriers in the way of aircraft powertrain applications. This subject will not be covered in depth here, but some of the more significant problems around hydrogen as a fuel are availability, delivery, ground storage and handling, refueling, storage on the aircraft (very low temperature, high pressure, off-gassing and the inability to store on the aircraft for anything other than the very short term), the volume required to store the gas, the immaturity of hydrogen fuel cell technology and hydrogen embrittlement of storage and distribution (on and off the aircraft) and powertrain components.

8 https://www.pipistrel-aircraft.com/products/velis-electro/
9 https://www.safran-group.com/products-services/engineustm
10 https://www.rolls-royce.com/products-and-services/electrical/our-electrical-power-and-propulsion-portfolio.aspx
11 https://press.siemens.com/global/en/pressrelease/siemens-sells-electric-aircraft-propulsion-business-rolls-royce
12 https://www.magnix.aero/

Control Systems

Almost all eVTOL aircraft lack any form of natural aerodynamic stability. This is a fundamental difference to helicopters and fixed-wing aircraft.

Helicopters have no stick-free stability and always require active pilot input. They are stable enough that they do not require software control to fly.

eVTOL aircraft require stabilizing software similar to quadcopters and other small UAVs. This type of vehicle stabilizing software has not been used for any manned aircraft or been certified before.

Manned aircraft approaching this low level of natural stability have only ever been developed for military applications. The level of aerodynamic stability for military applications is still maintained at the highest level possible considering the required mission envelope.

The technical risk of the control system for most eVTOL aircraft exceeds that of the F35, a $40Bn[13] military development program. This is not to suggest that it will cost this amount of money to develop and certify an eVTOL control system.

However, it is true to say that the technical risk for eVTOL control systems is greater than that accepted by large military programs with very high budgets.

Technical Summary

It is normal for aircraft developers to minimize technical risk to those areas that are absolutely required for the required incremental commercial improvement to justify the investment necessary for a new product.

eVTOL OEMs have adopted a new paradigm of accepting very high technical risks and spending very large amounts of money to make new systems mature and attempt adequate risk mitigation.

This approach is opposed to that which has been demonstrated to be consistently successful.

[13] https://en.wikipedia.org/wiki/Lockheed_Martin_F-35_Lightning_II_procurement

Commercial

The commercial risk is anchored on the MaaS (Mobility as a Service[14]) business model that almost every eVTOL company relies on for commercial justification for their product.

The Market

Sales of the aircraft and the commercial success of the venture are related directly to the market for the service the aircraft creates. The market for the service is related to the relative cost of that service compared to the available alternatives.

To observe the obvious, the higher the cost of the mobility service provided by an eVTOL aircraft the less competitive it is, the lower the demand for that service will be and the lower the demand will be for the aircraft.

The number of aircraft you can sell, or rather the rate at which you can manufacture and sell them directly affects the cost of manufacture. The lower the rate of manufacture the higher the unit cost of manufacture. This is the classic 'economy of scale' phenomenon.

If demand for a product dictate that a company manufactures at a lower rate than planned not only do they suffer a reduced revenue but they suffer a reduced margin.

This is a classic problem for aerospace OEM startups. They reach the market only to find that the demand is not what was projected. The worst case is that the cost of manufacture at the realized lower rate of manufacture is so high that a loss is made on each aircraft. Despite all the time and resources spent to get to market, and despite the excellence of the product, the company will fail after crossing the finish line. There are multiple examples of this outcome, the most notable are Sino Sweringen[15] and Eclipse[16]. Coincidentally, both programs spent a relatively very large amount of money to reach the general aviation market. In 2023 US dollars Sino Swearingen spent over $1.5BN and Eclipse over $2.5BN.

