# eVTOL Design Short Course


## by Dr. James Wang

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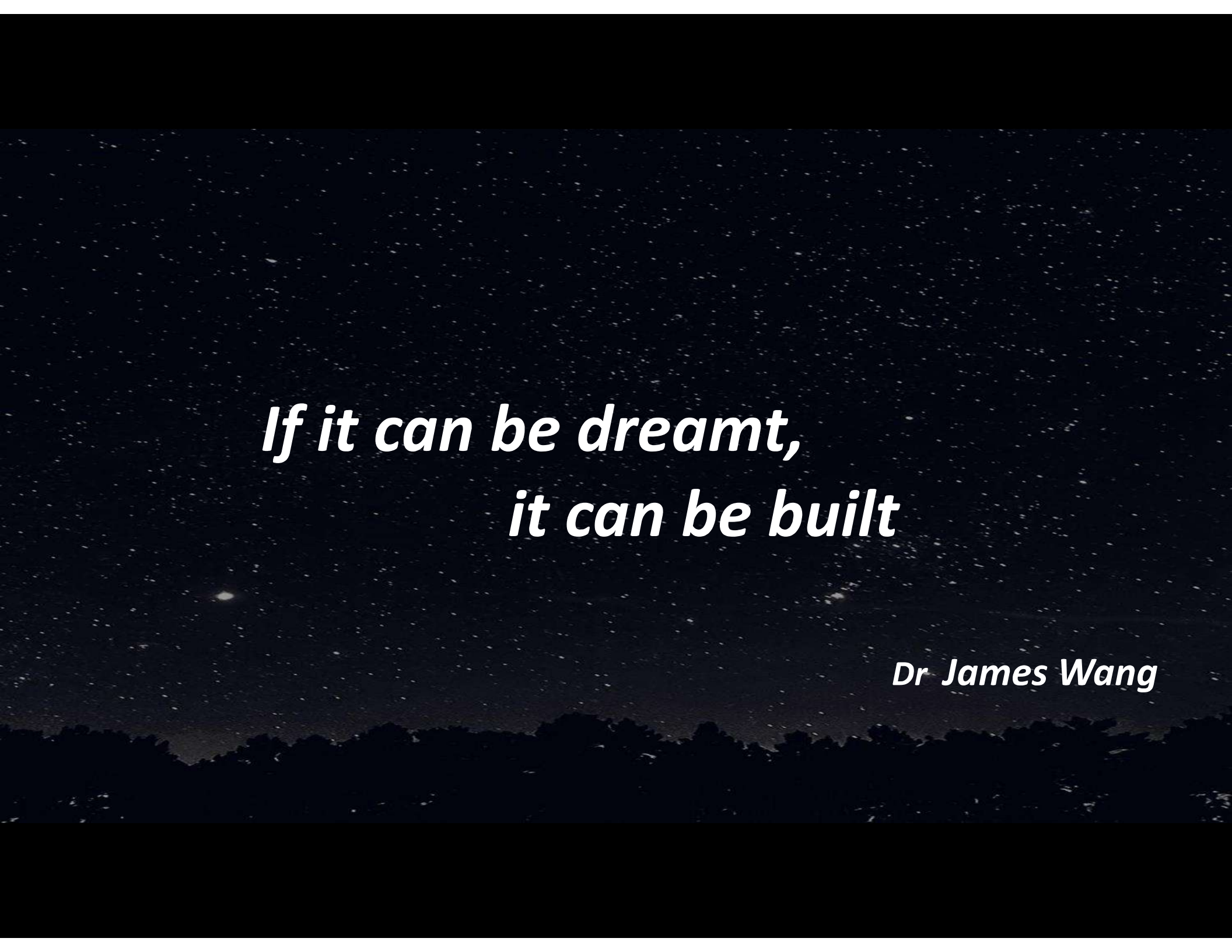
# Course Topics

1. Design Phases, Different eVTOLs
2. Battery and Energy Source
3. Electric Motors and Hybrids
4. Weight and Performance Estimation
5. Rotor Design, Stability & Control, Testing
6. Rotor and Vehicle Performance Analysis
7. Benchmarking and Cost Estimation
8. Certification and Vertiport Operation


If it can be dreamt,
it can be built
Dr James Wang

# Advance Air Mobility (AAM)

# NASA's Vision of AAM

- A safe, accessible, automated, and affordable air transportation system for passengers and cargo capable of serving previously hard-to-reach urban and rural locations

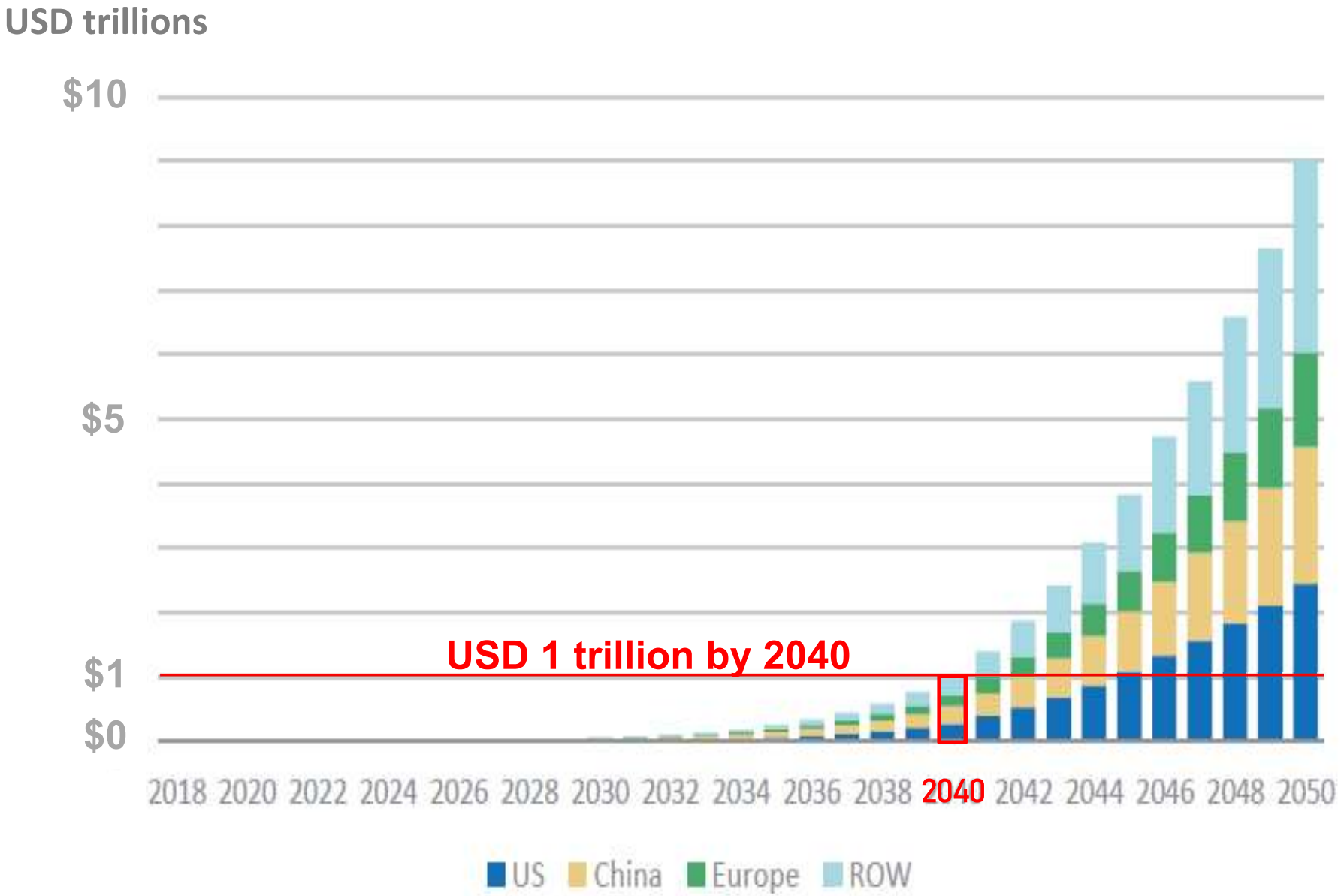
- by 2030 there will be as many as 500 million flights a year for package delivery services and 750 million flights a year for air metro services

- Larger air metro UAV's carry more passengers, but they fly between predetermined stops similar to how a bus or subway operates

- Urban Air Mobility (UAM) is a name given for flying in urban area

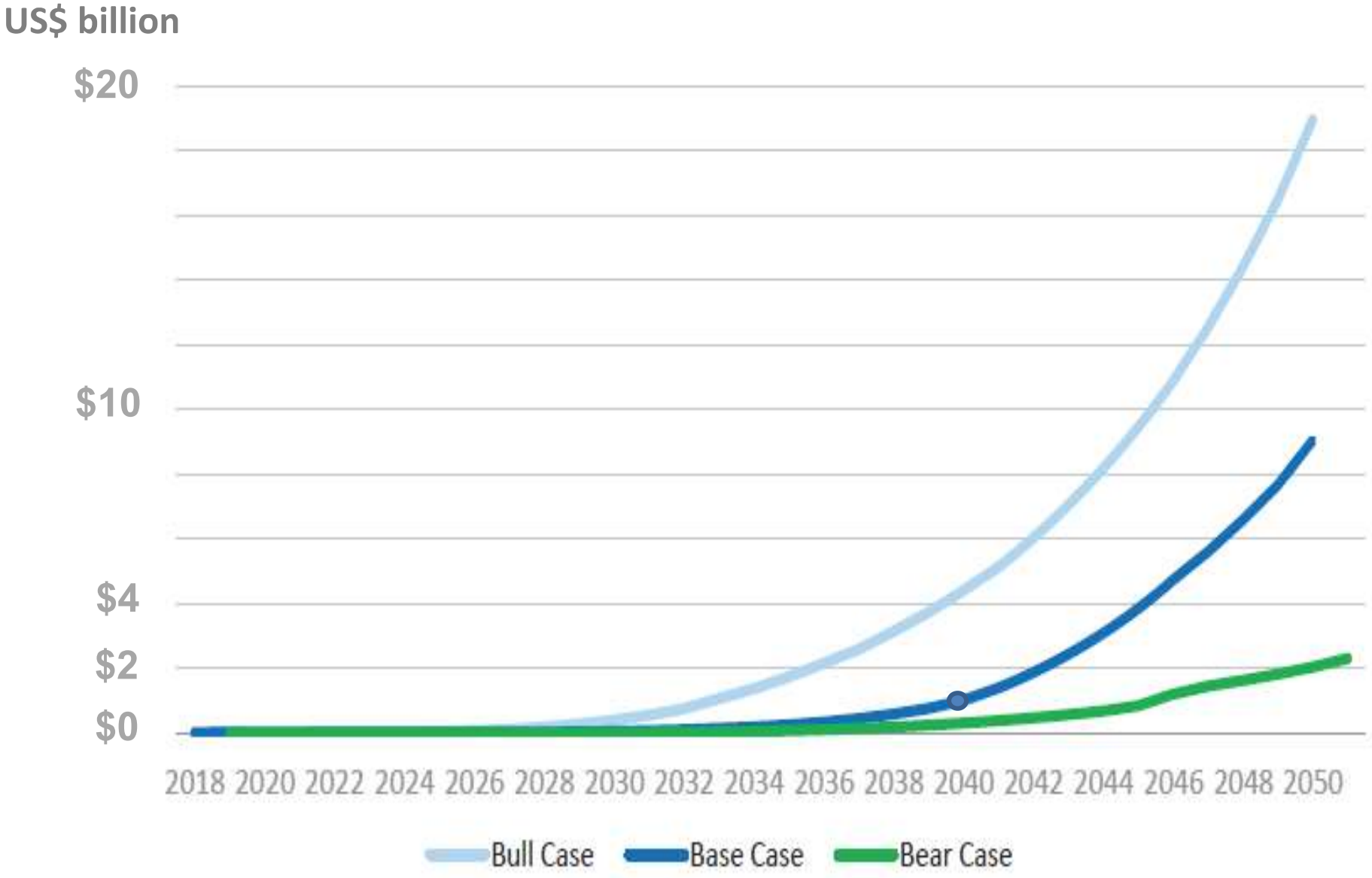
Source: https://www.nasa.gov/sites/default/files/atoms/files/what-is-aam-student-guide_0.pdf

# Predicted AAM Market Size (people and cargo)



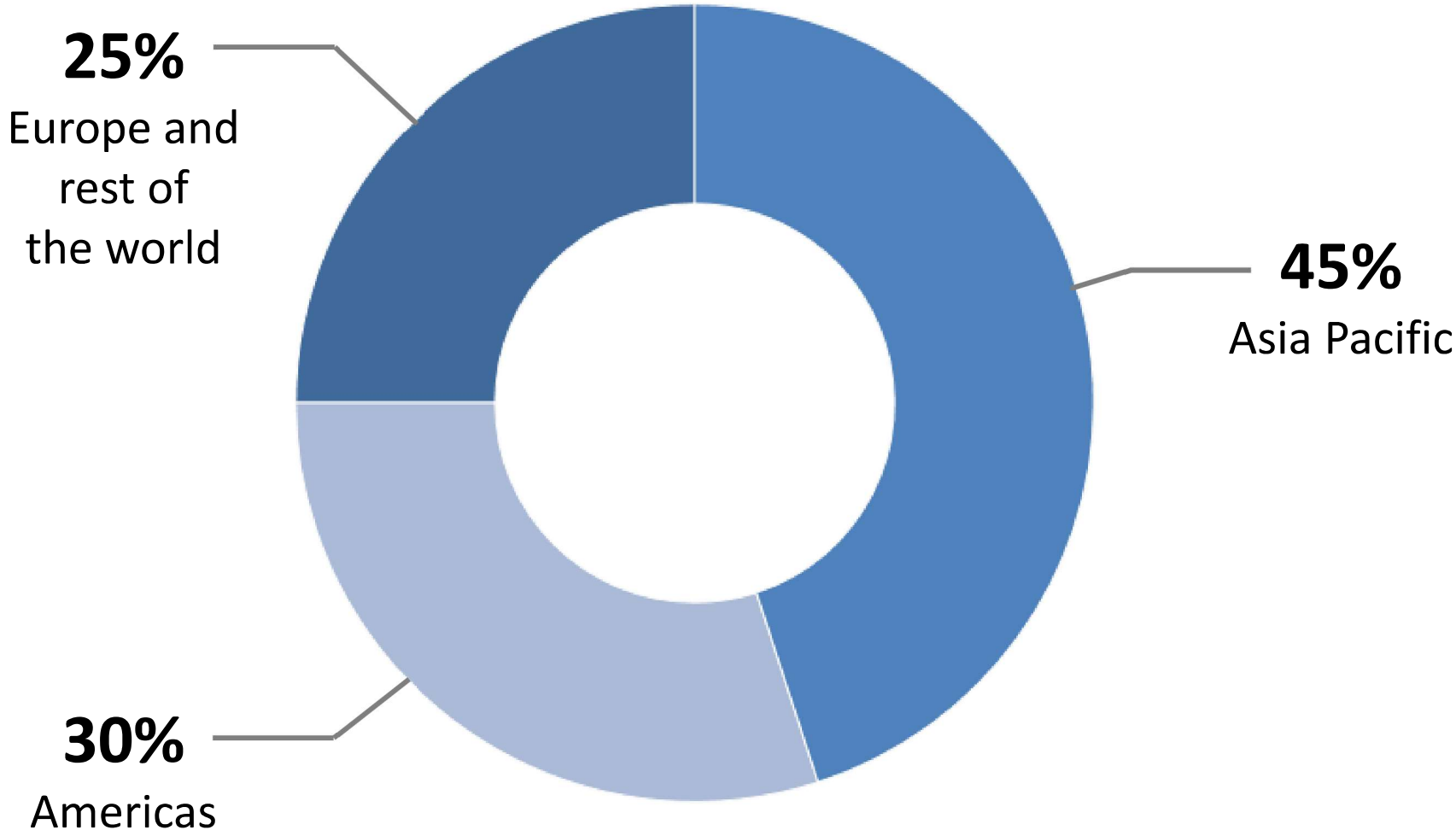

Source: Morgan Stanley Total Addressable Market Update 2021-05-06

# Predicted eVTOL Market Size (people and cargo)




Source: Morgan Stanley Total Addressable Market Update 2021-05-06

# Predicted eVTOL World Distribution 2035




Source: Porsche Consulting study

# Optimistic Global eVTOL Market Forecast

| | | |
|---|---|---|
| | 0 eVTOL | 0 trip/year |
| **2025** | | |
| | 10,000 eVTOL | 60 million trips/year |
| **2030** | | |
| | 200,000 eVTOL | 1 billion trips/year |
| **2040** | | |
| | 8,000,000 eVTOL | 45 billion trips/year |

Source: Boston Consulting Group 2018, Morgan Stanley 2018, Porsche Consulting 2018, UBS 2019, Lufthansahub 2021

# My Conservative Global eVTOL Market Forecast

| | | |
|---|---|---|
| **2025** | **0 eVTOL** | **0 trip/year** |
| | **500 eVTOL** | **1 million trips/year** |
| **2030** | **20,000 eVTOL** | **100 million trips/year** |
| **2040** | **2,000,000 eVTOL** | **10 billion trips/year** |

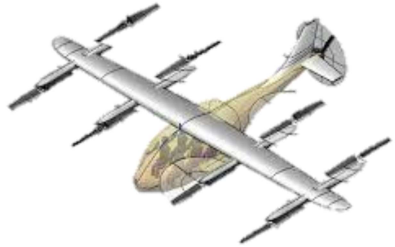
# eVTOL Is not Going to Replace All Helicopters

## Helicopters


Pros: proven, reliable, safe, certifiable long endurance, long range, trustworthy, large payload (as much as 50% of max gross weight

Cons: mechanically complex, more parts, expensive to maintain

## eVTOL aircraft



Pros: maybe quieter, fewer parts, lower cost of ownership, cool, hip, game-changing idea

Cons: unproven, can not autorotate if lost power, short endurance and short range because of battery, low payload capability

# 1. Design Phases for a New Aircraft Program
# Different types of eVTOL

by Dr. James Wang

SNUevtolclass@gmail.com

# Historically it Takes 7 to 9 years to Develop a New Aircraft

**Years for each task**

| | | | |
|---|---|---|---|
| 7-9 yrs | 1 | Conceptual design phase | |
| | 1 | Preliminary design phase | |
| | 2 | Detail design, wind tunnel test | <- Start marketing |
| | 1 | Make protoypes, fatique test | <- Start selling |
| | 3 | Ground vehicle test, flight test, certification, tooling prepare manual, training, etc | |
| | | Start delivery | |
| 40 yrs | | Average service life per aircraft. OEM will continuously improve the product during first 20 years and support the spares another 20 yrs | |

***Most eVTOL startups are trying to squeeze this into 5 to 6 years***

# Conceptual Design Phase

**Define business needs, mission, KPP**

**Trade studies, competitive analysis, sketches, brainstorm**

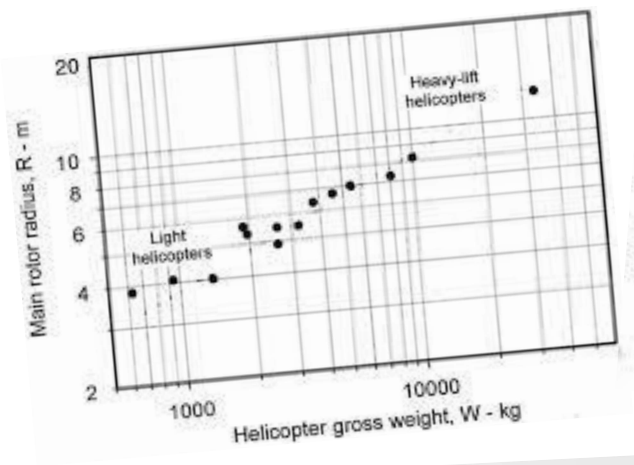
**Down-select to a couple concepts**

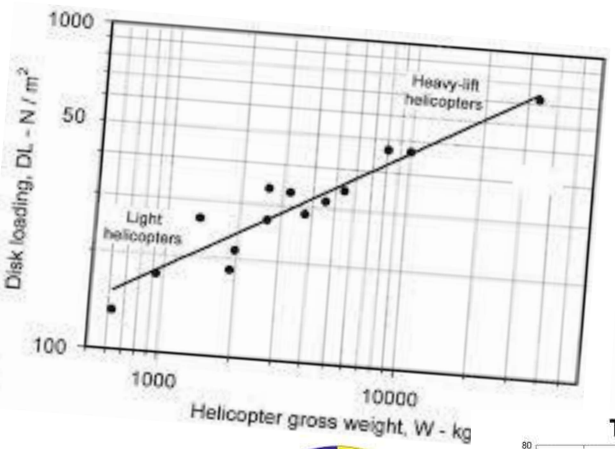
# Write Down Goals & KPP for Your Aircraft

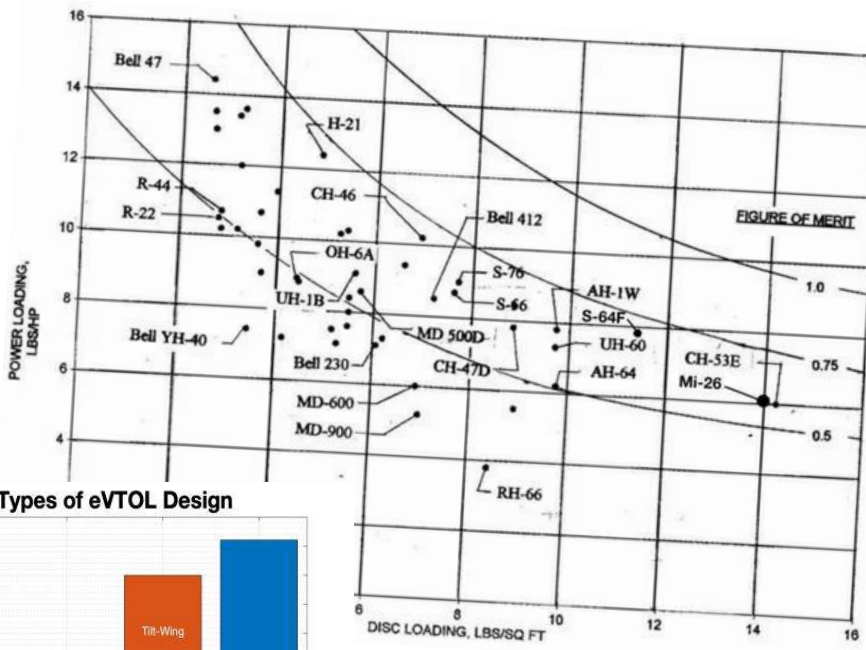
**(KPP = Key Performance Requirements)** Numbers for class examples only

