THE FUTURE OF ADVANCED AIR MOBILITY AIRCRAFT

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Abstract

Morgan Stanley recently predicted that the market for advanced air mobility (AAM) aircraft composed of air taxis and unmanned material handling aircraft, could exceed $9 trillion annually by year 2050 [1]. Presently there are over three hundred legacy and start-up companies developing air taxis.

This paper explores the development and deployment issues that air taxi companies will need to address as they move towards FAA certification and subsequent production:

- FAA certification challenges
- Air taxi configuration and performance
- Batteries as the sole energy source
- Airframe and propulsion integration
- Deployment
- Funding and production cost
- Epilogue

FAA Certification Challenges

Most air taxi companies are concentrating on the development of five to seven person air taxis under the belief that the future personal travel market is going to be centered around ride-sharing. However, ride-sharing is unlikely to make up a significant portion of this future personal transport market any more than ride-sharing by car does today. This is simply because travelers have different destinations and timetables. In addition, the traveler will need ground transportation at both ends of his or her trip, which makes airborne ride-sharing even more impractical than ride-sharing by car. Only 9 percent of workers carpool, which is a drop from 19.7 percent in 1980 [2].

Five to seven person air taxis may compete effectively against higher payload helicopters on dedicated routes, because they are potentially quieter and safer. However, the logistics of handling many flights per day from the top of a building or local Skyport is daunting if even possible [3]. This size aircraft would be looking for FAA certification under Part 21 to enter commercial services under FAA rule 135. FAA certification is a lengthy process even for a conventional design aircraft and can range from five to nine years [4]. Air taxis will be employing entirely new airframe designs and propulsion systems, which could make the timetable for FAA certification even more problematic. Developers are also concerned about the recent announcement that their aircraft will need to be certified under Part 21 rather than Part 23 as originally planned. Only the tilt rotor AW609 has ever attempted to be FAA certified under Part 21, which is an aircraft category called "Powered Lift Aircraft". The tilt rotor AW609 has been going through the FAA certification process for over 20 years as a commercial version of the military Bell XV-15 that first flew in 1977. Bell, Westland, and Augusta have spent many billions of dollars on the AW609's path to certification. A further concern is that Part 21 is not fully formulated and has never addressed batteries as a power source. This will make FAA certification even more challenging.

The FAA has provided a special approval category called light sport aviation (LSA) for one and two -person aircraft aimed at the private use market. This may make it possible to utilize variations of this category to gain experience with the unique nature of air taxis and their application to the future commercial market. The LSA category only needs to meet industry consensus standards to be FAA approved and requires a pilot certificate rather than a pilot's license. The FAA's ultralight aircraft is another special category but

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would need a higher weight limit to generate a useful air taxi. The ultralight class allows only one person while not requiring a pilot's license or FAA certification. Air taxis approval under either category would allow air taxis to obtain experience with their distributed propulsion, fly-by-wire controls and powerplant options, including engines, batteries, and both (hybrids). Following extensive experience in this private use application, FAA certification for commercial use could follow.

The FAA has recently proposed "Modernization of Special Airworthiness Certification" (MOSIAC). This rule would greatly expand every aspect of the LSA category and allow one and two-person air taxis for private use to follow a much easier path to FAA certification rather than under part 21 The industry consensus standard may then lead to FAA compliance rather than having to face certification under part 21. Air taxis carrying more than two persons will need to satisfy the demanding part 21.

Air taxi Configuration and Performance

For air taxis to dominate the commercial travel market by 2050 they will need to be as convenient to use as the automobile was at its best, while being able to travel much faster than present ground based transportation alternatives. This can only be accomplished if the air taxi is able to land almost anywhere, while meeting the local noise ordinance. Automobiles on average carry 1.5 passengers while 74.9 percent drive alone [[5]]. Therefore, one-person autonomous air taxis should dominate this future travel market.

Advantages of initially concentrating on the development of a one-person air taxi:

- As with the present ultralight category, it may be supported by the FAA because only the pilot is at risk.
- Operating autonomously, it has the potential to eventually replace most automobile trips.
- Could achieve 82 passenger-mile per gallon of gasoline (equivalent) at 124 mph (SL) or 178 mph (25000 ft) which is three times higher than that collectively for cars, light trucks, and SUVs.
- Following high volume production, economy of scale could result in user costs of less than $1per mile.
- Travel over ten times faster than the average automobile speed of 18.6 mph [[6]].

