The Electric VTOL Revolution

Mike Hirschberg, Executive Director

AHS International — *The Vertical Flight Society*

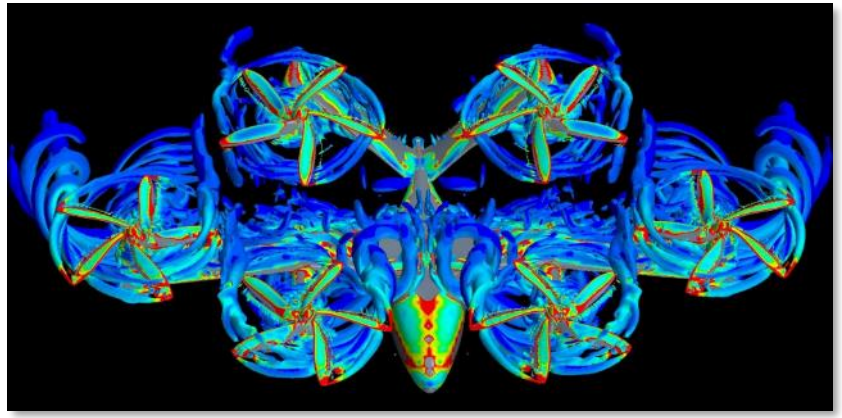
www.vtol.org & www.evtol.news | director@vtol.org

Kitty Hawk Cora
Released March 2018

Vertical Flight Society
www.vtol.org

What is The Vertical Flight Society?

- The international **professional society for those working to advance vertical flight**
  - Founded in 1943 as the **American Helicopter Society**
  - Everything from VTOL **MAVs/UAS** to **helicopters** and **eVTOL** to **STOVL** (everything vertical except rockets)
- **Expands knowledge** about vertical flight technology and promotes its application around the world
- Advances **safety and acceptability**
- Advocates for vertical flight **R&D funding**
- Helps **educate and support** today's and tomorrow's vertical flight engineers and leaders



CFD of Joby S4, Aug 2015

VFF Scholarship Winners at Forum 71, May 2015

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VFS Technical Committees

www.vtol.org/tech-committees

- Acoustics
- Advanced Vertical Flight
- Aerodynamics
- Aircraft Design
- Avionics & Systems
- Crash Safety
- Crew Stations & Human Factors
- Dynamics
- Handling Qualities
- Health & Usage Monitoring Systems (HUMS)
- History
- Manufacturing Technology
- Modeling & Simulation
- Operations
- Product Systems Technology
- Propulsion
- Safety
- Structures & Materials
- System Engineering Tools & Processes
- Test & Evaluation
- Unmanned VTOL Aircraft

Plus: Integrating Technical Teams for ***Electric VTOL***, Wind Energy, etc.

Technical Experts Working to Help Shape the Future

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VFS Technical Conferences

www.vtol.org/events

2018

Jan 16-19	Aeromechanics Design of Electric VTOL	San Francisco, Calif., USA
Feb 21-22	Airworthiness and HUMS	Huntsville, Alabama, USA
May 14-17	**Forum 74**	**Phoenix, Arizona, USA**
Sep 4-6	3rd Australia Indo-Pacific Army Aviation*	Adelaide, Australia
Sep 18-21	European Rotorcraft Forum (ERF)*	Delft, The Netherlands
Oct 24-25	Helicopter Military Ops Tech (HELMOT)	Hampton, Virginia, USA
Oct 30-Nov 1	7th Asian-Australian Rotorcraft Forum*	Jeju Island, South Korea
Nov 13-15	**Intl Powered Lift Conference (IPLC)***	**Bristol, UK**

2019

Jan 29-31	**Autonomous VTOL & Electric VTOL**	**Mesa, Arizona, USA**
Feb 20-21	Development of Complex Systems (FVL)	Huntsville, Alabama, USA
Feb 27-28	10th Australian Pacific Vertiflite Conference	Melbourne, Australia
May 13-17	**Forum 75**	**Philadelphia, Pennsylvania, USA**

* co-sponsored event

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75th Annual Forum

www.vtol.org/forum

- Annual Forum attracts 1,200+ engineers, scientists and leaders from industry, academia and governments
- VTOL aircraft CEOs/VPs/engineers, military leaders, researchers, etc
- ~250 technical papers
- ~50 panelists
- ~65 exhibitors
- Grand Awards Banquet
- eVTOL short course & industry tours

FORUM 75
VERTICAL FLIGHT SOCIETY
MAY 13-16, 2019 PHILADELPHIA, PENNSYLVANIA

CEO Panel at Annual Forum, May 2018

Jay Carter at CarterCopter Exhibit Forum 74, May 2018

Forum 75 is May 13-16, 2019 @ Philadelphia

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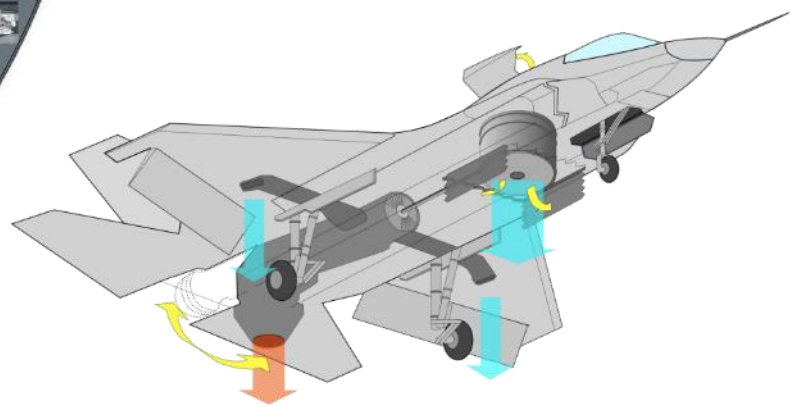
Time to Reinvent the Wheel!

The 20th Century proved that vertical flight was possible with combustion engines and drive systems

ASTOVL/JAST/JSF proved that the engine location could be decoupled from the center of gravity



Mechanical complexity led to high failure rate and fatal accidents for a "Wheel of Misfortune"
www.vtol.org/wheel

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The Electric VTOL Wheel of Fortune

Shown here are representative aircraft designs in major categorization of electric propulsion VTOL aircraft.