[14] https://maas-alliance.eu/homepage/what-is-maas/, https://www.capgemini.com/gb-en/insights/expert-perspectives/how-the-advent-of-advanced-air-mobility-will-pave-the-way-for-more-connected-and-sustainable-aviation/
[15] https://en.wikipedia.org/wiki/SyberJet_SJ30
[16] https://en.wikipedia.org/wiki/Eclipse_500

There are several limitations to the competitiveness of eVTOL MaaS. eVTOL aircraft are flying in the same environment as any other aircraft 'on demand' service and aircraft design has a limited effect on total aircraft operating economics compared to a conventional alternative. Some costs (insurance, landing fees, crew, etc) will remain the same or will be higher than conventional alternatives.

The projection of eVTOL operating costs varies, but the approach defined by Robert Mann appears to be universally adopted:

"*You can't sell any of this stuff if you don't make optimistic projections*," said Robert Mann….. R.W. Mann & Company[17]

Mobility Analyst, Asad Hussein writes: "Air taxi startup Lilium has claimed that the cost of a trip from Manhattan to JFK Airport could be $70, or approximately $4.40 per mile. Joby Aviation estimates the operating cost of its aircraft will be $3.80 per mile for a 25-mile trip, significantly below the cost of a $9-per-mile helicopter trip."[18]

A study commissioned by NASA and carried out by Booz Allen Hamilton[19] obtained the following results:

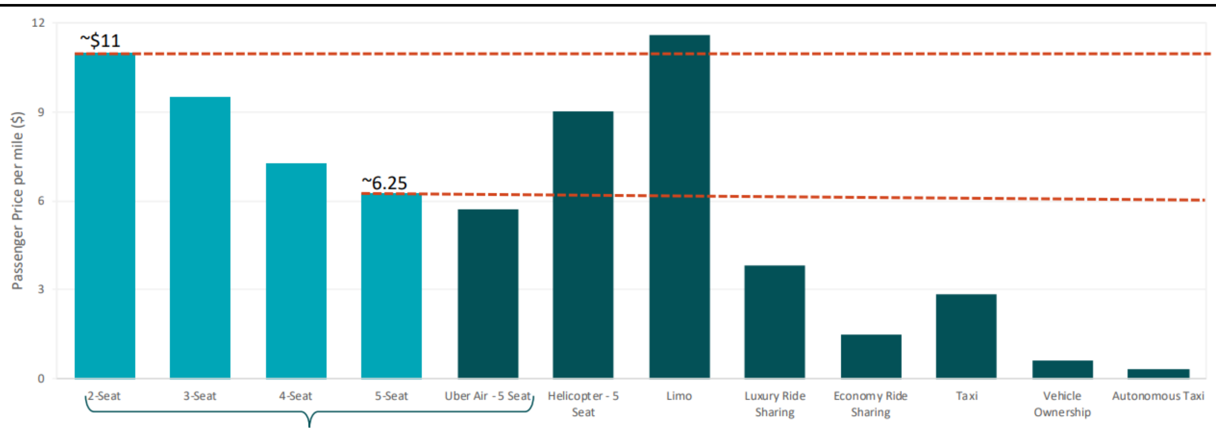


Figure 42: Price comparison with other modes of transportation

The results of their study show that an eVTOL aircraft only becomes competitive with a 5-passenger helicopter with (5 occupants) when it carries 4 passengers.

This reveals a small but potentially significant cost saving for operators. This saving is far less than the eVTOL operators claim, making truth of the statement by Robert Mann above.

[17] https://www.flyingmag.com/evtol-air-taxi-passenger-prices/
[18] https://www.aviationtoday.com/2021/04/09/air-taxis-likely-to-not-deploy-in-early-to-mid-2020s-as-predicted-report-says/
[19] https://ntrs.nasa.gov/api/citations/20190001472/downloads/20190001472.pdf

The same Booz Allen Hamilton report pointed out that up to 60% of further cost savings were possible for eVTOL with autonomy (pilotless flight) and ‘technological improvements’. No timetable for the adoption of these measures was made.

The criticality of projected economies of scale on eVTOL OEM business models cannot be overstated. Archer Aviation[20] has made their investor deck publicly available[21] and their volume production rate is mentioned on slide 44 as >5000 per year, although this is tempered on slide 47 as 2300 per year by 2030. To put this in context, GAMA (General Aviation Manufacturers Association) give global sale records of aircraft types[22]. In 2022 a total of 932 helicopters were sold.

