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The Case for the All-electric Aircraft

My analysis on the all-electric passenger aircraft (originally posted on Medium February 22, 2018).

Intro

> "For once you have tasted flight you will walk the earth with your eyes turned skywards, for there you have been and there you will long to return."
> — Leonardo da Vinci

The world of aerospace & defense has always been an interesting space. I've wanted to be a pilot of some sort (back in the days test pilot and astronaut), these days I'm slowly working on the PPL. Current turbofan jet engines (like the Rolls Royce Trent 1000 on the Boeing 787) are no doubt an engineering marvel, but I've been thinking about when we'll have the next innovation which is an all-electric aircraft. With over 57 well-known space-related startups from spacecraft to launch service startups such as: SpaceX, Blue Origin, Relativity Space, Rocket Labs and Accion Systems all point that actual aircraft will be developed and manufactured by startups.

When it comes to startups in the aerospace sector, you mainly have UAV/UAS startups such as PrecisionHawk and electric VTOL (vertical take-off and landing)/flying car/air taxi endeavors such as Joby Aviation, Lilium Aviation, Kitty Hawk/Zee.Aero, A³ by Airbus (Vahana) and Uber (Elevate). Then there's the supersonic flight companies such as Boom Aerospace, Spike Aerospace and Aerion Corporation. But the startups no one is really talking about are the startups working on the **all-electric passenger aircraft**, ones that would replace regional to wide body aircrafts. So I figured I write about where the world is currently (as of Feb 2018), in developing the all-electric aircraft.

With rising oil prices and environmental concerns due to large amounts of carbon emission, this space will become more exciting to watch in the years to come. As of February 2018, there is Airbus Group/Rolls Royce/Siemens (E-Fan X), Bauhaus Luftfahrt (Ce-Liner) and 3 known startups: Zunum Aero (ZA), Wright Electric (WE) and Impossible Aerospace (IA) all of them, are taking very different approaches and strategies to building the first all-electric aircraft.

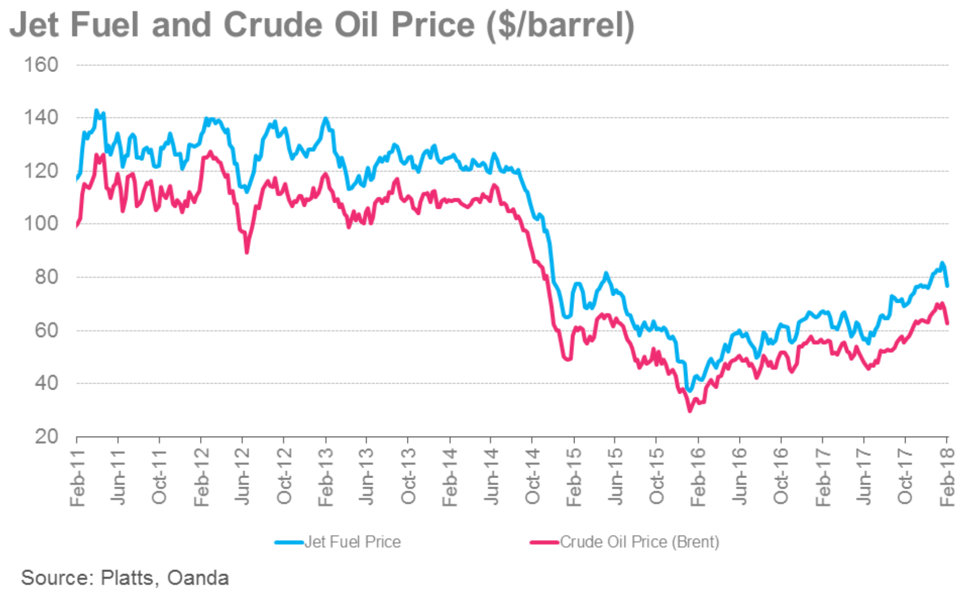
It appears to seem more airliners are shifting away from "jumbo-sized" wide-body aircraft (such as A380, B747) to smaller more efficient wide-body aircraft such as the A350 XWB, B787. This proves that fuel costs and razor margins are largely driving these trends and that airliners are looking into fuel-efficient aircrafts or aircrafts that don't rely on fuel at all. This opens new opportunities for a new kind of aircraft to compete in the market. Interestingly when you read the annual reports and 10Ks of virtually every airliner and even shipping/logistics company around the world on what risks adversely affects their business, that is fuel costs/supplies.

Yet you didn't see aircraft manufacturers rushing to develop an all-electric passenger aircraft. Instead, the focus is developing so-called " a more electric" aircraft. This means the manufacturers are moving towards supporting systems (such as cabin pressurization, air conditioning, de-icing), which all currently relies on bleed air (which is compressed air produced by turbine engines taken from the compressor stage) to becoming more electric. Doing this will also decrease costs since they are maintenance intensive. However recently Airbus set up a joint venture to explore the electric aircraft known as the E-Fan X. These recent trends in the industry provides opportunities for startups to develop electric aircrafts. No wonder in 2017 TechCrunch stated, "The next billion-dollar startup will be in aerospace". I certainly think one of these "next billion-dollar startups" will be developing an all-electric aircraft.

> "The industry will be capable of building hybrid electric aircraft for 100 passengers by 2030 with very short, local trip capabilities."
> — Tom Enders (Former CEO of Airbus Group) to the World Economic Forum

9 February 2018	Share in World Index	cts/gal	$/bbl	$/mt	Index Value 2000 =100	vs. 1 week ago	vs. 1 month ago	vs.1 yr ago
Jet Fuel Price	**100%**	182.6	76.7	604.6	209.6	-8.9%	-6.4%	15.2%
Asia & Oceania	22%	186.0	78.1	617.0	223.2	-7.8%	-2.1%	17.8%
Europe & CIS	28%	184.2	77.4	609.6	208.4	-7.9%	-6.1%	17.1%
Middle East & Africa	7%	180.8	76.0	599.2	226.8	-8.1%	-3.8%	17.4%
North America	39%	179.6	75.4	595.8	200.5	-10.2%	-9.2%	12.6%
Latin & Central America	4%	184.3	77.4	595.9	214.4	-10.4%	-9.3%	10.0%

Direct Source: http://www.iata.org/publications/economics/fuel-monitor/Pages/index.aspx