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Electric VTOL Categories

(*120+* aircraft a/o Sep 2018 on www.eVTOL.news)

Vectored Thrust

An eVTOL aircraft that uses any of its thrusters for lift and cruise:

- A³ Vahana
- aeroG Aviation aG-4
- AgustaWestland Project Zero
- AirisOne
- AirspaceX MOBi
- Aston Martin Volante
- Aurora Flight Sciences LightningStrike (defunct)
- Autonomous Flight Y6S
- Bartini Flying Car
- Bell Air Taxi
- Carter Aviation Air Taxi
- DeLorean Aerospace DR-7
- Digi Robotics DroFire
- Digi Robotics Droxi
- Dufour aEro2
- EVA X01
- HopFlyt Venturi
- JAXA Hornisse 2B
- Jetoptera J2000
- Joby Aviation Lotus (defunct)
- Joby Aviation S2 (defunct)
- Joby Aviation S4
- Karem Butterfly
- KARI PAV
- Lilium Jet
- Moller Skycar M200
- Moller Skycar M400
- Neoptera eOpter
- Opener BlackFly
- Piasecki eVTOL
- Pipistrel (unnamed)
- PteroDynamics Transwing
- Rolls-Royce EVTOL
- Sabrewing Draco-2
- Sikorsky VERT
- SKYLYS Aircraft AO
- Starling Jet
- Supervolant Pegasus
- Terrafugia TF-2 Tiltrotor
- Terrafugia TF-X
- Transcend Air Vy 400
- VerdeGo Aero PAT200
- Vertiia
- Vickers WAVE eVTOL
- Vimana AAV
- Vision VTOL
- VTOL Aviation Abhiyaan
- XTI Aircraft Trifan 600
- Zenith Altitude EOPA

Lift + Cruise

Completely independent thrusters used for cruise as for lift:

- AeroMobil 5.0
- Aergility ATLIS
- Aurora Flight Sciences eVTOL
- AutoFlightX BAT600
- EAC Whisper
- Embraer DreamMaker
- Flexcraft
- Hi-Lite Lynx-us
- HoverSurf Formula
- Kitty Hawk Cora
- Napoleon Aero VTOL
- Pipistrel (unnamed)
- Ray Research VTOL Aircraft
- Terrafugia TF-2 Lift + Push
- Urban Aeronautics CityHawk
- Zee Aero Z-P2

Electric VTOL Categories

(*120+* aircraft a/o Sep 2018 on www.eVTOL.news)

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Wingless (Multicopter)

No thruster for cruise – only for lift.

- Airbus Helicopters CityAirbus
- Alauda Airspeeder
- Astro AA360 ("Passenger Drone")
- Avianovations Hepard
- Axix SkyRider SuvA
- Boeing Cargo Aerial Vehicle
- Cartivator SkyDrive
- chAIR Multicopter
- Davinci ZeroG
- Dekatone (unnamed)
- EHang 184
- EHang 216
- Jetpack Aviation (unnamed)
- Kármán XK-1
- Kenyan Passenger Drone
- Kitty Hawk Flyer
- ManDrone
- NUS Snowstorm
- PAV-UL Ultralight
- PAV-X
- Pop.Up Next
- Skypod Aerospace Skypod
- Sky-Hopper
- Swarm Multicopter
- Volocopter 2X
- Volocopter VC1/VC2 (defunct prototypes)
- Volocopter VC200
- VRCO NeoXCraft
- Workhorse SureFly

Hover Bikes/ Personal Flying Devices

- Aeroxo ERA Aviabike*
- Assen A1
- Bay Zoltán Flike
- Electric Jet EJ-1
- Flyt Aerospace FlytCycle
- Georgia TechHummingBuzz*
- Gravity X
- Hero Flyer
- HoverSurf Drone Taxi R-1
- HoverSurf Scorpion
- Kalashnikov (unnamed)
- Kitty Hawk Flyer (defunct prototype)
- Leap Vantage*
- Malloy Aeronautics Hoverbike
- NASA Puffin
- Neva Aerospace AirQuadOne
- Penn State University Blue Sparrow*
- Ray Research Dart Flyer
- Scoop Pegasus 1*
- Silverwing S1*
- teTra 3*
- Telaria
- Texas A&M University Harmony*
- Trek Aerospace FlyKart 2*
- University of Kansas Mamba*

Electric Helicopters

An eVTOL aircraft that utilizes a helicopter frame

- Sikorsky Firefly
- Solution F
- Tier One Modified Robinson R44
- Volta

* GoFly Phase I winner

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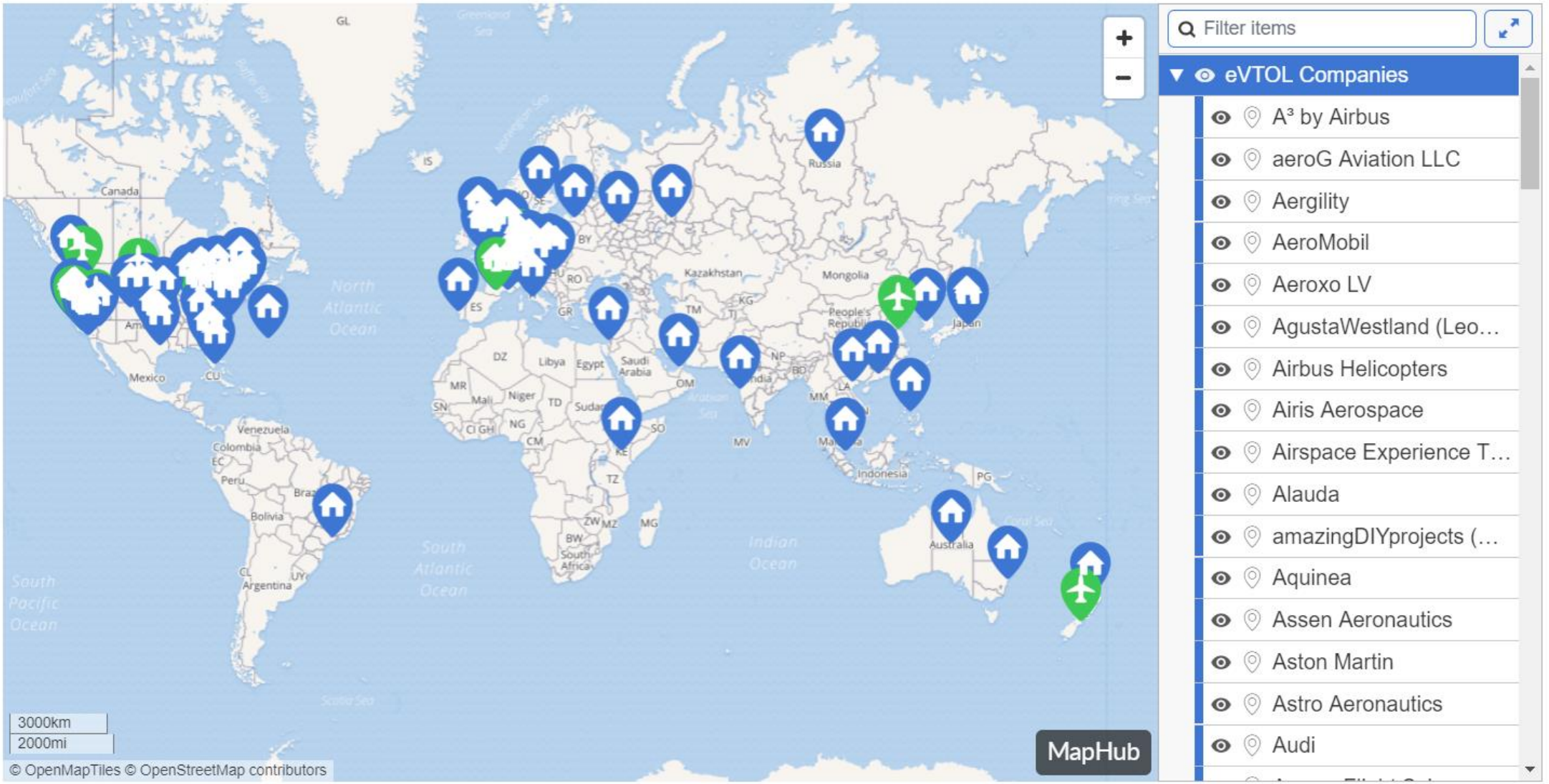
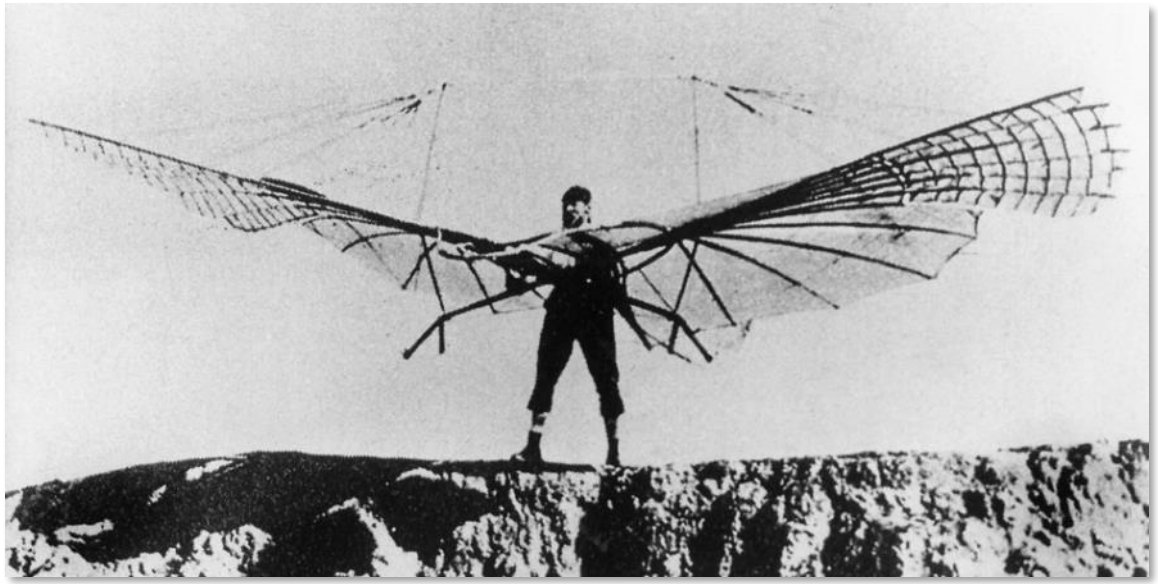
Where in the World?



