Joby Aviation Inc (JOBY)

Prepare for Turbulence

We are short shares of Joby Aviation, a $4.8 billion development stage aircraft manufacturer that we believe is years away from generating operating revenue and which we don't expect will ever earn an economic profit. Joby has designed an electric vertical-take-off-and-landing (eVTOL) plane and plans to manufacture and operate thousands of them in a global "aerial ride sharing network" for urban "journeys of 5 to 150 miles… at significantly lower cost" than road, rail, or helicopter.

Underlying Joby's project is the premise that battery-powered electric flight can be cheaper and safer than current alternatives. But is battery-powered flight even possible? Well, barely. Even the most advanced lithium-ion (Li) technology can't simultaneously optimize on the 3 axes of energy consumption: power, capacity, and rechargeability. Joby's eVTOL requires all 3: immense power for takeoff, landing, and climbing; capacity to enable range; and rapid recharge for efficient refueling. Joby claims its eVTOL will have 100-mile range and a 10,000-cycle life. But we estimate that, constrained by both Li limits and regulatory reserve requirements, maximum range will be 35 miles and the battery will last a few thousand cycles *at best*. That's not a jet; *it's a science project*.

Joby's plan to manufacture hundreds, or even thousands, of eVTOLs annually at a unit cost of just $1.3 million is only slightly less naive. The production forecast ignores the experience of seasoned airplane manufacturers, which – using the *same materials from the same vendors* – took years to scale their production lines, and even then barely got to 100 units/year. And that's at a lower degree of complexity and less rigorous demands for airframe robustness. The cost projection ignores, well, *everything*: there's no aircraft the size of Joby's in the world that can be manufactured at that cost, and Joby's competitors – who are by no means pessimistic – are projecting a number *3 times greater*. Is Joby immune from the laws of manufacturing? We think not.

Nor will it be immune from the laws of economics. Joby claims that fuel and maintenance savings will enable eVTOL flights at a fraction of the cost of comparable helicopter flights. But we broke down the cost of flying and found that the savings are negligible and don't account for the cost of the battery and the aircraft, which, when considered, make the eVTOL flight *more* expensive than a comparable helicopter. Just another instance of Joby's selective math and wishful thinking.

Speaking of which, Joby is guiding to type-certification by 2025, boasting of having completed 3 of the 5 certification stages. But those *were mostly comprised of paperwork*. Little real-life testing, analysis, and verification (Stages 4 and 5) have been achieved for the purpose of certification, and those make up the lion's share of time, cost and effort expended in the certification process. It's clear that it's still early days in that respect, particularly given that major safety concerns – such as battery fires and rotor-related accident scenarios – have yet to be appropriately addressed. The logistical hurdles of pilot training and air traffic control also remain, both of which may take years to clear given recent FAA proclamations.

Building a plane is not like writing code. The combination of unrealistic manufacturing assumptions, naïve demand forecasts, and improbable timelines can be catastrophic for a company trying to produce just thousands of units at million-dollar-plus unit costs. Doubly so for a product that's so operationally constrained that it has no realistic use cases. The *best case* for investors here is a rough landing. We think they should be bracing for a nose-dive.

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I. Investment Highlights

<u>The physical limitations of lithium-ion (Li) batteries make Joby's eVTOL a limited-use range-hobbled curiosity.</u> To create its eVTOL battery packs, Joby took "widely available, well understood" Li pouch cells "from the automotive supply chain," packaged them in "lightweight, durable casing," and designed an electronic battery management system (BMS) overlay. Joby claims this proprietary package enables a flying range of up to 100 miles at speeds of up to 200mph, going so far as to present a map that teases the ability to fly from Manhattan to either Philadelphia (about 85 miles) or the Hamptons (about 95 miles). The batteries will also supposedly be rechargeable in the minutes it'll take to deplane and load passengers and will last for more than 10,000 charge cycles.

Joby's claims may be carefully worded to avoid anything explicitly false, but the implications are highly misleading and can't be reconciled with the laws of physics: Joby's eVTOL will absolutely not be able to demonstrate those capabilities simultaneously. What's "well understood" is that it's physically impossible to optimize Li cells for high specific energy AND high specific power AND long cycle life. That's especially true for those "widely understood" cells from the auto supply chain, which are *specifically not optimized* for power (how often do you *need* to go from 0-60 in 3 seconds?). Even in cells that *are* optimized for it, high-power utilization (*and its inverse*, rapid recharging) physically stresses the battery, reducing both capacity and cycle life.

That's a problem for Joby because vertical take-off and landing, and to a slightly lesser extent climbing to cruising altitude, require *enormous power output*. Consider that Joby's battery will have about 150kWh of capacity compared to 82kWh on a Tesla Model 3, but will regularly need more than 500kW of power for hovering and 350kW for climbing compared to the Tesla's 15kW at highway cruising speeds. These high-power applications will consume more than *half* the energy required by the average mission, and Joby wants to rapidly recharge on top of that. Maybe Joby's batteries lasted 10,000 cycles in the lab, but we don't expect they'll last half that in real life.

Most importantly, the limits of power also impact range: Li batteries can't generate high power – for, say, vertical landing – on the last 15-20% of their charge, which makes that portion of the battery functionally useless for an eVTOL. Range will be further limited by both normal capacity deterioration and FAA emergency reserve requirements. Accounting for all range constraints, we estimate the maximum mission range of Joby's eVTOL to be about 25-35 miles and only in good daytime weather. At Joby's "top speed of 200mph," which uses more energy, that range is lower still. *A plane that can safely fly 25-35 mile missions at the speed of a helicopter only on sunny days may be an engineering marvel, but it's not a commercial aircraft.*

<u>Joby's plans to manufacture thousands of aircraft are laughable.</u> At the time it went public via SPAC, Joby forecast that it would make thousands of aircraft annually at a unit cost – "at scale" – of $1.3 million. The company hasn't commented recently on its production expectations, but at the current market capitalization, it seems like enough investors *think* that the company will be able to manufacture these eVTOLs by at least the hundreds annually. So it's worth pointing out that outside of Boeing and Airbus, there's really no precedent for manufacturing that many units of a single model per year. In our view, the most comparable plane to Joby's is the Cirrus Vision Jet, which was the most delivered business jet in the world every year between 2018 and 2022. By the time the Vision Jet received its type certificate in 2016, Cirrus had a backlog of 600 orders. Yet Cirrus – an established aircraft manufacturer with high-volume production experience – ramped production from 3 units in 2016 to 22 in 2017, 63 in 2018, and 81 in 2019.

Like the Vision Jet, Joby's plane will be made primarily of carbon fiber (sourced from the same vendor as the Vision Jet's) but will have a substantially more complex wing box that will house the rotors with their redundant distributed architecture design (in which each motor is powered by multiple independent battery packs) as well as the heavy battery packs themselves. Due to a much more aggressive ratio of airframe weight to maximum take-off weight (because of the batteries) – it will also need to meet much higher standards of structural integrity. It's *ridiculous* to expect that Joby will be able to accelerate aerospace-grade production of such a complex machine 10x faster than what's been accomplished by more seasoned manufacturers with simpler designs.

The $1.3 million unit cost projection was perhaps more absurd than the production forecast, and after 2.5 years of substantial inflation later it's even more absurd, though that hasn't stopped Joby from reaffirming it in recent filings. There's simply no comparable winged passenger aircraft *in existence* that can be manufactured at that cost today. We estimate that the Vision Jet, which is strikingly similar in its dimensions to Joby's design, cost over $2 million to manufacture before the recent inflation surge *excluding its engine*. Several of Joby's eVTOL competitors have estimated their scaled-up unit costs at $3-4 million (also before recent inflation), and even that is probably a bit of an optimistic assumption *at scale*.

"At scale" is an important qualifier, because if Joby assumes air taxi demand for thousands of jets, manufacturing scale may never arrive. The risk for Joby is that it will end up producing the first few hundred units – before scale – at a cost of millions of dollars per unit, consuming another $1 billion-plus of cash. Then, at the worst possible time – because the plan is to operate a taxi service with those planes rather than just sell them for cash – it will face underwhelming demand for air taxis. That'll mean generating *even less cash* than selling the plane at a loss for $1.3 million. Nothing can be more dangerous for a manufacturer than underestimating cost and overestimating demand. For Joby, we wouldn't be surprised if it led to an eventual bankruptcy.

There is no conceivable economic case for "air taxis" that wouldn't work for helicopters.
If you take Joby's management team proclamations at face value, then the "real" product that Joby is after is operating an air taxi service. Think Uber, but with cool electric airplanes. The idea is premised mainly on the assumption that an eVTOL taxi service will be cheaper and safer than a helicopter taxi service. We doubt the safety of eVTOLs (which we'll get to), but Joby's assertion that "low maintenance costs, low fuel costs and high operating speeds" of its eVTOL "combine to deliver an operating cost projected to be 1/4th of the cost per mile flown as a twin-engine helicopter" is so outlandish, we have to assume it's purposely disingenuous.

We broke down expected costs per mile for Joby's eVTOL and, unsurprisingly, we found that its estimate of a *fully burdened* cost of $3.80/mile was wildly off the mark. The actual fully burdened cost is undoubtedly going to be closer to $15-20/mile, so Joby was merely off by a factor of 4-5x. We found that the *direct* operating cost (DOC) per mile will be somewhere between $4.30 and $6.85, depending on how many cycles they can get out of their battery ($4.20 assumes the impossible 10,000 cycles).

But most important is the comparison with a helicopter. How much does Joby actually save in "low maintenance costs, low fuel costs, and high operating speeds?" Well, high operating speeds aren't going to happen using battery technology in the coming decade because they'll burn out the batteries even faster, and battery longevity is *already* going to be a problem even at moderate speeds. We found that at most, assuming Joby can get 10,000 recharges on its batteries, it will save a grand total of $0.55/mile compared to a helicopter in fuel and maintenance. At a still ridiculous 5,000 recharges, the eVTOL costs $0.35/mile *more than the helicopter*. And accounting for the capital cost of the actual aircraft – the eVTOL costs between 50-150% more than the comparable helicopter – it's no contest: the helicopter comes out cheaper.

So where did Joby get the notion that they can enable mass air taxis at a fraction of the cost of a helicopter? For one, they used an incomparable 16-seat long-range dual-engine oil-rig helicopter as a basis of comparison, which seems…wrong. But considering that they first made this comparison as part of their SPAC presentation, it's possible they just grossly exaggerated on this point, just like they did with their production forecast, their unit cost projection, their spec sheet, and their expected date of certification. There's simply no scenario in the foreseeable future where Joby's eVTOL will have *any* cost edge over a helicopter.

Joby is still relatively early in the process of obtaining a type-certificate. Joby originally told investors that it expected to have its aircraft type-certified in 2023. That's clearly not going to happen, and Joby now says that it has a "clear path to initial commercial operations in 2025," which obviously assumes a type-certificate by then. We expect that it will still be another 3-5 years before Joby receives a type-certificate, *if* it receives one.

In its most recent shareholder letter, Joby triumphantly announced that it substantively completed *its* part of the third of five stages to type certification, which makes it sound like they're 60% through with the process. Unfortunately for investors, the first 3 stages of the process are almost all paperwork, while Stages 4 and 5 involve the actual testing, analysis, and verification by the FDA of the real aircraft systems and operations.

Anyone involved with certification at an aircraft manufacturer will quickly tell you that the time and effort required for Stages 4 and 5 of certification are going to be *multiples* of what was expended in the first 3 stages. Not only that, but the FAA has been working slowly on responding to Joby's Stage 3 submissions, and at the pace that it's been going, it will take another *year* for the FAA to complete *its* part of Stage 3. Given the relative burden of Stages 4 and 5, we think a realistic target date for Joby's eVTOL to be type-certified is in the later years of this decade.

<u>Major safety concerns remain unaddressed by Joby.</u> Part of what the next stages of the certification process are supposed to do is ensure the safety of Joby's plane. By far the most critical safety issue for Joby is the enormous 150kWh batteries the aircraft will carry. High-power utilization – which we already saw will be a major obstacle to energy efficiency, cycle life, and range – also increases battery temperature, which raises the risk for thermal runaway.

Thermal runaway, in which a battery cell enters an uncontrollable self-heating feedback loop and can potentially catch fire, is a higher risk in cells not optimized for power (like the auto cells being used by Joby) and in pouch cells (which exhibit more extreme temperature increases at high power, and which are also being used by Joby). Even aside from the thermal effects of high power utilization, there's also the mechanical stress on the cell's internal components caused by high-power applications, which independently increases the odds of thermal runaway.

Though Joby recently announced that "we have a clear path to certify our battery packs" with the FAA, Joby's carefully worded language suggests that the FAA has not yet responded to its battery-related certification plans. Battery safety is going to be of utmost importance to both the eVTOL sector and electric flight generally, so we find it hard to believe that the FAA is going to set its certification standards solely as a response to Joby rather than through an industry-wide standard.

It's highly likely that whatever Joby submitted to the FAA will require revision, and potentially a re-engineering of the battery, which will further push out the certification timeline, and might even result in greater battery weight or other unforeseen engineering compromises. Considering the dynamics around the thermal and structural effects of high power, it's even possible Joby will have to go back to the drawing board on the battery, which could mean years of further work. We're not sure why investors seem so complacent on this point.