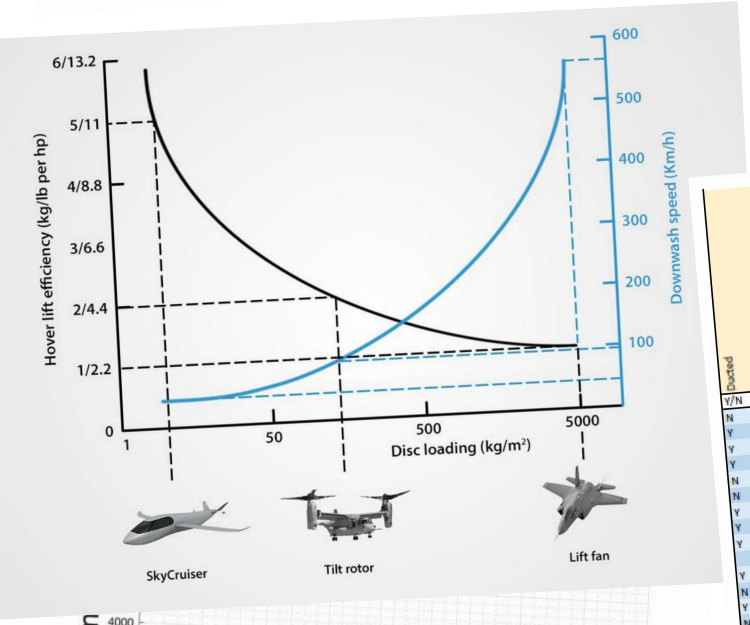
| | | |
|---|---|---|
| Maximum Never Exceed Speed (VNE) | 186 mph | 300 km/hr |
| Maximum Flight Speed (VH) | 149 mph | 240 km/hr |
| Best Range Cruise Speed (VBR) | ? mph | ? km/hr |
| Max ceiling | 8,840 ft | 3,000 m |
| Hover ceiling, in ground effect | ? ft | ? m |
| Hover ceiling, out of ground effect | ? ft | ? m |
| One motor inoperative service ceiling | ? ft | ? m |
| Range – Long range cruise at VBR at 4000 ft | | |
| With ? min reserve | ? miles | ? km |
| With no reserve | ? miles | ? km |
| Max takoff Gross weight | 7,000 lbs | 3,175 kg |
| Useful Load internal | 800 lbs | 363 kg |

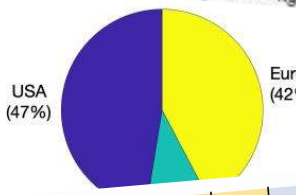
# Start with Trade Studies

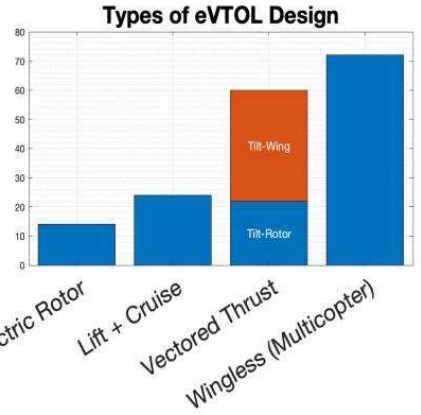


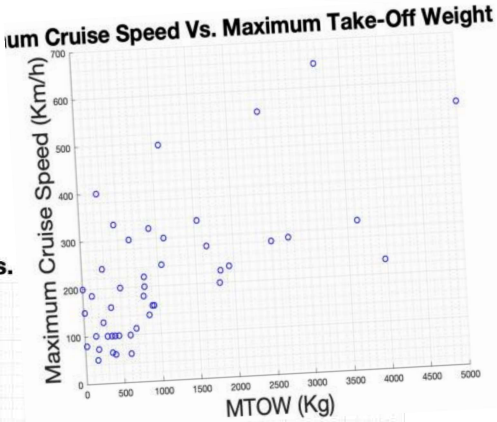



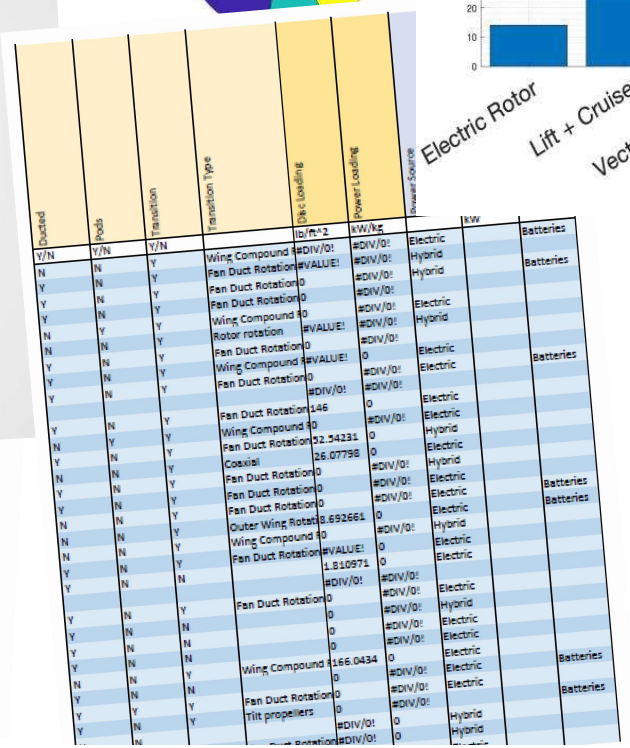



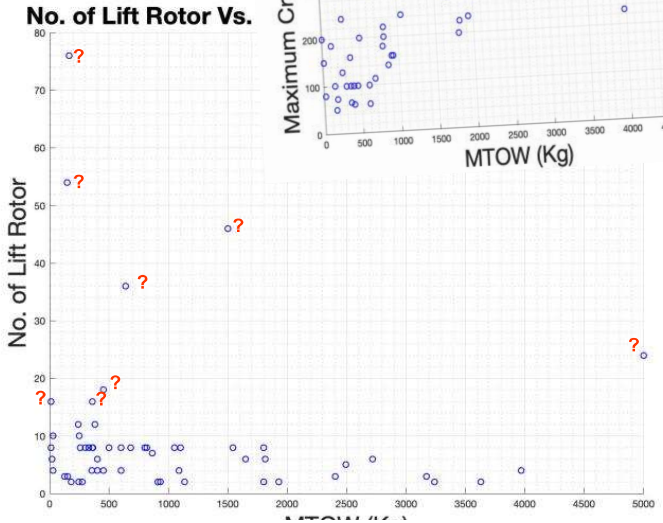



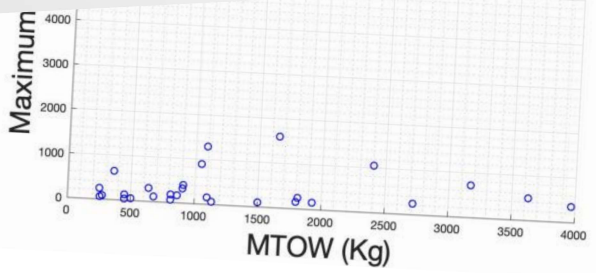



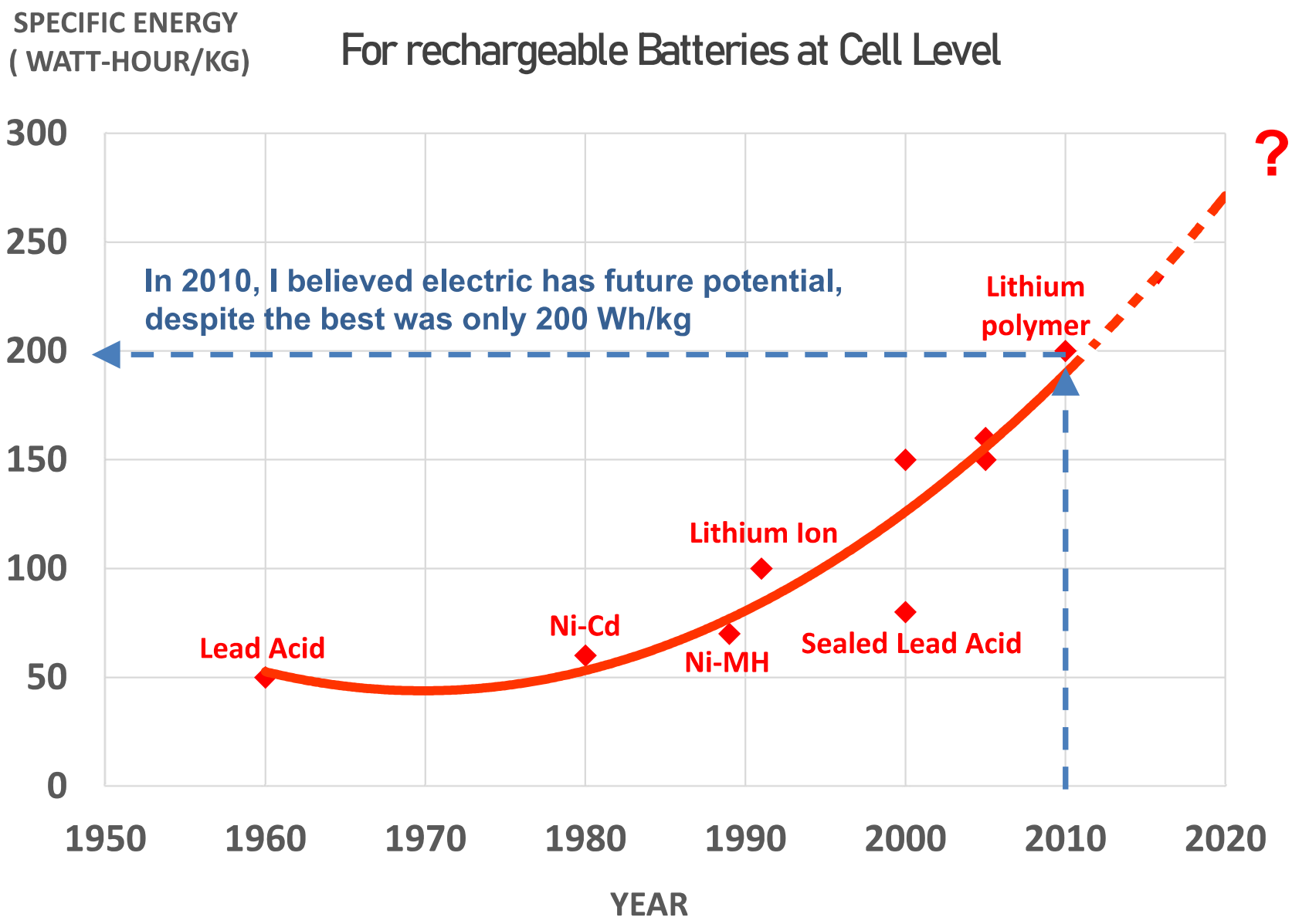



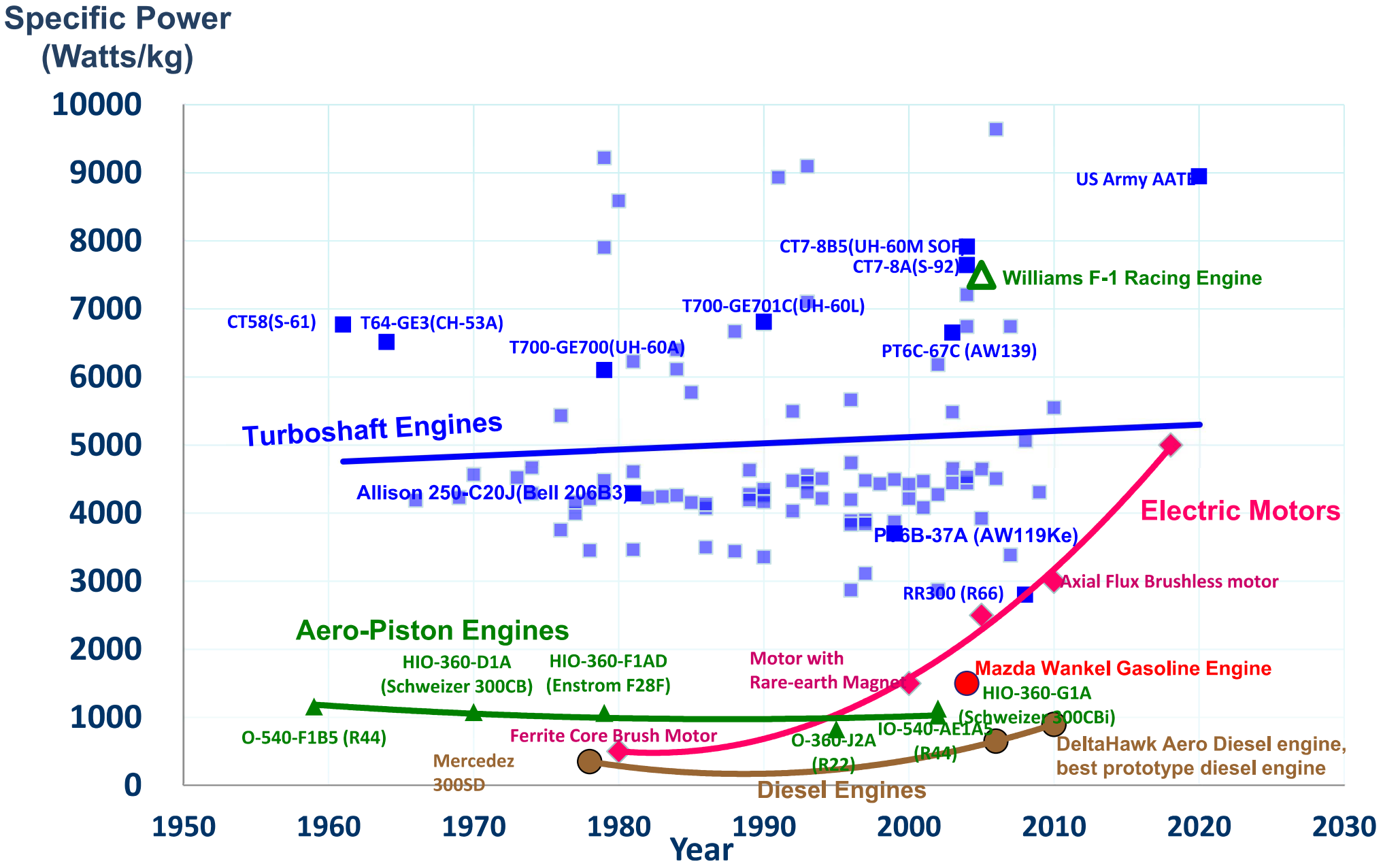



# Specific Energy Data up to 2010, then Extrapolate

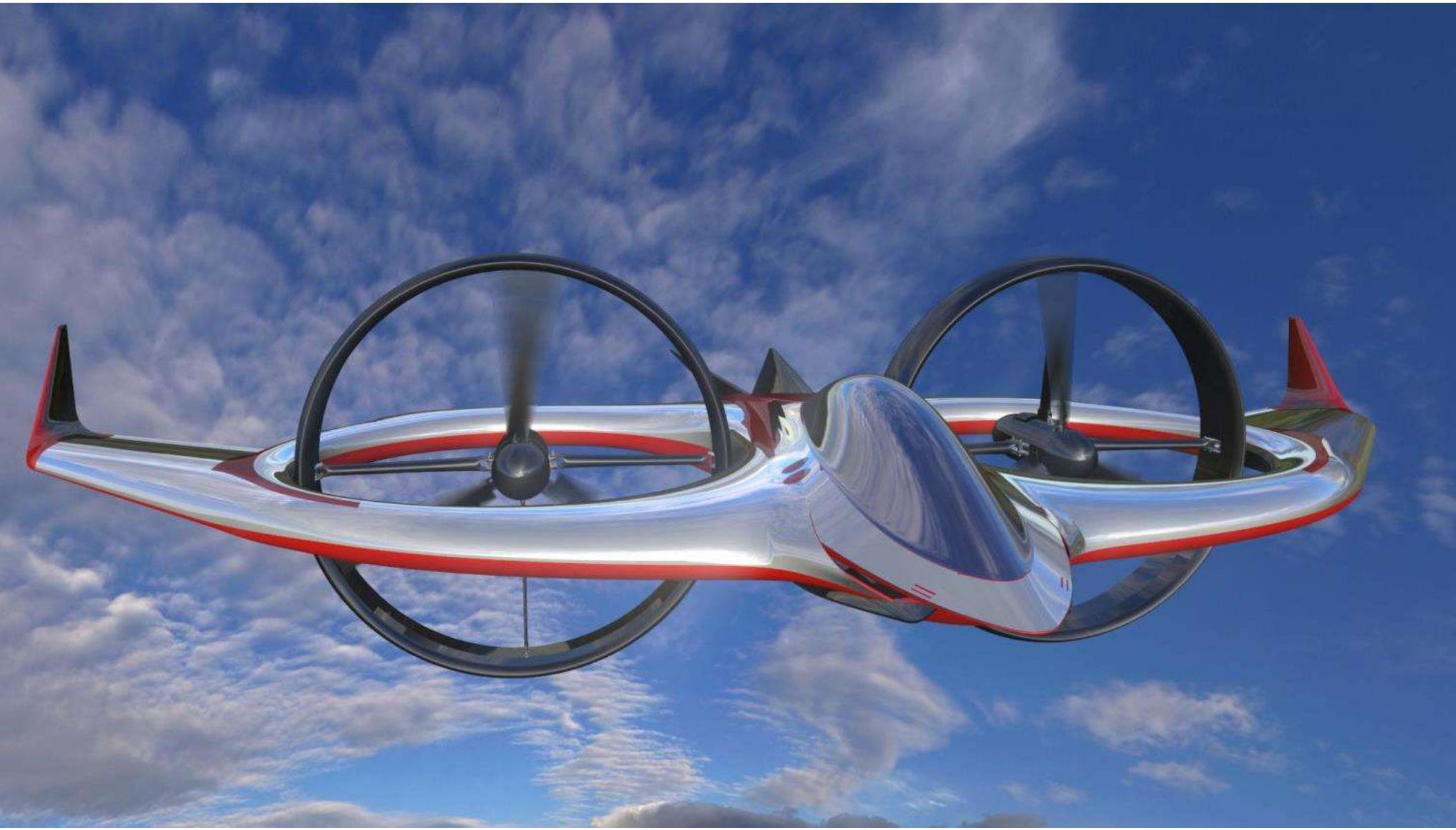


# Propulsion Specific Power Trend up to 2010




Note, 746 watts = 1 horsepower

# Conceptual Design Phase



Example Outcome: the AgustaWestland Project Zero Designed by Dr James Wang in 2010