120 Electric VTOL Designs!?

"To invent an airplane is nothing. To build one is something. To fly is *everything*."
Otto Lilienthal



"If you want to end up with a *small fortune* in aerospace, you need to start out with a *large one!*"
Anonymous

Is the Electric VTOL revolution going to revolutionize society … or will it flame out as have so many ideas before it?

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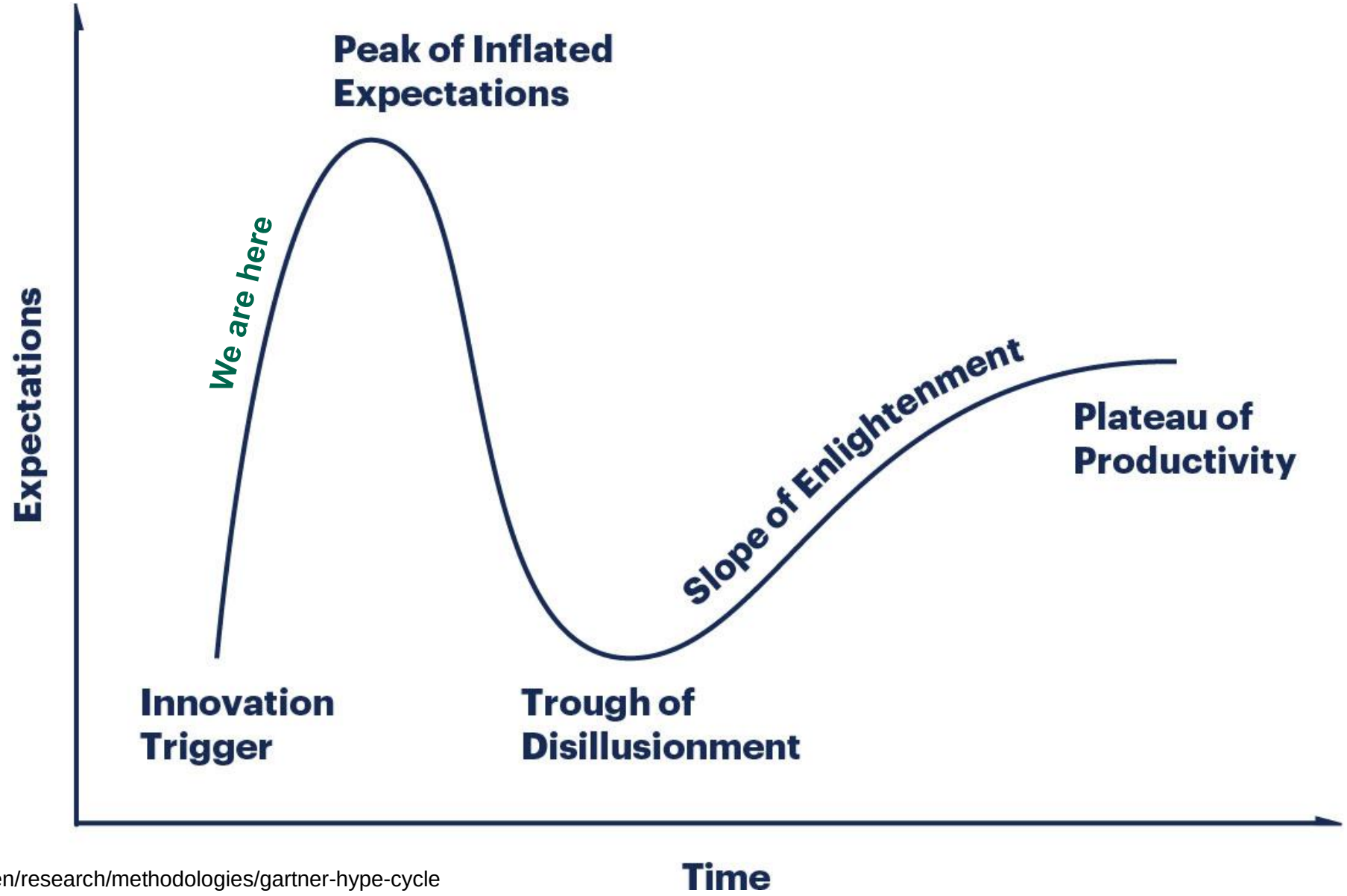
"The Hype Cycle"



https://www.gartner.com/en/research/methodologies/gartner-hype-cycle

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Why Now?

Advancements in electric motors
+ Advancements in batteries
+ Advancements in computer modeling and simulation
+ Advancements in composites
+ Low cost manufacturing
+ Movement to performance regs
+ Tech innovations
+ Tech investments >> $1B
= **Enabling new configurations and new innovations**

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Electric Helicopters?