Another safety concern our research revealed relates to the occurrence during flight of a vortex ring state (VRS), in which rotors lose thrust in a descent as they interact with their own wake. The Marine Corps' V-22, which is the only certified tilt-rotor aircraft, has had a slew of accidents in the last 20 years related to this phenomenon, and Joby's 6-rotor design makes it highly susceptible to the condition. We think it's possible that the FAA will mandate flight tests under induced conditions of VRS that a) carry some crash risk to the 2 sole Joby prototypes that exist and b) will result in pilot training and documentation requirements that further push off realistic commercialization of the aircraft.

<u>The logistical hurdles of managing pilot training and air traffic control will take years to clear.</u> The FAA recently proposed that eVTOL pilot training must include at least 25 hours of supervised operating experience (SOE) in a plane with dual controls, and that the rating earned by a pilot on one eVTOL will not transfer to any other.

For Joby (and other eVTOL manufacturers), whose plane is designed for a single pilot, the FAA made clear that it expects the custom assembly of a training model (or several) with dual controls that is substantively identical to the mass-production model. Every pilot who wants to be certified to fly a Joby eVTOL will need to complete 25 supervised hours flying in the dual-control Joby model. While the FAA won't make a final decision on this until the end of 2024, assuming it sticks with its proposal – and given the unique features of every eVTOL and the degree of difficulty flying them, we think it will – this will create an immense pilot-training bottleneck.

The lack of rating transferability, which we're even more confident will stick, means that, unlike a helicopter and small-plane certification, eVTOL pilots will require requalification for every individual model they will fly. That's going to both exacerbate the aforementioned pilot bottleneck as well as jam the market for pilots, leading to justifiably greater compensation demands from pilots who face constraints on the transferability of their skills.

Further logistical hurdles also await the eVTOL manufacturers in the form of air traffic control (ATC) development. Obviously, having a few hundred extra flights occurring every day in major urban areas is going to tax the current ATC system, and research on the issue – including research partially conducted by Joby! – has concluded that even a massively scaled back version of an air taxi service will "encounter constraints on… the ability to efficiently and safely interact with existing airport traffic." The FAA, meanwhile, is taking its sweet time addressing the looming issue and its last proclamation on the matter, this past July, simply recommended further detailed policy reviews. Considering how slowly ATC processes move – even compared to the normal regulatory slothfulness – it seems like this is a very under-the-radar obstacle to any meaningful eVTOL uptake.

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A plane with science-project specs. A delusional production plan. A business model with zero consideration of economic realities. And if that weren't enough, the actual manufacturing or implementation of the business plan will be stalled for years negotiating for type-certification, re-engineering for safety issues, and waiting for the trickle of certified pilots and ATC rulemaking. Sure, Joby has $1.2 billion in cash on the books, but it's going to burn through that well before mass production starts, and the burn rate will *increase dramatically* when it does. The end game here, in our view, is either *massive* shareholder dilution or bankruptcy. Or both.

II. eVTOLs – What are they Good For?

Joby Aviation Inc: Capitalization and Financial Results

Capitalization	
Share price ($)	$ 6.48
Fully diluted shares (mm):	
Shares outstanding	692.6
Dilutive impact of Options	14.9
Restricted Stock	29.6
Total	737.0
Fully diluted market cap (mm)	$4,776
Less: net cash	1,195
Enterprise value	$3,581

Financial Results	2021	2022	TTM
Revenue	-	-	-
Operating Income	**$ (259)**	**$ (392)**	**$ (414)**
Free Cash Flow	**$ (228)**	**$ (291)**	**$ (322)**

Source: company filings, Kerrisdale analysis

The novelty of electric vertical take-off and landing (eVTOL) aircraft is in their name: they use electricity instead of petroleum-derived fuel for propulsion, and they take off and land vertically by hovering upwards and downwards. Though that's a neat engineering feat, the relevant question for eVTOL developers and manufacturers like Joby is: what's the point of an eVTOL? What can they do better, cheaper, or more efficiently than existing airplanes or helicopters?

In a presentation at the Vertical Flight Society's annual forum last year, the late Joby engineer Alex Stoll and CEO JoeBen Bevirt framed the status quo and the potential to move beyond it as follows: "helicopters are limited in their suitability to civil transportation due to high operating costs, high noise levels, and safety levels below other forms of commercial aviation. Modern electric propulsion technology offers potential solutions to these drawbacks." In other words, compared to helicopters, eVTOLs are cheaper to operate, less noisy (allowing them to operate in areas where noise constrains helicopter operators), and safer. As an added bonus, battery-powered eVTOLs generate no CO_2 emissions, making them "sustainable."

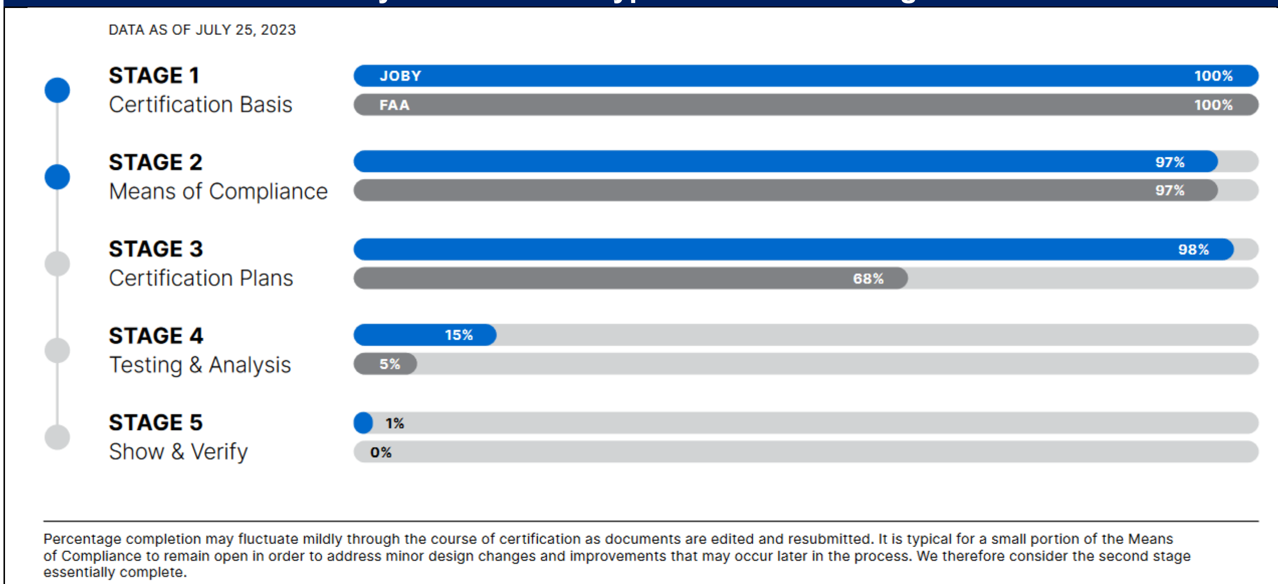
Free of a helicopter's operational shackles and environmental impact, Joby envisions eVTOLs enabling dramatic changes in the nature of short-range travel in the not-so-distant future. As described in Joby's recent annual report,

> Deploying eVTOL aircraft through the business model of app-driven, on-demand mobility that has been validated by ridesharing companies globally will provide a revolutionary new method of daily transportation. The low noise, low operating costs and zero operating emissions enabled by the all-electric powertrain, combined with the ability to takeoff and land vertically, unlocks aerial access to urban cores.

eVTOLs will be so cheap, quiet, and versatile that they'll serve as a common means of transportation in major cities, akin to ridesharing services like Uber and Lyft. How cheap? Joby says its eVTOL will cost $1.3 million to build at scale and will operate at *a quarter* of the cost per mile flown of a twin-engine helicopter. Charging $3/seat-mile will generate $2.2 million in *annual* revenue (we'll unpack this math later) and $1 million in profit *per plane* (implying all-in costs of $1.40/seat-mile). To put that in context, the average Uber ride costs a customer $1-2/seat-mile, so earning 40% profit margins charging $3/seat-mile *on a plane* really *would* be revolutionary. Joby plans to be fully vertically integrated, manufacturing (almost) all of its own components, assembling them into the final eVTOL, and operating an aerial commercial passenger ridesharing service, which it expects to begin in 2025. Eventually, it will be manufacturing hundreds of planes annually and operating thousands of them as a global air taxi service.

To be able to manufacture even a single civilian passenger vehicle – let alone the thousands Joby is promising – Joby's aircraft (and all it entails, including the manufacturing processes) will have to pass the rigorous FAA certification process, which culminates in a "type certificate" from the agency. The certification process, which we discuss at further length below, is meant to ensure the safety of the aircraft as well as adherence to the specifications that were agreed upon between the agency and the aircraft manufacturer. Since going public via SPAC in 2021, Joby has laid out a kind of certification roadmap for its aircraft, continually updating investors on its progress. The most recent update – below – depicts Joby as quite advanced in its journey to a type certificate, with the early stages of certification complete and stage 4 progress under way. Management says commercial operations will begin in 2025, obviously implying a type certificate will be earned by then.

Joby Aviation FAA Type Certification Progress



Source: Joby Shareholder Letter, August 2, 2023

At the end of June, with Joby announcing a Special Airworthiness Certificate[1] allowing flight testing of its first production prototype, the company laid out some of its key specifications:

- The plane will have a maximum payload of 1000lb, including a pilot and 4 passengers.
- The range of the plane will be up to 100 miles at speeds of up to 200mph. The final page of the presentation is a map showing that from midtown Manhattan, Joby expects the plane's range to include Philadelphia, Atlantic City, and the Hamptons.
- Joby also disclosed some details regarding the plane's electric propulsion system, which will be powered by lithium ion (Li) batteries with a specific energy of 235Wh/Kg (288Wh/Kg at the cell level) and peak power output of 236kW for each of the six rotors. The battery will last 10,000+ charge cycles and will be rechargeable "in the time it takes to deplane and load passengers."

The overall story that Joby tells about itself is straightforward: through a decade plus of concerted engineering effort, Joby has designed a cheap, quiet, clean, and sustainable short-range airplane that will replace helicopters and revolutionize flight in the process.

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The problem is that the story is a fantasy. Sure, Joby's eVTOL will be quiet and electric. But being electric is going to be a major *disadvantage* for as far out as the eye can see, and definitely for the next decade. It's going to mean higher operating costs and worse performance on almost every relevant metric including speed, range, and power. In fact, the specs that Joby has teased are going to be *impossible* to achieve with an FAA-certifiable safety profile using the current state of lithium ion (Li) battery technology. And that's even before we get to the structural safety and logistical issues related to eVTOL design. Quiet rotors are nice, but it's not noise that's the bottleneck for mass aerial commuting, it's the economics. There's no realistic manufacturing process or business model to enable it, and Joby's superficial projections are simply delusional. On top of all that, Joby's type certificate roadmap is laughably optimistic: Joby's eVTOL will probably get a type certificate. Eventually. Investors are going to discover the hard way that it's going to take at least another few years and a lot more money.

III. The Batteries Needed for Joby's Vaunted Specifications Don't Exist

Range, speed, battery life, and charging speed will depend on the batteries in Joby's eVTOL. The defining feature of an eVTOL – its ability to take off and land vertically by electric propulsion – is fundamentally dependent on the battery's power specifications. So it's worth understanding what Li batteries can and cannot do, and why the Joby eVTOL's real-world capabilities will be a lot more limited than the aggressive specifications announced in June.

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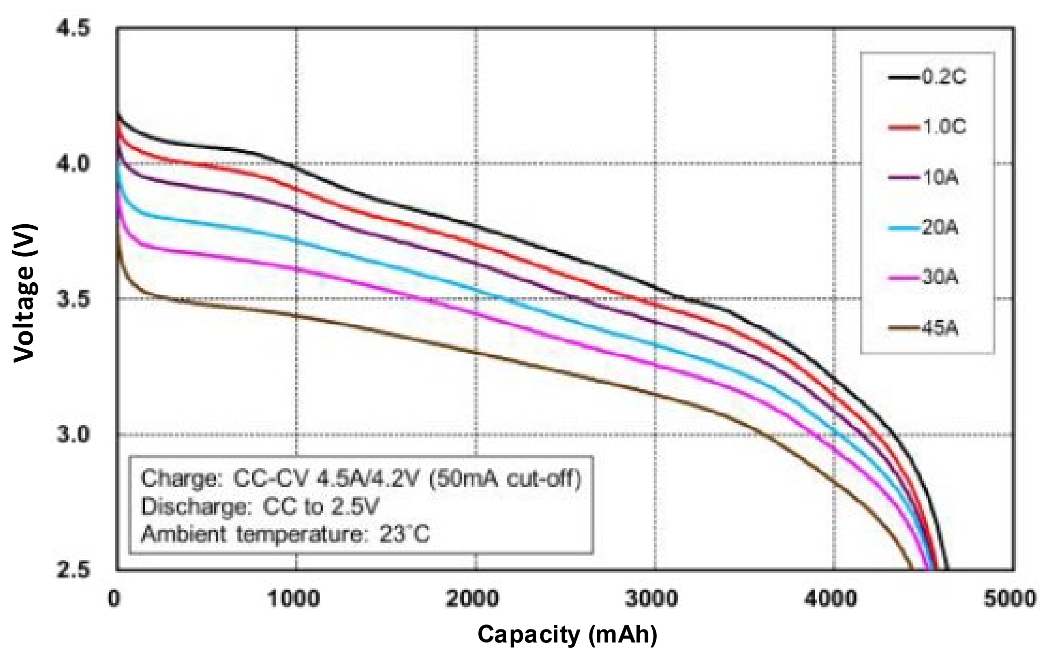
[1] A special airworthiness certificate is *NOT* a type certificate. It's merely an exception issued by the FAA that allows an operator or manufacturer to fly an aircraft that does *not* qualify for a standard airworthiness certificate. In this case, if you look up the aircraft registration – tail #N5421A – the FAA gave Joby an Experimental certificate for Research and Development, which according to the relevant FAA rule, is given for "testing new aircraft design concepts, equipment, installations, operating techniques, or new uses for aircraft."