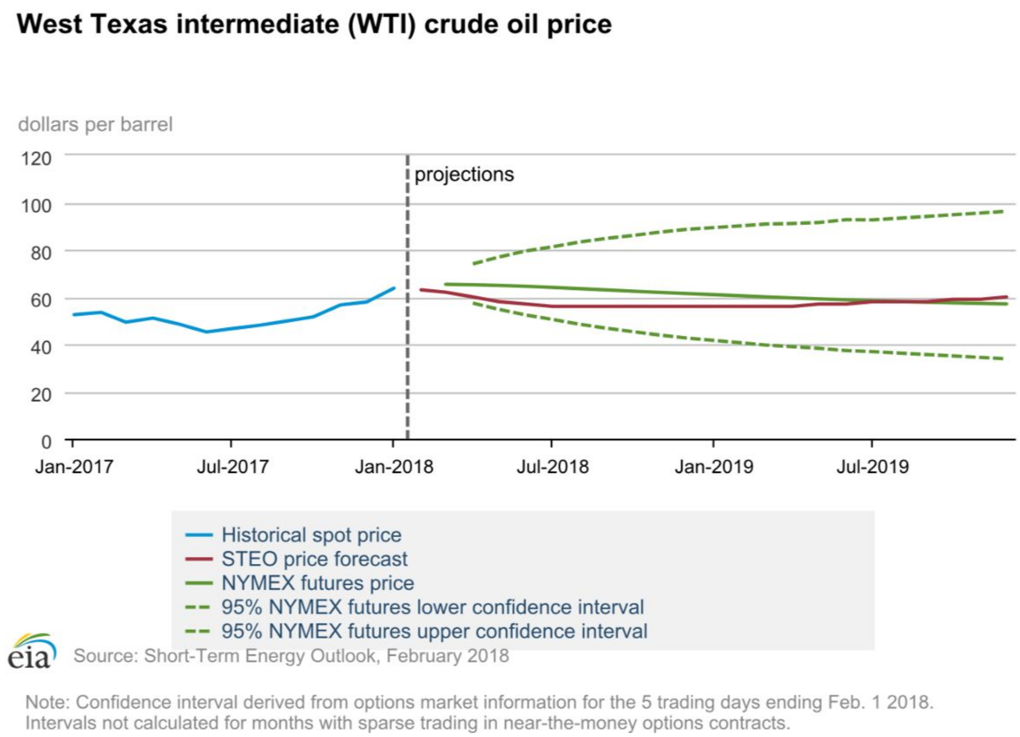


Direct Source: http://www.iata.org/publications/economics/fuel-monitor/Pages/index.aspx

Jet fuel prices dropped sharply in 4Q14 and continued to drop until February 2016, but has been climbing since then with the expectation to continue to climb throughout 2018.

> "Fuel spikes could have an impact," "But if it's just increases, given where we are, I think what you see is fares rise to levels to offset much of the fuel price increase."
> — Doug Parker (CEO of American Airlines) to USA Today

Despite the sharp increase end of 2017, EIA (US Energy Information Administration) forecasts that Brent prices will average about $62/bbl in both 2018/2019 compared with an average of $54/bbl in 2017 and WTI prices trailing roughly $4/bbl lower than Brent prices for both 2018/2019. It could be that oil prices may rise 10–15% by the end of the year causing jet fuel price to rise with.



Source: https://www.eia.gov/outlooks/steo/report/prices.php

Carbon Emission

The second reason is environmental benefits. Air travel accounts for a rapidly growing piece of our greenhouse gas emissions. Burning that fuel currently contributes around 5–10% to total CO2 (carbon dioxide) emissions (with 2015 at 5%). It is expected that CO2 emissions will rise to 22% by 2050. In 1992, air travel only accounted for 2% of total human-created (anthropogenic) CO2 emissions or about 13% of CO2 from all transportation sources. The world's air passenger traffic doubled from 1985 to 2000 with air cargo traffic growing even more quickly. In 2017, it was reported by IATA that air travel grew 7% from the previous year.

With air travel growing with CAGR of 3.7% to 7.2B passengers traveling in 2035, the question is really how much CO2 is emitted by an airplane? If you take one round-trip flight between NYC and LA, and you've generated about 20% of the greenhouse gases that a car emits over an entire year. To put in perspective a round-trip flight from EWR to LAX emits roughly 0.9 mt of CO2 per person. On a United Boeing 757–200 transcontinental flight which carries 130 passengers, it emits 11.7 mt of CO2. Imagine this, during the day there are up to 16K planes in the air globally and about 11K planes during the night (you can actually see this on flightradar24.com). The total number of flights in 2017 is 36.8MM with roughly 60–100K flights a day.

The First All-Electric Aircraft

The first all-electric aircraft will certainly be an exciting thing to witness even if it has a lot of problems and won't be able to fly for long. But when the technology gets advanced enough it will become a game changer. We'll have to wait a while before we see commercial planes that are fully electric.

> "I have crunched the numbers and I think we are still more than a decade away from having all-electric commercial airliners."
> "The performance gap you need to bridge, particularly when it comes to the energy density of batteries, is huge", "smaller-scale projects like Vahana have a real chance of becoming the first commercially feasible electrical aircraft."
> "You can scale gradually from there, but you have to start somewhere."
> "The first aircraft may not be that competitive, but, as happened with cars, governments may use regulation to support electric aircraft, on the basis that they are quieter and less polluting."
> — Bjorn Fehrm (aeronautical analyst for Leeham Co.) to CNN

Despite the challenges ahead, the industry provides enormous opportunities and excitement. The airline industry global market is USD $754B and $132B in the US, the global aerospace & defense industry is USD $674.4B, and the global commercial aerospace industry is USD $323.1B. Combined a startup in this space would be tackling a USD +$2 trillion industry combined globally.

Looking into the actual product, I think the first certified electric aircraft flying, will be hybrids (combination of both electric and traditional jet engine) with up to 70% fuel efficiency before eventually becoming fully electric. It might be that the jet engines will be used to get the plane into cruise altitude (which is typically FL350 or flight level 35,000 ft) and cruise will be done through electric fan/motors. So to look at the reason, the next question is what segment will the all-electric aircraft makes sense or what segment might see the first electric aircraft. The immediate segment will be regional jets followed by narrow-bodies, I intentionally didn't include the wide-body segment since it will be a very long before we see an all-electric competitor to the A380 or even the 787.

The following segments (regional jet and narrow-body) will attempt to describe the breakdown of costs of a regional jets and narrow-body jets in the US as an attempt to illustrate a business case for the two verticals that an all-electric aircraft startup should focus.

Regional Jet

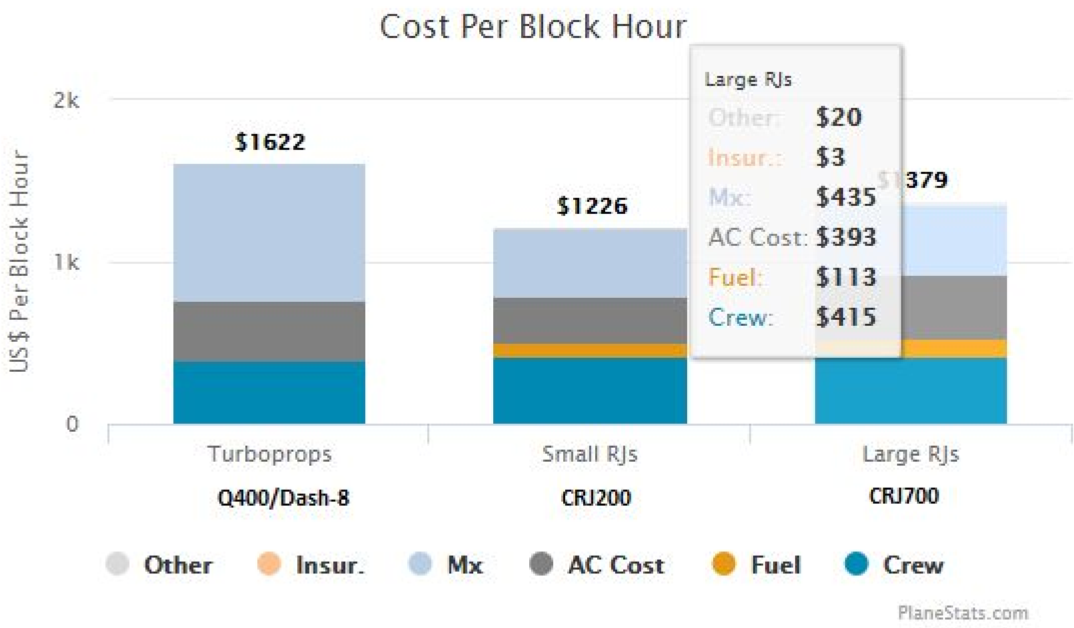
I believe the vast majority of electric aircraft startups will be targeting the small or large regional jets (RJ) in the beginning. I think this makes sense in that given the feasibility and timeline (5–10 yr). Today's large RJs are most cost efficient way for airlines to link thousands of communities to airport hubs and the global airline network.