- Not this!
- Cars were not buggies with mechanical horses

- Eliminate complex rotors!
  - Cyclic, collective, swashplate
  - Transmissions, gearboxes, shafting, hydraulics, etc.
- Distributed Electric Propulsion
  - Replace single complex system with multiple simple thrusters
- Get on a wing for efficiency
  - Higher speed, longer range
- Environment
  - Noise, noise, noise!
  - “Tailpipe” emissions

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Pre-Historic eVTOL

NASA Puffin
Single-Seat Electric VTOL Study
(2010)

AgustaWestland Project Zero
Unmanned
(July 2011)

Solution F
1st Electric VTOL flight
By Pascal Chretien
(Aug. 4, 2011)

e-volo
1st Electric VTOL Multicopter
Volocopter VC1
(Oct. 21, 2011)

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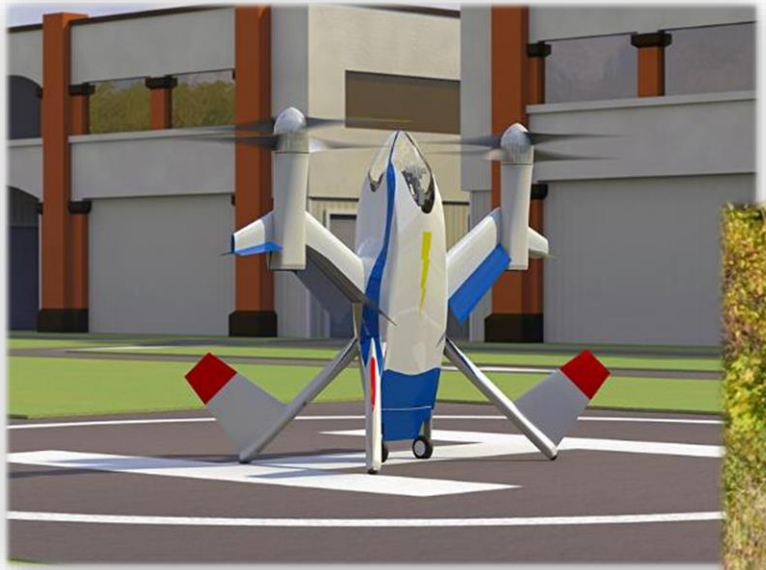
Pre-Historic eVTOL



NASA Puffin
Single-Seat Electric VTOL Study (2010)

Opener BlackFly (SkyKar Rebel)
Oct. 5, 2011

1st Electric VTOL flight
By Pascal Chretien
(Aug. 4, 2011)

AgustaWestland Project Zero
Unmanned

e-volo
1st Electric VTOL Multicopter
Volocopter VC1
(Oct. 21, 2011)

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Opener BlackFly

- SkyKar Rebel 1st fixed-wing eVTOL, followed by BlackFly V1, V2, V3
- V3 characteristics (predicted)
  - GTOW: 563 lb / 255 kg
  - Thrust: 900+ lb / 400+ kg
  - Max speed: 80+ mph / 130 kph
  - Max ROC: 1000 fpm (5 m/s)
  - Range: 40+ miles (65 km)

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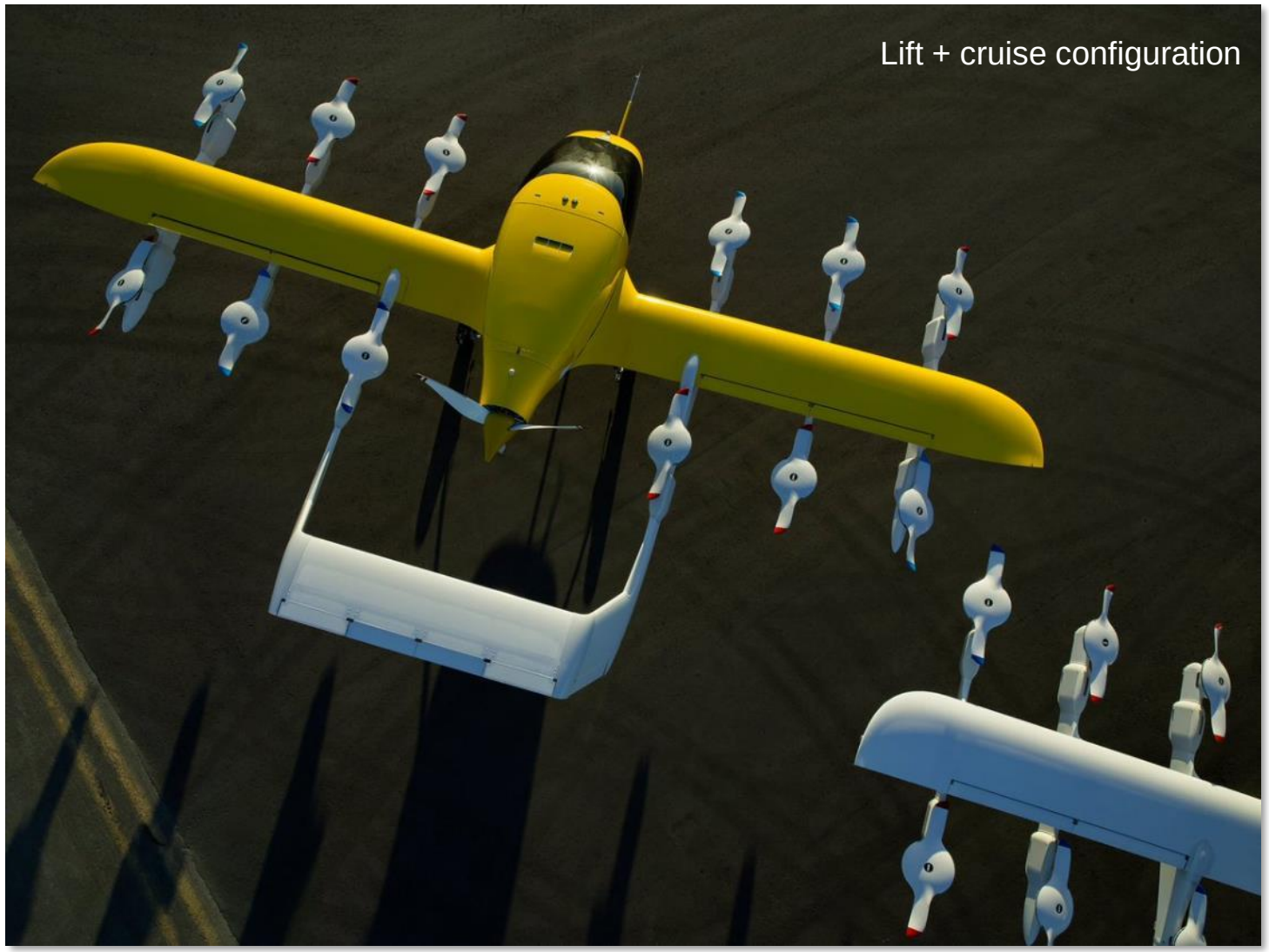
Kitty Hawk Cora