Batteries as the Sole Energy Source

In a best case analysis of the performance of air taxis [[7]] under development, batteries alone provided a range of approximately 40 miles if the FAA maintains its present 45 minute reserve flight time with a battery pack specific energy at 235 W.hr/Kg as specified by Joby Aviation for its Joby S4. This energy output is consistent with the claimed but unproven pack specific energy of solid state lithium-ion batteries. There are many other variables involved in maintaining a battery's specific energy which is highly dependent on its operating history:

- Rate of charging and discharging
- Number of cycles
- Level of charge and discharge during each cycle
- Internal and external operating temperatures.

Consequently, battery specific energy will reduce over time in ways that could be very difficult to quantify. It is like not knowing how much fuel remains in an engine powered aircraft. Despite a much lower battery discharge rate, electric cars have experienced many spontaneous fires. A recent article in Bloomberg News titled "Air Taxis Keep Crashing, Bursting into Flames in Testing Phase" [[8]] may be a cause for concern and

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lead the FAA to demand a less hazardous battery chemistry to eliminate this potential problem. Three of the four leading startup companies have lost their demonstration air taxi through a fire or crash.

A study by the AAA Foundation showed that the average automotive trip is 29.6 miles with most of those miles by just the driver. A one person autonomous battery powered air taxi could be a candidate to effectively provide this trip if it is small and quiet enough to land almost anywhere. However, if after nearly each trip it must return to a facility to be charged or swap batteries, the inconvenience and lost time would significantly affect the Uber like trip costs. The hybrid approach effectively utilizes the high energy of fuel and the high power of batteries and reduces this concern while significantly increasing range. If separate propulsion systems are used for VTOL and cruise then a hybrid air taxi would use an engine for cruise and electric motors for VTOL. If an engine can achieve the power to weight ratio of an electric motor then engines can be used for both VTOL and cruise, however batteries would still provide a meaningful backup and boost power source. During the cruise mode, an on-board engine driven generator could recharge the energy expended during VTOL while the battery pack size could be significantly reduced. Another advantage of a hybrid version, in addition to increased range, is that electric motors can more than double their continuous rated power output for two minutes from cold. This reduces the installed weight of the motors by over 50 percent if the FAA is prepared to allow the electric motors to operate at their maximum power output during VTOL and transition.

Airframe and Powerplant Integration

The complexity of the airframe design is determined by whether the lift and cruise propulsion systems are separated or combined. Leading startups like Joby, Lilium, Archer, and Vertical Aerospace use designs that combine lift and cruise propulsion systems, while the legacy aircraft companies like Wisk/Boeing, Airbus, Embraer, and Honda use separate systems. When lift and cruise are combined the propulsion system may require many more critically moving parts to allow component articulation during transition between VTOL and cruise. In addition, the propulsion efficiency is reduced in both flight modes. The legacy companies have chosen the higher airframe weight and profile drag resulting from the use of separate propulsion systems in return for lower production cost, higher propulsive efficiency, and potentially easier FAA certification.

Aircraft Deployment

It is reasonable to assume that by the year 2030 most air taxis will be operating autonomously. This is consistent with the expectation that automobiles will be doing so far sooner despite their much more complicated operating environment. Once the software and electronically controlled hardware are proven to be reliable, the fatality rate per mile of air taxis should approach that of today's commercial airlines that are operating nearly autonomously. This should lead to a fatality rate per mile traveled that is less than 0.7 percent of that for the automobile [9]. Automobiles operate in a quasi-one dimensional travel network versus two-dimensional off-road or water travel versus three-dimensional travel by air. Each dimension increase greatly improves safety by increasing the operating distances between a given number of vehicles.

Funding and Production Cost

The leading start-up air taxi developers (Lilium, Joby, Vertical Aerospace and Archer) have collectively raised billions of dollars through Special Purpose Acquisition Companies (SPAC). This has allowed them to undertake aggressive programs to bring their product to market. However, there are many unresolved issues regarding FAA certification of their products. These start-ups have been spending between $20 million and $50 million per month on designs that, for the most part, are substantially more complex than

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those undertaken by the experienced aircraft companies (Boeing, Airbus, Embraer, and Honda). In view of the five to nine years that may be required to obtain FAA certification of conventional designs, these novel designs offered by start-ups could take even longer. Consequently, despite having more capital at their disposal for the development of any aircraft in history in this weight category, the startups will need to raise additional capital. Unfortunately, their stock prices on average, have fallen by over 70 percent in the months following their SPAC funding raise. The experienced aircraft companies are self-funding development at a much lower spend rate, consistent with resolving FAA issues prior to investing in production. While further behind in development of their simpler designs, the experienced companies are in the process of determining whether battery powered air taxis are viable prior to committing to production. For example, Airbus's first air taxi version was a tilt wing battery powered model called Vahana that underwent thousands of hours of flight testing. Airbus abandoned this earlier design in favor of a much simpler version that should have an easier path to FAA certification.