Batteries are not Fuel[2]

Both jet fuel and batteries can store energy for propulsion, but that's about where the similarities end. The most obvious difference is in their respective specific energies, or how much energy can be stored per unit of mass. Joby says its state-of-the-art eVTOL battery has a cell-level specific energy of 288 watt-hours per kilogram (Wh/Kg), but after encasing and inclusion of the electronic battery management system (BMS), the specific energy at the battery-*pack* level is reduced to 235Wh/Kg. Jet fuel has a specific energy of about 12,000Wh/Kg, and though about two thirds of that is lost as heat, jet fuel still holds 15-20x the energy per unit of mass that batteries can store.

But a battery is not just fuel-but-heavier. Another obvious difference is that fuel can be variably dosed whereas a battery weighs the same no matter how depleted it is. To appreciate other critical differences, it helps to understand the battery discharge curve. The one below belongs to a Molicel ultra-high-power state-of-the-art cylindrical cell designed and intended for use in premium applications (including aviation) and sporting a nameplate 242Wh/Kg.[3]

Molicel Li Discharge Rate Curve



Source: Molicel INR-21700-P45B Data Sheet

[2] The foregoing discussion is based on conversations with aerospace and battery engineers, as well as the fundamental concepts of battery storage described by Rob McDonald in *Batteries are not Fuel*.

[3] That's not as high as Joby's claimed cell-level specific energy, but a) it's still very high, b) Molicel's cell is cylindrical while Joby is using pouch cells, which tend to have higher specific energy, and c) Molicel's cell is optimized for high power while Joby's cells, sourced from the auto supply chain, may not be.

Whereas a fuel tank stores gallons of fuel (not "energy" or kWh), a battery stores *charge*, as measured by amp hours (Ah).[4] The illustrated 70g battery cell stores 4200mAh. The amount of *energy* produced from the battery's *charge* (flowing electric current) depends on a few factors:

- Charge utilization: the more charge used, the more energy is produced. In the above graph, the red curve (labeled "1.0C") tracks the battery's discharge (usage) at a *rate* of 1 amp. The x-axis goes from 0mAh discharged (100% battery capacity) to 4200mAh discharged (0% battery capacity). The *area under the curve* is the energy – Wh – produced.[5] So the energy produced by discharging, say, 1000mAh when the battery is at 100% capacity can be calculated as the area under the red curve between 0 and 1000 on the x-axis.
- Rate of discharge: you'll notice that the graph features six discharge curves, each with different areas under the curve (different levels of energy production). Each of the curves measures a different *rate* of discharge, with the 1C (red) curve depicting battery utilization at 1 amp and the bottom-most curve (brown) depicting battery utilization at 45 amps (or 45 times faster). "Power" is the technical term for the *rate* at which energy is generated, and what you see from the above graph is that for *a given quantity of energy usage* (area under the curve) *more power* (jumping to a lower curve) *requires more charge*.
- Depth of Discharge: DOD is just a fancy name for the quantity of charge that's been used in the battery. Most of us know it as the "percentage battery" left on the top of our mobile phones, except DOD is the inverse – the percentage of battery charge that's been used. For the Molicel cell, 1000mAh used equates to a DOD of 24% (1000 ÷ 4200). The shape of the discharge curves – sloping downward – means that the more depleted the battery, the more charge it takes to generate a particular amount of energy. In other words, the energy "contained" in different parts of the cell are not equal. The same task will require more charge at 20% battery life than at 80% battery life.

So Li batteries have some fundamental limitations producing energy at high power and/or low battery life. These limitations are a function of the battery's internal resistance, which increases as the battery is discharged. As DOD increases to over 80% (or 20% battery capacity left), resistance increases exponentially, and because maximum power is a direct function of internal resistance, max power *also* declines precipitously at "low battery." That's unfortunate because the "VTOL" part of eVTOLs – the vertical takeoff and landing – requires enormous power generation, which is impossible as the battery approaches the final 15-20% of its charge. *For eVTOLs, that last portion of the battery's charge is basically useless*.

In addition, rechargeable Li battery performance has the extremely inconvenient tendency to degrade with cycling. With each discharge/charge cycle a) the physical stress of usage reduces nameplate capacity by a bit and b) internal resistance increases (*another* constraint on power).[6]

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[4] An amp is a measure of electric current – a given number of electrons moving past a point in a second. An amp-hour is the charge transferred by a 1-amp electric current for an hour. A milliamp hour (mAh) is one thousandth of a milliamp.

[5] We're not going to address the y-axis – voltage – here as it's not particularly relevant to the disadvantages of batteries in the eVTOL context.

[6] These phenomena are intrinsic to the physical and chemical processes that occur within the Li battery during charging and discharging. A good primer on this topic can be found here. The punchline is that "Cycling in mid-state-of-charge would have best longevity."

Both capacity fade and resistance growth occur more rapidly for batteries that are cycled (charged or discharged) at the lowest and highest ranges of DOD, as well as for batteries that are charged or discharged at higher rates (i.e., rapid-charge or high-power use). Joby claims that its battery will be able to endure 10,000 cycles while consistently subjected to rapid-recharge and high-power application, *which flies in the face of the very strong negative relationship between longevity and charge/discharge-rate*.

To summarize, unlike jet fuel, for which every gallon is pretty much the same as any other, and which has no realistic power limitations, Li batteries are fundamentally limited as follows:

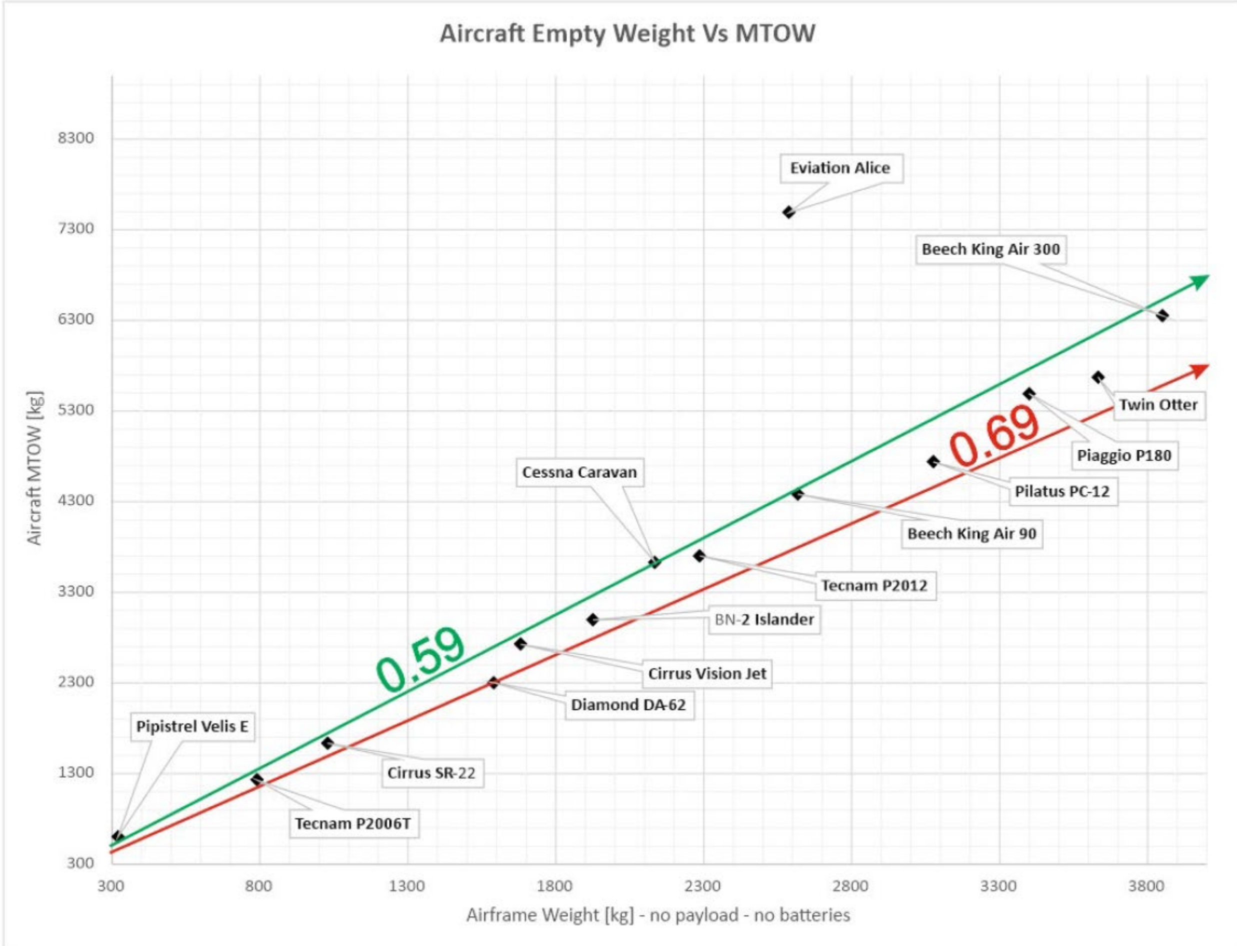
- High-power applications – like vertical take-offs and landings – are energy-inefficient and disproportionately deplete battery capacity.
- The exponential increase in internal resistance at high DODs makes high-power applications – like VTOL – impossible on the last 15-20% of the battery's capacity.
- Energy production efficiency declines as the battery discharges.
- Rapid recharging and discharging degrade *both* the battery's cycle-life and ability to generate power.
- Recharging and discharging at low-DOD/high-SOC (State of Charge) degrades the battery similarly.
- Recharging and discharging at high-DOD/low-SOC also degrades the battery similarly.

Back to Joby

Joby doesn't actually state the size or capacity of its battery, just that it's rated for 235Wh/Kg. But with a bit of triangulating, the approximate maximum size of the battery can be approximated. For context, consider that an airplane's maximum takeoff weight (MTOW) is comprised of the airframe, fuel, and its payload (passengers and cargo). At a given MTOW, the goal is to maximize the payload and the airplane's range, the latter of which is determined by the quantity of fuel. Alternatively, the goal is to minimize the weight of the empty airframe subject to safety constraints. After all, the airframe is comprised of the actual object that's going to fly.

On the next page is a graph depicting an array of aircraft models along two axes: their empty airframe weight on the x-axis (no fuel, no payload) and their maximum takeoff weight (MTOW) on the y-axis. There are limits to how light an airframe can be relative to the fuel and payload, and the most aggressive ratio of empty airframe weight to MTOW is at 59%. If we assume Joby can engineer to that ratio, we can back out the mass of its battery ("fuel") as (5300lb MTOW – 1000lb maximum payload – 3127lb airframe) = 1173lb/**532Kg battery with a 125kWh capacity** (that's 235Wh/Kg). At an even more aggressive 55% airframe/MTOW ratio, the resulting **628Kg battery would have a 148kWh capacity**.

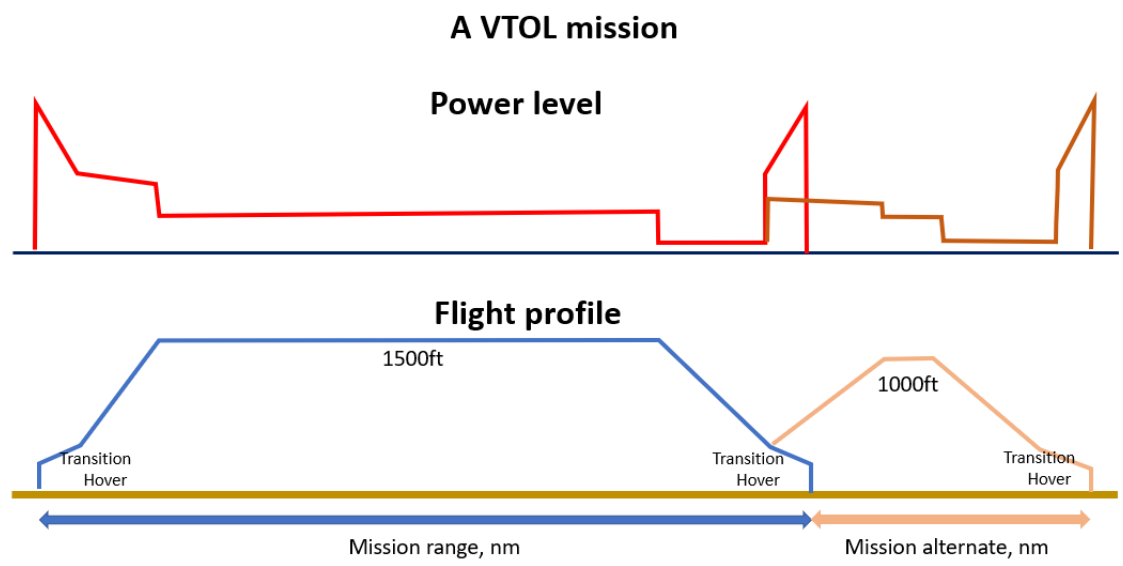
Airframe Weight Ratios of Small Aircraft



Source: Analysis of Aircraft Performances and Comparison with Official Claims of the Eviation Alice by Fabio Russo. Russo's analysis focuses on the purported specs of the Eviation Alice, which is represented by the extreme outlier data point on the chart above. Russo's point is that the Alice's claimed airframe/MTOW ratio is functionally impossible.