GAMA

March 10, 2023

General Aviation Aircraft Shipment Report

General Aviation Manufacturers Association

1400 K Street NW, Suite 801 | Washington, DC 20005 | USA

Rue de la Loi 67 | Brussels 1040 | Belgium

2022 Year-End Report

Aircraft Shipments[1, 2, 6] by Type Manufactured Worldwide

	QI	QII	QIII	QIV	Year-To-Date
Single-Engine Piston and Electric	238	331	344	453	1,366
Multi-Engine Piston	29	42	30	57	158
Total Piston Airplanes	**267**	**373**	**374**	**510**	**1,524**
Single-Engine Turboprops	95	120	116	174	505
Multi-Engine Turboprops	15	17	20	25	77
Total Turboprop Airplanes	**110**	**137**	**136**	**199**	**582**
Business Jets	118	171	157	266	712
Total Turbine Airplanes	**228**	**308**	**293**	**465**	**1,294**
Grand Total Airplane Shipments	**495**	**681**	**667**	**975**	**2,818**
Grand Total Airplane Billings	**$3,825,379,493**	**$5,277,963,616**	**$5,013,638,765**	**$8,748,817,819**	**$22,865,799,694**
Piston Helicopters	40	47	50	57	194
Turbine Helicopters	100	160	181	297	738
Grand Total Helicopter Shipments	**140**	**207**	**231**	**354**	**932**
Grand Total Helicopter Billings	**$511,098,532**	**$925,566,333**	**$1,120,735,781**	**$1,961,846,653**	**$4,519,247,299**

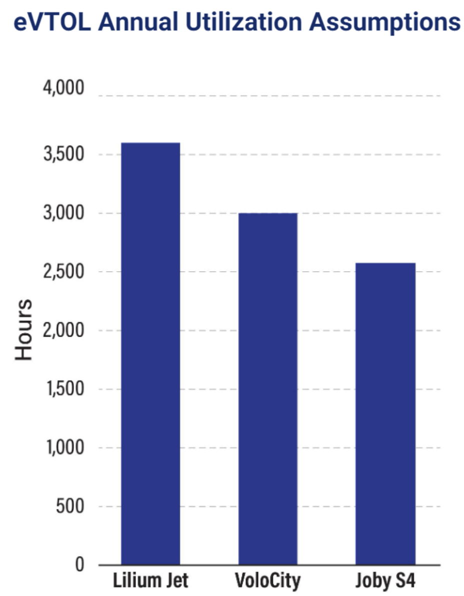
Archer’s business model requires that they sell nearly 2.5 times the entire global 2022 annual helicopter market in 2030.

The over optimistic projection of aircraft demand and production numbers creates a vast overestimation of production rates and reliance on unrealistically low production costs. The reality of higher aircraft operating costs, lower aircraft demand, lower production numbers and higher unit costs in manufacture will sharply contradict the optimistic business models. Company revenue will be reduced by at least one order of magnitude and the profit margin on each unit will disappear.

20 https://www.archer.com/
21 https://s27.q4cdn.com/936913558/files/doc_presentations/Investor-Presentation.pdf
22 https://gama.aero/wp-content/uploads/2022ShipmentReport2023-03-10.pdf

Reliability & MRO

The operating economics of leading eVTOLs rely on aircraft being operated at a very high number of hours per year[23]



The value used by the FAA for systems safety analysis for large (part 25) commercial aviation is an average use of 3000 hours per year[24]. It is not credible that aircraft operating over much shorter legs can exceed, equal or approach that value.

If eVTOL aircraft are to attempt to reach very high usage rates, the aircraft must have a very high dispatch readiness.

High dispatch readiness is related to both overall aircraft reliability and the ability to rectify, repair and replace whatever is needed to solve problems that arise and quickly return the aircraft to service.

Reliability

Aircraft electrical drive systems are often promoted as being more reliable than piston or turbine engine systems because they have fewer moving parts.
This is true (although turbine engines have surprisingly few moving parts) but has yet to be demonstrated.