Previous small RJs (50 seat or less) were largely inefficient, starting 2005, the RJ boom suddenly collapsed with increasing fuel prices and airline bankruptcies. The high per-seat operational costs of the classic 50-seat RJs (which cost slightly more vs. 66–104 seat RJs) have been exacerbated by an environment of ever-lowering fares. Additionally RJs increasingly were assigned to operate flights of two hours or more. This led to dissatisfied passengers, as their comfort and ergonomics compare unfavorably to the larger "mainline" jets which they replaced on these flights. The 50-seat RJs are being retired at accelerated rates, affecting both their resale value and the value of their parts. CRJ100/200 are seeing very high retirement rates (much higher than Embraer RJs), not only because of their inefficiency but because the airlines operating them also faced bankruptcies and reorganizations.

I believe that an all-electric RJ would further prove to be competitive against any high speed land based transportation such as the Hyperloop and even high speed trains (which do not exist in the US at the moment). Currently worldwide trains dominate the 200–300 mile routes (DC to NYC, Edinburgh to London, Tokyo to Osaka) but I believe the electric aircraft will be able to compete against the train with prices that of a bus fare since on short flights speed won't matter.

Bombardier forecasts there will be 12,550 deliveries in the 60–150-seat segment between 2017–2036 totaling a market value of USD $820B, where in 2009 Embraer estimated the 30–120-seat segment would have an estimated market value of US $220B over 20 years. It will be interesting to see how startups will manage to develop aircrafts in this segment with Bombardier CRJ100 program at $450M, CSeries program at US$ 5.4B (February 2015) and Embraer E-Series at US $850 million (June 1999).

I will illustrate a rough cost structure to operating RJs:
One of the metrics that the airline industry uses is flight operating costs (FOC) per block hour (FOC/BH) as a measure of cost to operating an aircraft. The block hour (or BH) is the time from the moment the aircraft door closes at the departure of a revenue flight until the moment the aircraft door opens at the arrival gate following its landing.



US DOT data for the year ended June 2017 includes operating cost and utilization for nearly 1,400 commuter aircraft. On average, small regional jets operate 7.5 hours per day, while large RJs operate 9.0 hours per day.

Source: planestats.com

Based on the 3Q17 (most recently available) data provided by Oliver Wyman (via planestats.com) shows the following rough estimate to operate a:

- **Bombardier CRJ200** (USD $24–39M per aircraft) roughly costs **USD $3.04M/yr** to operate with a FOC/BH of $1,142 (ExpressJet) operating 7.3BHs/day
- **Bombardier CRJ700** ($41M) roughly costs **$4.12M/yr** with a FOC/BH of $1,412 (SkyWest) operating 8.0BHs/day
- **Bombardier Q400/Dash-8** ($31.3M) roughly costs **$4.79M/yr** with a FOC/BH of $1,622 (Horizon) operating 8.1BHs/day
- Datas for **Embraer ERJ-130/140/145** weren't reported and some fuel costs may have been inaccurate, so I didn't include them here.

An immediate value proposition of an electric aircraft is having a FOC/BH of USD $250–300 (based on Zunum's estimate) vs. $1100–1500. Additionally maintenance (MX) costs would significantly decrease where we might possibly see a decrease in the 15–40% range.

As of 2016 SkyWest Airlines (which is the largest RJ operator in the US) owns/operates the following:

- CRJ200 (50 passengers): 186
- CRJ700 (66–78): 85
- CRJ900 (97–104): 36

Hypothetically speaking — the cost to operate the following RJs per year (if the aircraft was used everyday):

- **CRJ200**: $1,295 x 7.6BH x 365 days = $3.59M x 186 units = **$667.7M**
- **CRJ700**: $1,412 x 8.0 x 365 = $4.12M x 85 = **$350.2M**
- **CRJ900**: $821 x 11.3 x 365 = $3.39M x 36 = **$122M**

It roughly costs SkyWest USD $1.13B/yr to operate the 307 CRJ series jet and 8–11% accounts for the fuel cost (~ USD $90M–124M). A realistic estimate shows that the aircraft are used 85% out of the year with 15% grounded for various maintenance schedules (A/B/C checks and not accounting D checks which occurs every 6–10 years).

This puts my estimate closer to **USD $960.5M/yr** and the fuel costs somewhere between **$76.8M–105.6M** (a quick sanity check shows SkyWest paid **$122.2M** in 2016).

A hypothetical hybrid that uses 70% less fuel would cut $53.7–73.92B in fuel cost and an all-electric aircraft will be able to cut between $76.8M–105.6M in cost.

Narrow-body

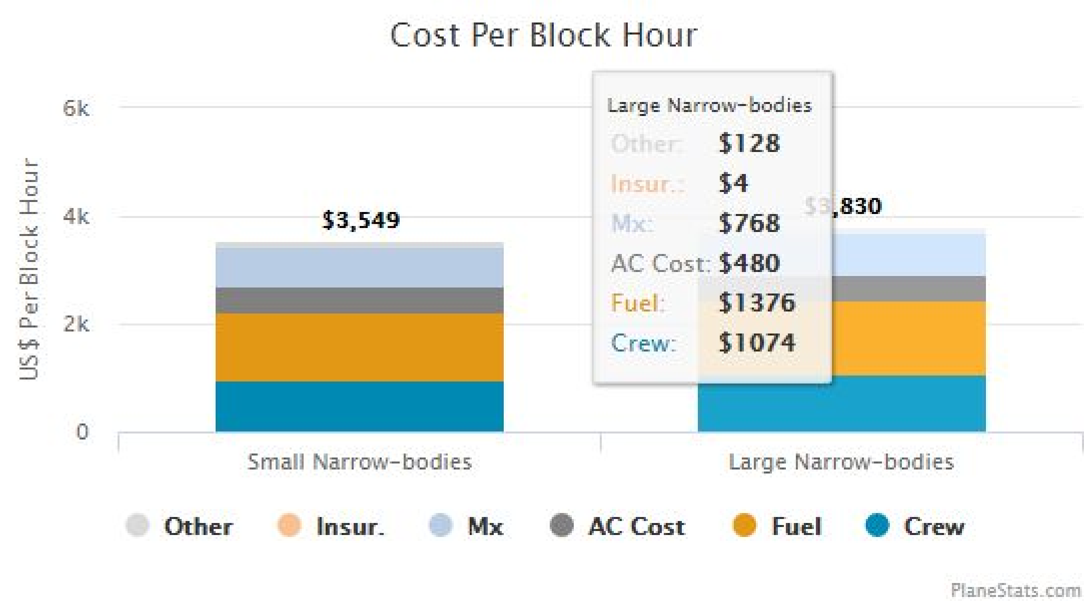
The long term goal for an all-electric aircraft will be to take on the short to medium range aircrafts known as narrow-body (or single aisle), it seems this is where most are aiming for. Examples in this category are Boeing 737, Airbus A320 family, and to a certain degree Bombardier CSeries and Embraer E-Jet family (specifically the E-190/195) which both hover between RJs and narrow-bodies. I think this is more likely 5–15 years after the development launch of an all-electric RJ.