The typical Joby mission will be straightforward: take off vertically via hover, transition to forward flight, climb to cruising altitude, cruise, descend to hover altitude, transition back to hover, and land. An aircraft is only certified to fly a mission in which it can be diverted if for some reason it can't land at the targeted destination, so the plane must also be able to do a "mini-mission," repeating most of the steps from the standard mission (excluding the initial hover-takeoff) but cruising a shorter distance to an alternate landing site. Below is a graphic depiction of the different parts of the typical mission, including the required reserve for diversion, as well as the power requirements of each segment (neither of these are drawn to scale).

eVTOL Mission – Power Level and Flight Profile – Visual Depiction



Source: Leeham Consulting, Analysis of "Batteries and a typical VTOL mission"

Breaking up the different segments of the mission and their power requirements,[7] we can approximate the capabilities of Joby's eVTOL:

- By far the most energy-intense portions of the mission are the take-off and landing. Using Joby's disclosures regarding the aircraft's weight and rotor dimensions, it's straightforward to calculate the approximate energy it would require to get off the ground, transition to forward flight, reverse transition at the end of the flight, and then hover again to land vertically. Assuming the total time for these maneuvers is about a minute, and a power requirement of 600-800kW, the energy requirement will be 10-13kWh. Recall from the prior discussion on battery energy efficiency that at these high-power levels, those kWh will be very inefficiently generated.
- The next most energy-intense segment of the mission is the climb to cruising altitude, which requires less power than the hover – there's lift generated by the wings – but the required

[7] The calculations and approximations we make in this section are based on Joby's disclosed aircraft specifications, as well as standard formulae that have long been used for helicopters and airplanes to calculate energy requirements. Detailed discussions of the engineering concepts and the applications can be found in James Wang's Seoul National University lecture slides on "Weight and Performance Estimation for eVTOL aircraft," Fabio Russo's analysis of the theoretical battery requirements of the Eviation Alice, Bjorn Fehrm's blog posts on eVTOL battery requirements and mission calculations, and Fukumine and Lei's *Estimation of eVTOL Flight Performance Using Rotorcraft Theory*. Almost all the analyses use Joby's initial weight spec, which was about 10% lighter and for which we adjust.

thrust is still much greater than while cruising.[8] Assuming a 2 minute climb at 350-500kW, the energy requirement for this mission segment is 12-17kWh.[9]

- Cruising power for Joby's eVTOL can be achieved at approximately 125kW at the optimal energy-efficient speed.[10] For Joby's aircraft, that speed has been estimated to be about 120-130mph, about 35-40% slower than Joby's headline grabbing 200mph top speed. At 125kW, every minute of cruising requires about 2.1kWh. Alternatively, each mile flown requires about 1kWh. At faster speeds, the increased drag would require more energy and more power, a double penalty in terms of the battery's charge. The last few miles of each mission will comprise the descent, which will require less energy per mile traveled.

A realistic mission range has to account for the energy reserve requirement, which depends on the flying conditions for which the aircraft is certified. Visual flight rules (VFR) apply in conditions under which the pilot can see the horizon and the ground and stay out of the clouds. Instrument flight rules (IFR) apply under conditions in which safe flight isn't possible using just visual cues, and advanced aircraft instruments are necessary. In addition to requiring a different level of aircraft instrumentation and more advanced pilot training, IFR conditions mandate stricter reserve requirements. Under helicopter regulations, VFR conditions require enough fuel reserves to allow for 20 minutes of cruising beyond the planned mission, while IFR rules require enough fuel for 30 minutes of cruising. For regular fixed-wing aircraft, those numbers are 30 and 45 minutes, respectively. At night, IFR reserve requirements apply even in benign visual conditions. For eVTOLs, the FAA recently proposed applying the VFR rules for planes, which would mean a 30 minute reserve requirement during the day and 45 minutes at night.

The mission range also has to account for the Li battery limitations previously discussed:

- Because the end of the mission – the landing hover – requires a surge of power, the last 15% or so of the battery's capacity is functionally useless because it can't deliver that kind of power.
- Batteries age and Joby is not going to be using only new batteries in its missions. For official and planning purposes, then, the assumption will be that *at least* 5-10% of the battery's nameplate capacity has been degraded (a typical degradation after a few hundred charge/discharge cycles).
- The use of high levels of power at takeoff, climb, and landing is intrinsically energy inefficient, discharging more than its theoretical proportional impact. If the 25-30kWh of energy is nominally about 20% of the 150kWh capacity, actual capacity consumption will be about 10% more than that (closer to 22% of the battery's capacity). The consistent use of high power for 20%+ of the battery's capacity *every mission* will also degrade the battery even faster.

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[8] This is actually a complex topic that was addressed by Joby's engineers in a 2022 paper. At some points and within some configurations, the power necessary for this stage of the mission might even be *greater* than what's required for the hover. The various calculations made in this paper suggest this portion of the mission would require 55-75% of the power needed for hovering.

[9] See the previous footnote. Also see estimates by Wang, who assumes the previous lighter iteration of Joby's eVTOL and gets 13.3kWh.

[10] Adjusting estimates from Wang and Fukumine (see previous footnotes), who estimate about 115kW, and Leeham, who estimates 140kW using the most recent 5300lb weight estimate.

- If Joby wants to maximize cycle life (which matters for batteries that will cost $1000/kWh at the cell level), it must avoid cycling (discharging or recharging) in the first and last 20% of DOD. The last 20% is already useless because of power limitations, but obsoleting the first 20% is going to further reduce the possible mission range.

Of the 150kWh capacity we expect the battery to start with, about 22-27% (33-41kWh) is lost to (i) battery aging and (ii) the power limitations when batteries are 80-85% depleted as the aircraft readies for landing. A further 25-30kWh is used by takeoff, landing, and transition. That leaves, at best, 90kWh for the mission's cruising plus required reserves. 45 minutes of reserves is about 90kWh, which leaves nothing for the actual mission. *So under the current FAA proposal, Joby's eVTOL will not be able to fly at night*. During the day, the FAA's proposed 30-minute reserve requirement requires about 60kWh, which leaves 20-30kWh – **about 12-16 minutes, or 25-35 miles** – for the main mission. Even if the FAA gives eVTOLs a bit more wiggle room by reducing the daytime reserve requirement to 20 minutes, that'll leave 40-50kWh for the main mission – about 20-25 minutes, or 45-55 miles – which is still very limited (and will definitely not get anyone from Manhattan to the Hamptons).

We would also note that our reserve estimate posits a very favorable diversion scenario in which the eVTOL pilot gets diverted before trying to land. If the FAA were to require enough reserves for an *additional* climb (hypothetically, if a pilot brings the airplane down to low altitude and gets diverted at the last moment due to a congested helipad), our range estimate would be reduced even further.

Let's go back to Joby's specs, most of which it reiterated during its production launch in June:
- 100 mile range, just enough to get to the Hamptons, Atlantic City, and Philadelphia, from Manhattan.
- Speeds of up to 200mph
- 10,000+ cycle life
- Recharge "in the time it takes to deplane and load passengers," or in less than 10 minutes.
- 30kWh utilization for the average (24-mile) mission (Joby last mentioned this number in its December 2021 investor presentation, and it's not clear if the company still stands by it).

It's obvious that all those features in combination are impossible. First of all, Joby's 100-mile range claim only makes sense for a mission flown at optimal speed (120-130mph) with no emergency reserves, and no headwinds or flight issues. The pesky reserve requirements – which amount to over a third of the battery capacity – will make a 100-mile trip impossible.

Secondly, the 200mph top speed is a red herring. It's like saying that a Honda minivan can drive at 150mph, which might technically be true, but under most mission criteria, and assuming the durability of the vehicle is a consideration, you wouldn't try it.

That ties in to the third bullet point about cycle life. We don't think a 10,000+ cycle life is possible even under the most optimal of conditions considering the enormous power requirements of VTOL. But it's *completely impossible* if Joby's going to regularly fly its planes on

25-mile missions, or at speeds over 130mph, or make use of rapid-recharge. All those are going to cause more rapid battery degradation:

- The rapid recharge (6 minutes was the number Joby gave in its SPAC presentation, though it has wisely chosen to state it more vaguely in recent iterations) might be *possible* in theory, but won't be optimal in practice because it degrades battery life. A 25 mile flight will consume 40-45kWh, or about 30% of capacity. Recharging 30% of capacity in just *10 minutes* will markedly reduce cycle life.
- The same goes for speeds consistently over 130mph, which will require disproportionally high power production and thus also markedly reduce cycle life.
- The FAA range-requirement is going to force Joby to utilize and recharge the first 10-20% of the battery's capacity for almost every mission, and as discussed previously, cycling at low levels of DOD unduly strains the battery, reducing cycle life.

And these cells are *already* going to be exposed to constant high-power capacity-degrading VTOL every time the plane flies. These batteries will cost about $150,000 per plane to start,[11] so the difference between 10,000 and 2,000 cycles is going to meaningfully affect operating costs (especially under Joby's fairy tale business model we discuss in the next section).

Finally, we simply don't think that Joby's original 30kWh estimate for its average mission (inclusive of takeoff, climb and landing) is credible. We've spoken with aerospace engineers and pored over dozens of different energy and power estimation methodologies for eVTOLs, and we don't believe that 30kWh is possible. Even if the mission mileage is reduced by 10 miles and conditions are absolutely *perfect* such that the lower range of our high-power energy-use estimates apply, it's difficult to get to 30kWh, especially considering that our estimates don't even account for other energy uses such as avionics, climate control, energy-chain losses, and incidental electricity usage.

In real life, conditions are almost never perfect and contingencies happen often. As such:

- 40-45kWh is a realistic energy-use estimate for Joby's hypothetical average 25-mile mission, inclusive of takeoff and landing.
- A realistic but still favorable range estimate is around 50 miles (less if optimizing for long term battery cycle life), and closer to 30 if the FAA sticks to its conservative reserve rules.
- Recharging will take longer than 10 minutes if Joby plans on optimizing battery cycle life.
- Cruising speeds will almost never exceed 130mph.
- Battery life will still be well short of 10,000 cycles.

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[11] Tecnam, the Italian aircraft manufacturer, put their electric aircraft development plans on indefinite hold in June, partly due to "aerospace batteries likely to cost at least $1,500/kWh." Leeham consulting surveyed "the top five battery system suppliers to the electric airplane and VTOL industry. They all say that aeronautical grade battery cells, whether originally made for the automotive industry or not, *will be subject to screening and tracing demands that cause aeronautical battery modules to cost north of* ***$500/kWh end of the decade (right now, the cost is more than double this level)***." Our $150 thousand estimate assumes a $1000/kWh cost, which seems generous at present.

- *The plane will only be able to fly in VFR conditions and only during the day*. Battery life constraints and IFR reserve requirements make any reasonable mission in IFR conditions literally impossible.

The battery technology to enable much more than the above *simply doesn't exist*. Battery tech suffers from what the industry calls "the 'and' problem" – you can't optimize for battery capacity AND cycle life AND high power. For any one of these three underlying capabilities, optimization leads to unacceptably low performance on the other two metrics. In the trade journals for the aviation and battery industries, even the most optimistic insiders expect that massive strides in new battery chemistries over the course of at least a decade are necessary to make progress on the "and" problem and make electric flight a viable phenomenon, even for relatively short distances.

Joby's promised specs are hypothetical feats that *might* be achievable *in isolation under perfect circumstances and no contingency plans*. They're not serious hardware specs to compare to proven and certified aircraft. An airplane that can fly for 20 minutes and 50 miles and only when it's sunny outside is not a plane as much as it's incontrovertible evidence that electric flight is still decades away. As we'll see in the next section, the idea that ubiquitous "air taxis" will be the company's possible saving grace is also very much a fantasy.

IV. Joby's Production Guidance is a Fantasy and the Air Taxi Business Model is Delusional

Led by [its] founder…[the company] is applying innovations created in the technology industry to drive down cost, increase performance, improve safety, and spur a new type of air travel — the air taxi.

Perhaps the company's greatest contribution is making jet technology available to a larger segment of the population. With an acquisition cost one-third of today's small jets and the lowest operating cost per mile of any jet, the [aircraft] provides the lowest jet costs ever achieved.

In an endorsement to the nomination, Microsoft founder and [company] investor Bill Gates said: "True to the spirit of excellence and advancement that the Robert J. Collier award stands for, I believe the [aircraft] represents the best of aviation's rich past—and its bright future."