# Afterward, conduct a CoDR (Conceptual Design Review)

# Preliminary Design Phase

**More detailed calculation**

**Small flying models, wind tunnel, software simulations**

**Talk to potential suppliers/partners, find investors**

**Down-select to one concept**

**Build a large scale demonstrator**

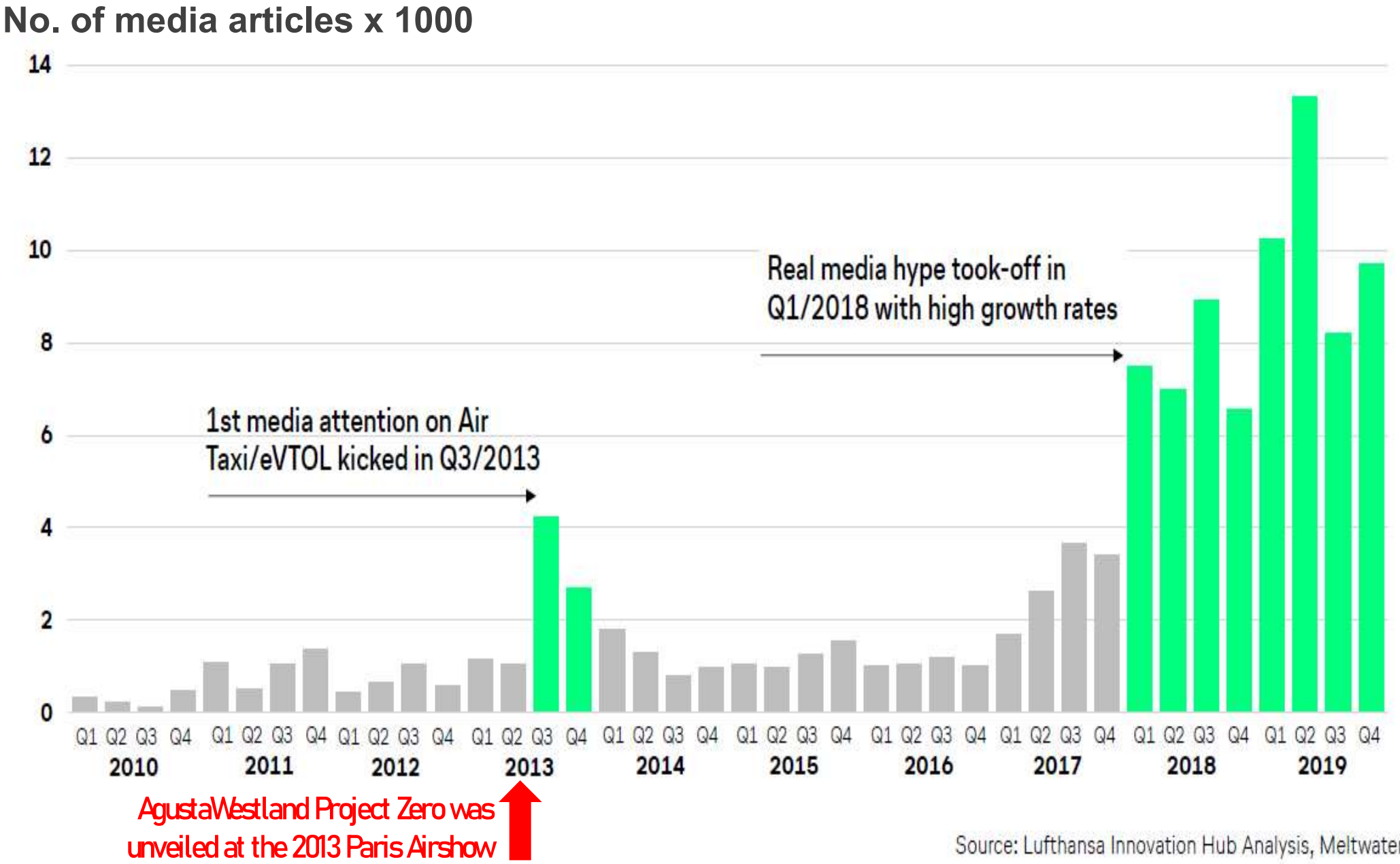

**Project Zero technology demonstrator in 2011**

# Afterward, conduct a PDR (Preliminary Design Review)

**Usually this is when come out of the stealth mode**


Project Zero unveiled at the 2013 Paris Airshow

# Number of Media Reports on eVTOL and UAM



# Airbus started eVTOL in 2015

# Bell started Nexus in 2018

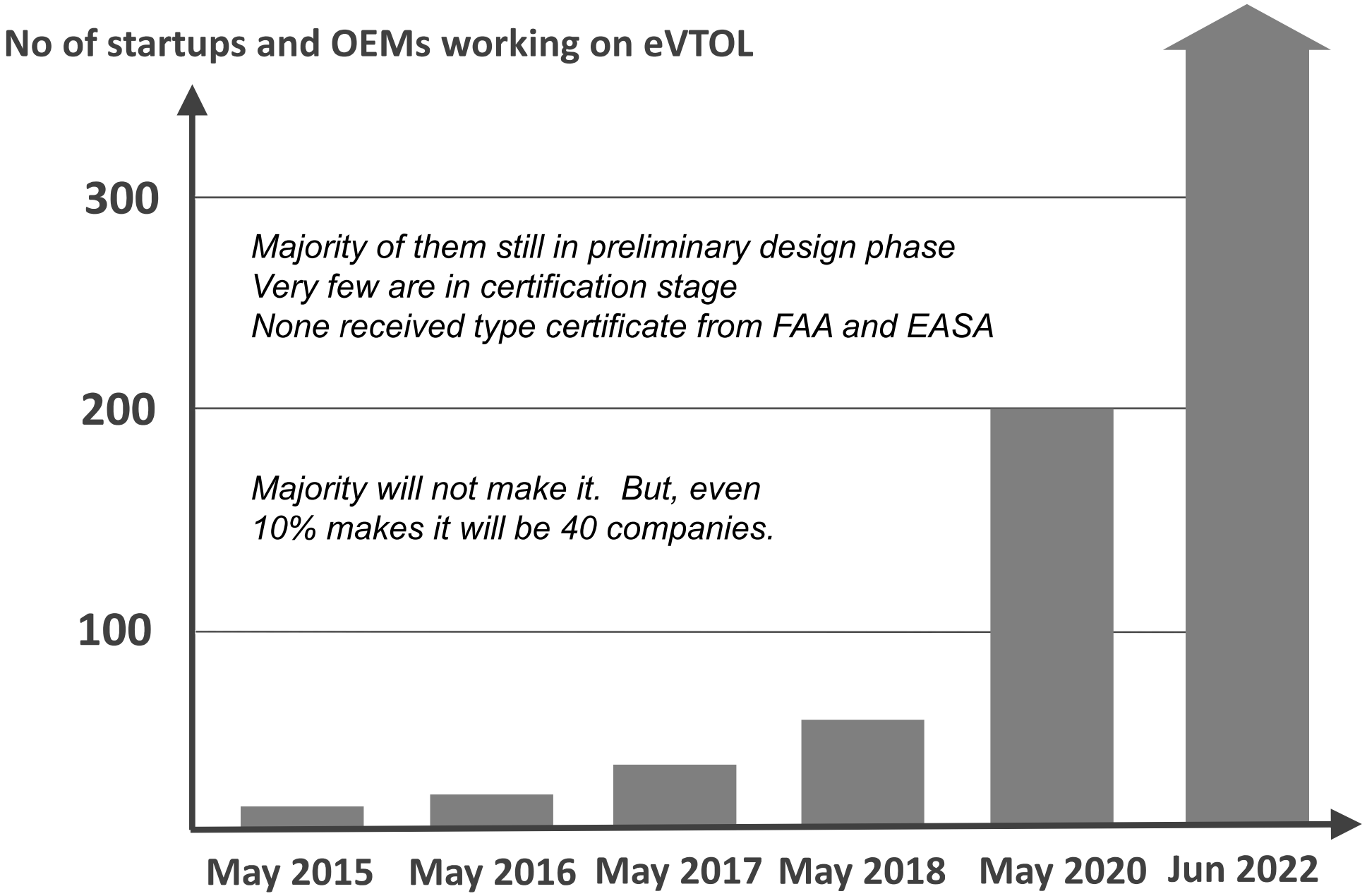
# Boeing Started PAV in 2018

2018, Purchased Aurora Flight Science

2019, Start collaborate with Google, Porsche.

Boeing just invested $450 million into Wisk

# Exponential Growth in eVTOL R&D



# Detail Design Phase

One aircraft concept remains

Do all the detailed calculations, analysis, designing

Generate all the detailed drawings for producing

Work with suppliers, engage certification authority

Conduct laboratory tests, more flight test of demonstrator

# Afterward, conduct a CDR (Critical Design Review)

# Prototype

Build 3 to 4 prototypes, each at few months apart

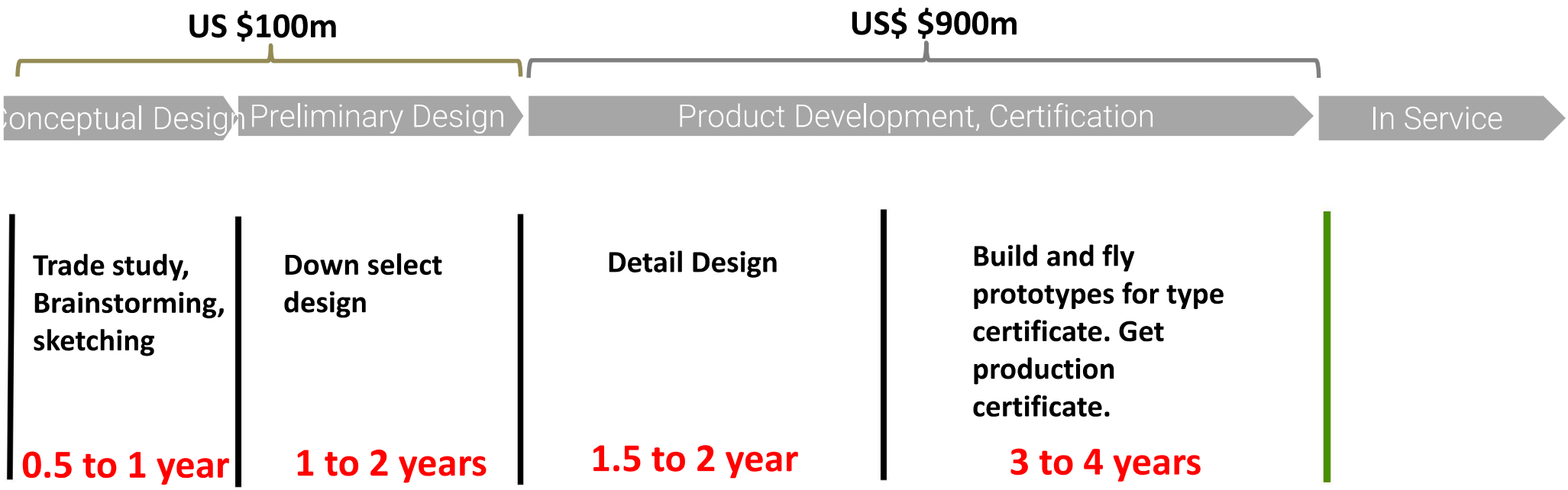
Conduct fatigue tests, whirl test, EMI test, software test, hardware in the loop test

Fly the prototype toward type certificate

Start tooling and plant build up, work toward production certificate

# FRR before flying the prototype (Flight Readiness Review)

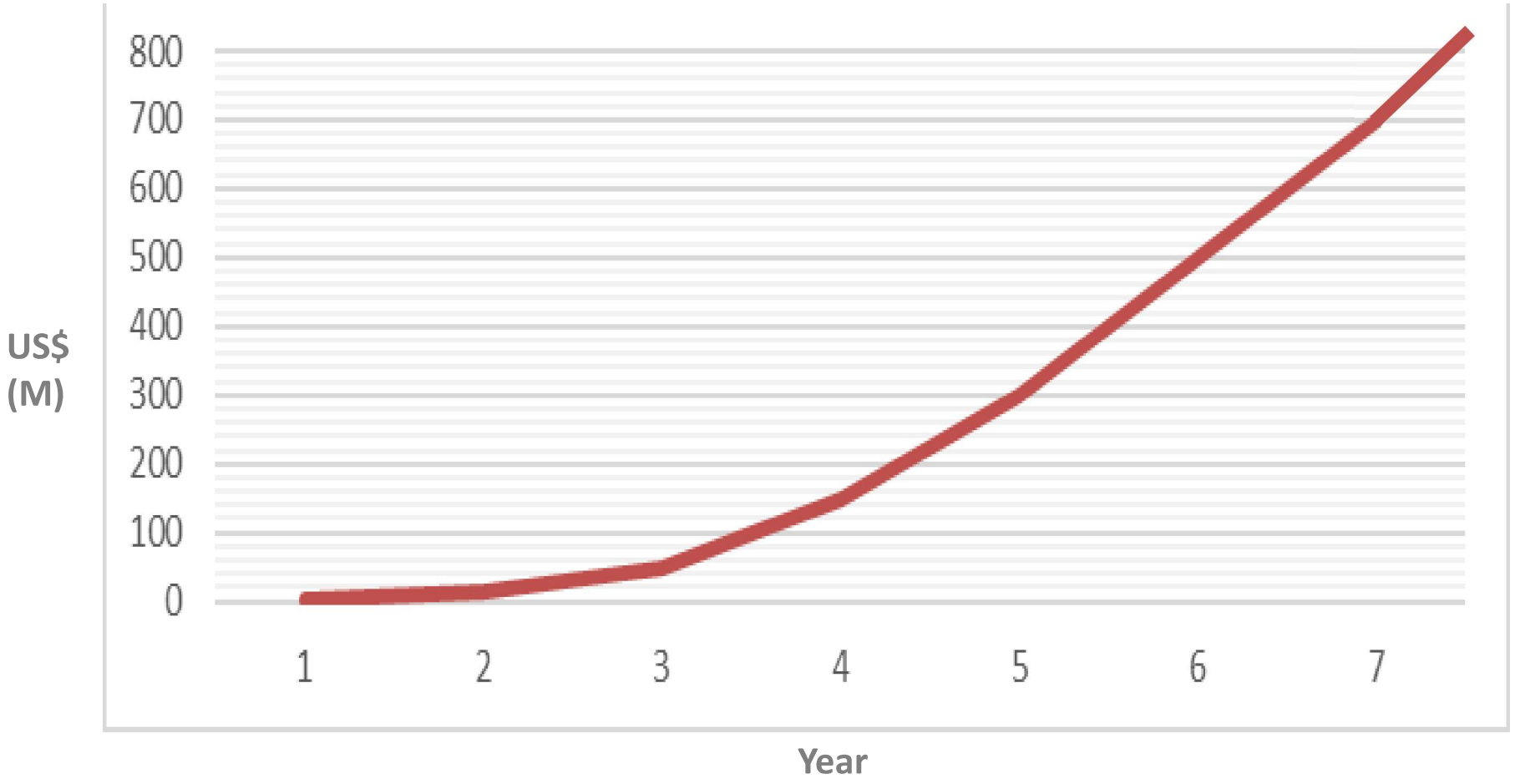
# eVTOL Schedule and Budget (average 7+ years)




Schedule by James Wang

# You have decided to start an eVTOL company or program

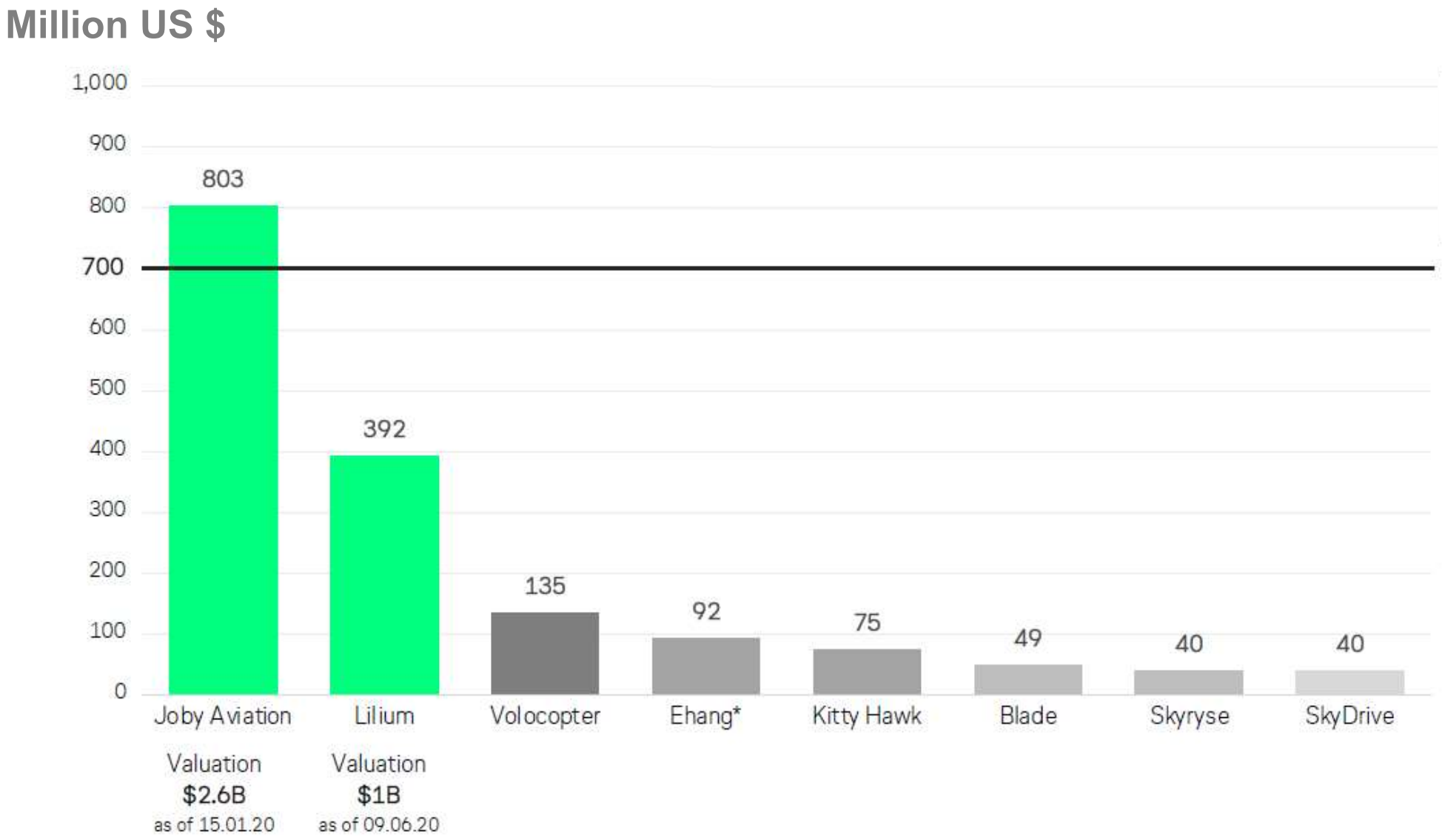
# Investment Required to Develop an eVTOL Aircraft




Note, US $ will be used through out this short course in order to compare to other international programs

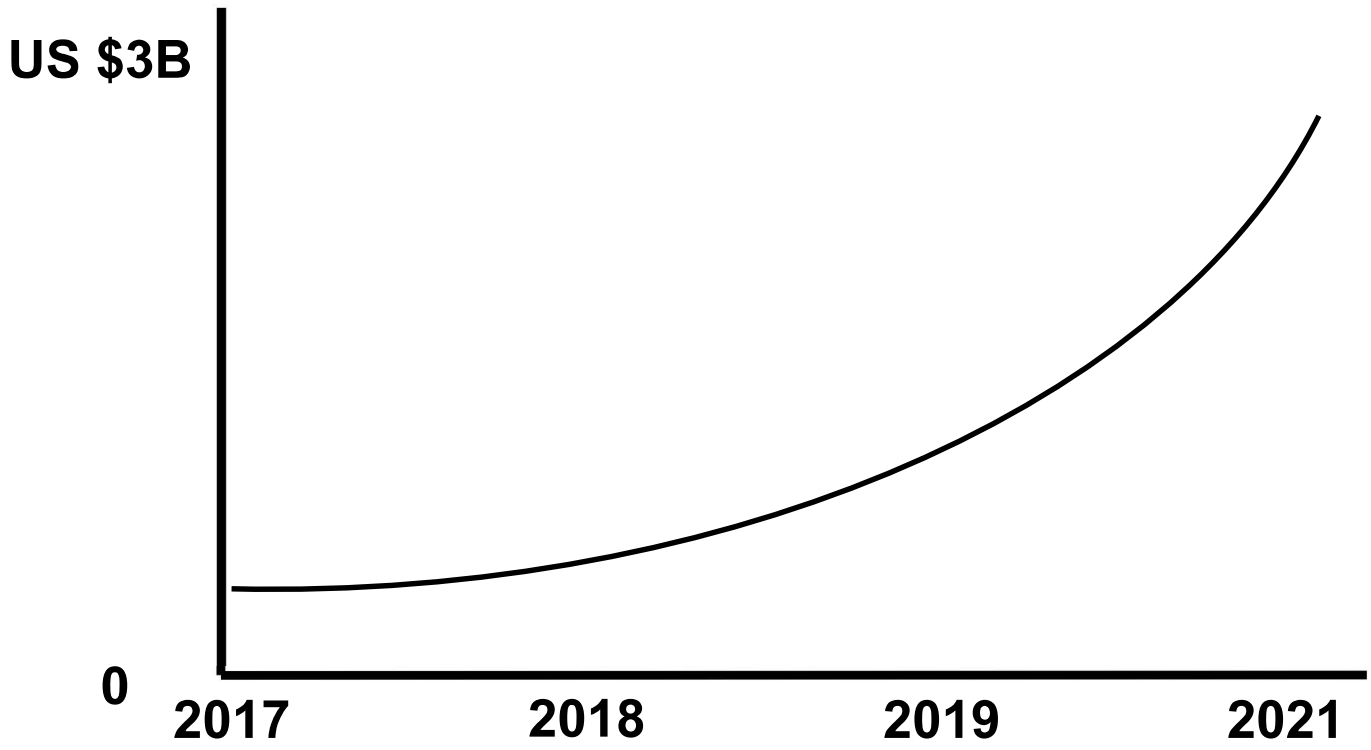
calculation by James Wang

# Need > US $1 billion from Soup to Nuts




Source: Lufthansa Hub Report 2021, numbers have gone up in 2022

# Amount of Investment Worldwide on eVTOL



# VC and Corporate Ventures Invest in eVTOL

These are funding and not valuation

| Start-ups | Funds | Investors |
|---|---|---|
| Joby | $1,800m | Toyota, Intel, JetBlue,… IPO Feb 2021 |
| Lillium | $930m | Tencent, Freigest, Obvious, Atomico, Baillie Gifford, Qell,… IPO Sept 2021 |
| Archer | $850m | Atlas Crest Investment,… IPO February 2021 |
| Beta technologies | $510m | UPS, Amazon, FedEx, Fidelity, United Therapeutic,.. |
| Eve | $500m | Embraer, Zanite, Azorra Aviation, BAE Systems,… |
| WISK | $480m | Google, Boeing, Porsche,… |
| Vertical Aerospace | $380m | RR, Am Airlines, Avolon, Honeywell,.. IPO Dec 2021 |
| Volocopter | $380m | Daimler, Geely, Intel, DB Shenker,… Mitsui Sumitomo, MS&AD, Translink, Blackrock,… |
| EHang | $130m | United Therapeutic, Lung Biotech,... IPO Dec 2019 |
| SkyDrive | $40m | Suzuki, DBJ, NEC, ENEOS, Itochu Corp, Obayashi, VeriServe, Sumitomo Mitsui Finance and Leasing,… |
| Overair | $25m+$145 | Hanwah Systems |

Note the numbers will change continuously

# Many Cross-Industry Collaborations

- Archer + Fiat Chrysler + United Airline +…
- Boeing + Kitty Hawk + Porsche +…
- Airbus + RR/Siemens + Audi +…
- Joby + Toyota + Intel Capital + Uber + Agility Prime + Garmin +…
- Vertical + RR + Honeywell + GKN+ Solvay + Bristow + Leonardo +…
- Lilium + Ferrovial + Honeywell + ABB + Lufthansa + Customcell + Toray + City of Orlando + Azul + Aciturri + …
- Volocopter + Mercedes + Geely + Intel +…
- EHang + United Therapeutic + Lung Biotechnology +…
- Supernal + Hyundai + Uber +…
- Beta Technologies + United Therapeutic + Agility Prime + UPS +…