With large wide-body aircraft such as Airbus A380 struggling and the Boeing 787 making significant impacts on the airline industry. The 787 is a relatively small, super-efficient, long range aircraft has allowed for the advent of long-haul budget airlines and for traditional airlines to open up long-haul routes between smaller markets. Furthermore several airlines such as Avianca uses the 787–8 on short-haul flights (Bogota to Cartagena) during the summer season in which the flight is roughly 1hr and 30 min.

Looking at current aviation trend, this hypothetical narrow-body can ultimately turn to replace the aging Boeing 757 (total number in service is 689). The Boeing 757–200 entered service in 1983 and production ended in 2004 (which to some is one of the greatest mistakes Boeing made). The 757 was intended to replace the 727 on short and medium routes and needed more seats than the 737. In 1986, the FAA approved RB211-powered Boeing 757 for extended-range twin-engine operational performance standards (ETOPS) operations over the North Atlantic (which originally required 3 or more engines). Under ETOPS, airlines began using the 757s for mid-range intercontinental routes.

Although the 757 were not originally intended for transoceanic flights, they have become the primary choice. United flies the 757–200 on routes from Newark to Shannon, Birmingham, Edinburg, Lisbon and Stockholm. It might be that a viable all-electric MoM vs. RJ or narrow-body will become an option as they look to replace the aging 757s. This electric aircraft will also serve middle of the market (MoM) between a narrow-body and wide body (which includes the B737 MAX, B757, B767, A321LR and A330). Targeting MoM will allow this hypothetical aircraft to effectively capture a larger market globally serving several needs.

The following will illustrate a rough cost structure to operating narrow-bodies:



Small narrow-bodies (fewer than 150 seats) operate 9.8 hours per day while making 4.4 departures per day according to the most recent US Department of Transportation data. Large narrow-bodies (more than 150 seats) operate 10.6 hours per day and depart 3.4 times.

Source: planestats.com

Based on the 3Q17 (most recently available) data, rough estimate to operate a:

- **Embraer E190** (with an upfront cost of USD $46.2M) roughly costs **USD $11.0M/yr** to operate with a FOC/BH of USD $3,091 (JetBlue) operating 9.8BHs/day
- **Airbus A319** ($89.6M) roughly costs **$10.19M/yr** to operate with a FOC/BH of $3,035 (American) operating 9.2BHs/day
- **Airbus A320** ($99M) roughly costs **$16.2M/yr** to operate with a FOC/BH of $3,496 (JetBlue) operating 12.7BHs/day
- **Boeing 737–700/LR** ($82.4M) roughly costs **$12.91M/yr** to operate with a FOC/BH of $3,846 (United) operating 9.2BHs/day

- **Boeing 737–900/ER** ($104.1M) roughly costs **$13.67M/yr** to operate with a FOC/BH of $3,437 (United) operating 10.9BHs/day
- **Boeing 757–200** ($65M) roughly costs **$18.15M/yr** to operate with a FOC/BH of $4,605 (United) operating 10.8BHs/day (757-300 was not reported but based on similar specs I will assume the same FOC/BH)

As of 2017 United Airlines owns/operates the following narrow-bodies:

- B757–200: 56
- B757–300: 21
- B737–700: 40
- B737–800: 137
- B737–900/ER: 148
- A319–100: 61
- A320–200: 97

Hypothetically speaking — their cost to operate the following narrow-bodies per year:

- B757–200: $4,605 x 10.8BH x 365 = USD $18.1 x 56 units = **USD $1.01B**
- B757–300: $4,605 x 10.8BH x 365 = USD $18.1 x 21 = **$381M**
- B737–700: $3,846 x 9.2 x 365 = $12.9M x 40 = **$516M**
- B737–800: $4,009 x 10.0 x 365 = $14.6M x 137 = **$2B**
- B737–900/ER: $3,437 x 10.9 x 365 = $13.67M x 148 = **$2.02B**
- A319–100: $3,926 x 8.1 x 365 = $11.6M x 61 = **$707M**
- A320–200: $4,073 x 9.4 x 365 = $13.97M x 97 = **$1.35B**

Hypothetically speaking — it costs United roughly **USD $7.99B/yr** to operate the 560 narrow-bodies in 2017. Fuel cost is ~35% of total costs, which is $2.79B and MX is ~20% which is ~$1.59B.

Following the 85% utilization rule from previous (i.e. the RJ case), my estimate shows it will cost United roughly **USD $6.79B/yr to operate 560 narrow-bodies**. Fuel cost are **$2.37B** (a quick sanity check shows United paid $5.8B in 2016) and MX cost are **$1.35B**.

The **hypothetical hybrid that uses 70% less fuel would cut $4.75B** in fuel cost and **an all electric aircraft will be able to cut $2.37B** in cost.

The Current Competition

Currently (as of Feb 2018) there are three known startups which are Zunum Aero, Wright Electric and Impossible Aerospace. Along with the startups there are also 2 institutional partnership programs the E-Fan X and Ce-Liner. Not much is known publicly on the exact details of the startups, except ZA which has released some details of their first 12-seater. Both ZA and WE are taking a hybrid approach using different propulsion before developing an all-electric aircraft where as Impossible is developing a UAV first and scaling up to passenger aircrafts.

	Zunum Aero	Wright Electric	Impossible Aerospace
Headquarters	Kirkland, WA	Los Angeles, CA	Sunnyvale, CA
Website	zunum.aero	weflywright.com	impossible.aero
Stage	Pre-series A	Pre-series A	Seed (possibly raising Series A)
Partnerships	JetBlue	EasyJet NASA	N/A
Segment	Regional Jet	Narrow-Body	UAV (first)
Type	Ducted fan hybrid	Distributed propulsion hybrid	Possibly propeller
First Funding	2018	2017	2017
Total Funding	$3-$5M (estimated)	$1-5M (estimated)	$1.8M
Investors	JetBlue Technology Ventures HorizonX (Boeing) State of Washington	Y Combinator Renegade Capital	Eclipse Western Technology Investments (WTI)

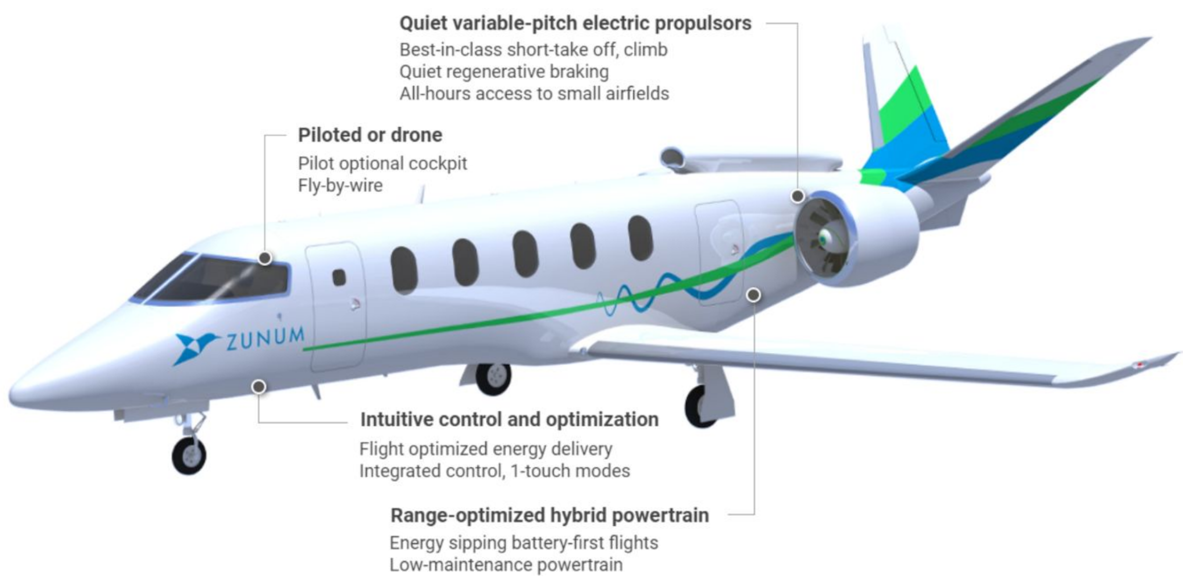
Note: Some of the information in the table are “best guesses”