NAA Collier Trophy Press Release, 2/16/2006

The Eclipse program…is the single worst aviation program Teal Group has ever covered. It isn't the aircraft itself. Rather, it was a business plan that makes no sense, except to attract investors who don't know much about the aviation business. The plan called for 1,000 deliveries per year. As a reference point, in 2007 the world's manufacturers delivered a total of about 4,000 turbine-powered aircraft of all types and models. This one company, an unknown start-up, proposed to grow that global figure by 25%...

> *The formula was remarkably simple. A completely unrealistic production rate was predicated on an unrealistically low price (less than $800,000, at first). That impossibly low price was predicated on the unrealistically high production numbers. This formula (promoted as a revolutionary paradigm) worked, as long as people gave Eclipse money. As soon as they stopped… reality caught up to Eclipse, and it began hemorrhaging cash.*
>
> *Teal Group Evaluation of the Eclipse VLJ Program, October 2008*

Joby's trajectory – in fact that of the eVTOL phenomenon in general – echoes the Very Light Jet (VLJ) frenzy that gripped the commercial aerospace industry just about 20 years ago. We replaced the name of Eclipse Aviation and its founder with nondescript brackets in the quote from the Collier Trophy press release in 2006 to highlight the striking similarity of the claims made by the VLJ and eVTOL industry upstarts: new innovations to drive down costs, the "air taxi" conceit, production and operating costs at a fraction of the comparable status quo, and plans to produce a level of units that would be unprecedented in the history of commercial aviation. They even share the tech-boom cultural cachet of their respective eras.

We expect that Joby is going to hit the same exact walls that VLJ manufacturers did. First, manufacturing planes is hard, which means the production ramp is going to be a lot slower than Joby or its investors think, probably by orders of magnitude. Second, manufacturing planes is expensive: Joby's $1.3 million target production cost is *never* going to happen, and chances are that it's going to cost triple that even at scale. Finally, even if Joby can get the cost per eVTOL down closer to its target, a realistic business model for air taxis does not exist.

Joby can't – and won't – Manufacture Thousands of Planes at Low Cost in just a few Years

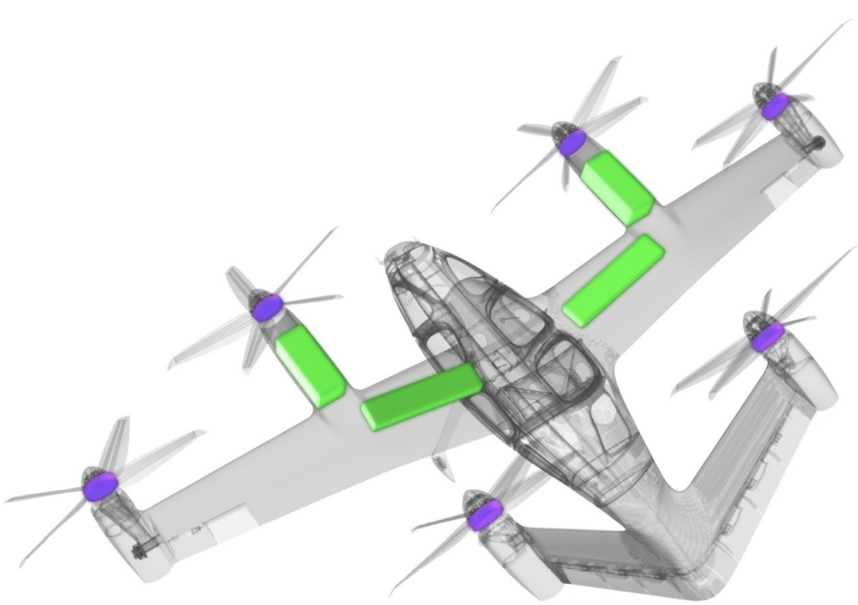
Joby's original business plan, as detailed in its SPAC presentation in February 2021, had the company operating 14,000 eVTOLs generating $10 billion in revenue "in approximately 10 years." In retrospect, that was probably just another outrageous SPAC forecast that never had a chance of materializing (the certification and commercialization timelines articulated in that plan were also misleadingly aggressive and have since been pushed back). But what would be a realistic production ramp? Some recent VLJ manufacturing history can give us a pretty good idea, especially once we put it in some context.

Cirrus's Vision SF50 was the most-delivered business jet in every single year between 2018-2022. The jet is made entirely of carbon fiber and is powered by a single engine (the first civilian aircraft to be certified as such). It received its type certificate in late 2016, by which time Cirrus had 600 outstanding orders for the airplane. The production ramp on the Vision Jet from 2016 to 2019 (it's unfair to ding Cirrus for Covid-related production interruptions in 2020) went from 3 jets in 2016 to 22 in 2017, 63 in 2018, and 81 in 2019. And that's for a company with a 600-unit backlog and high-volume production experience in a 750-person factory.

While it's highly unlikely that Joby (or any other eVTOL manufacturer) is going to be able to ramp faster than this, there are good reasons to expect the ramp to go slower. The first one is the battery weight we discussed in the last section, a key implication of which is that the underlying airframe (the aircraft structure and its components excluding payload and fuel) have to be unusually light relative to the maximum takeoff weight. There's also the intricate propulsion mechanism comprised of 6 mechanically adjustable tilting rotors. Both considerations necessitate materials as stiff and light as possible, which means – like the Vision Jet – carbon fiber (CF), but at even more stringent specifications.

The problem with carbon fiber, which Joby is sourcing from Japan-based Toray Industries (who also supplies CF for Boeing's 787 Dreamliner), is that the production methods that guarantee aerospace-grade properties are slow and expensive. Toray is an established aerospace CF supplier and we already have a pretty good idea of the speed of their production process, not least because they happen to also be the CF supplier for the Cirrus Vision Jet.[12] But the wing box for Joby's eVTOL – the structure for which the strength and stiffness of the carbon fiber is most critical – is immensely more complex than it is for the Vision Jet considering that Joby's wing box both houses the ~30% of the plane's weight that's comprised by the batteries *and* holds 4 of the plane's 6 rotors (see the Joby diagram below).

The Locations of the Battery Packs and Propulsion Motors in Joby's eVTOL



Source: Stoll and Bevirt, Development of eVTOL Aircraft For Urban Air Mobility At Joby Aviation

[12] The Vision Jet originally procured its carbon fiber from TenCate Advanced Composites, which was acquired by Toray in March of 2018.

Of course, it's not just the carbon fiber airframe. An aircraft powered by electric propulsion has never been mass produced before. In theory electric motors are simpler than those powered by traditional engines, but Joby's 6-rotor design – a redundant distributed architecture in which each motor is powered by multiple independent battery packs – is not a trivial production problem. That kind of manufacturing complexity can't be overcome through a partnership with Toyota and the magical transposition of their efficient manufacturing prowess. Toyota makes cars, and as with batteries, there's no straightforward way to map the automobile production process onto aircraft: the stakes are higher, the regulations are stricter, and the conditions of operation are much harsher. There's a reason that "aerospace grade" is associated with an unmatched level of robustness and durability. Honda, another automobile manufacturer highly respected for its manufacturing ethos, is a great example of an auto company that *did* enter the aviation arena, but whose VLJ production has never surpassed 43 in a single year.

It's completely unrealistic to expect that Joby – which, unlike Cirrus, has never built a plane before at *any* volume – will be able to accelerate certifiable aerospace-grade production of their eVTOL at a rate *10x faster* than what's been accomplished with *simpler aircraft* by *more experienced manufacturers*. Considering that Joby's specs require even higher-performance materials and components, we expect Joby to meaningfully lag that production pace, especially in the early years.

Joby's cost projections are just as impossible as its production guidance. In its February 2021 investor presentation, Joby forecast that in 2026 it would be able to manufacture 550 eVTOLs at a unit cost of $1.3 million. More than 2 years – and a lot of inflation – later, Joby is sticking to that number. It's hard to understand how they get there because there's no comparable winged passenger aircraft that can be manufactured at that cost today (let alone 5 years from now).[13] The closest analog is once again the Vision Jet, which has similar dimensions as Joby's aircraft, and which we estimate costs about $2.4 million to build. *Excluding the engine* that number is just about $2 million,[14] though the experience with automobiles indicates that replacing the internal combustion engine with electric motors doesn't materially impact build cost. Joby's $1.3 million per eVTOL flies in the face of everything currently known about building aircraft.

It's also entirely out of line with the expectations of every other eVTOL hopeful. Joby's cost per unit guidance doesn't exist in a vacuum; there are at least half a dozen eVTOL-manufacturing competitors that have raised capital at billion dollar valuations in anticipation of building planes comparable to Joby's. Under the terms of its agreement with United Airlines, Archer Aviation expects to sell the aircraft for $5 million, implying an expected cost of at least $3 million at scale, and probably closer to $4 million. Embraer-backed Eve plans to sell its eVTOL for $3 million, implying a cost to produce at scale that's about double Joby's. Vertical Aerospace's pre-sale deals assume a price of £4 million, implying a build price at scale of over $3.5 million. While even those prices are probably optimistic, Joby's $1.3 million is just *delusional*. The company

[13] It's possible to find small single-engine turboprops manufactured for less than $1 million, but they're not comparable in size, weight, complexity, or features, and none of them are made of carbon fiber.
[14] The MSRP on the Vision Jet's lowest-end model is $2.85 million, and private jet operating margins are typically in the 10-20% range.

has never made any rigorous attempt to justify it, assuming that investors will continue to just plug another impossible SPAC assumption into their models.

Joby's build-cost fantasy is related to its production volume fantasy. It's only at the impossibly scaled-up production of thousands of planes annually that Joby says it will reach its unit-cost target. The problem is that a manufacturing plan projecting thousands of units will only reach profitability after the first few hundred units are manufactured, resulting in continued *large* cash outflows in the early stages of production. This is an iron rule of almost any kind of manufacturing: the efficiency of scale is the result of continuous improvement and iterative learning. Every aircraft manufacturing program in modern history – from the 787 to the Cirrus Vision Jet – has gone through that kind of manufacturing learning curve, losing money on initial production and only generating profit in the out-years.

The catch is that if demand doesn't materialize according to plan, the losses incurred will be even worse. At the extreme, if demand doesn't materialize, a bankruptcy is virtually guaranteed. This is more or less what happened with the Eclipse 500, which was initially expected to price at an unheard-of $775,000. As the program developed, Eclipse incrementally raised prices, eventually reaching $1.45 million before a single plane had been sold. A year and a half after production began, the price was once again increased, this time to $2.15 million, almost triple what the company had originally expected, because "it costs more to build the Eclipse 500 than they thought it would and they aren't able to build them in the kind of volume they thought they could so they had to increase the price." Two years after production began, Eclipse Aviation declared bankruptcy.

Because Joby's production targets are going to be impossible to hit, and because the plane is going to be a lot more expensive to manufacture than Joby expects – especially in the beginning – we expect a similar outcome. If it's not bankruptcy, it's going to be massive shareholder dilution. The result for current shareholders is going to be almost identical anyway: they're going to own a small fraction of their current stake in a business that's fundamentally challenged.

But Joby's financial situation is actually going to be *even more* precarious because it doesn't plan to sell the aircraft to anyone but rather to operate an air taxi service with them. If demand for short distance eVTOL rides is underwhelming, the financial losses will be further compounded because the payback period for each unit will be measured in years rather than a single customer payment. It also introduces a new variable into the solvency equation: not only will demand for Joby's air taxi service need to meet impossibly high expectations, the company will also need to efficiently operate an entirely different business – aviation-based ride sharing – while manufacturing airplanes. The startup learning curve won't be an option because early losses in the ride share business will only multiply the effect of losses on the assembly line. We expect that – should Joby even get to that point – the company is going to discover that every aspect of its projected air taxi business is an economic loser.

The Math on "Air Taxis" just doesn't Work

In its late June "Production Launch" presentation, Joby's management stressed that "the product we're here to build is an air taxi service" and the problem it's trying to solve is "congestion and traffic." The constraints on operating an air taxi service with, say, helicopters, include noise, emissions, and supposedly safety (we'll get to that in the following section). But the real obstacle is cost. Everyone knows this, including Joby, which is why the company insists that "low maintenance costs, low fuel costs and high operating speeds" of its eVTOL "combine to deliver an operating cost projected to be 1/4th of the cost per mile flown as a twin engine helicopter" (10k). Like Joby's manufacturing projections, this turns out to be a misleading fantasy.

Joby's air taxi assumptions were first laid out in its SPAC presentation as follows:

- Average load factor will be 2.3 passengers per trip
- It's going to charge $3/seat-mile (or $1.73 per available seat-mile)
- The average trip will be 24 miles long
- Net revenue per plane will be $2.2 million annually
- Annual profit per plane will be $1 million annually

As with Joby's list of aircraft specs, some of these explicit assumptions – in this case the average trip length and load factor, which were last articulated in Joby's December 2021 investor presentation – have been quietly removed over time in favor of keeping things as vague as possible, which conveniently makes the business model more difficult to stress-test. Nevertheless, Joby's outlandish claim that it can deliver "an operating cost projected to be 1/4th of the cost per mile flown as a twin-engine helicopter" has endured. In conjunction with reaffirming unit-level revenue and profit forecasts and the $3 price/seat-mile expectation (all repeated in the most recent 10K), it's mathematically certain that Joby's underlying business model assumptions have remained the same. It's easy to extrapolate these into the following:

- First of all, at $166/flight (24 miles x 2.3 passengers x $3/seat-mile), $2.2 million in revenues implies over 13,000 flights per year, or 36 per-day per-aircraft 365 days a year, which is just laughable, especially considering the daytime-only, VFR-only conditions in which the aircraft will be certified to operate.
- At the average per-flight revenue of $166 and 45% operating margins ($1 million in "profits" on $2.2 million in revenue), the implied cost per mile is $3.77 ($90.55 in costs divided by 24 miles), or $0.95 cost-per-available-seat-mile (CASM).