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[23] https://aviationweek.com/business-aviation/opinion-there-will-be-blood-dissecting-evtol-business-models
[24] https://www.federalregister.gov/documents/2022/12/08/2022-26369/system-safety-assessments

A statement that is more likely to be true would be something like this. "When aircraft electrical powertrains are fully mature and all common service issues are understood and mitigations and resolutions fully developed there is a very good chance that they will prove more reliable than existing piston and turbine engines."

The inherent theoretical reliability of a system is only one component of real-life reliability. When aircraft electrical powertrains are first used in service it would be rational to assume that they will be as reliable or less reliable than existing aircraft powertrains.

The potential increase in reliability can be realized over time with experience. We will only understand what this learning curve looks like after the fact.

The same can be said of the software control systems that these aircraft rely on to remain airborne. Development simulations and flight tests cover a subset of combined service conditions, vehicle states and pilot inputs when compared to what may happen in real life.

When these vehicles are first introduced into service the complexity and chaos of real operational conditions will be imposed on the control software. The limitations of the software will be revealed, airworthiness will be affected, and remedies will be required. It should be expected that Airworthiness Directives will be issued as a result and these vehicles will face restrictions and limitations or even grounding for some time.

These likely reliability risks apply just as much to any other component of new technology employed in these vehicles. Unique glass cockpits, control systems servo motors, sensors, et al.

MRO

The supply chain for LRUs (Line Replaceable Units)[25] for conventional aircraft has consolidated over decades to the point where there is a commonality of suppliers and components between multiple aircraft manufacturers and aircraft models[26].

[25] https://en.wikipedia.org/wiki/Line-replaceable_unit
[26] https://blog.partstat.com/the-consolidation-of-the-aerospace-supply-chain/

Commonly used aircraft vendor components are kept in stock at MRO centres all over the world and are available in minutes, replacement can occur, and the aircraft returned to service quickly. This requirement to minimize time out of service typically drives new aircraft to consider the inclusion of as many existing vendor components for their aircraft as possible. There may be a small performance penalty to pay but it has a disproportionate effect on serviceability.

If there is an entirely new class of aircraft and each aircraft in that class employs a set of unique components that are unique only to that model of aircraft, the number of new components that may require replacement, repair or servicing will impose an excessive burden on the capabilities of an MRO organization.

If a set of unique components is required by only one aircraft type out of tens or hundreds of models of aircraft that an MRO centre serves, it is not economical to invest in the inventory and dedicate the warehouse space to keep these items in stock.

These aspects can delay the resolution of aircraft problems to the extent that the minutes required to get an aircraft back into service can extend to days or weeks.

Training the maintenance technicians on correct storage, handling, installation, and quality checking of the new components is a further challenge that must be addressed.

If multiple eVTOL aircraft are brought to market within a short time frame, each with a unique set of new LRUs, at best there will be a lag for MRO operations to catch up. At worst eVTOL may suffer in the longer term until their electrical system and drive components consolidate to the point where broad commonality makes local warehousing practical and enables timely MRO support. This may take decades.

Other Commercial Issues

Insurance

The insurability/cost of insurance for eVTOL aircraft is unknown. The risk of a new aircraft type based on new technology will be represented as a comparatively high cost of insurance.

Landing fees

The investment necessary to create the vertiport infrastructure for high volume eVTOL deployment will have to be recovered by levying landing fees for the users of the facilities. Landing fees are projected to be as high as $300 per passenger[27].

Residual Value

The appeal of eVTOL aircraft to fleet operators will be affected by the residual value of the product. This is another unknown. The residual value of electric cars may indicate that optimism is not warranted[28].