Zunum Aero

Founded in 2013 by Ashish Kumar (former Microsoft, Google, Dell and McKinsey, PhD in aerospace), Zunum Aero (ZA) is a Seattle based aerospace startup with backing from Boeing (HorizonX) and JetBlue (JTV). Based on recent funding from HorizonX in January 2018 (likely USD +$1M), as well as previous funding (at least USD $800K+$800K in matching grants from the State of Washington’s Clean Energy Fund) ZA has built an impressive team to tackle this space. It also appears that ZA is owning building the aircraft end-to-end. Based on technological feasibility, it appears that ZA may be the first in succeeding in building something comparable to an Embraer Phenom 300 or Learjet 70/75 or larger by 2020.

The first aircraft in the product portfolio is a 12-seat hybrid small jet that will carry battery packs and a small fuel reserve for a backup engine. It is estimated that this aircraft will be available within the next 5 years or less. ZA’s RJ will fly about 700 mi, capable of routes from Boston to DC or SF/Silicon Valley to LA/Orange County. More importantly the noise reduction (up to 75%) and STOL (short take-off and landing) capabilities with a takeoff run of 2,200 ft (671 m) and landing of 2,500 ft (762 m) means the 12-seater (and the RJ variants) can operate out of smaller airports throughout the country, compared to a CRJ700 has a take off run of 5,265 ft (1,605 m)and landing of 5,040 ft (1,536 m).

> “As much as 86% of the total door-to-door travel time for such short-haul trips is taken up with driving to and from larger airports. By allowing more passengers to use the 5,000 regional airports, much of that would no longer be necessary. And that could make it possible to cut the average time for a trip between Silicon Valley and Los Angeles from more than five hours today to two-and-a-half hours, or to cut in half the time and cost of flying from Boston to Washington DC”
> — Ashish Kumar to Fast Company



Source: Zunum Aero

The architecture of the ZA’s 12-seater is hybrid with ducted fans powered by batteries alone for short trips and a range-extending generator providing 1 MW (1,300 hp) to 4–5 MW (5,400–6,700 hp). This model is expected to receive it’s airworthiness certification sometime in 2020 and being flying by 2022.

It is estimated that the ZA aircraft’s FOC/BH will be less than USD $300, as opposed to the average $1,226 for small RJs. It also appears that ZA is planning to compete in the regional jet space first before moving into narrow-bodies (effectively competing against WE) as well as traditional narrow-body manufacturers. Furthermore, it is interesting that ZA holds a broad US patent titled: [System and methods for implementing regional air transit network using hybrid-electric aircraft]() that utilizes a battery/power source and generator along with a propulsion system (derived from any electric motor), but also covers an end-to-end regional jet network including the ability to refuel and recharge.

Source: Zunum Aero

General characteristics (from Zunum Aero)

- Crew: 0 (unmanned), 1–2
- Capacity: 2,500 lb (1,134 kg) payload, 12 economy/9 premium/6 first
- Dimension: length 42 ft (13 m), wing: 52 ft (16 m), height: 18 ft (5.5 m)
- Empty weight: 8,200 lb (3,719 kg)
- MTOW (Max Take Off Weight): 11,500 lb (5,216 kg)
- Fuel capacity: 800 lb (363 kg), <2,300 lb (1,043 kg) batteries
- Powerplant: 1× Series hybrid, 1,300 hp (1,000 kW) , two ducted fans
- Powerplant: 1× turbogenerator, 670 hp (500 kW) range extender

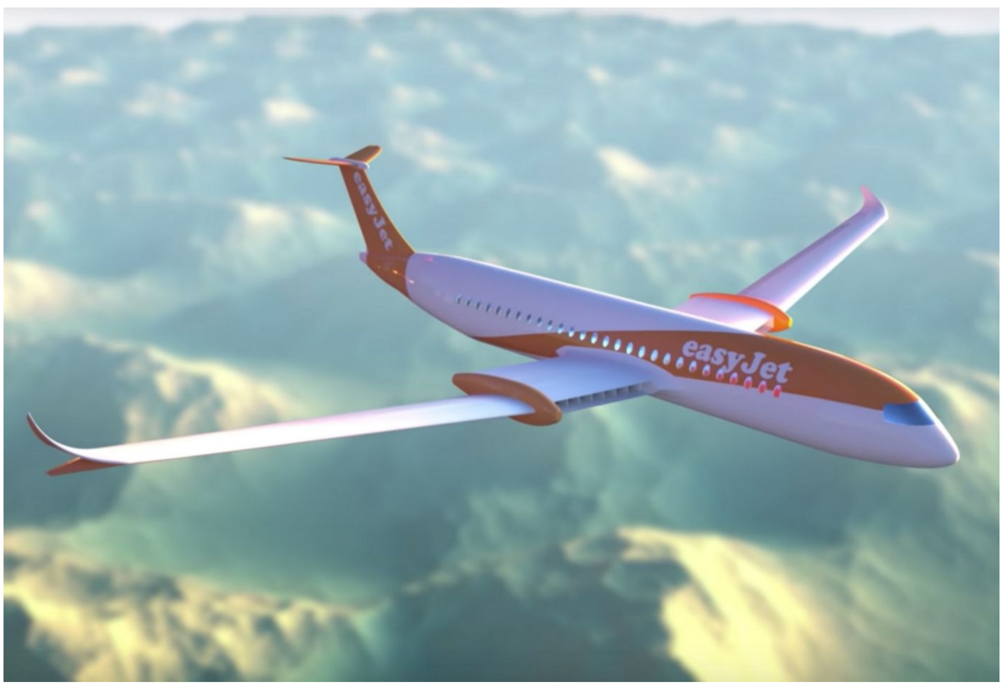
Performance

- Max cruise speed: 340 mph (547 km/h; 295 kn)
- Stall speed: 84 mph (135 km/h; 73 kn)
- Max range: 700 mi (608 nmi; 1,127 km)
- Max altitude: 25,000 ft (7,600 m)
- Time to altitude: 18 min to FL250 (25,000 ft above mean sea level)
- Fuel consumption: 0 to 0.0955 lb/mi (0.0000 to 0.0269 kg/km), per seat
- Takeoff run: 2,200 ft (671 m), landing: 2,500 ft (762 m)

Lastly, I think it is very interesting that ZA's development methodology to develop the aircraft will be that of software development. As someone with both a software and hardware product management background, this intrigues me, even if this methodology is applied to just developing it's propulsion system. A paper details using software development on India's first civilian aircraft NAL Saras (14-seater small jet) developed by National Aerospace Laboratories. One of the details the paper pointed out is the challenges in developing a new safety critical software (specifically the Stall Warning System) for civil aerospace application for the first time. One of the major challenges I see with developing aircraft software is the dependability requirements being so high with RTCA DO-178B (US) and EUROCAE ED-12B (EU) which require systems to be designed (and thoroughly tested) so that if any failure occurs preventing a safe continual flight, landing of the aircraft would be extremely improbable.