A further concern is the projected cost of the air taxi and how that could affect the market opportunity. The start-ups have all taken significant non- binding pre-orders priced from $5 to $10 million per aircraft. These are pre-FAA certification prices and are certain to rise post-FAA certification. Historically aircraft prices following FAA certification have been more than double the pre-certification non-binding prices. None of the following aircraft were nearly as novel as air taxis powered by batteries using fly-by-wire controls and distributed propulsion.

Aircraft	ICON	AW609	Eclipse Jet
Pre-FAA certifcate price	$139,000	$10 million	$869,000
Post FAA certificate price	$369,000	$25 million	$2.5 million
Years from first flight to FAA certification	7 years	20+ years	5 years

In view of the revolutionary nature of battery powered air taxis, it is certainly possible that the versions proposed by the start-ups could have a sales price of more than $10 million each following FAA certification. A six-person helicopter like the Airbus EC335 sells for $5.7 million with a trip cost of around $5 per passenger-mile. The higher cost air taxi could end up with a trip cost of $7 to $9 per passenger mile, or more than three times higher than the cost of the Uber ground transport. In any case the inconvenience of airborne ride-sharing will limit the air taxi's ability to be a major competitor to ground transport or see a lower air taxi cost without the benefit of economy of scale. By contrast, if one or two person air taxis can offer the convenience of the automobile as it existed before congestion reduced its usefulness, then economy of scale should reduce its cost in future dollars to near that of today's quality automobile.

Epilogue

- Battery powered air taxis may not be viable if the FAA does not substantially shorten its reserve flight time requirement.
- Significant ride-sharing by air with five to seven person air taxis is improbable other than on dedicated routes for the same reasons it failed with ground transportation, namely, travelers have different destinations and timetables. Furthermore, travelers will still have to find ground transport at both ends of their airborne trips.

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- A one passenger air taxi with the ability to land almost anywhere could challenge the 75 percent of all automobile trips now made by a sole driver.
- The legacy aircraft companies generally separate the lift propulsion system from cruise propulsion. This approach increases weight and profile drag but reduces airframe component articulation, improves propulsion efficiency, and should reduce the time to achieve FAA certification. This approach also enables the lift motors to be mounted separate from the wings, which should enable one or two-person air taxis to fold their wings and thereby, become small enough to land almost anywhere.
- Startups like Joby, Lilium, Vertical Aerospace and Archer have a lead over the legacy aircraft companies. However, this lead is likely to disappear as their complex designs are overtaken by the experienced aircraft companies with designs that could lead to a shorter FAA certification path.
- `The fire hazard presented by lithium-ion or lithium-polymer batteries is significant enough that the FAA may require a different battery chemistry from that presently in commercial production.
- The ability to land anywhere requires wings that fold. This generally precludes the lift/propulsion system being mounted on the wings. The choice is then to mount ducted fans on the fuselage or lifting motor/propellers on a separate support structure.
- The simplest path to FAA certification may be to initially seek FAA approval for a one-person private use air taxi under a higher weight ultralight category or seek under the special LSA category.
- Following extensive private use with alternative power sources, fly-by-wire controls, and distributed propulsion, the FAA could be satisfied that safe operation has been established, commercial use could follow.
- Five to seven person air taxis may cost substantially more than competing helicopters to manufacture. The resulting cost per passenger-mile could limit air taxi usage to dedicated routes. As a result, they would not benefit from economies of scale as has been anticipated.
- The leading start-ups have underestimated the time required to achieve FAA certification. Their capital burn rate of $20 to $50 million per month reflects a totally unrealistic expectation of achieving FAA certification by 2025. Consequently, additional capital will need to be raised. This will be difficult if not impossible due to the dramatic fall in their stock price and the emerging competition from the legacy aircraft companies.

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ADDENDUM

Brief history of the author's efforts to create a VTOL capable air taxi.