Market Acceptance and Customer Psychology

A high utilization rate presupposes a high market acceptance amongst potential users. Fear of flying is a problem that can affect a significant proportion of the population[29]:

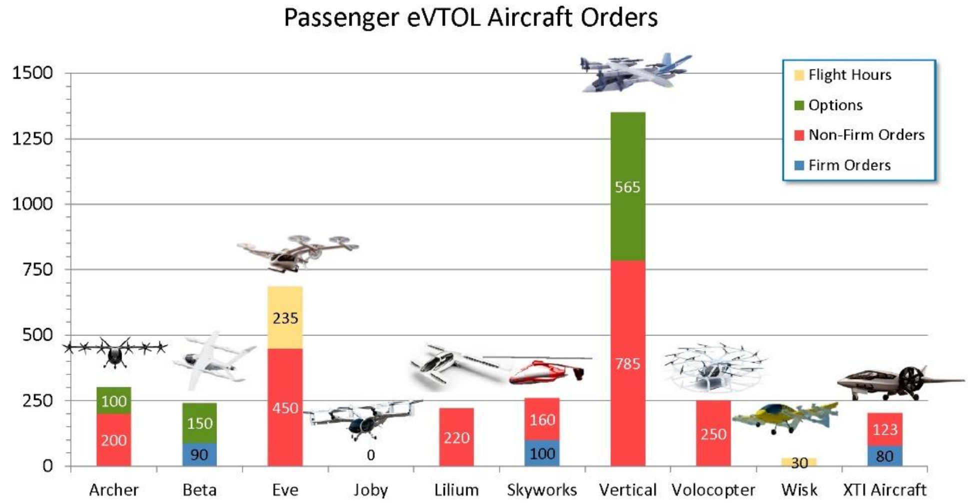
- Between 33% and 40% of all people experience some form of anxiety when it comes to flying.
- 60% of sufferers experience generalized anxiety during the flight (and leading up to it) that they can easily manage on their own.
- Between 2.5% and 5% of the population have crippling anxiety, a genuine fear of flying that is classified as a clinical phobia.
- People report their first fear of flying “attack” at the age of 27 on average.

The introduction of a new, small type of aircraft will receive a greater than average phobic response and this will reduce the size of the available market for commercial operations.

Orders

Orders with deposits are the greatest indication of demand from operators and confirmation of the commercial viability of the aircraft product. The proportion of overall eVTOL orders that are ‘firm’ is very low[30].

[27] https://evtolinsights.com/2023/05/feature-how-much-does-it-really-cost-to-run-an-air-taxi/
[28] https://leasingbrokernews.co.uk/ev-drivers-need-residual-value-protection/
[29] https://www.stratosjets.com/blog/fear-of-flying-statistics-trends-facts/
[30] https://evtol.news/news/vertical-eve-add-orders-for-hundreds-of-aircraft



"While orders represent an important signal of demand, most of them are conditional, non-firm and not requiring any deposits, essentially allowing the operators to walk away from the deals."[31]

The lack of firm orders from eVTOL signals a lack of confidence from commercial operators.

Commercial Summary

The commercial case for eVTOL rests on very high utilization rates. It is incorrect to assume that eVTOL will achieve higher utilization rates than existing aircraft types in similar operations. Low initial reliability and low LRU availability will have a profound negative effect on utilization.

Commercial viability is also likely to be negatively affected by insurance costs, higher than projected landing fees and customer acceptance.

Unknown residual value will make fleet purchasers reluctant to invest in an asset of uncertain value.

A negative commercial outlook is confirmed by the lack of firm orders for eVTOLs.

[31] https://altonaviation.com/alton_insights/evtol-orders-2022-wrapped/

Compliance

As with most business activities, the 2000lb (907.185kg) elephant in the room is the government.

The government has three major impacts across multiple markets in different ways.

These impacts are unique to eVTOL as they are new and unique products. As such they require new regulatory approaches in product certification, operation and pilot licensing. Aircraft that are certified under existing airworthiness regulations (part 23 or part 27) can use existing regulations and avoid almost all compliance risks.

Product Certification

Every aircraft must be qualified to a set of product-related regulations that define the design details, reliability and standards of safety that must be inherent in the design of the aircraft.

For eVTOL, these standards are completely new. Not only are they completely new, but they are different across different jurisdictions. In Europe, there is a different set of standards to the standards used in North America. This causes significant difficulties for products developed in Europe gaining exports to North America and products developed in North America gaining exports to Europe.