Part of the issue analyzing that operating cost assumption, and comparing it to helicopter operations, is that Joby's notion of "profit" is somewhat confusing. Within its original SPAC presentation, Joby at times alluded to "fully burdened" costs including pilot salaries, landing fees, customer service, maintenance, SG&A, depreciation, and even interest expense (!). In the same context, it also referred to "contribution margin," which includes only variable costs and excludes interest, depreciation, and the fixed portion of the operating cost structure (not an insignificant proportion). In the aforementioned December 2021 presentation, Joby broke out the cost drivers and – aside from the completely absurd assumptions for pilot salaries, maintenance costs, and landing fees – didn't mention anything about depreciation, SG&A, customer service, or interest expense. It's also strange that Joby didn't break out projected direct operating costs (DOC) per hour, which is an industry-standard metric that's easily comparable across helicopters and private jets.

We assume that this confusion, as well as Joby's sub-$1 CASM assumption, is the product of imaginative silicon valley SPAC modeling unconstrained by annoyances like internal consistency or easily obtainable realistic cost assessments. It's not that hard to build a bottoms-up per-flight, per-hour, per-mile cost model, even incorporating some of Joby's fairy tale assumptions, and see that a "fully burdened" $3.77/mile is actually impossible. The major direct operating costs (DOC) are as follows:

- Crew – on average, US-based helicopter pilots make about $150,000 and fly around 700 hours annually. That comes out to about $1.65/mile (assuming 130mph speeds).
- Maintenance – while an eVTOL has no traditional engine, it's still an aircraft with both moving (6 propellers and their associated drivetrain) and stationary parts that will be continuously exposed to extreme conditions (altitude, speed, electric current, takeoffs, landings, etc). The *non-engine* related parts of a 4-passenger single-engine helicopter cost about $200,000 to overhaul every 2000 flight hours (that's about 20% of the cost of the entire helicopter). Generously assuming the same $200,000 for Joby's plane implies a maintenance cost of $0.77/mile. Consider, though, that the Cirrus Vision Jet accrues about $320 per flight hour in expected maintenance costs. Even if half of that is engine-related (engine-related maintenance is usually 35-40% of the total maintenance bill), that would imply about $160/flight-hour in maintenance costs for Joby's eVTOL, or about $1.20/mile.
- Energy – this is pretty straightforward. Assuming 40-45kWh/flight, energy will cost about $0.22-0.38/mile (assuming a $0.13-0.20/kWh commercial cost of electricity). This is the one place where an eVTOL has an unambiguous advantage over a helicopter.
- Capital cost – At Joby's ridiculous $1.3 million cost/aircraft, a 10-year useful life, and 13 thousand flights per year, the amortized capital costs will be about $0.60/mile using a 7% cost of capital. At a more realistic (but still optimistic) $2.5 million cost/plane and 8,000 flights per year, that cost will be closer to $1.85/mile.
- Insurance – At a fairly standard 3% of the aircraft's sticker price per year, insurance would run about $0.15-0.25/mile, but this too is generous because the cost of insurance is obviously going to be directly related to utilization. The typical 3% assumed by the helicopter business is based off an average 500 hours of operation annually. Joby's operating assumption of 2500 hours is *quintuple* that. At even half of the relative hourly insurance cost, the per-mile cost of insurance is $0.35-0.60.
- Battery – last, but certainly not least, batteries need to be swapped out for new ones when their capacity is sufficiently degraded, which will depend on mission frequency and cycle life (e.g., at 10 thousand missions annually and a 10 thousand-cycle life, the battery will need to be replaced every year). The cost of the high-specific-energy kind of battery that will power Joby's plane is on the order of over $1000/kWh, which, at 150kWh comes out to $150,000. At the absurd 10,000 charging cycles Joby says its battery will last, that's $0.50/mile, adjusted slightly for salvage value of the used battery. At a still very-optimistic 5,000 charge cycles, the net battery cost per mile will be about $1.

Add it all up, and you get the summary table on the next page. Using the most aggressively unrealistic assumptions for every aspect of Joby's manufacturing and air taxi operations (which in combination are probably impossible) results in a direct operating cost/mile of $3.94. A more realistic set of assumptions gets us to $6.53. And this is *far* from "fully burdened" because it excludes major costs like landing fees (for NYC heliports, these run $200/flight or a whopping $8-10 per mile for the typical Manhattan-to-JFK route), hangar and aircraft storage costs, continued R&D and other technology maintenance in what is shaping up to be a very competitive business, not to mention G&A, marketing, advertising and other overhead. "Fully burdened" per-mile costs are going to be *at least* $15-20. Though that may come down a bit over time as battery technology advances, battery-related costs are only about 20% of the direct operating costs of the aircraft, and those are just about a third of the total cost. There's a lot more to making a real "profit" than just the flight margin.[15]

How does the eVTOL cost structure compare to that of a helicopter performing the same mission? Joby claims that "lower maintenance costs and low fuel costs" will "deliver an operating cost projected to be 1/4th of the cost per mile flown" of a helicopter. It's definitely true that an eVTOL will have lower fuel costs and no engine maintenance costs. But what do those cost per-mile for a helicopter? The most comparable helicopter for this analysis is the popular Robinson R66, a single engine, single pilot vehicle with a 4-passenger capacity, a cruising speed of 110kn (130mph), a top speed of 140kn, and a 400 mile range. At a current cost of about $6/gallon and 22gph at cruising speed, the fuel cost/mile is almost exactly $1. The R66's engine also requires a $175,000 engine-maintenance overhaul every 2000 hours, which comes out to another $0.68/mile in cost. In total, as shown in the comparison in the table below, the eVTOL saves about $1.70/mile in fuel and engine costs. But offsetting that is about $0.75-1.40 in battery and electricity costs as well as $0.60-$1.85 in incremental capital costs, which means that there is *little to no economic advantage to running an air taxi service with an eVTOL over a helicopter* and – as a comparison of the last two columns in the table on the next page suggests – there's probably even a slight disadvantage.

[15] "Flight margin" – somewhat analogous to gross margin – is defined as Revenue minus the direct operating costs (DOC) but excluding overhead and other costs – like R&D – that are centralized.

Direct Operating Cost (DOC) Scenario Analysis – Joby eVTOL vs R66

	Joby eVTOL				**R66 Helicopter**
	Fairy Tale Assumptions		Very Optimistic Base Case		
Crew		$ 1.65		$ 1.65	$ 1.65
Maintenance	Similar to helicopter	$ 0.77	Similar to Vision Jet	$ 1.20	$ 0.77
Fuel	40kWh @ $0.13 (nat'l avg)	$ 0.22	45kWh @ $0.20 (NY avg)	$ 0.38	$ 1.00
Capital	$1.3M cost/aircraft	$ 0.60	$2.5M cost/aircraft	$ 1.85	N/A*
Insurance	@ 3% of vehicle cost	$ 0.20	Partial mileage adjustment	$ 0.45	$ 0.17
Battery / Engine Overhaul	@ 10K cycle-life	$ 0.50	@ 5K cycle-life	$ 1.00	$ 0.68
Total DOC/mile		***$ 3.94***		***$ 6.53***	***$ 4.27***

Source: Kerrisdale Analysis, Robinson Helicopter Company R66 Estimated Operating Costs
** The capital costs for the R66 are negligible outside of engine overhaul costs, and an old helicopter after an engine overhaul will routinely sell for 90% of the cost of a new helicopter.*

Blade, which operates passenger helicopter flights in New York, Vancouver, and Southern Europe, has reached a similar conclusion. [16] The company has a lot of experience managing exactly the kind of short passenger flights in which eVTOLs would supposedly be used, but – once you acknowledge the lack of any economic advantage of eVTOLs over helicopters – presents a cautionary tale for Joby investors. The company has consistently achieved positive flight margins in the 10-25% range over the last 4 years (see the table on page 26 of its recent investor presentation), and was last generating passenger revenue at an annual run rate of over $100 million. Still, it's been unable to eke out more than low-single-digit EBITDA margins *at best*. Blade's shares are down 77% from its SPAC price and it currently sports a measly $25 million enterprise value while continuing to burn cash.

All of this math is critical in assessing the prospects of Joby's air taxi service. Avoiding emissions is nice. Eliminating noise is potentially even nicer. But the reason we don't have flying vehicles shuttling around commuters like in Joby's investor presentation fantasy world has almost nothing to do with noise or emissions, and everything to do with cost. And Joby's eVTOL is not going to make *any* dent in that problem. Joby's original SPAC projections purporting to show an apples-to-apples comparison between a $95 25-mile eVTOL trip and a $393 helicopter trip of the same length could at the time be chalked up to imprudent overoptimistic modeling that typified many SPACs. But when the company keeps repeating the statistics in its current

[16] On page 37 of its most recent investor presentation, the company discloses that the Manhattan-to-JFK route costs $500 (***$100/available seat***) on the Bell 407 helicopter and is expected to cost $430 (***$107/available seat***) with an eVTOL. That comparison actually flatters the eVTOL because the Bell 407 is a larger, more expensive, twin-engine helicopter compared to the R66.

regulatory filings, it more closely resembles a lie it's trying to repeat long enough for investors to believe it's the truth.

If Joby's air taxi business model made any sense, it would have happened by now because helicopters represent more or less the same opportunity. It hasn't happened because any way you slice it, putting people in the air is expensive – it requires billions in R&D to design a large and safe machine that will then cost a lot and take a lot of time to produce. Electrification *might* – in the very long run – reduce the fuel and engine costs of flights, but the rest of the costs – the overwhelming majority – will remain. The promise of tens of thousands of air taxis shuttling passengers within cities globally is a great science fiction meme, but as an investment prospect, it's a delusion that's going to cost Joby investors billions of dollars. For 24-mile commutes, we anticipate travelers will continue to drive cars, for a very, very long time.

V. Final Certification of Joby's S4 is Uncertain and, in any case, Won't Happen Anytime Soon

At the time of the announced acquisition of Joby by the Reinvent Technology Partners SPAC, the accompanying investor presentation (slide 24) projected that in 2023 Joby would demonstrate its air taxi service in select markets, bring its mass production facility online, and achieve FAA type certification for its eVTOL. That was laughable even back then (and probably just flat out misleading), and Joby has since wisely refrained from explicitly targeting a date for type certification. In its latest quarterly shareholder letter, though, Joby coyly teased that it "welcomed the publication of the FAA's AAM (advanced air mobility) Roadmap in July, which outlines a clear path to initial commercial operations in 2025." That's the kind of sentence that's perfectly crafted to create the impression that Joby's eVTOL will be certified by 2025 without actually committing to a hard target.

We expect that Joby's eVTOL will *eventually* be certified, but it's by no means a certainty. If a type certificate is issued, it's going to take at least another few years even if all goes well, and we expect that there will be some significant delays due to foreseeable safety concerns that will need to be resolved.

The Most Difficult Stages of Type Certification are Yet to Come for Joby

In its 2022 second quarter shareholder letter (pages 10-11), Joby conveniently laid out a primer on type certification, delineating and briefly describing the five stages of the process. These are:

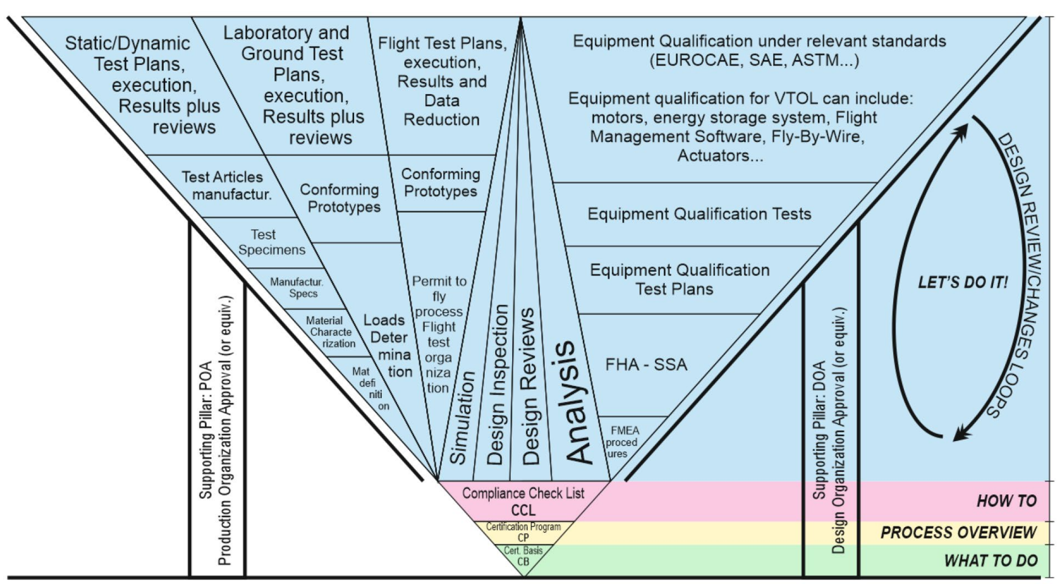
- Stage 1 – Certification Basis, in which the FAA and the aircraft manufacturer define the type of aircraft being built and which rules and regulations will therefore apply.
- Stage 2 – Means of Compliance (MOC), where the company works with the FAA on its *plan* to sufficiently demonstrate that it's complying with all relevant safety rules.