Note, the data change continuously

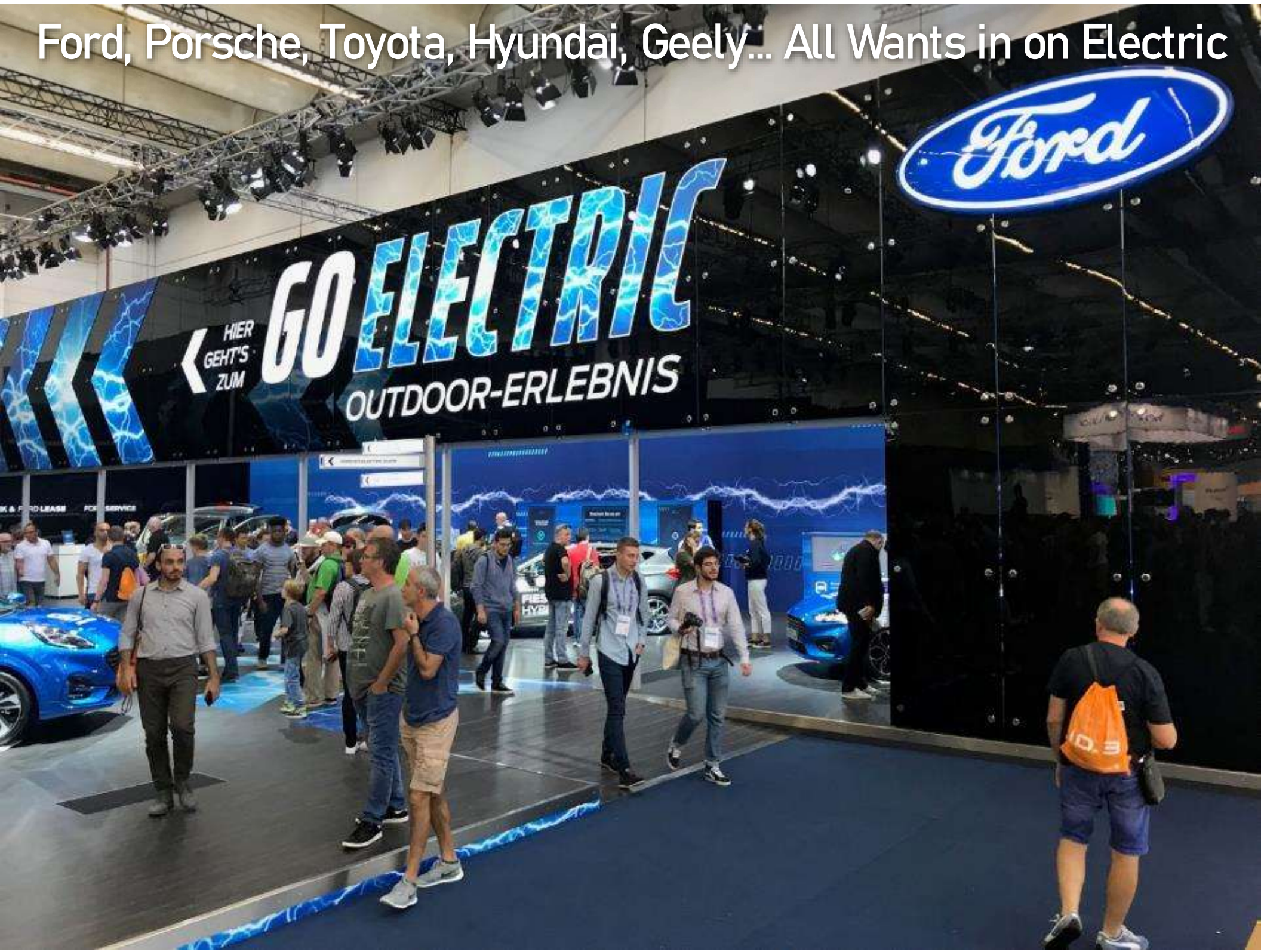
# Good Time to Start eVTOL

2019 Dyson wanted to invest US$4.3B, but Dyson cancelled because that is a drop in the ocean compared to the wealth of the automotive giants who are waking up to the epochal shift away from internal combustion engines.

Volkswagen alone has announced plans to invest US$50 billion in electrification as it targets production of at least two million electric vehicles a year by 2025.

Look at 2019 Frankfurt Autoshow, its all about Electric.

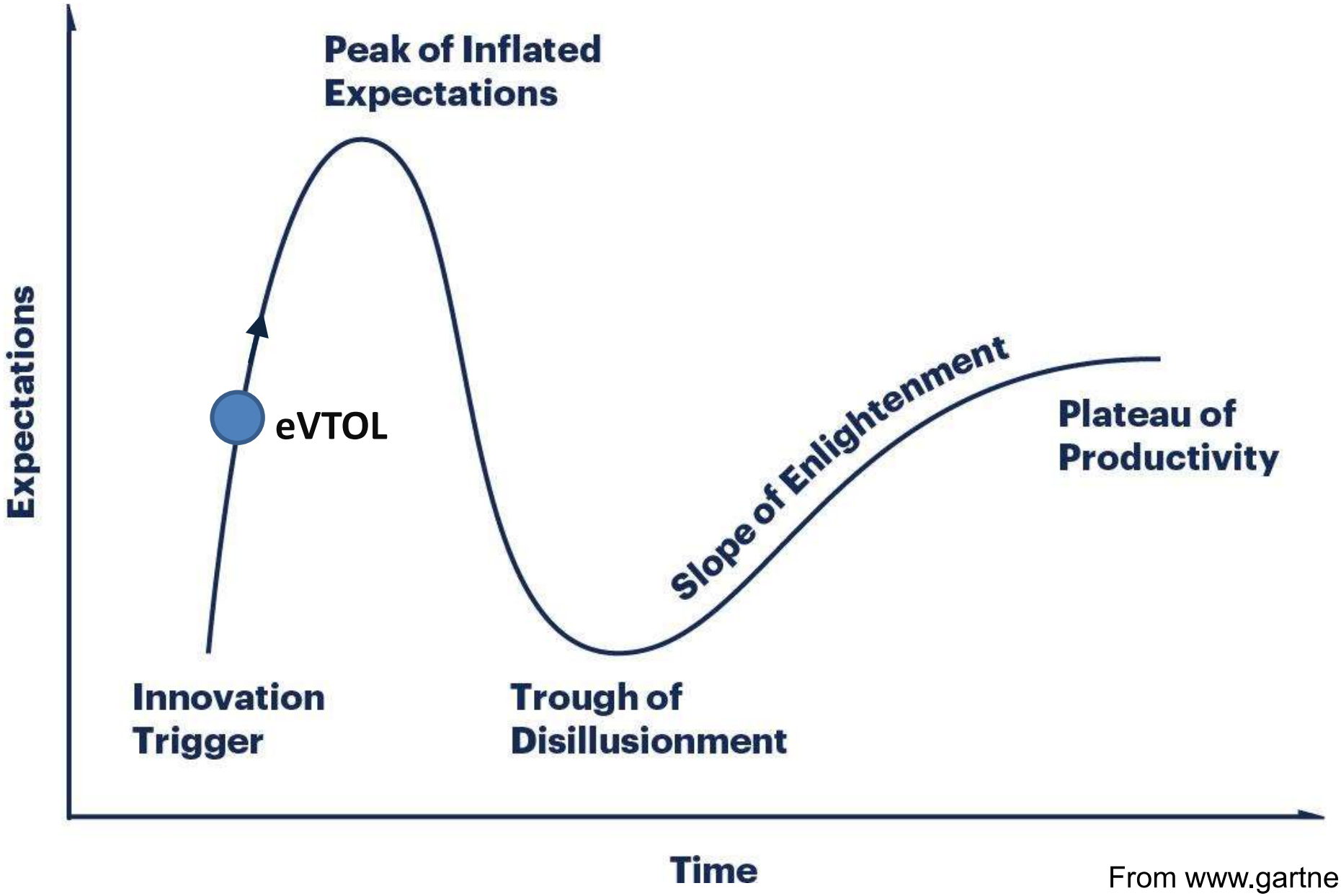
# Ford, Porsche, Toyota, Hyundai, Geely... All Wants in on Electric



# Old Fashion Manufacturing in Small Quantity

# Automatic Automotive Style Manufacturing

# Gartner's Hype Cycle




From www.gartner.com

# Requirements for Success

**Primary**

- Seed money (savings, or know rich friends)
- Leadership (Is that you?)
- Technical team (Hire the best experts, advisors)

**Secondary**

- Proprietary technologies, geography, partnerships, etc…

# Requirements to Continue the Program

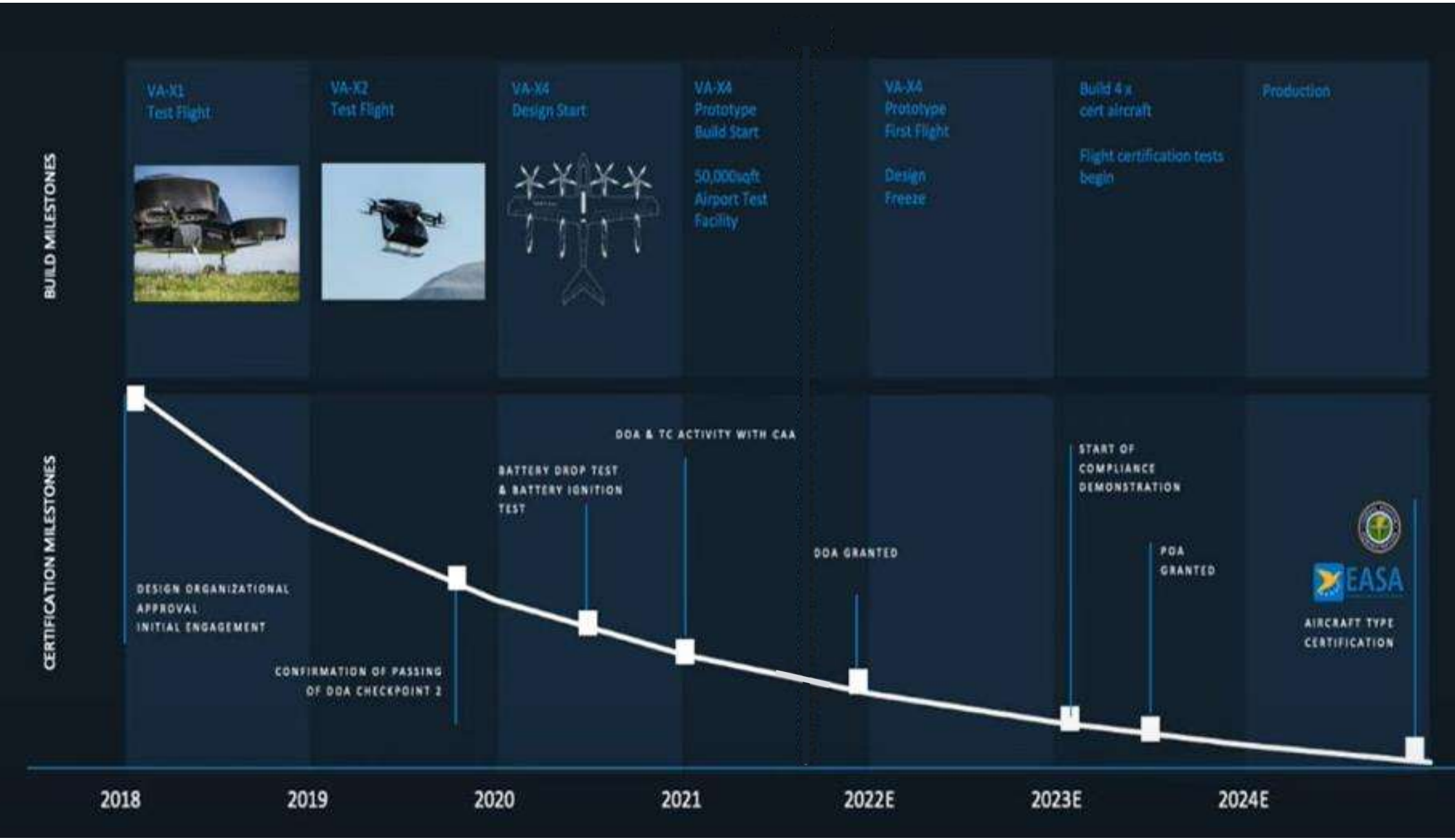
- *More funding*
- Testing and data for validation
- Grow certification expertise
- Grow manufacturing expertise

# You Will Need More $$$
# Investors will evaluate you on

- Leadership and technical team
- Your financial situation
- Design matureness
- Airworthiness/certification
- Business and industrial plan

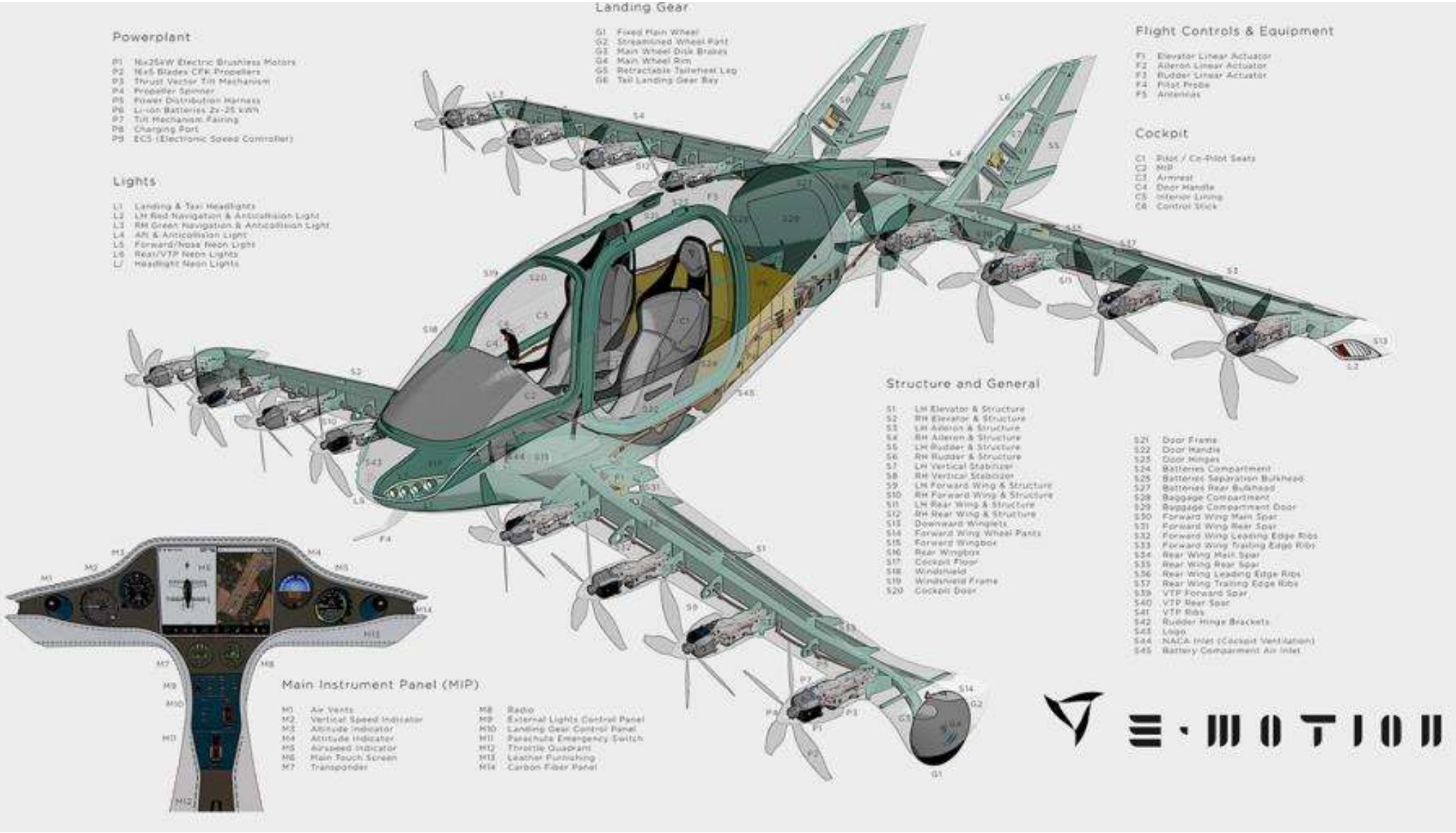
# It takes longer than expected

# Example of an Ambitious Schedule



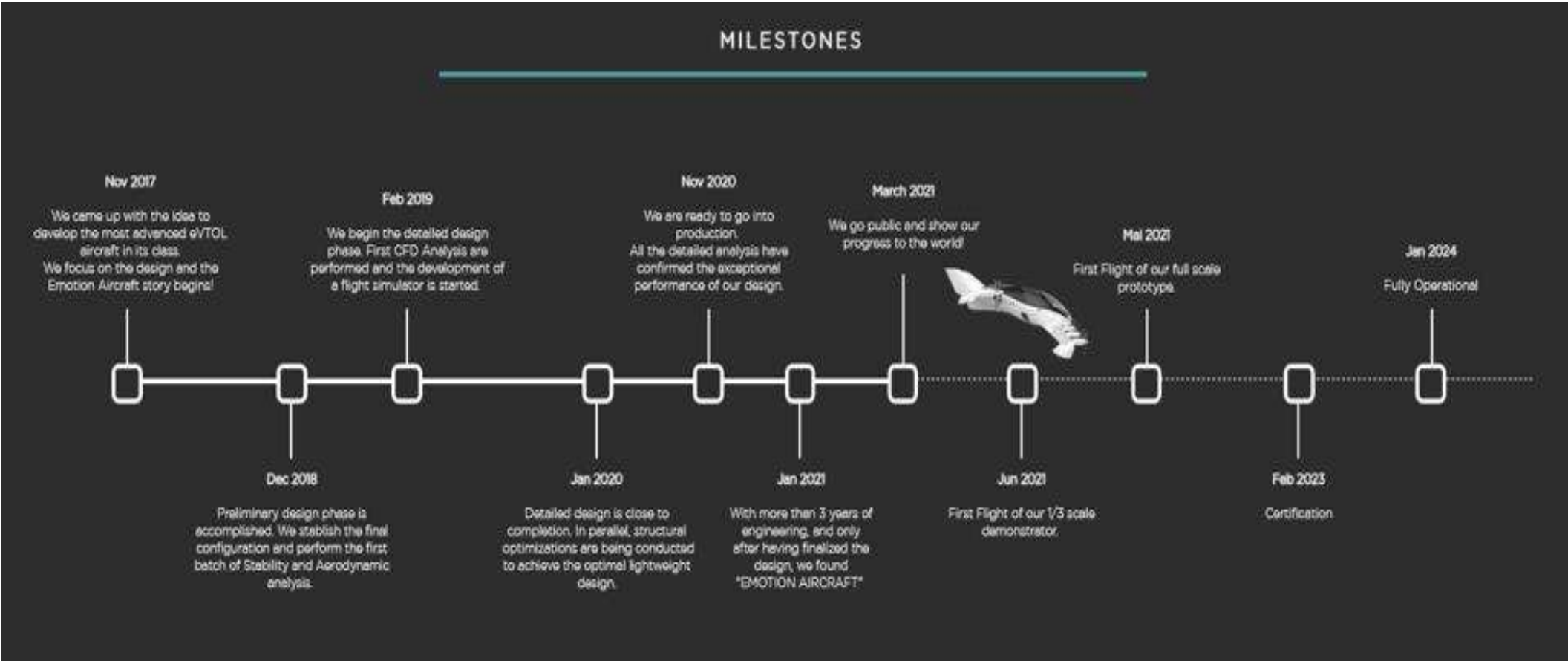

**7 years from concept to receive certification**

# Example: an eVTOL from Emotion of Germany




Source: https://www.youtube.com/watch?v=MvE6tpf3060&ab_channel=EmotionAircraft
https://www.emotion-aircraft.com/