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Kitty Hawk Flyer

Electric Ultralight (Part 103 <254 lb)

e-volo 2x Multicopter
Now in pre-production

Photos courtesy of Volocopter GmbH

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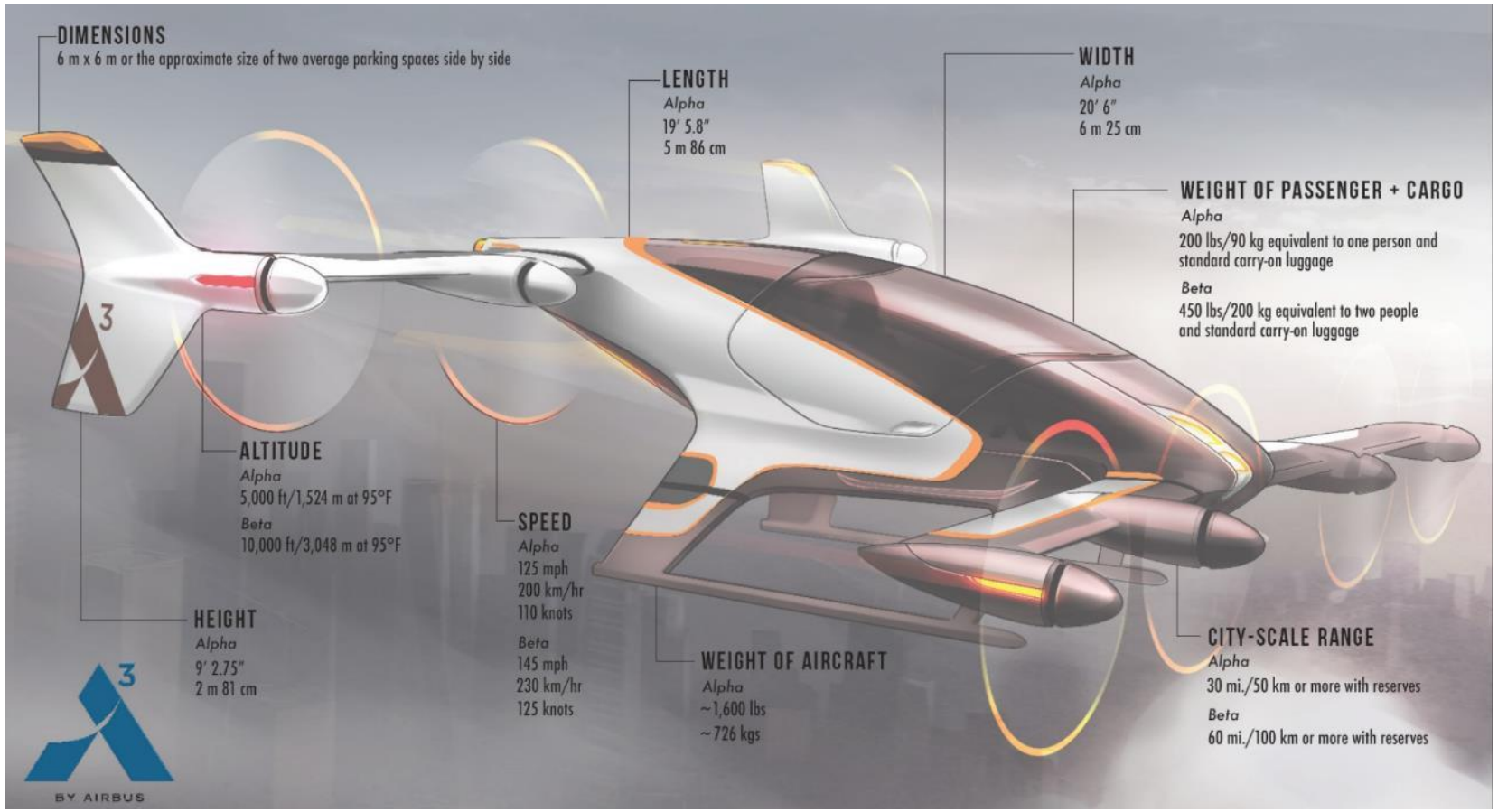
A³ By Airbus Vahana



Autonomous tandem electric tiltwing

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Joby Avation S4

Bloomberg Businessweek

February 1, 2018, 5:00 AM EST

Air-Taxi Startup Has a Working Prototype and a Fresh $100 Million

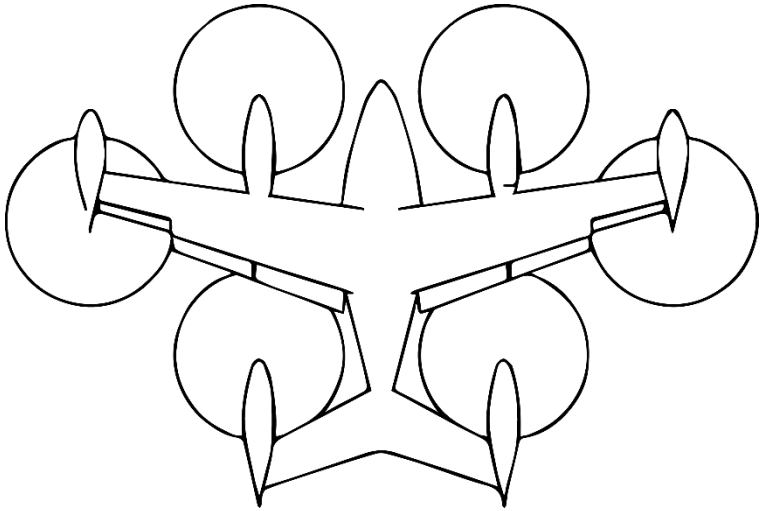
● Joby Aviation hides its craft at a secretive private airfield.

By Ashlee Vance and Brad Stone

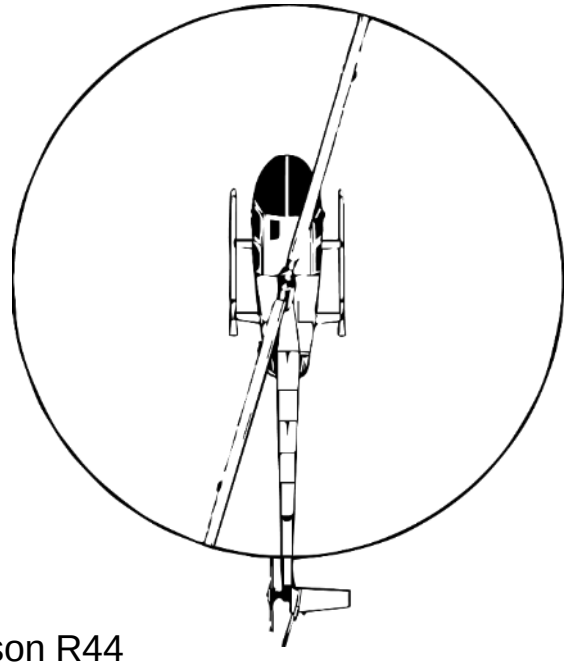
Hyperdrive

ILLUSTRATION: INKEE WANG FOR BLOOMBERG BUSINESSWEEK

"The pilot managed a vertical takeoff, 15 minutes of flight in a 15-mile loop, and a safe landing. Powered by electric motors and sophisticated control software, the taxi performs like a cross between a drone and a small plane, able to zip straight up on takeoff and then **fly at twice the speed of a helicopter while making about as much noise as a swarm of superbees.**"