- Stage 3 – Certification Plans, in which the company details exactly which tests it will perform for each system area in order to satisfy the MOC.
- Stage 4 – Testing & Analysis, in which the company actually executes the Stage 3 plan, completing and documenting thousands of inspections, tests, and analyses.
- Stage 5 – Show & Verify, in which the results of Stage 4 are verified by the FAA.

These stages, in contrast to the impression we think Joby is trying to give, are not remotely comparable with each other in terms of degree of difficulty, required effort, and time-to-completion. When Joby disclosed in its most recent shareholder letter that it has substantively completed its part of Stage 3, it's important to understand that this is by no means equivalent to completing 60% of its requirements towards a type certificate. Joby is in fact just getting started with the rigorous parts of certification.

In a detailed white paper focused on explaining the certification process of new aircraft designs, Fabio Russo drew the following diagram to provide an idea for readers "about how the [certification] process looks like in terms of *weighted mass* of each certification step." Just a quick spoiler alert: Joby's having completed Stage 3 of the certification process is the equivalent of fulfilling the tip of the inverted iceberg through the "How To" stage, which is characterized by the final delineation of a compliance checklist.[17]

"Weighted Share" of Certification Building Blocks



Source: Fabio Russo, Analysis Paper to Highlight Potential Timing Gaps between Claims and Certification Reality

[17] Russo is writing for a European audience using EASA's general process, but as he explains, almost the same exact process applies at the FAA and other major civil aviation authorities, primarily because these regulatory agencies have cooperated to ensure that their respective decisions are easily validated by one another.

Russo is a respected aerospace engineer and the head of R&D at Tecnam, an Italian aircraft manufacturer that, under Russo, has invested many years of effort in the attempt to design a useful and certifiable electric plane only to shelve the project in recent months due to the inability of current battery technology to enable desirable mission profiles. His point in the paper, which he illustrates with the example of a basic de-icing requirement, is that while a hypothetical 5-paragraph means-of-compliance might not be that difficult to formulate, achieving it requires real-life safety assessments, laboratory tests, flight tests, equipment qualifications, and then the review and potential revision by the civil aviation authority (CAA, which is the FAA in Joby's case). As Russo summarizes, the compliance requirement

> is a small droplet compared with the global amount of certification reports and tests. One single article can easily turn into a massive effort of thousands of report pages (each to be reviewed and approved by the CAA), tens of tests and often a certification conforming prototype is needed: extremely time consuming activities when view as a whole!

The progression of Joby's certification process reveals a level of difficulty and time commitment related to working with the FAA that Joby has never explicitly mentioned. On the next page, we show the quarter-by-quarter certification progress disclosed by Joby since the second quarter of last year. While there are limits to what can be gleaned from Joby's narrow and possibly subjective interpretation of its percentage of completion, note that 1) it took the FAA just over a year to approve about a third of Joby's certification *plans* (Stage 3) and 2) it took Joby just over a year to complete just 8% of its testing and analysis (Stage 4, which also seems to have achieved close to zero progress in terms of FAA agreement).

Now, it's true that until June, Joby didn't even have a production prototype with which it would be able to conduct the lion's share of Stage 4 and 5 processes. But considering the real-life time and effort required for Stages 4 and 5 compared to the document-heavy stages 2 and 3, it's completely unrealistic to expect a 2024 or 2025 date for the issuance of a type certificate. This is not a new iteration of a jet with an established regulatory pathway for testing, analysis, display, and verification. It's a completely new aircraft type that will likely require multiple rounds of regulatory reviews, requests, and changes to which Joby will have to respond, react, and re-engineer. Joby is likely looking at the later years of this decade for a final type certificate.

Joby Progress to Type Certification

		2022 Q2	2022 Q3	2022 Q4	2023 Q1	2023 Q2
Stage 1	Joby	100%	100%	100%	100%	100%
Certification Basis	FAA	100%	100%	100%	100%	100%
Stage 2	Joby	99%	96%	97%	97%	97%
Means of Compliance	FAA	74%	84%	94%	93%	97%
Stage 3	Joby	94%	94%	93%	96%	98%
Certification Plans	FAA	37%	37%	53%	63%	68%
Stage 4	Joby	7%	13%	14%	14%	15%
Testing & Analysis	FAA	3%	4%	5%	5%	5%
Stage 5	Joby	0%	1%	1%	1%	1%
Show & Verify	FAA	0%	0%	0%	0%	0%

Source: Joby Shareholder Letters from 2022 Q2 through 2023 Q2

Serious Safety Issues on Joby's eVTOL are Unresolved

Much (almost all) of the certification process with Joby's eVTOL is going to focus on safety. Joby's claim is that in addition to solving for noise and emissions, its eVTOL will also improve substantially on a helicopter's safety. That will be accomplished through multiple layers of redundancy – six propellers, each powered by two inverters; each inverter wired to a separate battery pack; and four isolated battery packs. But we expect that the same engineering and design innovations – electric propulsion and tilt-rotor vectored thrust – developed in order to "solve" the (very overstated) problems with helicopters are going to pose safety and certification problems.

Batteries

In its most recent quarterly shareholder letter, Joby disclosed that the building blocks for its batteries are "pouch cells from the automotive supply chain." In a tweet from a few weeks earlier, Joby explained that the pouch cells from the auto supply chain are "widely available, well-understood, and meet our primary needs."

In contrast to the Molicel premium cells that served as our archetype for aerospace applications, cells from the auto supply chain are "well understood" to not optimize for high-power applications. A dual-motor Tesla Model 3, for example, with an 82kWh capacity (a little more than half of what we expect Joby's aircraft to hold) will use merely 15kW of power to cruise and have a maximum power output of 366kW (both motors' top power spec combined). But the battery cells – and this is true for more or less all auto batteries – are optimized for range and cycle life rather than power output because high-power applications are assumed to be rare and brief. After all, it takes just a few seconds to accelerate from 0-to-60 in the shortest possible time, and almost no driver is doing that consistently. Contrast that with Joby's plane, in which we estimate that the batteries will hold about 150kWh, and which Joby has said will have a maximum combined power output of over 1400kW. The plane will require over 100kW to cruise, and will routinely require more than 5x that for minutes at a time – more than 10% of the total average flight time – to take off and land (which obviously happens during every flight).

When cells that are not optimized for power are regularly used for high power output, the most obvious problems will be reduced range and reduced cycle life, which we discussed previously in detail. Less obvious, but just as relevant for Joby, is that high power output is an expression of a faster battery discharge rate, and faster discharge rates cause increased battery temperatures, thus increasing the risk for thermal runaway.

Thermal runaway – the phenomenon in which the Li cell enters an uncontrollable self-heating state – and the uncontrollable battery fires that it's often associated with pose substantial risks in the context of an airplane hovering 100 feet (or higher) in the air. This kind of discharge-caused temperature increase is a lot more likely to occur in a battery cell that's not optimized for high-rate discharge, like the auto-supply-chain cells that Joby is relying on. Joby's choice of pouch cells (as opposed to cylindrical or prismatic cells) makes matters a bit worse in this respect because while pouch cells are lighter (which is obviously a key consideration), high discharge rates result in an even more dramatic temperature increase in pouch cells than in the cylindrical or prismatic kind. Finally, high discharge rates also result in increased mechanical stress on the cell's internal components, which also causes cycle life deterioration and increases the risk of physical defects that are associated with thermal runaway.[18]

Of course, overlaying the thousands of auto-supply-chain battery cells in each aircraft will be a battery management system that Joby has developed in-house. The BMS will monitor and manage charging and discharging at the cell-level, making sure that voltage, temperature and charge- and discharge-rates don't occur outside their operational envelope, and shutting off risky cells when necessary. There will also be physical cooling and cell-packaging features that will work to reduce the risk of an out-of-control thermal runaway.

All these features will have to be tested and analyzed by Joby in Stage 4 of the certification process, eventually proving (Stage 5) that they can meet the FAA's battery-fire risk-mitigation standards. At present *it's unclear what those standards will be*. In the wake of Boeing's 787 battery-fire in 2013, the FAA adopted Minimum Operational Performance Standards for Rechargeable Lithium Batteries and Battery Systems (DO-311), which recommended a baseline test in which thermal runaway would prove contained after purposely "initiated by overheating or overcharging the *entire battery*, forcing all its cells into near-simultaneous failure." An alternative test – proving containment when thermal runaway would be purposely initiated in different pairs of cells across different batteries – was also published in DO-311, but it also mandated much higher levels of design assurance (demonstrating a miniscule probability of catastrophic failure). The European Union Aviation Safety Agency (EASA) recently published thermal runaway means-of-compliance that included a test that is similar to the alternative test from DO-311 but

[18] The thermal and structural effects of discharge *rate* on battery cells are explored in depth by Xu, et al, *Decoupling the thermal and non-thermal effects of discharge C-rate on the capacity fade of lithium-ion batteries*

more comprehensive,[19] but also left open the possibility that an applicant could propose its own thermal runaway tests as long as they met a long list of EASA guidelines, which includes proving containment of an actual thermal runaway.

Joby has asserted that "with all of our area specific certification plans now submitted, we have a clear path to certify our battery packs." In our view, it's pretty clear that means that Joby has completed what management *thinks* is *its part* of Stage 3 with respect to its battery packs – submitting its detailed *proposal* for which tests it will perform in order to satisfy the MOC – but that the FAA has not yet approved it, or even responded to it. That makes a lot of sense considering that the FAA's policy on electric plane battery pack certification is closely watched and highly anticipated.

Whatever the FAA decides for Joby is potentially going to be the standard it sets for the rest of the industry, so it's highly likely that the agency is going to respond with its own battery-pack certification standards rather than simply accept Joby's draft certification plans, similar to the agency's actions on reserve requirements we detailed in previous sections. The FAA's proposal is then going to be debated and finalized, with just the dialogue between the agency and industry likely to take a few months. Once that's complete, there's a pretty good chance that Joby will have to go back and adjust its battery pack design to meet the FAA standard, and only then will it begin testing, analysis, and verification.[20] Not only is that whole process going to take many months, it also might result in more weight (and less range) and further engineering compromises added to the aircraft. Even then, considering the dynamics around high power and its effects on thermal and structural battery properties, it's just not certain that Joby's battery packs will meet the standard. "A clear path to certify our battery packs" more precisely translates into "we're not even close."

Vortex Ring State

Perhaps Joby's most impressive engineering feat is the tilt-rotor system that will provide (vectored) thrust for its eVTOL. But that same design (which is also featured on the eVTOLs belonging to Archer, Lillium, and Wisk) also puts it at greater risk for entering what's known as a vortex ring state (VRS). VRS is a flight "regime" entered into by a rotor-powered aircraft (usually helicopters) in their descent/landing phase. While somewhat oversimplified, VRS can be described as a condition in which a rotorcraft descends slowly enough into the wake of its own rotor that the physical dynamics of that wake interfere with the aircraft's descent. That

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[19] The test requires a minimum of 20% of the cells in the battery system forced into a thermal runaway that must be contained.

[20] It's worth noting in this context that as recently as this past June, Joby raised the maximum weight specification of its eVTOL from 4800lb to 5300lb, a massive 10.5% increase. Leeham Consulting's Bjorn Fehrm believes this was safety/certification-related, and that's even before getting to the onerous stages of certification. Further safety-related weight-increases might make the plane even more useless than it already is within the regulatory and battery-enabled range parameters.

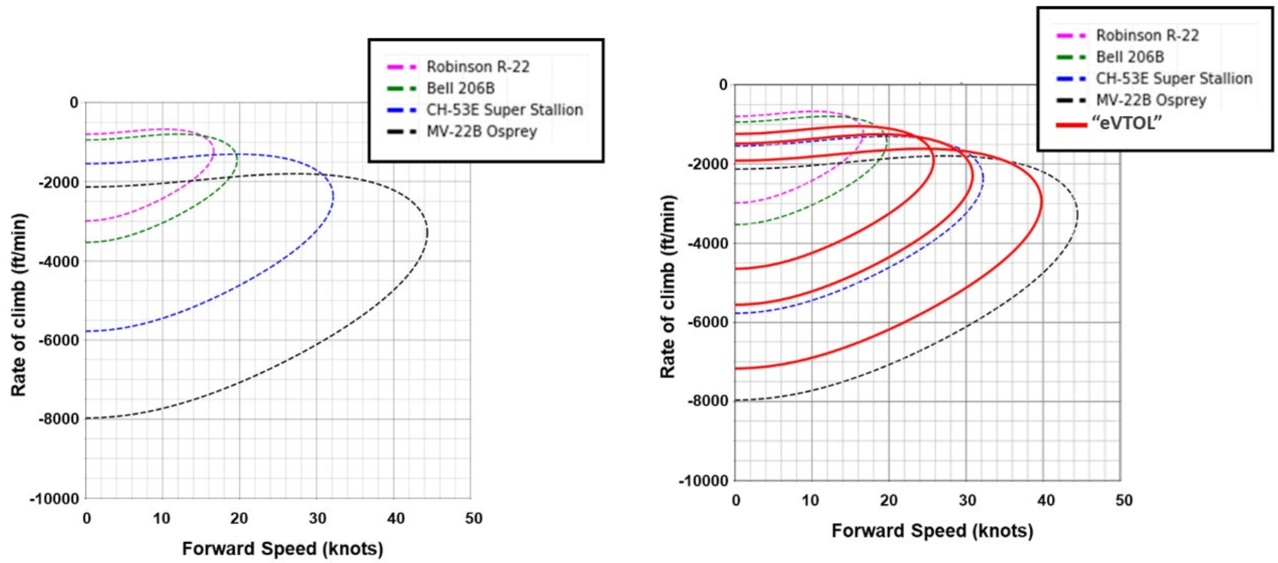
interference takes the form of a loss of thrust from the rotor, which results in a rapid descent/drop of the aircraft, in the worst case so rapid that it crashes violently into the ground.[21]

The susceptibility of an aircraft to VRS – or, in other words, the extent of the flight envelope in which the aircraft is at risk – increases as a function of "disc loading." Disc loading is a fairly intuitive parameter – a rotorcraft's weight divided by the 2-dimensional area covered by its lifting rotors. Basically, disc loading measures the burden, or "loading," that's placed on the rotors, or "discs."