Wright Electric

Founded in 2016 by Jeffrey Engler (former Rock Health, HBS, various startups) and Doug Griswold (former Cirrus, Hawker Beechcraft, Cessna and General Dynamics). Wright Electric (WE) is a Los Angeles (somewhat) based aerospace startup with backing from Y Combinator and is estimated >10 employees. Like ZA, WE is building an all-electric passenger jet, but they are focusing on competing in the narrow body segment with no RJ or smaller aircrafts except prototypes to prove it's technology. WE currently have an announced partnership with EasyJet and is known to have been working with NASA to develop it's aircraft. However there are reports suggesting there is no formal agreement between WE and EasyJet yet.



Source: Wright Electric

Wright Electric stated they recently developed a 2-seater proof-of-concept that uses a 272 kg (600 lb) battery. WE is planning to scale up (but not develop battery in-house) with substantially lighter new battery chemistries that will enable 291 nmi (540 km) range within 5 years. WE plans to develop a 10-seater as a proof of concept and directly build a 120 passenger aircraft to be used as a short haul airliner with 50% lower noise and 10% lower costs.

WE's aircraft would suit easyJet's requirement since the ideal range is ~335 mi (540 km) and can accommodate up to 120 passengers (which the A319 carries 150). This version would theoretically cover 20% of seats flown by EasyJet currently. This aircraft can service routes such as Belfast to London, Bristol to Edinburgh, London to Amsterdam, Berlin to Vienna and Geneva to Paris.

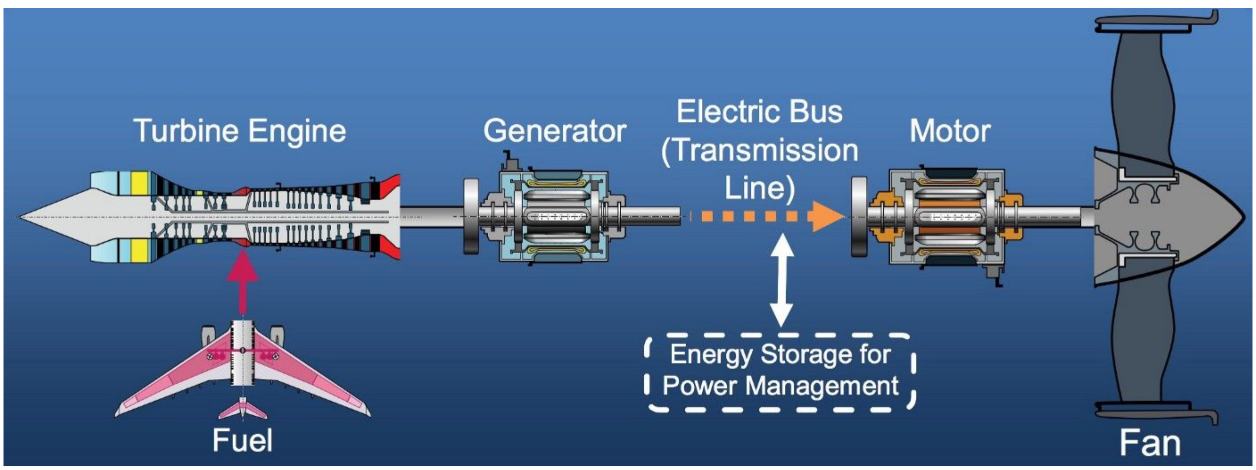
Source: TechCrunch (shows Engler presenting the ECO-150 during YC demo day)

Source: https://www1.grc.nasa.gov/aeronautics/hep/airplane-concepts

It also appears that the WE aircraft seems to be a successor to an earlier project known as ECO-150 which is being (or was being) developed by ESAero through NASA Armstrong Phase 1/2/3 SBIR (worth up to $8M) for SCEPTOR (Scalable Convergent Electric Propulsion Technology Operations Research). The ECO-150 also appears to be a derivative of several other NASA programs which are Distributed Electric Propulsion (DEP), Subsonic Fixed Wing (SFW) and Advanced Air Transport Technology (AATT). It may also be that ESAero merged or was acquired by WE.

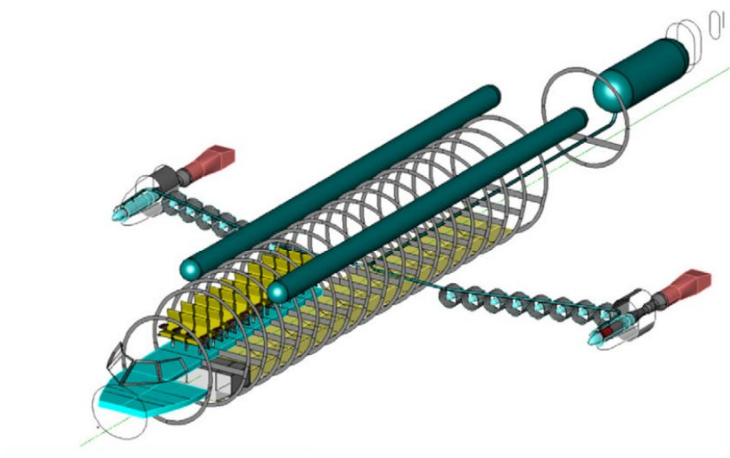
> "Unlike jet engines, the efficiency of electric motors doesn't benefit from size, so instead of two or more large engines under the wings you can have many smaller motors distributed along the fuselage."
> "This would lead not only to quieter, cleaner aircraft, but also ones that look radically different to those in the air today."
> — Jeff Engler to CNN

The original concept N3-X uses a HBWB (hybrid blended wing body) and distributes 10 electric fans in a continuous line across the upper surface of the wing near the trailing-edge and ingests the boundary layer, while the gas turbine generators are mounted near the wing tips. This particular concept uses a turboelectric distributed propulsion (TeDP) system.