<u>Joby S4</u>
4-Seat all-electric
6-propeller tiltrotor
Ultra-quiet
200 mph



<u>Robinson R44</u>
4-Seat piston
Single-main rotor
135 mph

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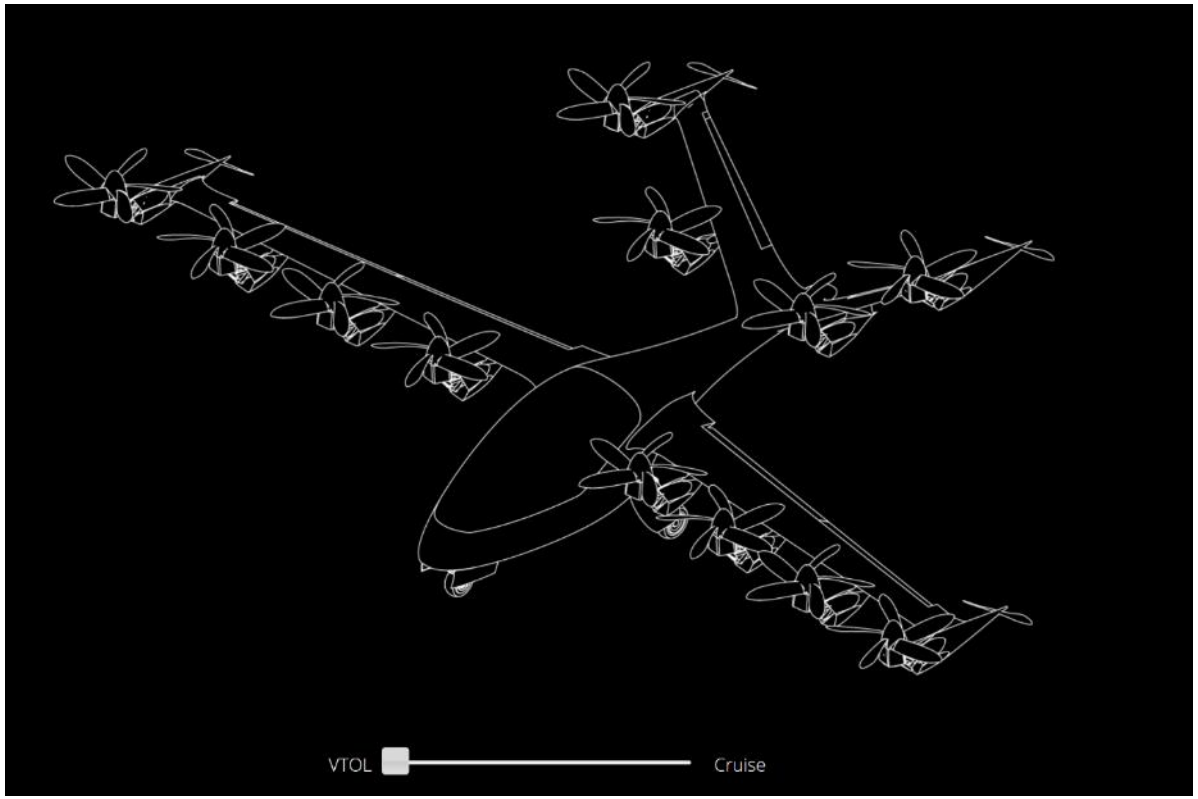
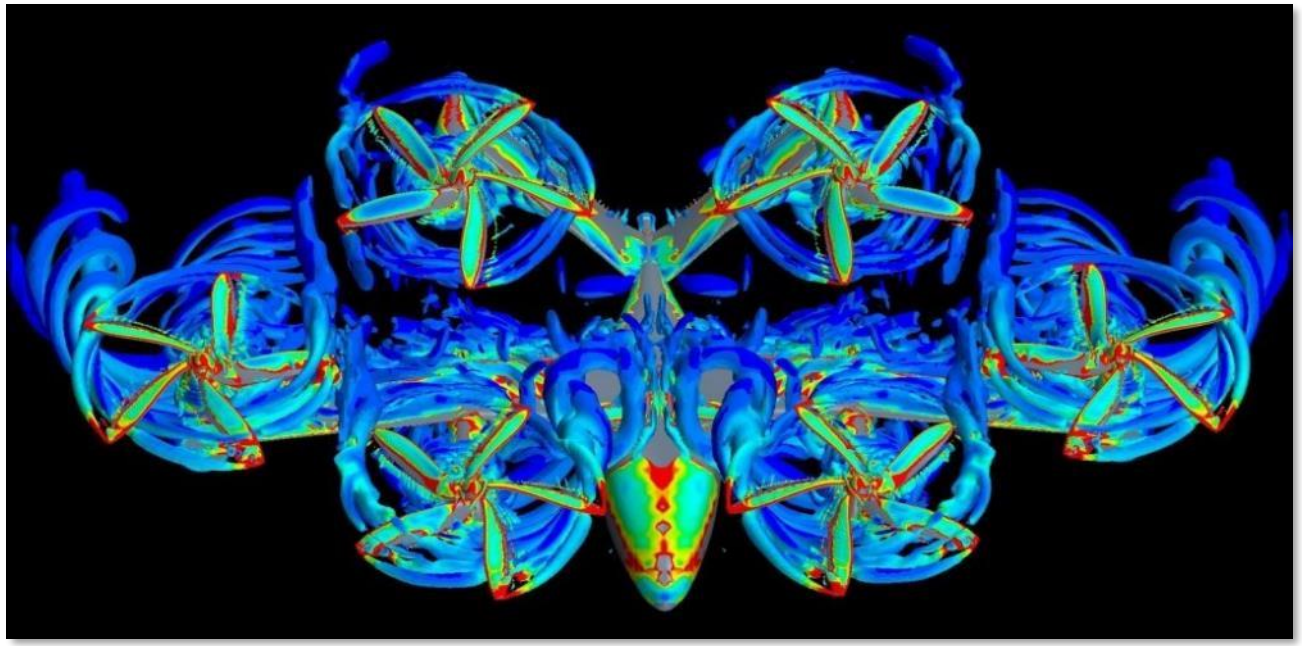
Joby Aviation



Original 2-seat Joby S2
12 lift/cruise propellers + 4 cruise propellers
All electric