This is unlike existing regulations for fixed-wing and rotary-wing aircraft which are almost completely harmonized across all jurisdictions across the world. eVTOL regulations are new and unharmonized.

Using existing and time-tested regulations also removes the safety risk of immature regulations. The current regulations have been reformed over time, through repeated updates and amendments spurred by repeated incidents and tragedies. With a completely new set of regulatory standards, these incidents and tragedies have yet to occur, but they inevitably will.

The higher safety risk of using an immature set of regulations will be reflected in a higher incident rate and a higher insurance cost.

Another effect of using new sets of regulations is the eVTOL developers must develop new methods of compliance for these new regulations. This.is very time-consuming and very expensive. It can be seen from the difference in the projected time to market and the actual time to market of almost all eVTOL programs. This effect on schedule and budget has been consistently underestimated by eVTOL developers.

For example, Joby started their program in 2009[32]. It was only in the last year[33] (2022) that they achieved approval for their first compliance plan, the official description of their means of compliance. Having an approved compliance plan means that you can start your compliance activities. 2009-2022, 13 years is a long time to get to an approved compliance plan. This is reflected in the amount of money ($2bn USD[34]) that Joby has raised to get to this stage of their program.

When a program completes a part of its demonstration of compliance, it then must find someone at the regulator or an individual with delegated responsibility, who will sign off on a finding of compliance against a completely new set of regulations via a completely new means of compliance. This will be a challenge. eVTOL OEMs may have discarded risk aversion, but the regulator and delegated individuals will be less accepting of risk.

Achieving eVTOL-type certification has proven to be and will continue to be excessively time-consuming and expensive.

Operational Certification

Once a company completes the product certification process, they must put their aircraft into commercial or private operation. This involves complying with a set of operational standards. These standards are also new, or they are adapted from existing standards for conventional aircraft operation.

eVTOL operational standards like product certification standards are not harmonized across international jurisdictions. The FAA in America and EASA in Europe have developed different operational standards for these types of vehicles. Some aspects of the design of the vehicle are driven by compliance with the operational standards. Because of this, intrinsic aspects of the vehicles may create a barrier to export between two major markets. Designs will require significant changes and re-certification to achieve export sales and foreign operations.

[32] https://en.wikipedia.org/wiki/Joby_Aviation
[33] https://www.jobyaviation.com/news/joby-completes-submission-stage-three-certification-plans/
[34] https://www.crunchbase.com/organization/joby-aviation/company_financials

A further problem created by operational certification is any regulator may decide that a very conservative approach is required. For example, the FAA has taken the reserve requirements from part 29 large rotorcraft of forty-five minutes for IFR (Instrument Flight Rules) operation and applied that reserve requirement to what they call powered lift category aircraft, or eVTOL[35]. Battery-driven aircraft have relatively low endurance and applying a very high reserve requirement to them will severely degrade commercial viability.

It is worth noting that the FAA operational regulations[36] consist of over 137,000 words, while EASA has opted to consider UAVs and UAM in the same category and has issued an NPA[37] that consists of over 118,000 words.

Every OEM who wants to sell their product in the North American and European markets will have to read, understand, compare, reconcile and demonstrate compliance with these hundreds of thousands of words of differing regulatory standards.

If designing a single vehicle to meet these two different sets of requirements is at all possible it is expensive and onerous. This places additional and unique demands on an aircraft type whose performance is already compromised by the immature technology and low energy density of the chosen energy storage medium.

Pilot Training and Availability

The status of pilot qualification has only recently beeen addressed by the regulators. Different eVTOL aircraft have different modes of operation, different flight control software systems creating different pilot feel and different pilot interfaces. In this context, pilot training and qualification is a non-trivial task.

Comparing the difference in pilot interfaces between leading eVTOL projects some of the problems can be seen.