A model of VRS susceptibility, based on both actual data as well as a validated mathematical model of the phenomenon, can be seen the chart on the left on the next page. What it shows are the parameters – forward speed and descent rate – *within* which different aircraft are vulnerable to VRS. The size of the envelope is small for small helicopters, larger for larger helicopters, and *much* larger for an aircraft like the V-22 Osprey, a dual-tilt-rotor vectored thrust aircraft used by the US Marine Corps that has experienced enough accidents – a large number of them VRS-related – to merit an "Accidents involving the V-22" Wikipedia page. The theoretical risk-envelope for tilt-rotor eVTOLs can be seen in the graph on the right, and its size and similarity to the V-22's risk-envelope should at least raise some eyebrows.

[21] A much more detailed explanation of the physics of VRS is given by Dr. Richard Brown in this presentation on the phenomenon. Brown is an aerospace engineering consultant focused on VRS, most recently as it pertains to eVTOLs.

VRS-onset Boundaries for Various Aircraft



Rotorcraft are vulnerable to VRS under very specific conditions – below a particular level of forward speed (the x-axis on each chart), and at specific rates of descent (the y-axes). The "area to the left" of the above curves show the combinations of speed and descent-rate at which particular aircraft are vulnerable to VRS. The left side includes two small helicopters, a big helicopter (CH-52E), and the V-22. The range of flight conditions under which the V-22 is vulnerable to VRS is several times larger than that of small helicopters. The chart on the right includes the same information for several hypothetical eVTOLs in red, and suggests that the range of speed and descent rates at which eVTOLs will be vulnerable to VRS is much larger than that of helicopters, and close to that of the risky V-22.

Source: Richard Brown, Are eVTOL Aircraft Inherently more susceptible to the Vortex Ring State than Conventional Helicopters?

What makes the V-22 – and eVTOLs like Joby's – even riskier is that, unlike helicopters, they don't have just one rotor that generates lift. The V-22 has two rotors – one on each side of the aircraft – and Joby's vehicle has 6 rotors. One of the more well-known V-22 accidents was the tragic Marana incident in which the aircraft flipped in the air while descending steeply and then crashed into the ground nose-first. In this peculiar instance, only one of the V-22's rotors got caught in VRS, which created an imbalance in the aircraft's lift, forcing it into an unbalanced and then sideways configuration that ended with a horrific crash, all in the span of 6 seconds. The VRS risk from multiple rotors increases further, not just from the number of rotors that can go into VRS, but also as the plane's maneuvering while landing – and the resultant changes in its roll and yaw (the way it tilts on its longitudinal and vertical axes, respectively) – increase the probabilities of one or more rotors getting sucked into VRS. The risk increases even more as it pertains to eVTOLs due to the uneven urban environments in which they're meant to operate, which will introduce structurally imbalanced impacts on the aircraft's physical frame.

To avoid VRS-related accidents in eVTOLs, the FAA can start by mandating that eVTOL developers conduct flight tests under conditions of induced VRS (the same way it can mandate induced thermal runaway, or an induced stall during flight testing). The risk here would be that if not handled properly, the airplane could crash, which – considering the small number of test aircraft (2 at present in Joby's case) – would set back testing and certification by many months. Once the parameters of VRS risk are better understood, the next regulatory step would be pilot training requirements and proper flight manual documentation.

To summarize, we're almost certain that Joby's eVTOL is at relatively high risk for VRS-related safety incidents given its disc loading, multiple rotors, and operating environment. We're also certain that Joby has considered VRS (though it has not spoken about it publicly) but that the research that the Joby team has published on the matter – which incorporates computational fluid dynamics (CFD) modeling – does not take into account the complexity of VRS that more recent research and models have revealed. It seems likely that the FAA will require Joby to address VRS risk through some combination of testing, training, and engineering, which is going to further push out the certification and commercialization timelines. Appropriately extensive testing may also endanger the flight-testing prototype, and a VRS-triggered testing accident would both put certification on further hold as well as create substantial eVTOL headline risk.

Logistical Difficulties Await eVTOLs Even After Certification

Beyond regulatory risks and delays inherent in Joby's project, we think investors should consider the logistical difficulties that Joby's business plan will inevitably face. Two areas of particular concern are pilot training and air traffic control (ATC).

Pilot Training

The VRS discussion above should at least clarify that flying an eVTOL will entail a degree of difficulty far beyond that of helicopters or turboprops. Aside from VRS, there's the difficulty of flying any plane that transitions from hovering to forward winged-flight and back. As John Hansman – a professor of Aeronautics at MIT, a frequent FAA advisor, and a pilot – explained in a lecture this past January, "all of these vehicles [eVTOLs] are very difficult to fly during the transition…transitioning from the static to the forward is tricky from a flight control standpoint." The accident record of the V-22, which operates similarly and has the benefit of being flown by elite Marine pilots, indicates that training pilots for eVTOL missions is going to take a lot of time and money, and even then the *inherent safety profile of these planes is going to be riskier than helicopters or commercial airplanes*.

That training is going to be further complicated by the fact that Joby's aircraft (like most eVTOLs) is a single-pilot design that can't accommodate traditional dual flight instruction. That will make simulation incredibly important, and it's unclear how simulator creators are going to account for the degree of difficulty in flying these aircraft or how the FAA is going to manage that process.

But simulation is not going to be enough. In June, the FAA released a proposed Special Federal Aviation Regulation (SFAR) that addressed pilot certification and training for eVTOLs and which will significantly complicate Joby's push for commercialization. The proposed rule mandates the different kinds of ratings that certified eVTOL pilots will have to hold, and the training experience and testing that will be required to earn those ratings. The salient points in the FAA's proposal that will affect Joby (and other eVTOL manufacturers) include the following:

- "The FAA expects [eVTOL] manufacturers to develop a version of the aircraft to contain fully functioning dual controls" for the purpose of meeting SOE (supervised operating experience) requirements. The relevant SOE requirements for earning the appropriate ratings include, most importantly, 25 hours of flight time as a pilot-in-command (PIC) under the direct observation of *another* qualified PIC in an aircraft of the same category and type for which the rating is being sought. In other words, if Joby wants certified pilots, *simulation training will not be sufficient*. It's going to have to build dual-control planes that are functionally identical to their production-model and have every pilot train for at least 25 hours under the supervision of *another already certified pilot*. That's going to create a *massive* pilot bottleneck.

- A rating earned by a pilot on one eVTOL (a "type-rating") will not transfer over to any other model. eVTOLs "have complex and unique design, flight, and handling characteristics with varying degrees of automation" and each one "can have different configurations, unique inceptors, diversified flight controls, and complicated and distinctive operating characteristics." This is in stark contrast to helicopters and small airplanes in which a type rating isn't required (except for extremely large models) because it's assumed that a pilot that knows how to fly one helicopter or plane can fly any other given the essential equivalence of flight controls among different models. In addition to aggravating the pilot bottleneck created by the SOE requirement, this will make the market for eVTOL pilots highly frictional, potentially disincentivizing pilots' personal investments into eVTOL type ratings and requiring different incentives – in the form of dollars – to compensate.

  As Bjorn Fehrm put it in an analysis by Leeham Consulting:

  > Training and its tools like simulators will be special for every VTOL, and the requalification of a pilot from one VTOL type to another will take longer and be more costly than if there was some standardization of how to fly the VTOL. Critical situation training will take longer and be more costly as the situations must be repeated until the pupil has reprogrammed his muscle memory…Over the last decade, there have been shortages of qualified pilots for the air transport industry. The emergence of thousands of eVTOLs will bring this to a major crisis. The non-standardization of how you fly a VTOL will exacerbate this crisis.

On the bright side, the SFAR creates "a process through which pilots who work for eVTOL manufacturers would serve as the initial cadre of flight instructors, providing training to instructors who work at flight schools, training centers, and air carriers," which solves the chicken-and-egg problem inherent in fulfilling the SOE requirements when no actual category- or type-rated pilots exist. The FAA also proposed allowing Joby and other eVTOL operators to provide training, which is an exemption from the current rules that prohibit air carriers from training their own pilots. But the logistical difficulties of establishing a corps of eVTOL pilots are going to be immense.

Air Traffic Control

Another concern – if we're to assume a massive air taxi fleet – is going to be air traffic control (ATC). Any of the air taxi use cases, especially the obvious airport-shuttle mission, are going to be comprised of flights in large cities with large swaths of Class B controlled airspace, which means the pilot will be communicating, at least occasionally, with ATC. Does the current ATC infrastructure have the capacity to double or triple the number of daily flights that it handles in urban airspace? In a research paper published jointly last year by NASA and, well, *Joby*, focused on potential eVTOL use-cases in the Dallas-Fort-Worth metropolitan area, the authors' conclusion was that the current ATC system can't handle any appreciable increase in eVTOL air traffic:

> The findings that emerge…suggest that initial UAM [urban air mobility] operations could occur under today's airspace and procedures in a busy terminal area, such as DFW and DAL, *but will encounter significant challenges when scaling up and some desirable flight paths are constrained by existing traffic*. As UAM aircraft navigate in and out of Class B airspace…*this is likely to have an impact on controller workload*…Also, the UAM aircraft will be flying near established conventional traffic flows and will require careful management…The two major constraints and concerns emerging from this use case development that ***UAM operations will initially encounter are controller workload and the ability to efficiently and safely interact with existing airport traffic.*** (emphasis ours)

Those seem like pretty significant constraints and concerns! And if DFW is bad, it doesn't take much to imagine how incapable the ATC infrastructure in New York or Los Angeles will be (coincidentally the two metro areas Joby says it wants to pilot its service). "Policy and rule changes and dedicated airspace structures (e.g., corridors) are likely to be needed to enable longer-term scalability," according to that same research paper.

Where's the FAA in the process of setting these things in motion? According to its "Advanced Air Mobility Implementation Plan" released in July, the FAA's Air Traffic Organization (ATO) concluded a review of the matter in June 2022 and "identified 55 recommendations to help address the integration of AAM operations in the near-term," many of which "require changes to FAA policy and guidance directives." At present, the ATO is still recommending "a detailed policy review be conducted to determine if other associated orders and ACs [Advisory Circulars] need to be updated or developed." ATC policies and procedures are notoriously slow in being updated, and the process – currently focused on identifying which updates are even necessary – is in its relative infancy. It's another in the long list of data points that indicates that large scale eVTOL use is a science fiction fantasy and not actually feasible.

VI. Conclusion

Joby is currently burning through about $100 million in cash per quarter and that will inevitably increase as certification work ramps. In addition, the company recently committed to spending $500 million on building a manufacturing facility in Ohio beginning in early 2024. When (if?) larger scale manufacturing begins – and we don't expect it to begin for years – the cash burn rate will accelerate even more dramatically, particularly as the "air taxi" concept bombs and manufacturing costs explode. Joby's management team is not completely blind to all this, which is why they've been raising more capital even with their billion-dollar war chest.

The Wall Street consensus has Joby generating close to a billion dollars in revenue, and getting to EBITDA breakeven, in 2027. But no such thing is going to happen. It'll be a miracle if Joby's eVTOL is even certified by then, and even when that *does* happen, production dynamics, demand shortfalls, manufacturing costs, and logistical bottlenecks will remain obstacles to any meaningful eVTOL commercialization for years. Joby's current $1.2 billion in cash is going to have run out long before that – in less than two years given the aforementioned cash burn rate and investment commitments – and investors will have to continue to fund billions of dollars of cash outflows until then if Joby is to survive.

That's the best-case scenario, though. As it currently stands, there's really no battery technology that's going to enable an eVTOL that's more than an interesting engineering spectacle. The now-standard low-single-digit annual percentage improvements in Li battery capacity might be enough to get automobiles over the mass-adoption hump over the next 10-20 years. But to achieve aerial flight ranges of more than 50 miles, or the ability to fly at night and in less-than-perfect weather, completely new battery chemistries will need to be invented and commercialized. That might happen, but it's no certainty, and by the time it does – 2040? 2050 perhaps? – Joby will have long become a historical footnote.

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