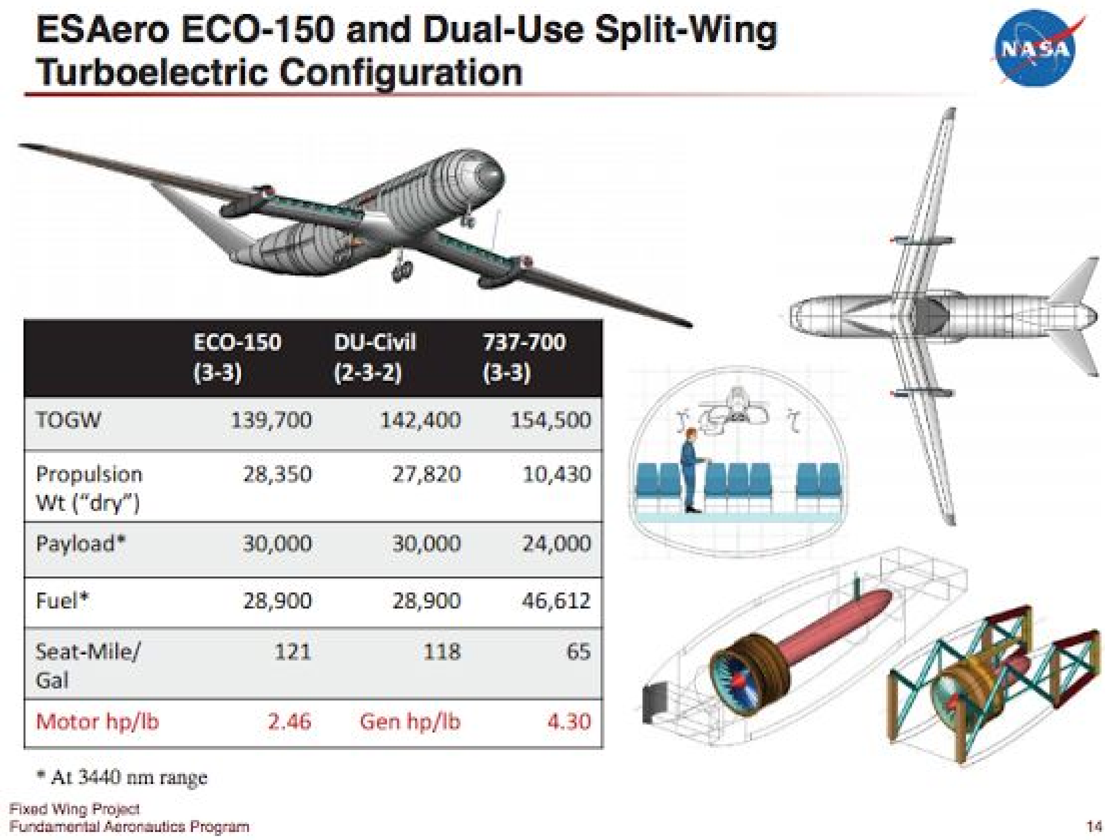


Source: NASA

However based on renderings by WE and from NASA, it looks like TeDP but is utilizing a split wing (on a conventional airliner design), with a sort of cryogenic electric propulsion system, using cooled liquid hydrogen to cool superconducting generators. It appears that the turbogenerators are located midpoint of the wings as opposed to the wing tip. Some of the earlier renderings show joined wing designs but both earlier and current renderings wings are both high aspect ratio, most likely for the efficient aerodynamic properties as well as less induced drag.



Source: https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20100036222.pdf



Source: NASA

Impossible Aerospace

Founded in 2016 by Spencer Gore who previously worked at Tesla as a battery module design engineer, where he focused on the module design and analysis for Model S/X P100D and Model 3. Not much information is known about Impossible Aerospace (IA) nor have they said anything publicly other than that they are looking to build an all-electric aircraft and is competing with ZA and WE. As of 2017 IA has raised a USD $1.8M seed from Eclipse Ventures with additional funding from WTI (Western Technology Investment) recently (in 2018). Unlike ZA and WE, the team is comprised of mainly junior engineers (1–3 years experience) but with very strong engineering backgrounds. IA is currently 8-9 employees with the majority of the employees being former SpaceX and Tesla engineers which will be crucial. It also appears that IA's strength is in battery since a lot of their current focus is power. It's likely that IA may struggle to land partnerships with an established airliner (major or low-cost) and therefore lag behind ZA and WE, which already have customers. The other hypothesis is that IA may become suppliers of the core battery technology to both ZA and WE.

It is also interesting they are focusing on productizing their "core technology" and developing an NLOS (non-line of sight) UAV (for commercial or government applications) as opposed to building an actual aircraft. It also appears that IA is using some sort of propeller as it’s propulsion source vs. a ducted fan (ZA) or distributed propulsion (WE). Because IA is the only one developing a UAV out of the 3 mentioned, it may be possible that IA may end up building a UAV/UAS systems that could rival RQ-1/MQ-1 Predator, MQ-9 Reaper/Predator B and the RQ-4 Global Hawk (all which have endurance over 12 hr), becoming solely “a low cost” NLOS UAV company instead.

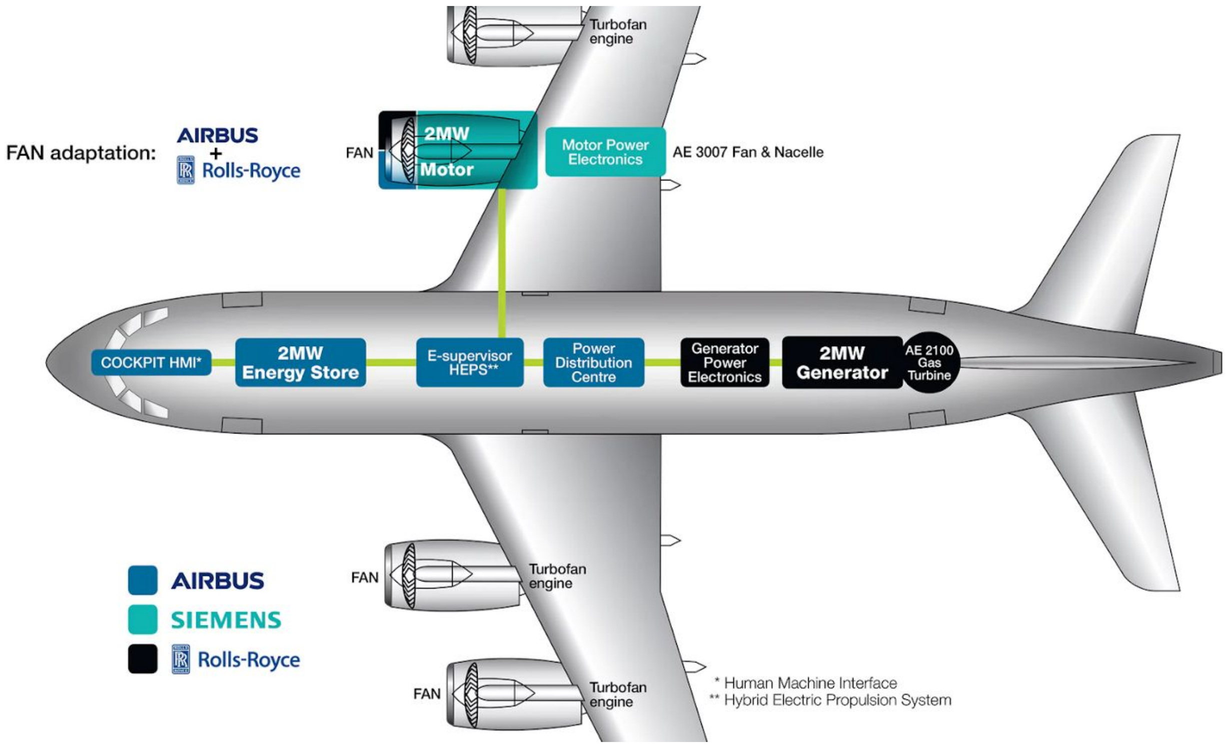
Airbus/Rolls-Royce/Siemens

Airbus with Rolls-Royce plc and Siemens (through a joint venture) announced E-Fan X in 2017 which is a hybrid-electric fan powered aircraft aimed for service in 2030. The program is the direct successor to the previous E-Fan program which originally developed a dual ducted fan powered two-seater (E-Fan 2.0) for use as a trainer, and a four-seater (E-Fan 4.0) touring aircraft which was canceled in 2017.