# Example of the Schedule from Emotion

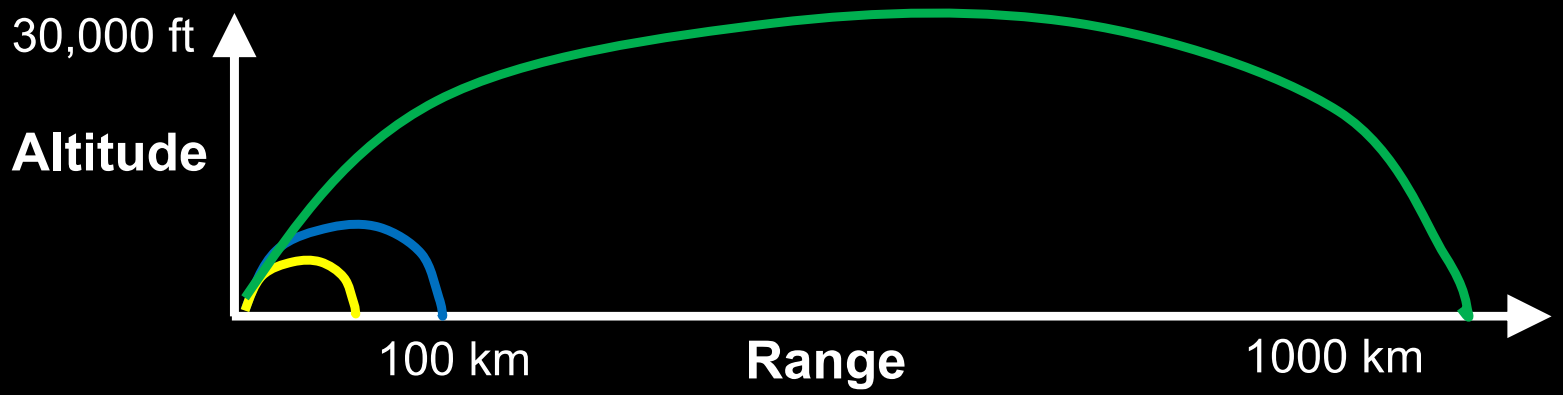



**Total 8 years is reasonable**

**18 months from first flight to receiving certification is short**

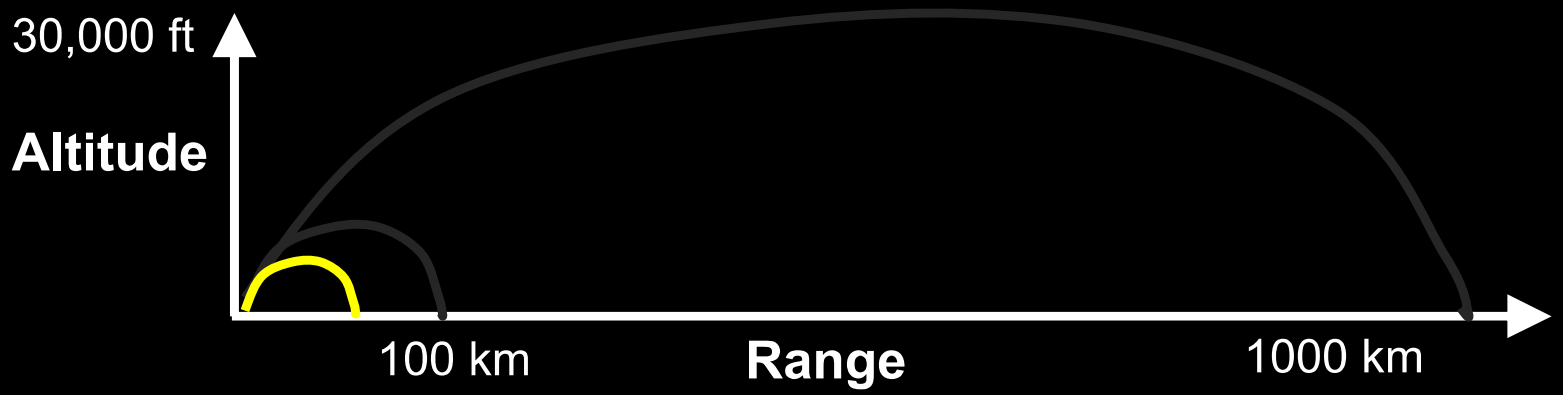
# *Three eVTOL Niches*

- **Personal eVTOL (GoFly competition)**
- **Short haul point-to-point business and inter-city (XTI TriFan)**
- **Public transport – urban air mobility (UAM)**



# *First eVTOL Niches*

- **Personal eVTOL (GoFly competition)**
- **Short haul point-to-point business and inter-city (XTI TriFan)**
- **Public transport – urban air mobility (UAM)**



Ten winners of GoFly Phase 1

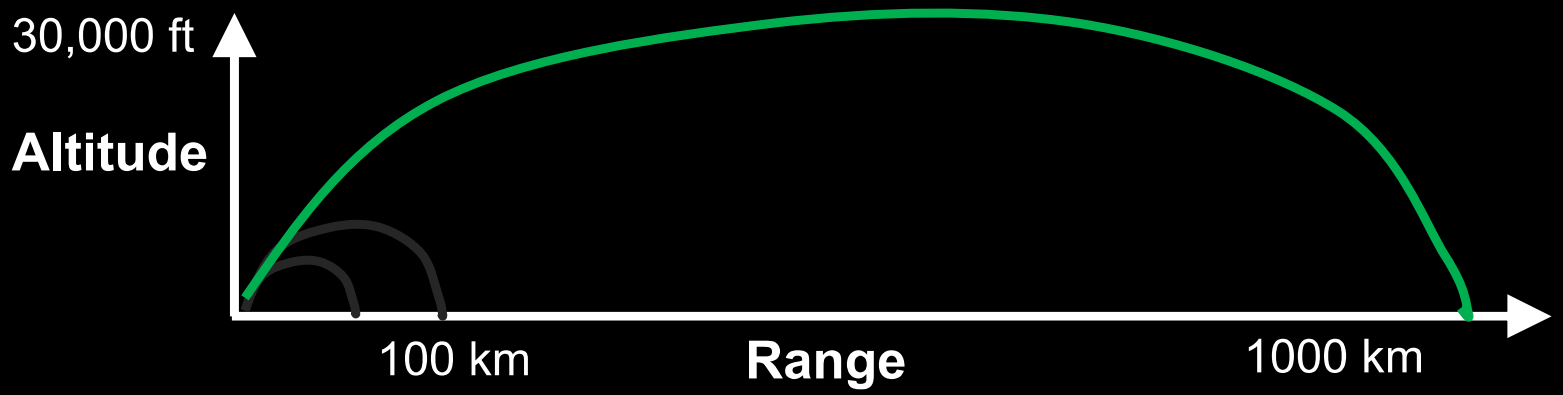
# GoFly Final Flyoff at NASA Ames Feb 2020

**No team completed the $1m prize requirements !**

# Team Tetra from Japan won Disruptor Award

# *Second eVTOL Niches*

- Personal eVTOL (GoFly competition)
- **Short haul point-to-point business and inter-city (XTI TriFan, Pegasus)**
- Public transport – urban air mobility (Uber)



# Trifan from XTI, USA

## 1. Aluminum and composite Structure

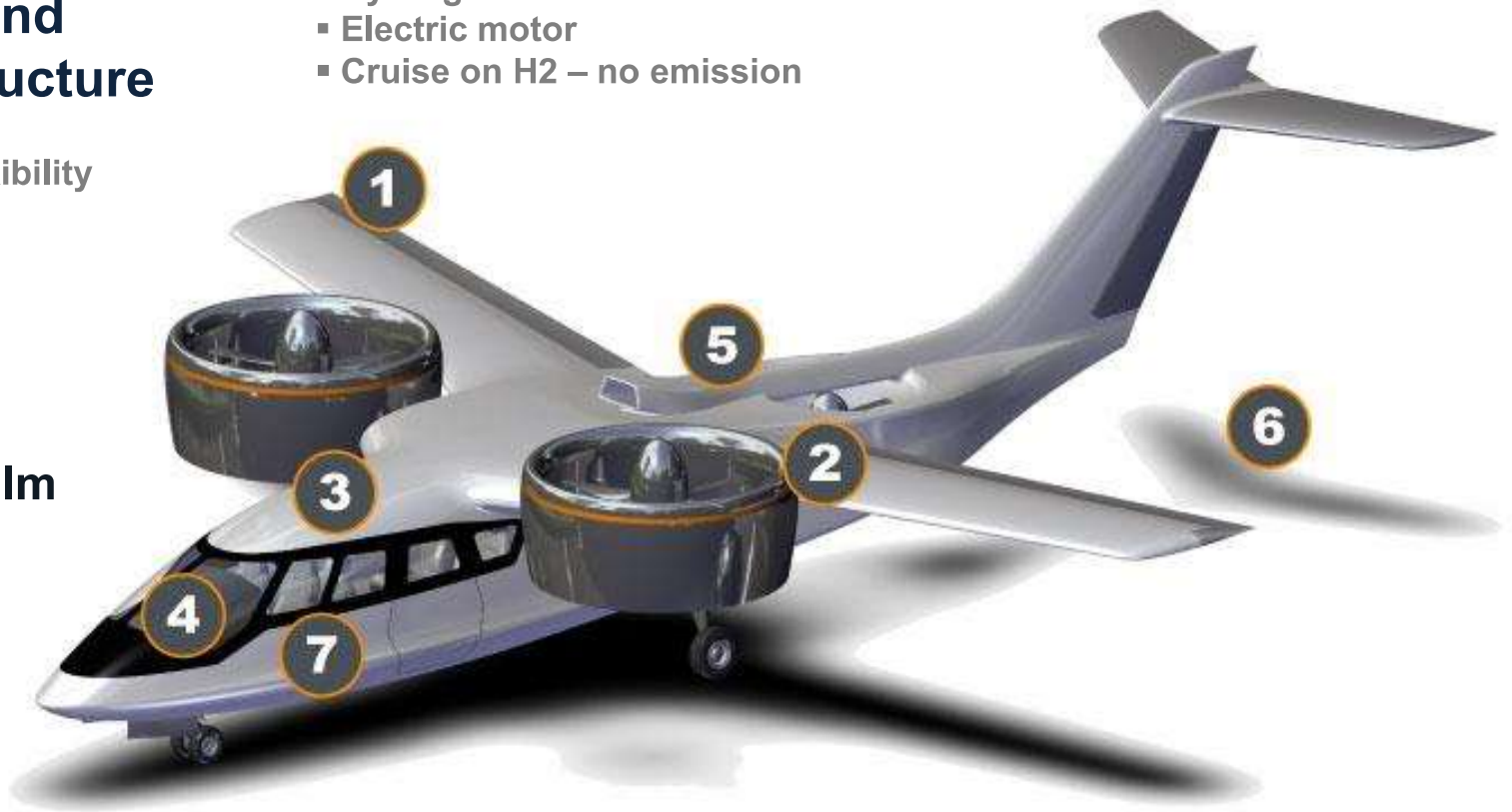
- Lighter weight
- Greater design flexibility

## 2. Hybrid Energy System (HES)

- Hydrogen fuel cell
- Electric motor
- Cruise on H2 – no emission

## 3. Embedded Solar Film

- For ground power
- No noise pollution
- Zero emissions
- Low operating cost




## 4. Garmin 3000 Avionics

- Certified for single pilot operation
- Installed in hundreds of aircraft

## 5. Efficient turboshaft engine

- 100% Sustainable Aviation Fuels (SAF) compatible
- Fuel efficient, highly reliable
- Supplemental power in vertical mode

## 6. Digital Engineering

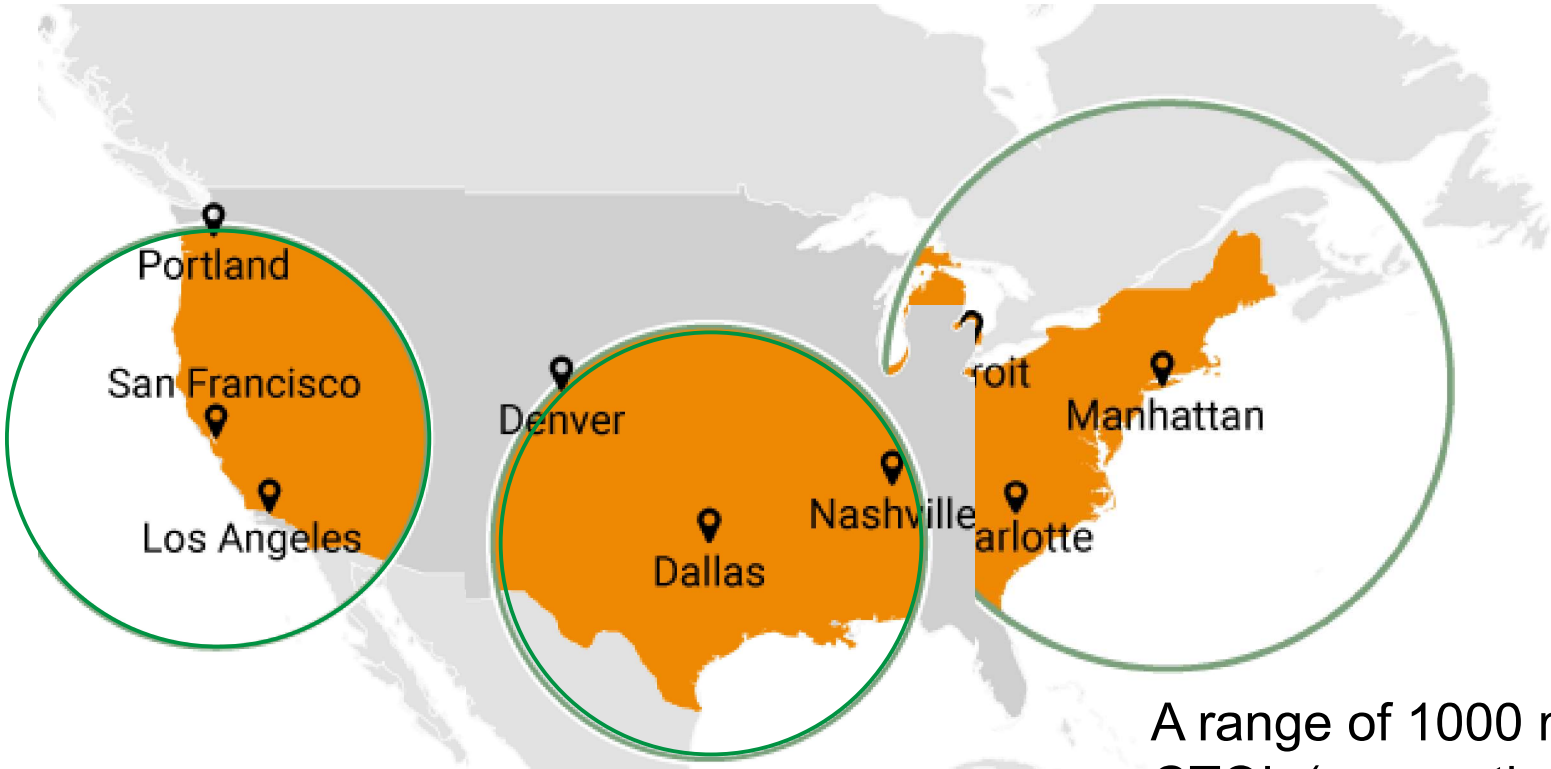
- 3D modeling
- Product Lifecycle Management
- Agility, efficiency

## 7. 'Fly by wire' Flight Controls

- Reduced pilot workload
- Stability enhancement

Source: from XTI public release 2022-02

# Trifan from XTI, USA




A range of 700 miles for VTOL (vertical take off and landing) mode

A range of 1000 miles for CTOL (conventional take off and landing) mode

Source: from XTI public release 2022-02

# Example: Pegasus Universal Aerospace

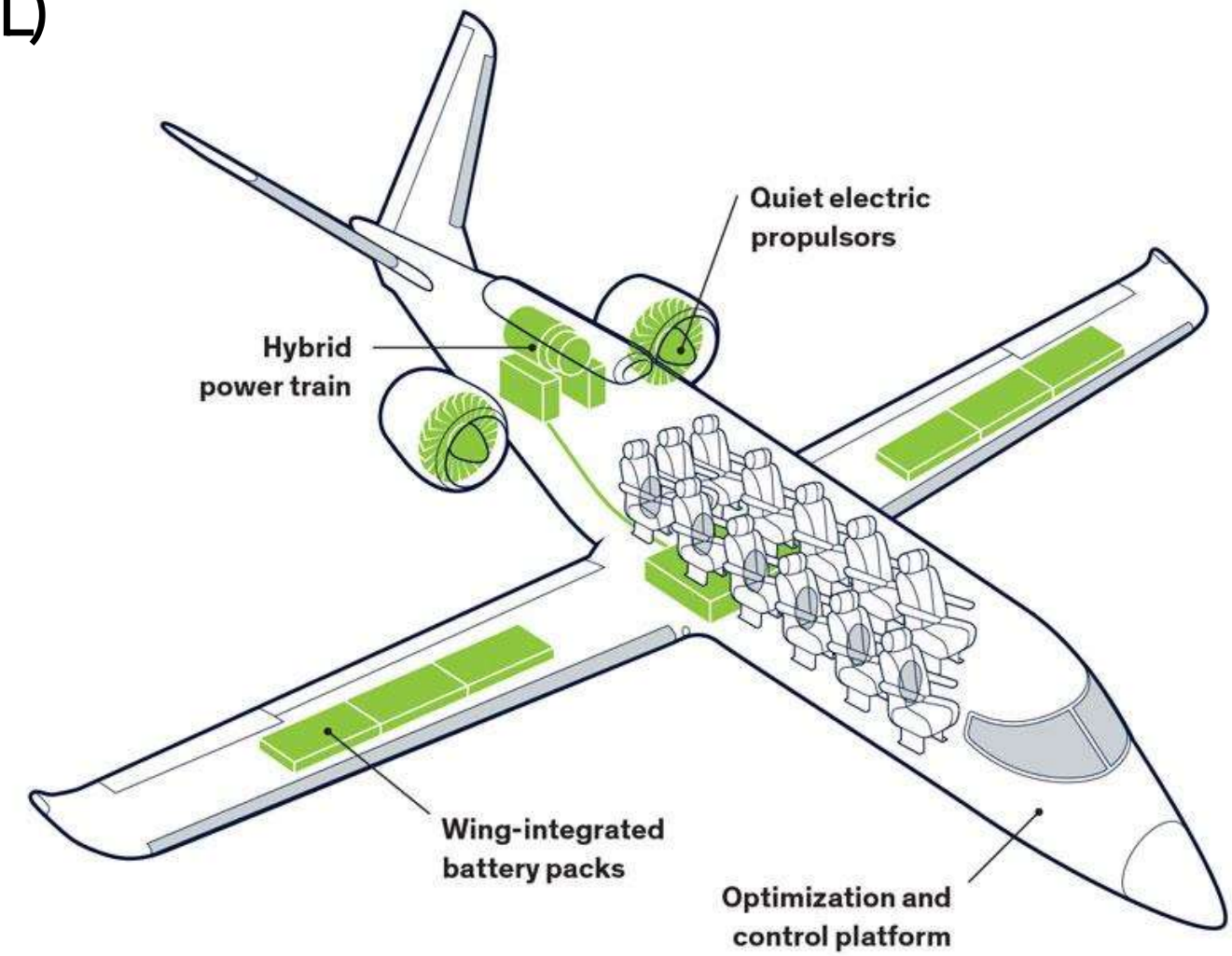
Source: https://evtol.news/pegasus-universal-aerospace-vertical-business-jet/

# Example: Eviation Alice Electric Airplane

(Non-VTOL)

# Example: Zunum Hybrid-Electric Airplane

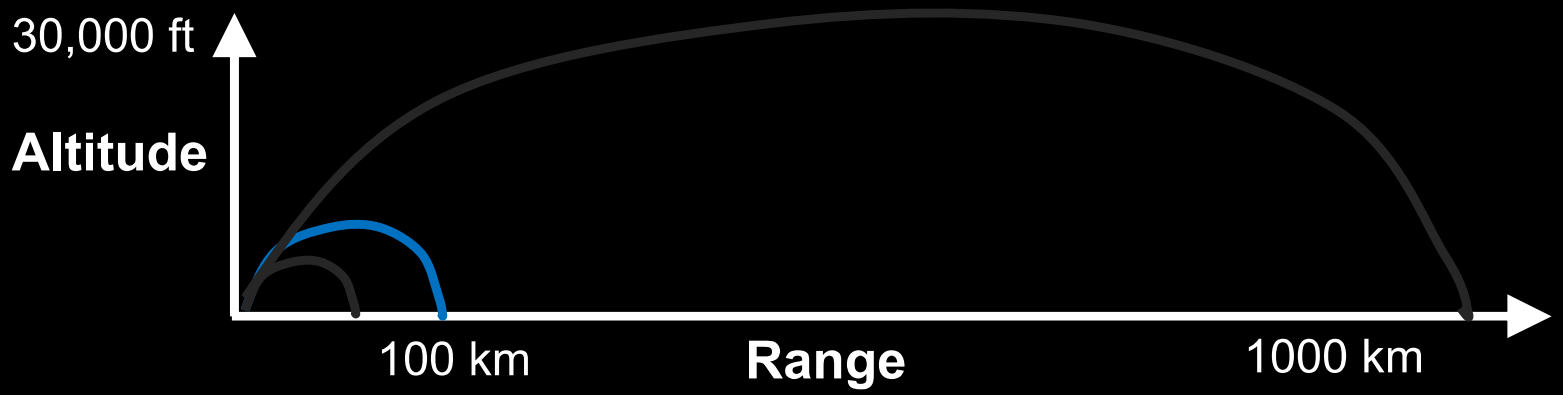
## (Non-VTOL)




Source: https://spectrum.ieee.org/aerospace/aviation/zunum-aeros-hybrid-electric-airplane-aims-to-rejuvenate-regional-travel

# *Third eVTOL Niches*

- **Personal eVTOL (GoFly competition)**
- **Short haul point-to-point business and inter-city (XTI TriFan)**
- **Public transport – urban air mobility (UAM)**



# This is the Most Competed Niche


Lilium Jet, Germany


Hyundai S-A1, Korea


EHang, China

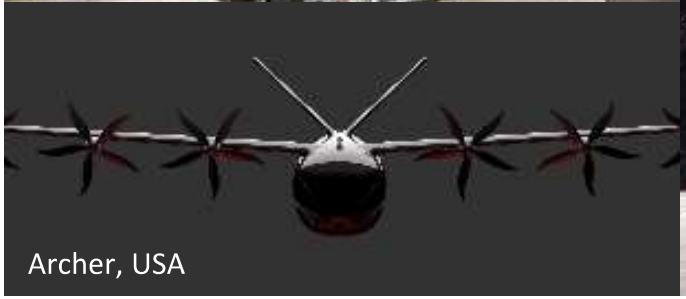

Volocopter Volocity, Germany


Bell Nexus 4EX, USA


Beta Technologies Alia, USA


Airbus CityAirbus, France


Cora Wisk, USA


Archer, USA


Joby S4, USA


Vertical Aerospace, UK

**Often called Urban Air Mobility, it includes air taxi, shared ride, VIP transport, cargo delivery, organ transport, emergency services…**

# Why Share Ride Car is Successful?

- **They provide additional transportation mean to help people**
- **A new user experience: on-demand, no cash.**
- **30% of millennials do not plan to buy cars**
- **$215 billion revenue by 2025**
- **Can this be repeated for air mobility? Where to find thousands of pilots? Can they beat the regulation again?**

# Exponential growth of Uber car share-ride may be an indication for UAM

| **Uber's market** | **End of 2019** | **Jan 2020** |
|---|---|---|
| Countries: | 60 | 66 |
| Daily trip: | 15 millions+ | 19 millions+ |
| Monthly active riders: | 75 millions+ | 100 millions+ |
| Total Rider served: | 10 billions+ | 15 billions+ |