In 1957 Dr. Paul Moller received a diploma from the Southern Alberta Institute of Technology (SAIT) that qualified him as a certified airframe and powerplant technician. This was followed a year later by a diploma in Aeronautical Engineering from the same trade school. He then spent two years as an engineer at a Canadian aircraft company. In 1960 he was offered a fellowship at McGill University and graduated in 1963 with a M Eng. and a PhD in mechanical and aeronautical engineering. Upon graduation he was offered a teaching position at the University of California in Davis and became responsible for creating their Aeronautical Engineering program. While teaching he also began construction of his first VTOL aircraft with financial support from the University of California. This single person aircraft called the XM-2 was flown before the international press in 1967. In 1968, a two-person VTOL aircraft called the XM-3 was completed and made a limited number of flights in ground effect. In 1969 he and a partner undertook the following:

- *Created an S corporation called M Research (later expanded to become Moller International)*
- *Leased a 2,000 ft^2 facility*
- *Began development of the XM-4, which later became known as the Neuera 200*
- *Identified the Wankel rotary engine as the ideal powerplant for the XM-4*
- *Acquired a number of rotary snowmobile engines from Fichtel-Sachs in Germany, the first company to put rotary engines into volume production.*

To meet its performance goals the Neuera needed to increase the power to weight ratio of the FS rotary engine and develop artificial stability and fly-by-wire control systems. The R&D effort to undertake this development required a well-funded team. To raise the necessary capital, Dr. Moller together with a number of supporters undertook the following:

- *Developed the 40-acre Davis Research Park and constructed a 35,000 ft^2 facility.*
- *Created SuperTrapp Industries that became the leading aftermarket manufacturer of engine muffling systems in the world. ST was later sold to help fund rotary engine and airframe development.*
- *Completed a number of government-funded contracts that included the delivery of various unmanned aerial vehicles (UAV) to the US Army, Navy, and Air Force.*
- *Raised millions of dollars from private investors.*
- *Acquired the entire rotary engine production assets of Outboard Marine Corporation (OMC), which is the only US company to put a rotary engine into volume production.*

Funding enabled Moller International (MI) to create a technical team of approximately thirty engineers and technicians to develop its Rotapower® rotary engine that produced 70 percent more power for its weight than the OMC engine it is based on. Concurrent with this engine development, artificial stability, and fly-by-wire control systems were also developed. On May 10, 1989, Dr. Moller piloted the Neuera before the international press. It was the first aircraft to introduce the concept of "distributed propulsion" that he had patented in 1971 (patent number 3614030). Distributed propulsion is now used by all of the over 250 different battery powered air taxis being developed throughout the world. The Neuera is able to uniquely perform a number of tasks, like search and rescue, border patrol, crop spraying or as an all-terrain recreational vehicle; however, a true air-taxi that could provide viable personal airborne travel requires a more ergonomic human interface, higher speed, and inherent aerodynamic stability during cruise.

In 1990 the development of the M400 Skycar® began. For technical reasons the Skycar® configuration has a higher disc loading (Weight/fan area) which demanded a further increase in the Rotapower®'s power to weight ratio. During the following period this ratio was increased to over three compared to a ratio of less than one for today's

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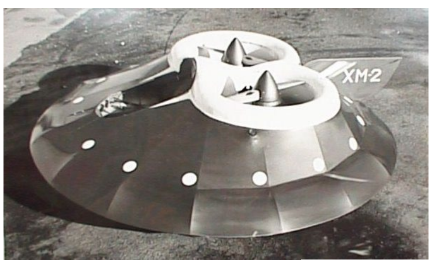
best small aircraft engine (Rotax 915). This enabled a demonstration flight of the M400 Skycar® in 2002 before the local press at MI's annual stockholder's meeting.

In 2002, as a result of widespread interest in its Rotapower® engine, MI exclusively licensed Freedom Motors (FM) to further develop, manufacture, and distribute Rotapower® engines for numerous worldwide applications other than aircraft. Today, after two decades of engine development by FM, the Rotapower® engine has raised the power to weight ratio to over three, extended its life from 2,000 hours to over 20,000+ hours, significantly reduced fuel consumption, toxic emissions, enabled the efficient use of renewable methanol as a carbon neutral fuel, and essentially eliminated exhaust noise. These and other technical improvements have led to six engine related patents now in process by FM following over a dozen earlier engine patents by MI.

The recent development of hundreds of prototype air-taxis powered by batteries encouraged Dr. Moller and his team to review the state-of-art of air taxi designs and their marketability. A key conclusion drawn from this review is that one-passenger autonomous air-taxis will accommodate over 80 percent of all travel trips and will dominate this future personal airborne mobility market. Consequently, the MI's team is prioritizing its one passenger Skycar® 100. Until the FAA's position regarding the use of batteries as an energy source is determined, MI will seek FAA approval for both hybrid and engine only powered versions. Approval will be sought under a variation of the FAA's light sport aviation (LSA) special category for recreational aircraft, which was recently proposed to include up to two person air taxis under the "Modernization of Airworthiness Certificate" (MOSIAC rule).



XM-2 **XM-3**




Neuera 200 **M400 Skycar®**

Skycar® 100X

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