Current 4-seat Joby S4
6 lift/cruise propellers
All electric

Graphics courtesy of Joby Aviation
Santa Cruz, California, USA

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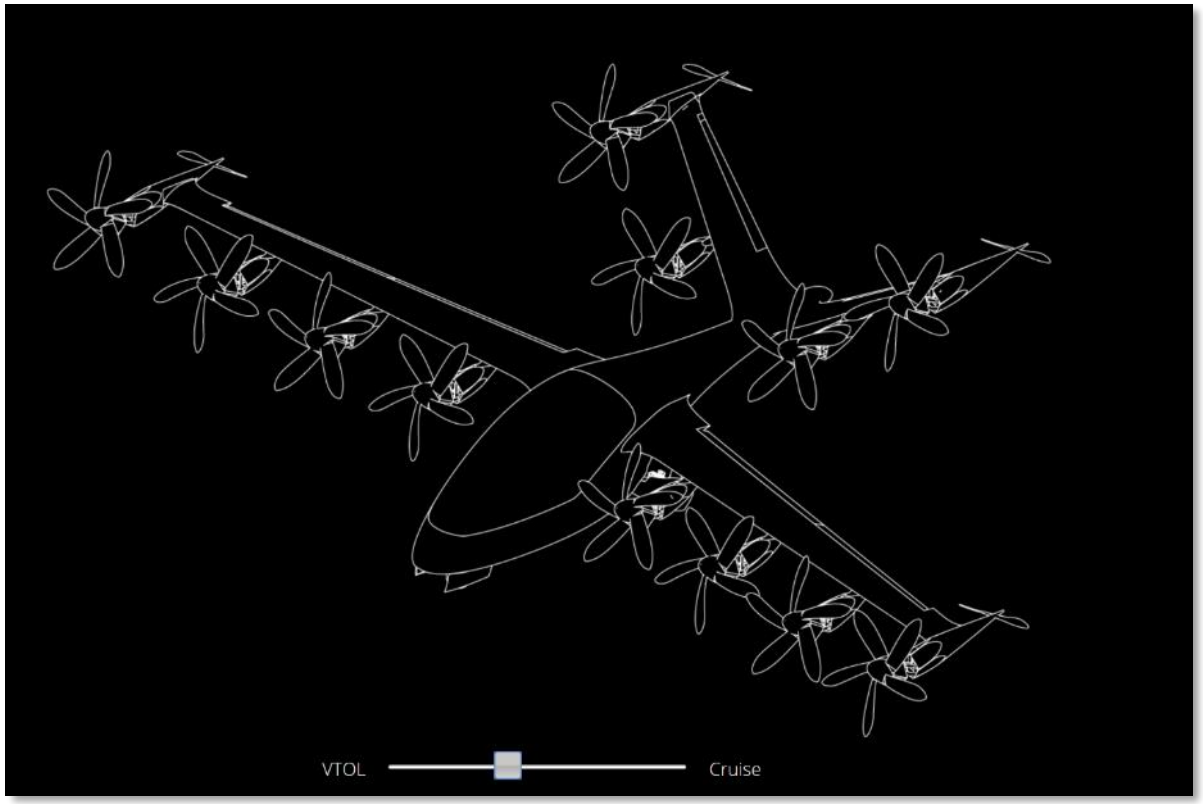
Joby Aviation



Original 2-seat Joby S2
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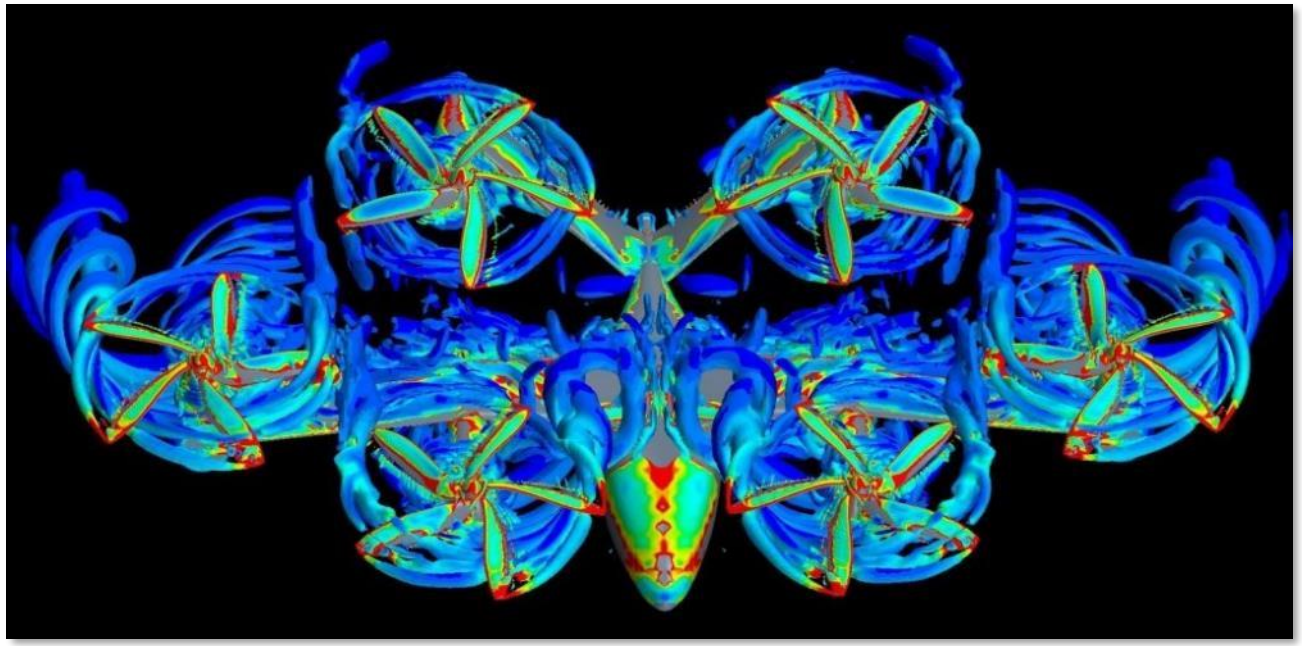

Current 4-seat Joby S4
6 lift/cruise propellers
All electric

Graphics courtesy of Joby Aviation
Santa Cruz, California, USA

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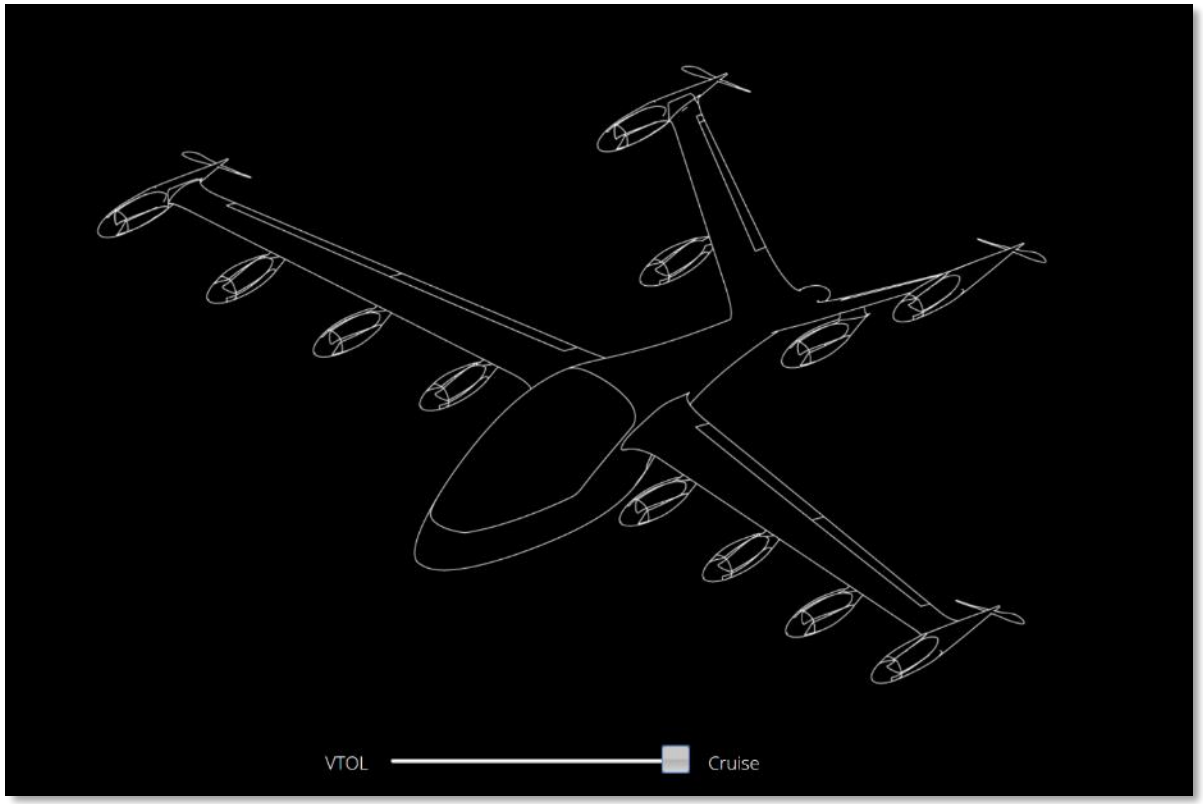
Joby Aviation