Data presented by Uber at VFS Jan. 2020

# First, Set Up Intra-City Air Taxi Hubs

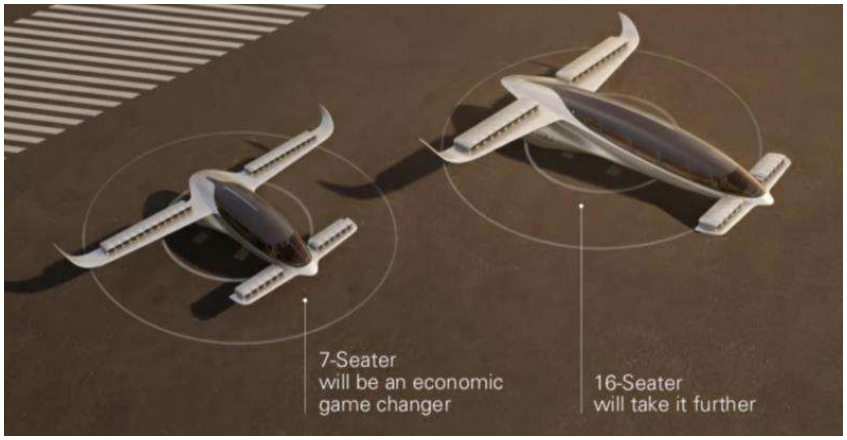
View of Dubai
Picture from Uber brief

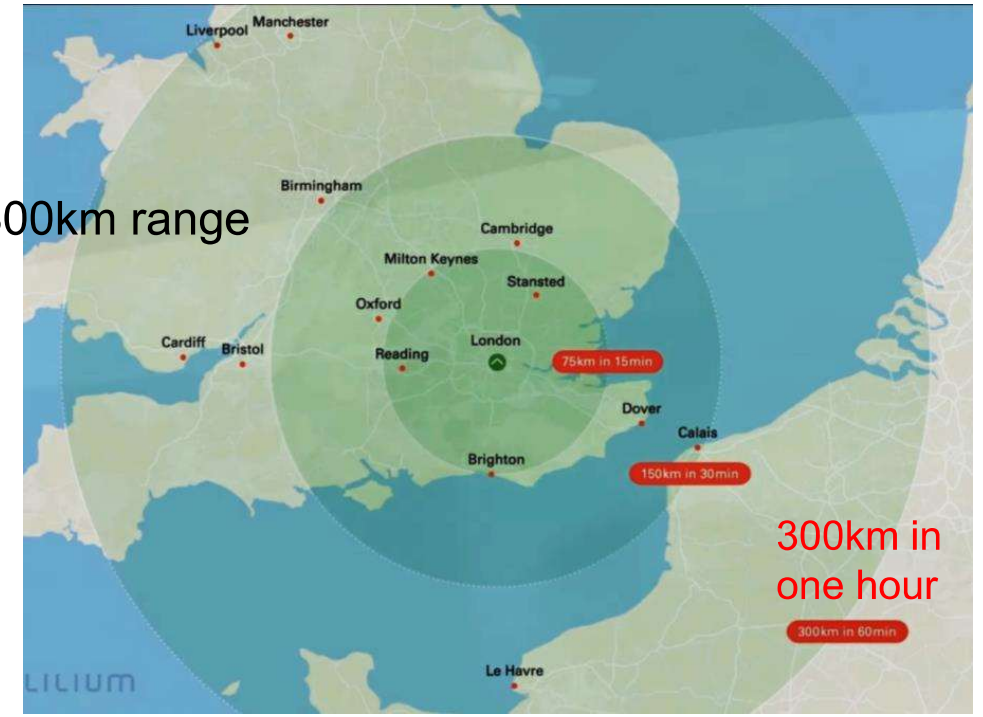
# UAM Will Require Setting Up Many Air Taxi Hubs

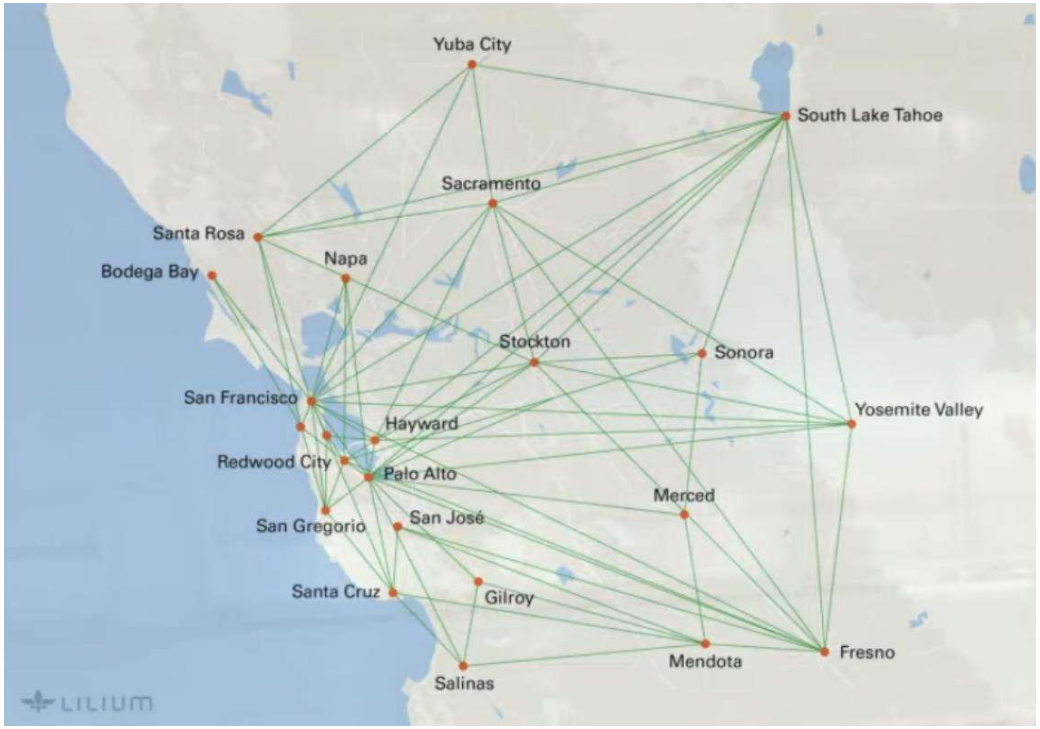
View of Los Angeles
Picture from Uber brief

# Expands to Inter-City

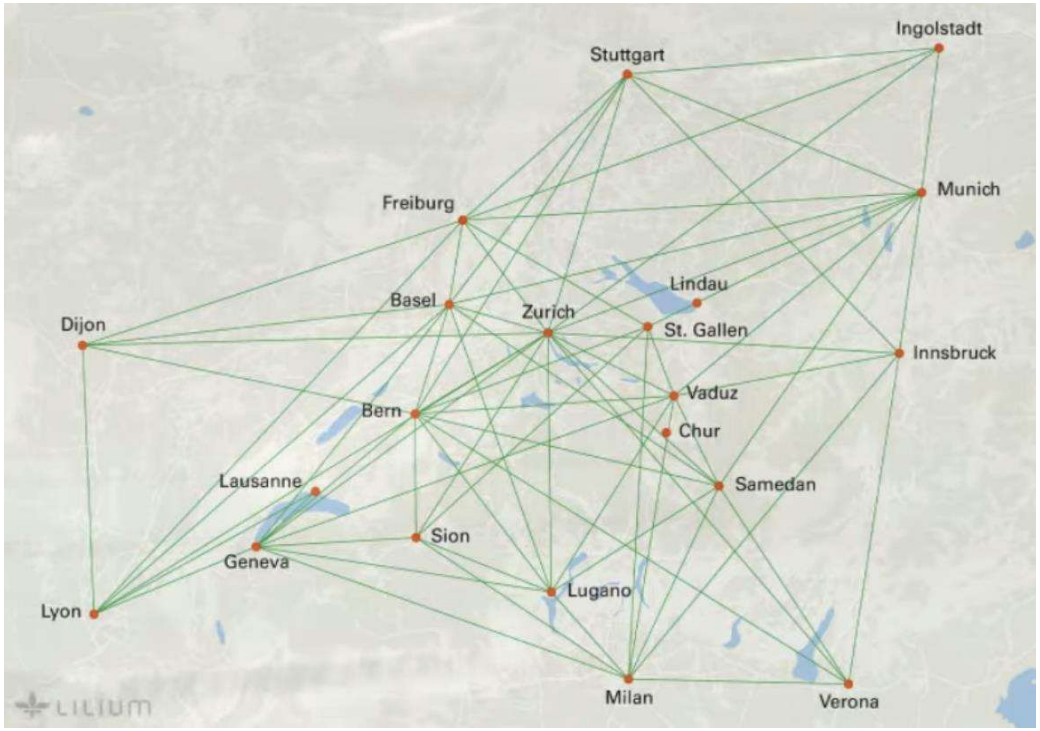
Example: Lilium's goal is 300 km/h speed and 300km range




**Connecting Northern California cities**




**Connecting Germany, France, Switzerland, Austria, and Italy**

# Linking Singapore, Malaysia and Indonesia

# Example of a Roof Top Vertiport

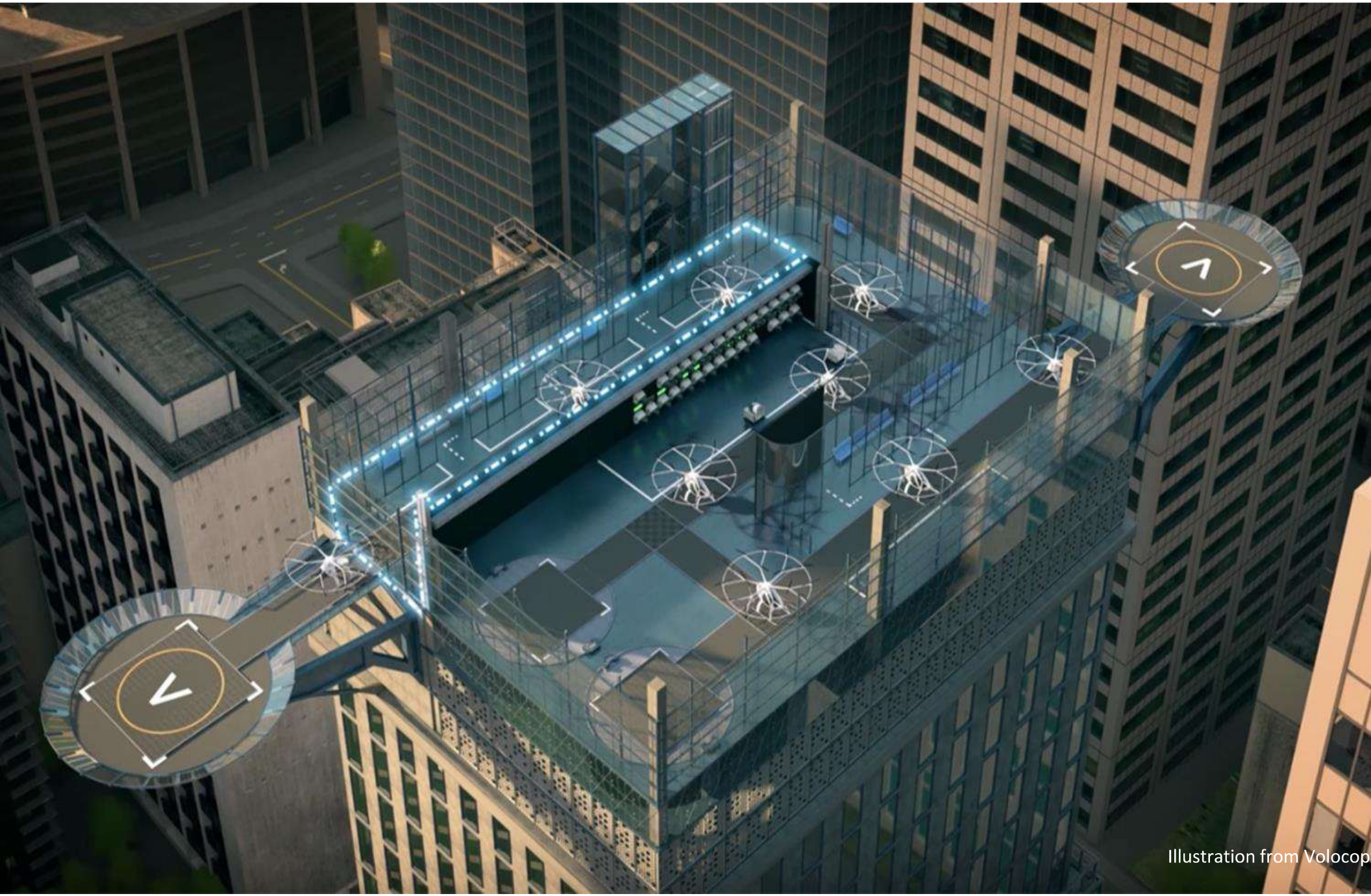


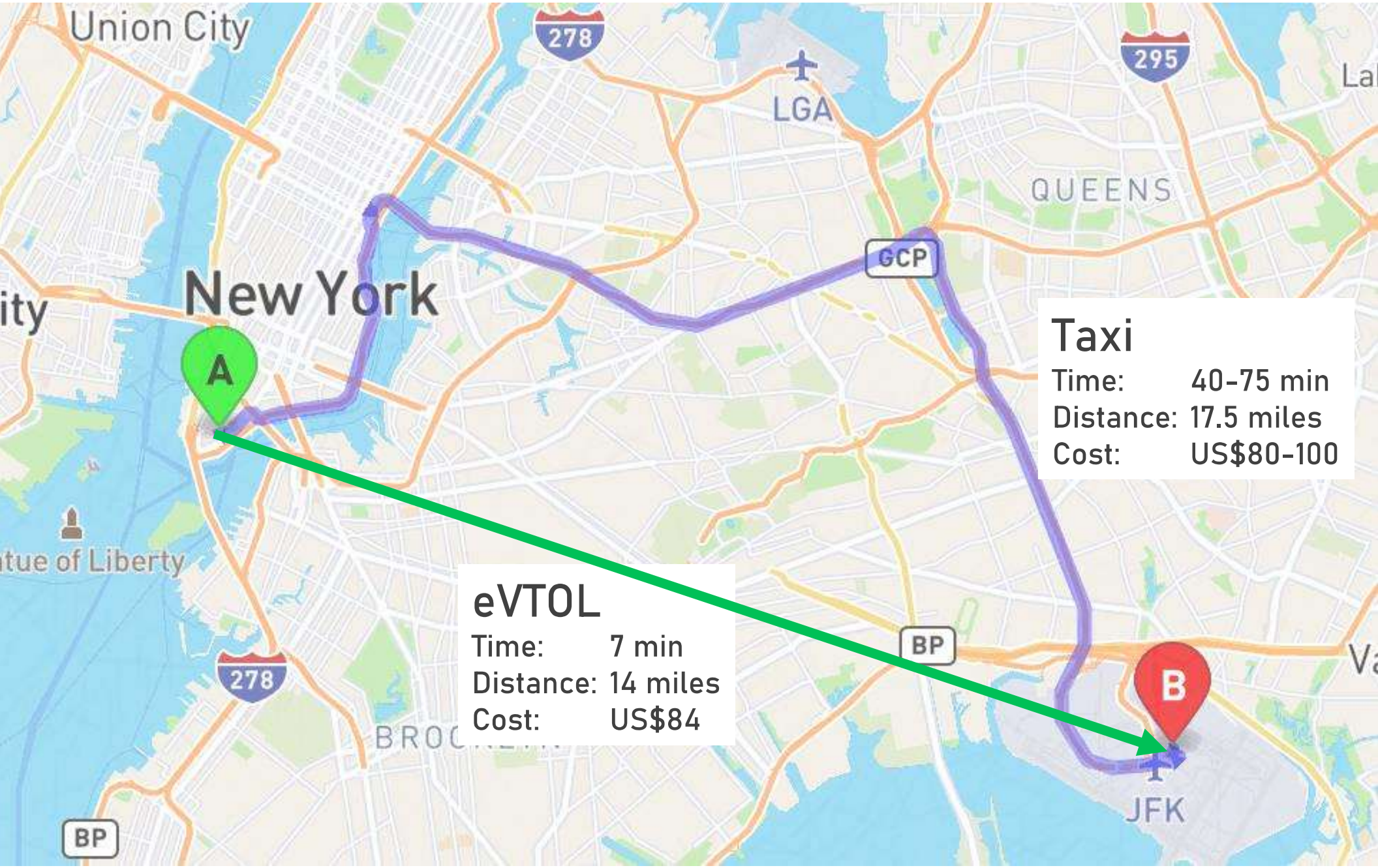
Illustration from Volocop

# Over 50 Cities Are Exploring UAM for People and Cargo

- Los Angeles, Dallas, Melbourne, Dubai, Osaka, Rio de Janeiro,… want to launch UAM by 2025.
- Paris wants to debut air taxi at the 2024 Summer Olympic.
- Singapore may provide sight seeing rides by 2023

# Price to Ride UAM

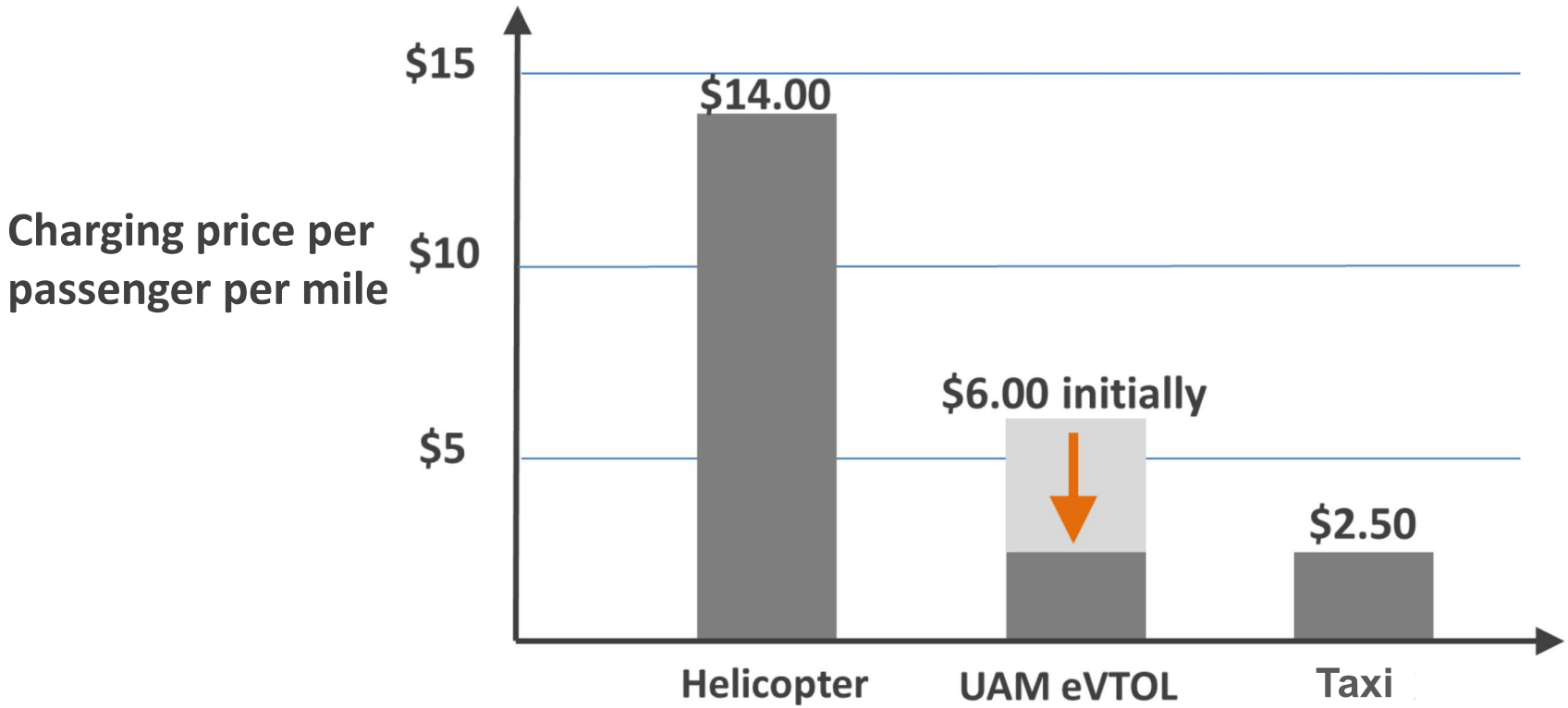
# Example: NY Wall Street to JFK Airport




Today Blade operates helicopter flight from NYC to JFK Airport.
Only 7 minutes for 14 miles. Blade charges $195 per passenger

# How Can eVTOL Reduces Air Taxi Price

- Goal is for eVTOL to cost less to buy & operate by 2027
- Further reduction through mass production by 2030 to 2035