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35 https://www.federalregister.gov/d/2023-11497/p-1032
36 https://www.federalregister.gov/documents/2023/06/14/2023-11497/integration-of-powered-lift-pilot-certification-and-operations-miscellaneous-amendments-related-to
37 https://www.easa.europa.eu/en/document-library/notices-of-proposed-amendment/npa-2022-06

There are two main layout types – 'single seat two sticks' and the 'two seats one stick'.

Joby type Cockpit[38], two control sticks, single cockpit seat – no space for pilot trainer in cockpit. Layout similar to Lilium, Vertical and Archer

Volocopter type Cockpit[39], single stick for the pilot's right hand, space for pilot trainer in RH seat. The layout is similar to Ehang.

Both pilot interfaces are different to conventional fixed wing and helicopter controls, and they are different to each other.

This creates a problem of transferring pilot qualifications from conventional aircraft to eVTOL and between eVTOL types.

38 https://www.aviationtoday.com/2021/11/12/joby-aviation-evtol-ready-faa-aircraft-conformity-inspection/
39 https://www.volocopter.com/en/newsroom/cae-and-volocopter-partner-to-create-global-air-taxi-pilot-workforce

Each new pilot qualification for each new type of vehicle will need definition and international harmonization. It will take many years to reach international agreement on the standards and training requirements for private and commercial pilot licenses.

The cost of qualifying as a pilot able to fly commercial service is at least $50,000[40]. The total projected number of eVTOL aircraft in service by 2030 by the OEMs is in the tens of thousands.[41] (In contrast McKinsey estimates the total number in 2030 number to be 1000[42]).

Taking the OEM figures and placing a cap of 10,000 aircraft in service by 2030 the total cost of pilot training will be $500,000,000.

A commercial pilot for existing aircraft types requires about 250 hours flying time[43]. For 10,000 pilots his equates to 2.5M flying hours. If pilot training starts in 2025 and is split over 5 years up to 2030, this is an average of 2000 pilots and 500,000 flying hours per year. We can reasonably estimate that each training or personal aircraft is flown 4 hours per day and is operating 200 days per year. To train the required number of pilots over 5 years 625 eVTOL aircraft will have to be dedicated solely to that task.

There will have to be pilot training instructors, simulators and training facilities made available. There is no indication that the investment is being made at this time, or if investment will be made to support the eVTOL OEM timeline for the number of pilots necessary to support production projections.

Compliance Summary

Compared with an equivalent aircraft which is certified and operated under existing regulatory standards, an eVTOL aircraft faces an array of delays and problems.

It is not known if there is a route through type and operations certification that can result in a viable aircraft product.

The pilot qualification route is not defined and the infrastructure is not available to create the numbers of pilots necessary to allow commercial operation of eVTOL at a scale necessary to support OEM business models.

40 https://www.thrustflight.com/cost-to-become-pilot/, https://www.flaviationcenter.com/post/professional-pilot-how-much-does-it-really-cost-and-is-it-worth-it
41 https://www.linkedin.com/pulse/6000-midnight-evtol-aircraft-could-hit-skies-2030-daniel-bland/, https://verticalmag.com/news/archer-plots-a-data-driven-approach-to-flight-safety-from-the-c-suite-to-the-cockpit/
42 https://www.kdcresource.com/insights/could-we-see-commercial-evtol-by-2030-assessing-the-market-potential/
43 https://www.aopa.org/training-and-safety/active-pilots/safety-and-technique/operations/commercial-pilot-certificate

Conclusion

eVTOL projects violate established risk management principles of aircraft development across multiple domains.

The technology is immature, the operational cost models are flawed, the compliance landscape is only just being developed and there is a lack of pilot qualification standards or training infrastructure.

There is a compound technical, commercial, and compliance risk that makes the successful introduction of a viable product to market a practical impossibility. Investment in the sector is entirely speculative and extremely high risk.

The problems are too varied and too profound to be solvable, no matter the amount of money thrown at them.

Arc Aero Systems has developed solutions to serve the eVTOL market without excessive technical, commercial and compliance risks.

https://arcaerosystems.com/pegasus/
https://arcaerosystems.com/linx-p9/

Arc Aero Systems, November 2023