The E-Fan X uses the BAe 146 as a testbed/platform, where 1 out 4 Lycoming ALF 502 turbofan engines are replaced with a Citation X/ERJ-145 AE3007 nacelle (housing separate from the fuselage that holds the engines) modified with an electric motor/inverter capable of producing roughly the same thrust as the ALF 502. The exact breakup of the joint venture is that Airbus will be building the control architecture and integrate the systems. Rolls-Royce will adapt the Siemens motor and the fan into an AE3007 nacelle and integrate turboshaft, generator and power electronics. Siemens will develop the electric motor and power electronic control unit, inverter, DC/DC converter and power distribution. It appears that Siemens and Airbus also developed an electric acrobat prop 2-seater known as the Extra 330LE.

Source: Airbus

The E-Fan X will carry an onboard 2 t (4,400 lb)/2 MW (2,700 hp) battery in the cargo holds. It is also interesting to note the max payload for the 146 is 14660.74 lb, this might not be a problem as battery technology advances. Based on testing, Airbus plans to replace the second turbofan, bring it to 2 out of 4 being electric. However it is hypothesized that the performance of high-power propulsion systems will most likely be challenged by thermal effects, electric thrust management, altitude and dynamic effects on electric systems and electromagnetic compatibility issues where traditional jet powered aircrafts can endure.



E Fan-X Serial Architecture (Source: Airbus)

The highlights of E-Fan X are:

- Airbus, Rolls-Royce and Siemens will work together to develop a hybrid-electric engine and it's components where up to 2 of the engines will be electric and the other 2 being jet engine.
- The program aims to have a fully functional prototype in the air (certified) within 3–5 years.
- The ultimate goal is to enable a hybrid-electric propulsion architecture for a single-aisle aircraft at the scale of the A320 family that has the range of around 20 MW for cruise and 40 MW of max power.

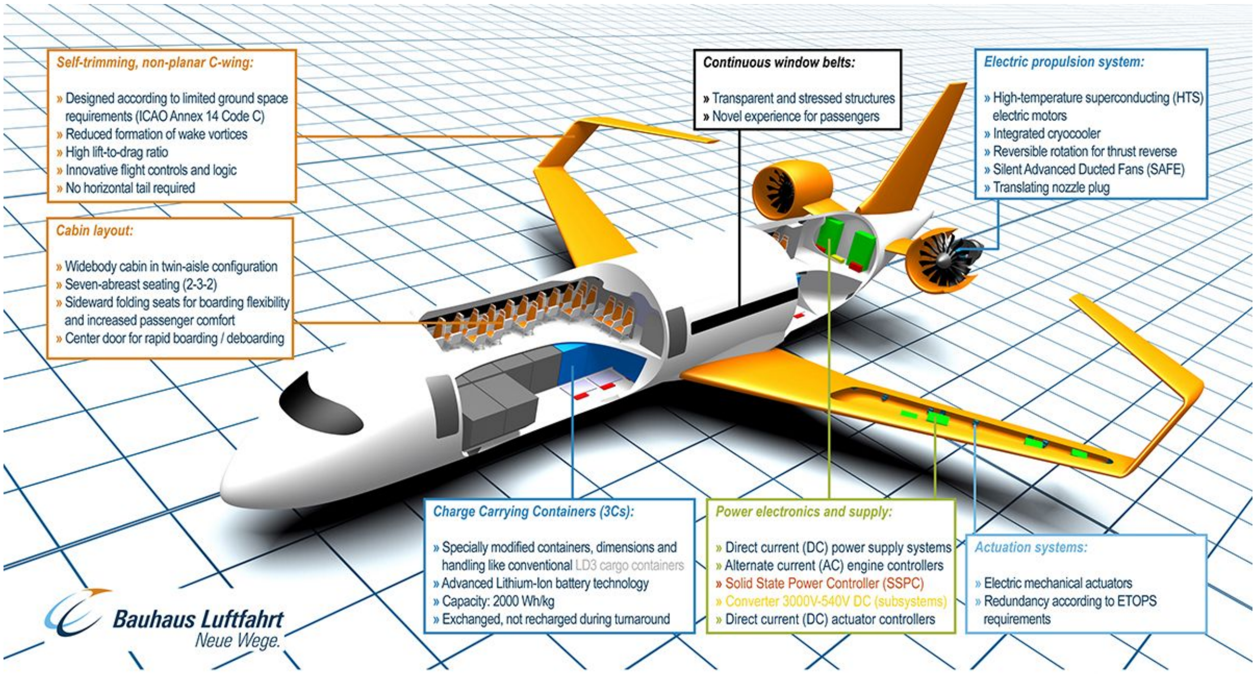
  "We are making very good progress. For smaller planes, we're in the last stages before going on the market."
  — Dr. Frank Anton (EVP and Head of Siemens AG eAircraft) to Handelsblatt

Bauhaus Luftfahrt

Though not a commercial endeavor, Bauhaus Luftfahrt (BL) is a joint research institution with Airbus Group, IABG (known for conducting structural tests on the A380 and A350), Liebherr Group (known for manufacturing earthmover, mining, cranes and aerospace and transportation systems), MTU Aero Engines (which develops, manufactures and provides service support for GE, Pratt & Whitney and Rolls-Royce) and the People's State of Bavaria.

Source: Bauhaus Luftfahrt

In 2012 BL announced a research program on an all-electric aircraft known as the Ce-Liner concept aimed at 2035 with capabilities of flying 189 passengers (in an all-economy class layout), 2 pilots and up to 5 flight crew. The propulsion system the concept uses is powered by two ducted fans driven by high-temperature superconducting electric motors fed through a universally electric systems architecture (UESA) which draws energy from "advanced" lithium-ion battery modules installed in cargo containers, known as Charge Carrying Containers (3C). The batteries would be "switched out" vs. recharged.



Source: Bauhaus Luftfahrt

BL believes that battery technology to support an aircraft (180–200-seats) flying 600 nmi (1,110 km) range would be achieved by 2030. Furthermore BL stated that the required energy density for the latter was estimated with 2,000 Watt-hours per kilogram, roughly 8–10x as much as state-of-the-art batteries achieve today. Beyond a research report released on 2013 it is unknown if the program was merged with Airbus's E-Fan X or if BL has partnered with other manufacturers to develop the aircraft, my best guess is that the research went over to Airbus since Airbus was a founding member of BL.

Final Thoughts

The long term hope is that we will have an all-electric narrow-bodies and wide-bodies in service with some of the major airlines, but realistically the first aircraft (within the next 2–5 years) will be either a 2 or 4-seater that will resemble piston/single engine aircraft such as the Cessna 172 or Piper Archer III to a small turboprop such as the Cessna Caravan and twin turboprop such Cessna SkyCourier. Already the first certified all-electric 2 seater, exists which is the Alpha Electro by Electro.Aero and Pipistrel which is powered by two lithium-ion batteries with a run time of 1 hour.

So all in all, it will be interesting who and what the first all-electric aircraft will be since developing the modern aircraft encompasses many disciplines (structures, aerodynamics, controls, systems, propulsion) with complex interdependencies and many variables (including high program costs) making it very difficult for a startup to solve and build.

Will the usual; Boeing, Airbus, Bombardier and Embraer create the first all-electric passenger aircraft? Will one or all the startups end up getting acquired? Will the first truly electric aircraft be a RJ where we might see them with United Express, Delta Connection (which are actually mainly SkyWest) or will they be narrow-bodies on United servicing a transcontinental flight from LAX to EWR or low cost carriers such as Southwest or JetBlue?

It's nothing short of a technological marvel to see the first passenger electric aircraft!