# eVTOL Reduces Hardware and Operating Cost

US $3.5 millions
2027

US $2.5m
2027

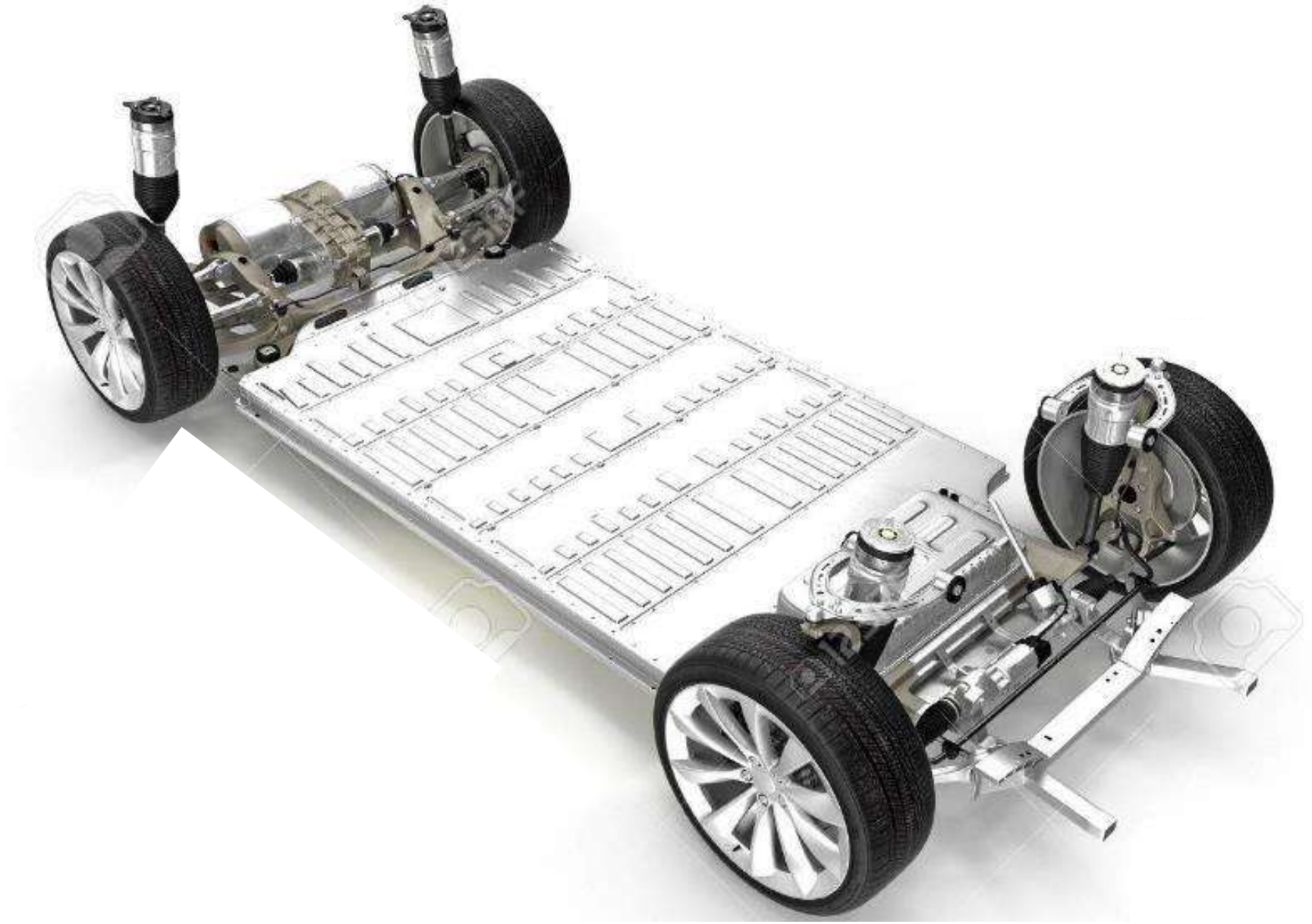
→

US $2m
2032

(Note, in 2027 $ value)


Helicopters Have Many Parts.  Expensive to Buy, Operate and Maintain

# Electric Vehicles Have Much Fewer Parts

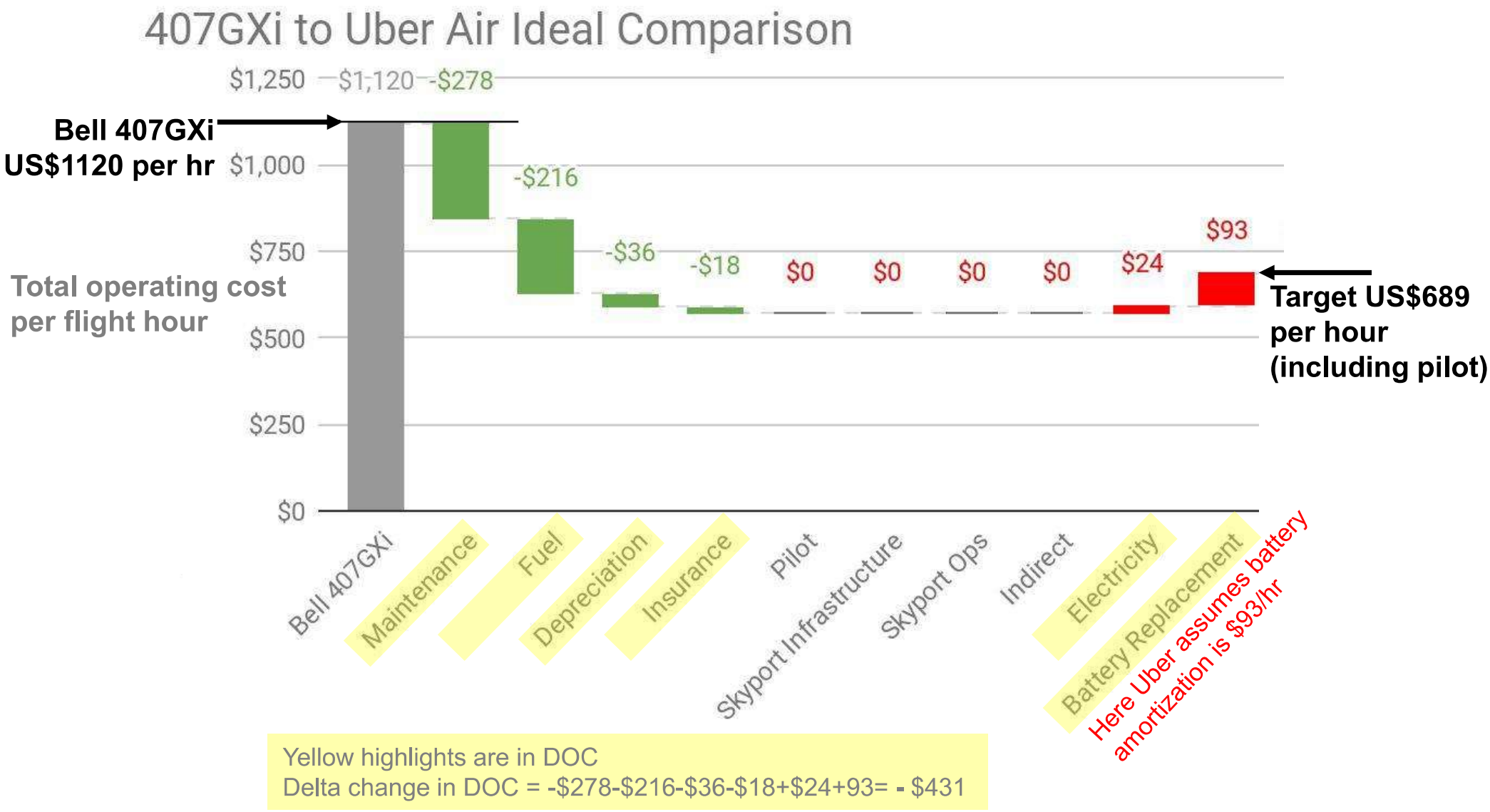


# Electric Vehicles Reduces Parts Count

Whereas cars with a combustion engine need about 30,000 components, an electric vehicle needs just 11,000 parts, according to research from Goldman Sachs Group. That reduction in complexity has lowered the barriers to entry for the automotive market and caused a surge in the number of new electric carmakers.

We can also expect significant reduction from a light helicopter to an eVTOL aircraft.

# UberAir Targets a Total Operating Cost for eVTOL to be 35% lower than operating helicopters




Yellow highlights are in DOC
Delta change in DOC = -$278-$216-$36-$18+$24+93= - $431

Source of graph: Uber presentation at 2019 VFS Forum, Philadelphia

**Total operating cost =**
**indirect operating cost + direct operating cost**

**Lets find out the direct operating cost for eVTOL**

# Comparing Different Operating Cost Definitions

| | | ATA | AEA | +I | F41 | TUB |
|---|---|---|---|---|---|---|
| Ownership | Depreciation | ● | ● | ● | ● | ● |
| | Interest | ○ | ● | ● | ○ | ● |
| | Insurance | ● | ● | ● | ● | ● |
| Flight | Fuel | ● | ● | ● | ● | ● |
| | Cockpit Crew | ● | ● | ● | ● | ● |
| | Cabin Crew | ● | ● | ● | ● | ● |
| | Fees, Landing | ○ | ● | ● | ● | ● |
| | Fees, Navigation | ○ | ● | ● | ○ | ● |
| | Fees, Ground Handling | ○ | ● | ○ | ○ | ● |
| Maintenance | Airframe, Labor | ● | ● | ● | ● | ● |
| | Airframe, Material | ● | ● | ● | ● | ● |
| | Engine, Labor | ● | ● | ● | ● | ● |
| | Engine, Material | ● | ● | ● | ● | ● |
| | Burden | ● | ○ | ● | ● | ● |
| | Utilization Function | ● | ● | ◑ | ○ | ● |
| | A/C Price Function | ○ | ○ | ● | ○ | ● |

Source: https://www.researchgate.net/publication/322310413_Comparison_of_Direct_Operating_Cost_and_Life_Cycle_Cost-Benefit_Methods_in_Aircraft_Technology_Assessment/link/5ef1e895a6fdcc73be96e923/download

# Direct Operating Cost for Helicopters and eVTOL

| | | | | |
|---|---|---|---|---|
| BASE AIRCRAFT PRICE (USD) | $3,225,000 | $3,450,000 | $3,200,000 | $2,500,000 |
| MANUFACTURER | Bell | Airbus Helicopters | Airbus Helicopters | Generic |
| AIRCRAFT TYPE | 407GXi | H130 | H125 | eVTOL |
| DIRECT OPERATING COST | $ 589 | $ 640 | $ 627 | <$300 |
| DOC / NM | $ 4.43 | $ 5.00 | $ 4.61 | $2.78 (for 108 nm) |
| DOC / NM / SEAT | $ 0.74 | $ 0.71 | $ 0.77 | $ 0.56 |
| MAX CRUISE SPEED (KTAS) | 133 | 128 | 136 | 108 |
| MAX RANGE (NM) | 337 | 333 | 341 | 45 |
| USEFUL LOAD (LBS) | 2300 | 2299 | 2189 | 1100 |
| TOTAL SEATS | 6 | 7 | 6 | 5 |

**Bell 407GXi's IOC = total op cost – DOC = US$1120/hr - $589 = $531/hr**

**eVTOL's DOC = total op cost – IOC = US$$689 - $531 = $158/hr** Seems optimistic

**Or eVTOL's DOC = DOC – changes = $589 - $431 = $158/hr**

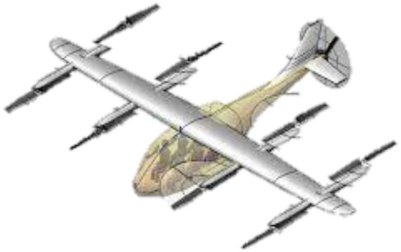
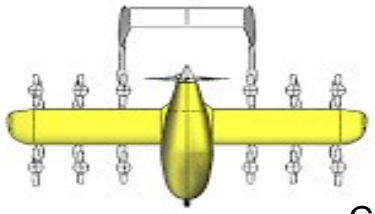
# Types of eVTOL Aircraft

# Name for different VTOL Aircraft Configurations

- Drone = UAV (unmanned air vehicle) = UAS (unmanned air system)



- Multirotor, multicopter



Cora


- Lift + cruise


V22

AW609

- Tiltrotor


CL-84

Vahana


- Tiltwing



- Tail sitter

# Name for different VTOL Aircraft Configurations

- Helicopter

Bell-407

Kamov Ka27

Ch-47

- Compound

Piesecki

Sikorsky X2

Airbus X3

- Autogyro

eCavalon

- VTOL jet

Harrier

F35B

# Definition

$$\text{Disk loading} = \frac{\text{Max Takeoff Gross Weight (lbs)}}{\text{Total rotor disks area (ft}^2\text{)}}$$

# Coaxial Rotor

For coaxial rotor type when we calculate the disk loading, we typically use only the disk area of one set of rotors

# Multirotor and Multicopter



# Lift + Cruise

eHANG VT-30


Cargo drone

Boeing PAV


Beta Alia

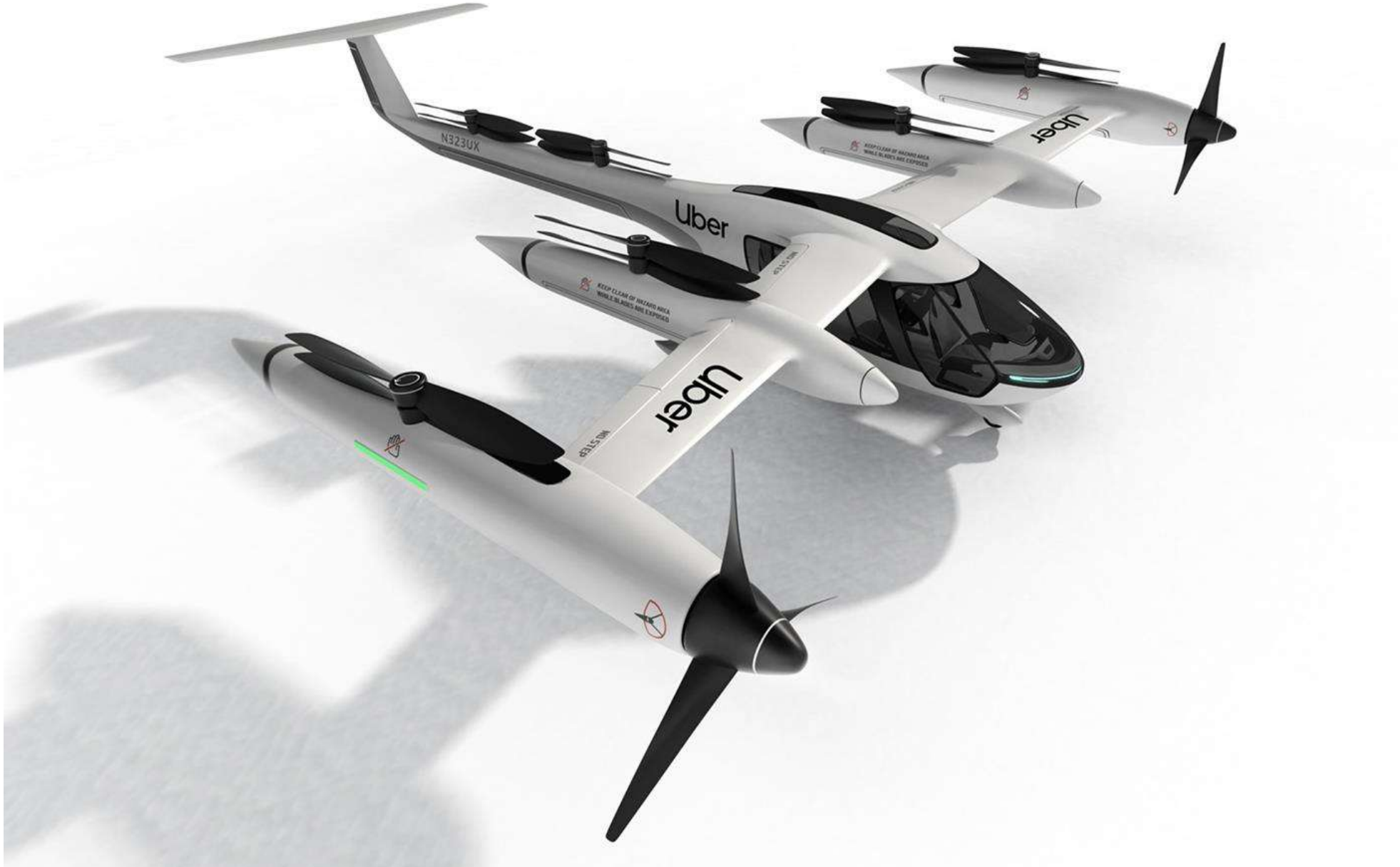
# Lift + Cruise

https://www.droneassemble.com/product/long-endurance-drone-3-hours-vtol-v-tail-for-mapping-surveillance-vtol-frame-kit/

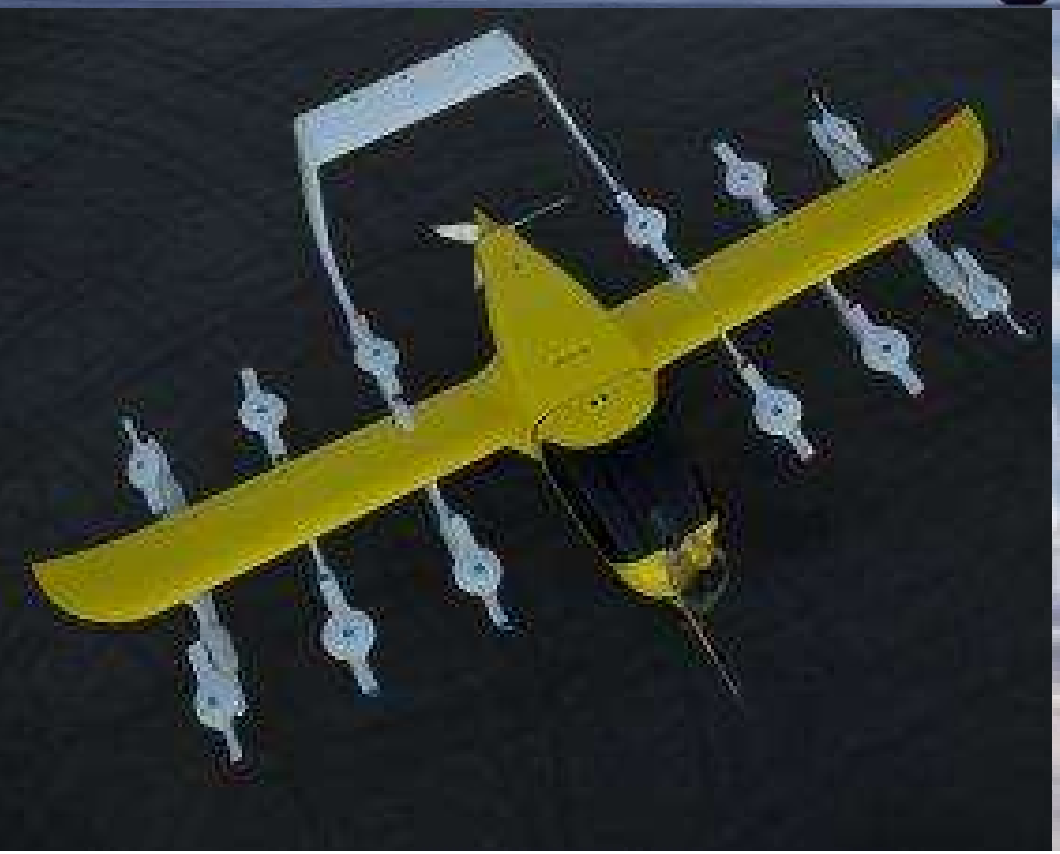
# Lift + Cruise


KEEP CLEAR OF HAZARD AREA
WHILE BLADES ARE EXPOSED
UBER
NO STEP
N323UX
UBER
KEEP CLEAR OF HAZARD AREA
WHILE BLADES ARE EXPOSED

# Lift + Cruise



# Kitty Hawk Cora (Lift + Cruise Type)



# Tiltrotor

V22


AW609


AW609

Bell Nexus

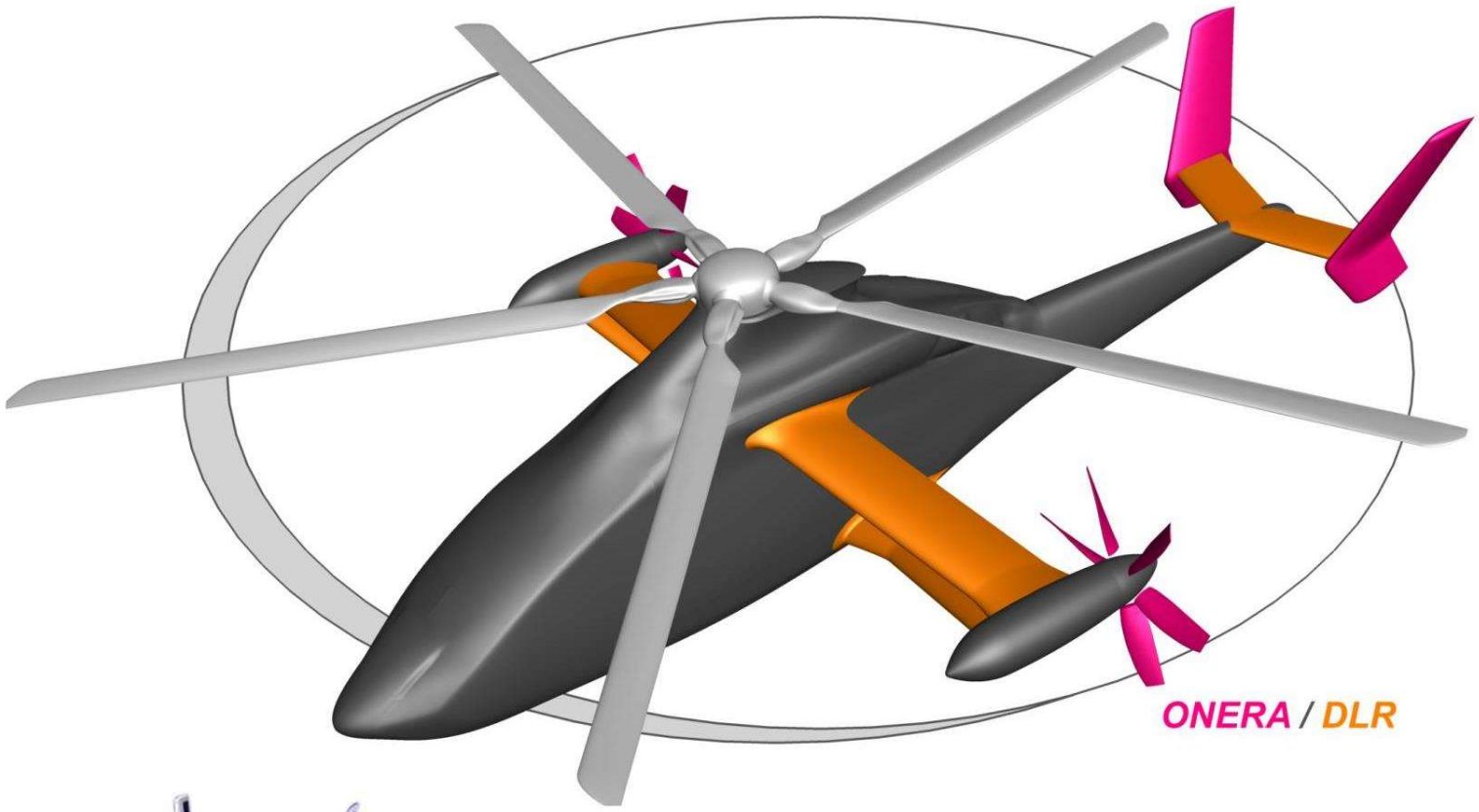

KAREM
AIRCRAFT, INC.
UBER
25 mile mission repeated indefinitely
4 passengers + pilot (1,100 lb payload weight)
9-minute, 2C charge
6-mile reserve
Unlimited operations during peak time
Tiltrotor (vector thrust)

# Tiltwing


Canadair CL-84


Airbus Vahana

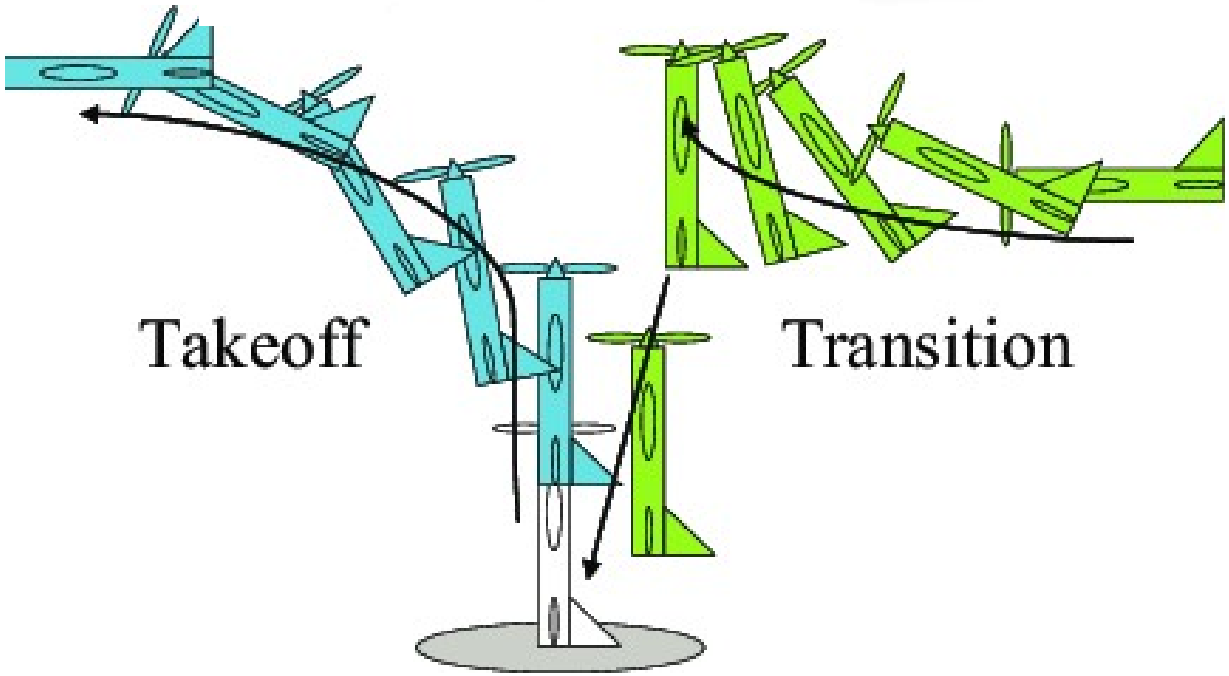
# Compound Helicopter - Airbus X3




# Tail Sitter

## Drawbacks: visibility and passenger comfort





# Autogyro (eSTOL)

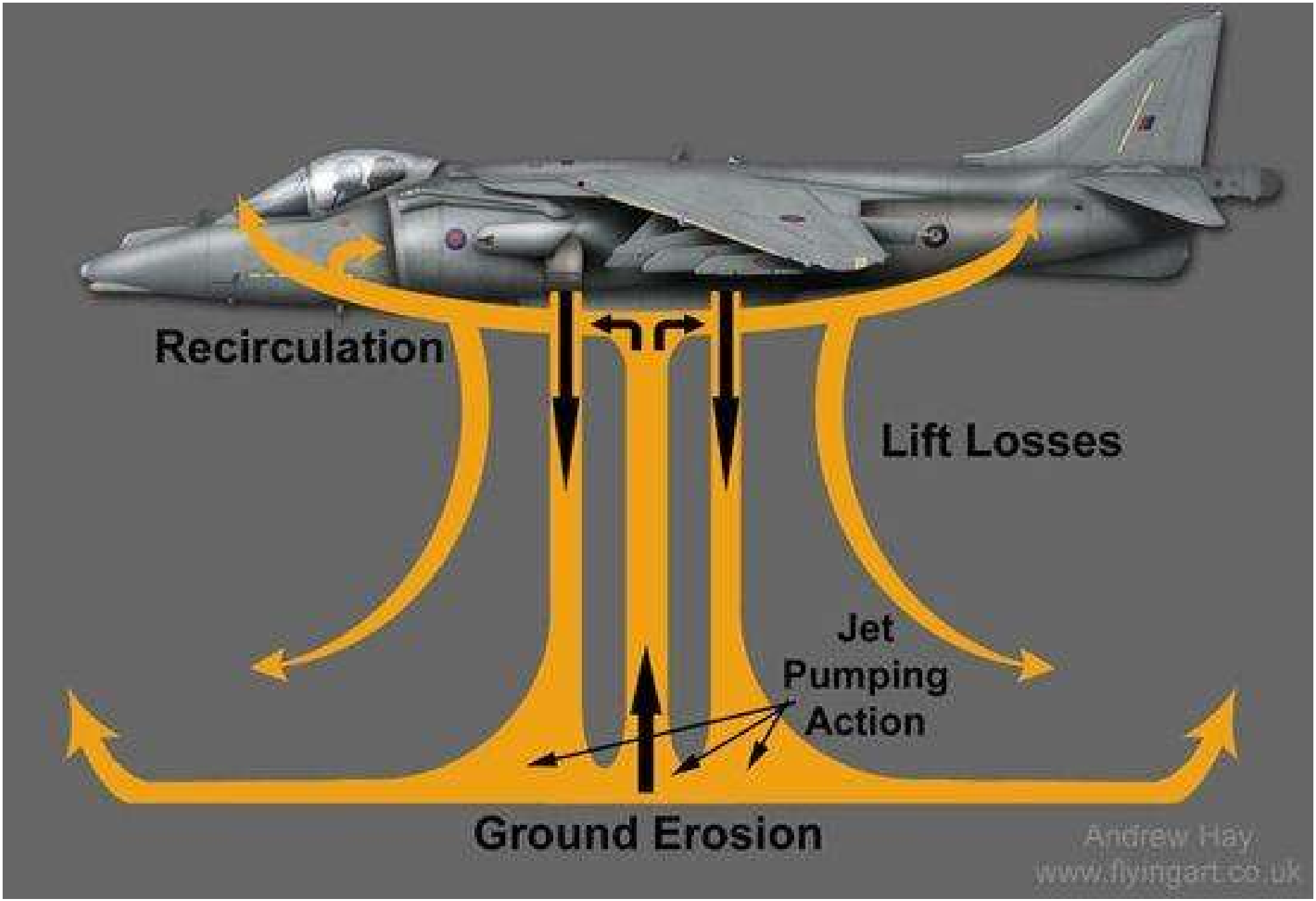

**Characteristics:**

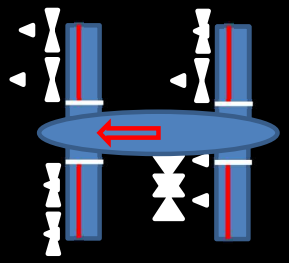
- Passengers: 2
- Empty weight: 300 kg (661 lb)
- Gross weight: 500 kg (1,102 lb)
- Powerplant: 1 × Siemens motor 107hp (80 kw)
- Main rotor diameter: 8.4 m (27 ft 7 in)
- Propellers: 3-bladed composite
- Endurance: 30 minutes
- Cruise speed 90 mph (145 km/h), top speed is 99 mph (160 km/h)

AutoGyro GmbH
Hildesheim, Germany
www.auto-gyro.com

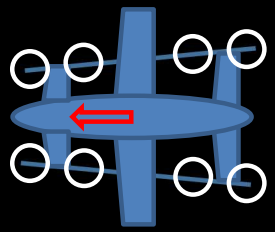
# Autogyro (R-Evolution, a Swiss study)

# VTOL Jets

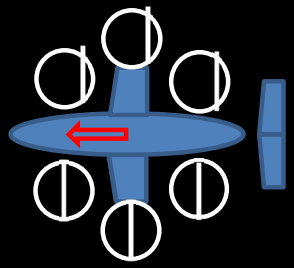

Recirculation
Lift Losses
Jet
Pumping
Action
Ground Erosion
Andrew Hay
www.flyingart.co.uk



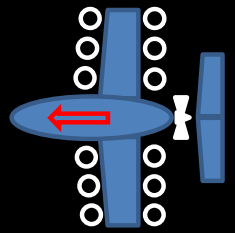
Vahana
*Airbus*



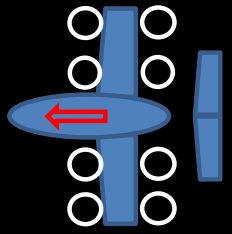
Passenger Air Vehicle (PAV)
*Boeing*



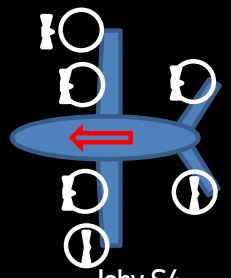
Bell Nexus
*Bell Flight*



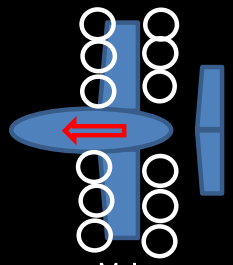
Cora
*WISK*



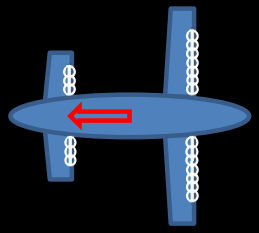
VZX1
Vertical Aerospace



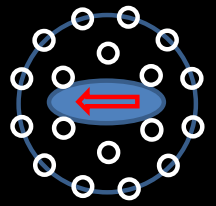
Joby S4
*Joby Aviation*



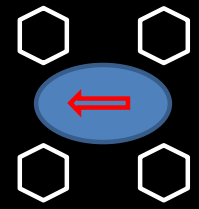
Maker
*Archer*



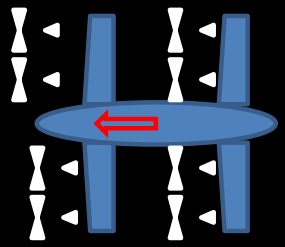
Lilium Jet
*Lilium*



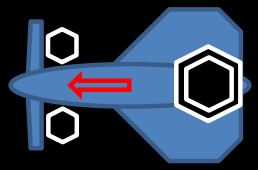
Volocopter
*Volocity*



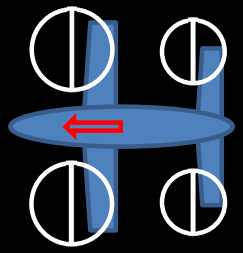
SureFly VTOL
*Workhorse*



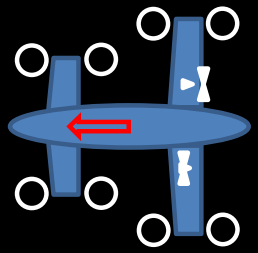
BlackFly v3
*Opener*



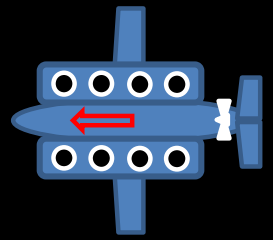
Aston Martin Volante Vision
*Supervolant*



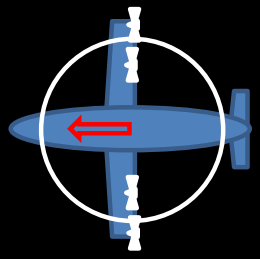
Overair



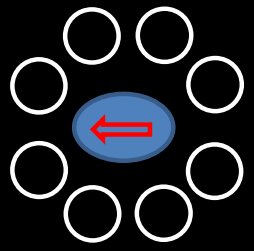
EmbraerX eVTOL
*Embraer SA*



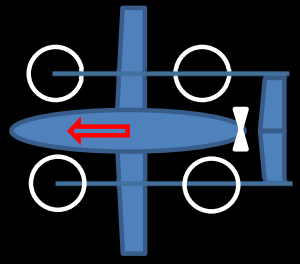
Pipistrel 801 eVTOL
*Pipistrel*



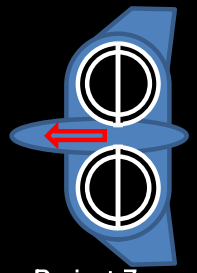
Jaunt Air Mobility eVTOL
*Jaunt Air Mobility*



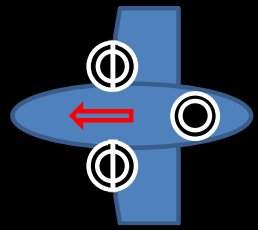
Ehang 216
*eHANG*



Alia
Beta Technologies

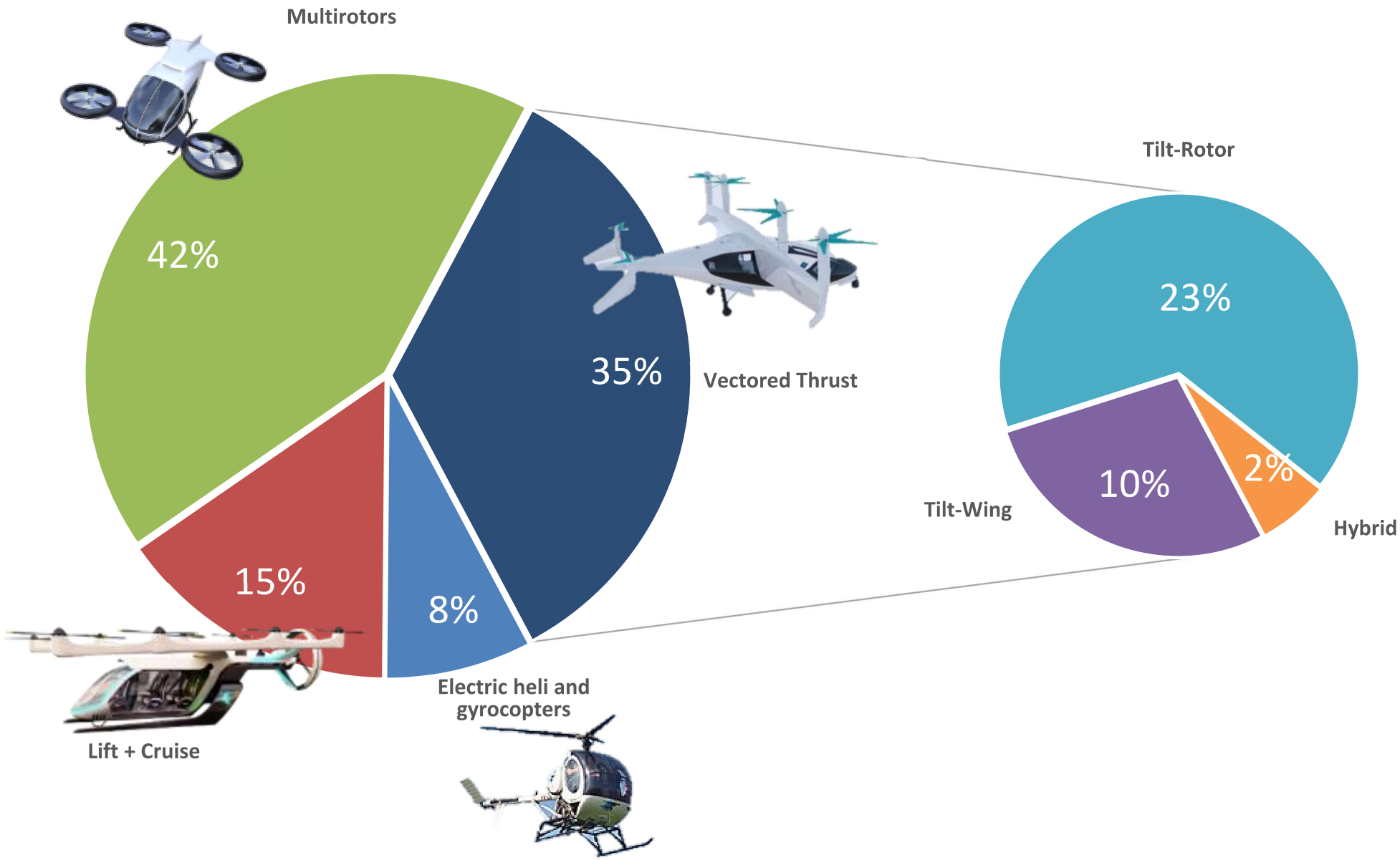


Project Zero
*AgustaWestland*



TriFan 600
*XTI Aircraft*

# Types of eVTOL Aircraft in Development




Compiled by James Wang

# Trend is Multirotor Replaced by Lift+Cruise

Volocity 2019

Voloconnect
May 2021

EHang 216 2019


Ehang VT-30
May 2021

# Rotor Comparison

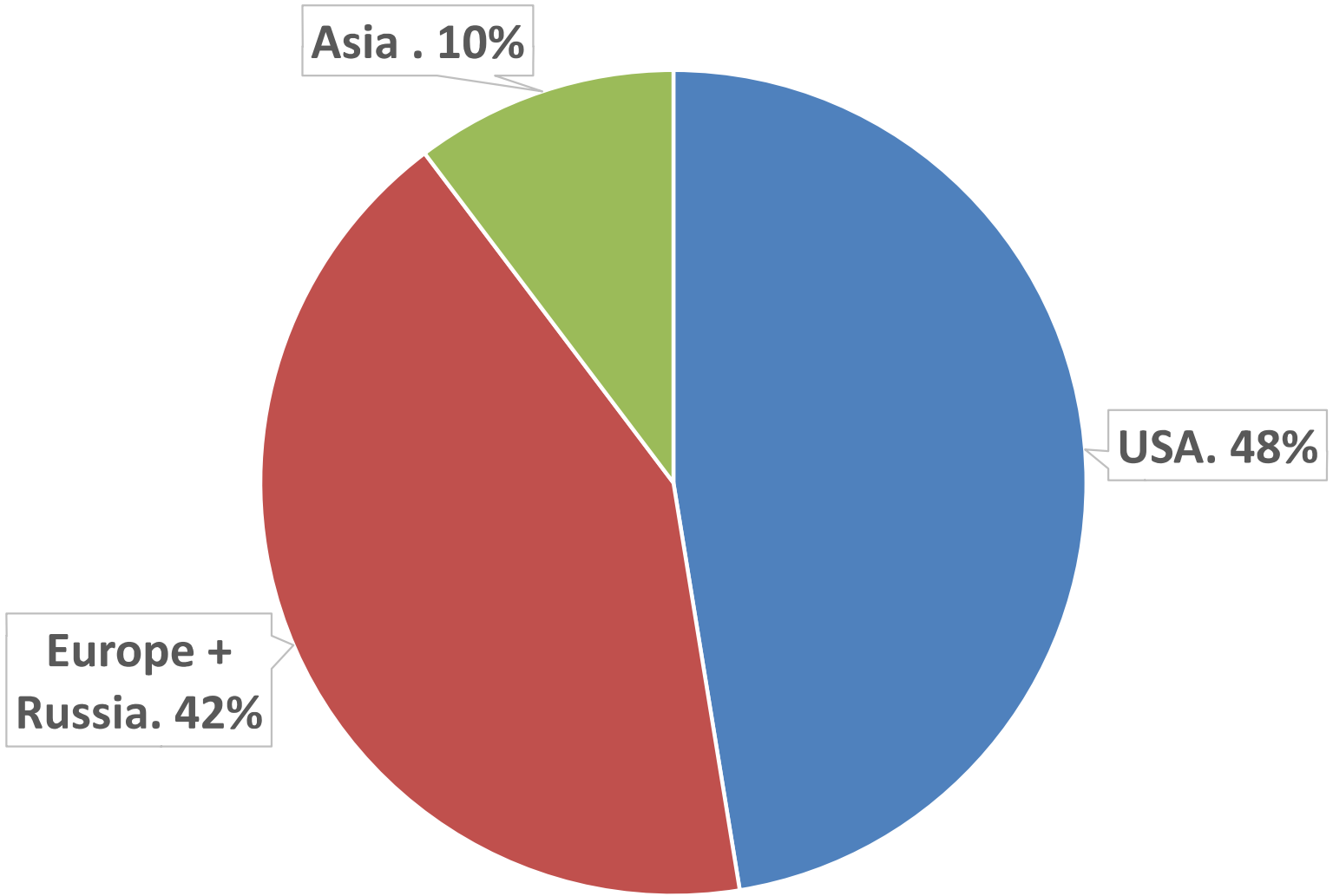
Lower disk loading <10 lbs/ft$^2$ — Higher disk loading >20 lbs/ft$^2$

Lower L/D <4 — Higher L/D >8

Better hover, less range — Better cruise, more range

Less rotors, lower redundancy — More rotors, greater redundancy

# eVTOL Developmental Regions



# Recent Technology Enablers for eVTOL

- Better rechargeable batteries
- More powerful electric motors
- Silicone carbide inverters
- Lower cost sensors and autonomous flight control
- Light weight composite structure
- Distributed propulsion architecture
- Better computation tools

# Key Challenges to eVTOL and UAM

- Fine tuning the technologies
- Creating appropriate infrastructures
- Collaboration and partnerships
- Regulating an entirely new industry
- Overcoming public psychological barriers
- Public acceptance and affordability

# 1. Design Phases for a New Aircraft Program
# Different types of eVTOL

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