Original 2-seat Joby S2
12 lift/cruise propellers + 4 cruise propellers
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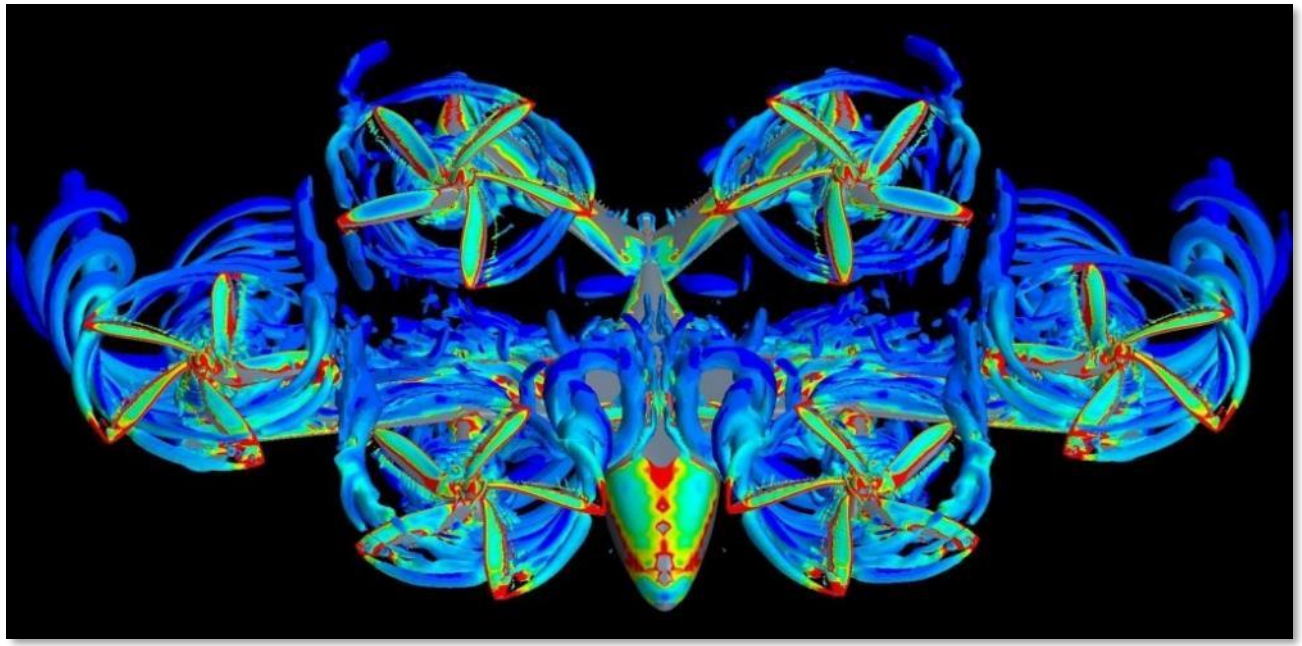

Current 4-seat Joby S4
6 lift/cruise propellers
All electric

Graphics courtesy of Joby Aviation
Santa Cruz, California, USA

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Lilium Jet

2-seat “Eagle” LiliumJet prototype
640 kg, all electric

New 5-seat
LiliumJet concept

- 36 electric fans
  - 24 on wings
  - 12 on canards
- 160 kt (300 km/h)
- “Eagle” first flight April 2017

Graphics courtesy of Lilium
Garching, Germany

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EHang 184 (and “216”)

1 Passenger
8 Propellers
4 Arms
Unveiled at CES 2016

2 Passengers
16 Propellers
8 Arms
Unveiled Feb. 2018

Graphics courtesy of EHang

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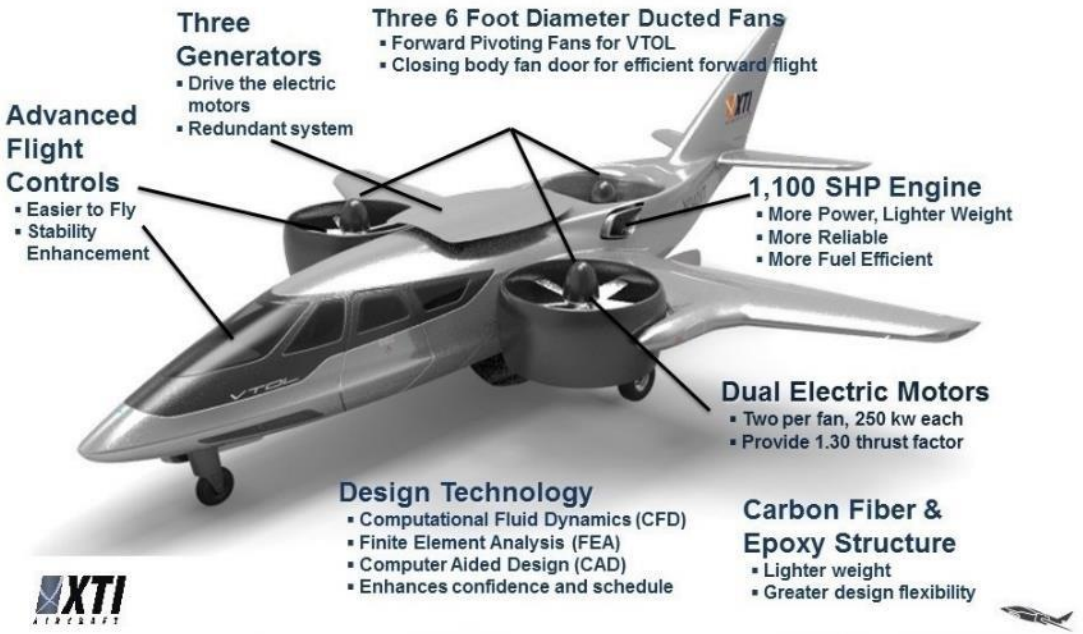
XTI Aircraft: TriFan 600

Hybrid-electric concept



Vertical Aerospace

- Full-Scale eVTOL concept: 750 kg / 1,650 lb
- Flown unmanned in June 2018
- Demonstrated 80 kph / 50 mph

Graphics courtesy of
Vertical Aerospace, Bristol, UK

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PteroDynamics

- Flying 4 ft span model since Jan 2017
- First hover of 12 ft demonstrator Aug 2018
- Targeting delivery drone and air taxi applications
- Efficient distance flight permitting lift/drag ratios >20
- Compact during VTOL and on the ground
- Payload capacities >40% of maximum takeoff weight

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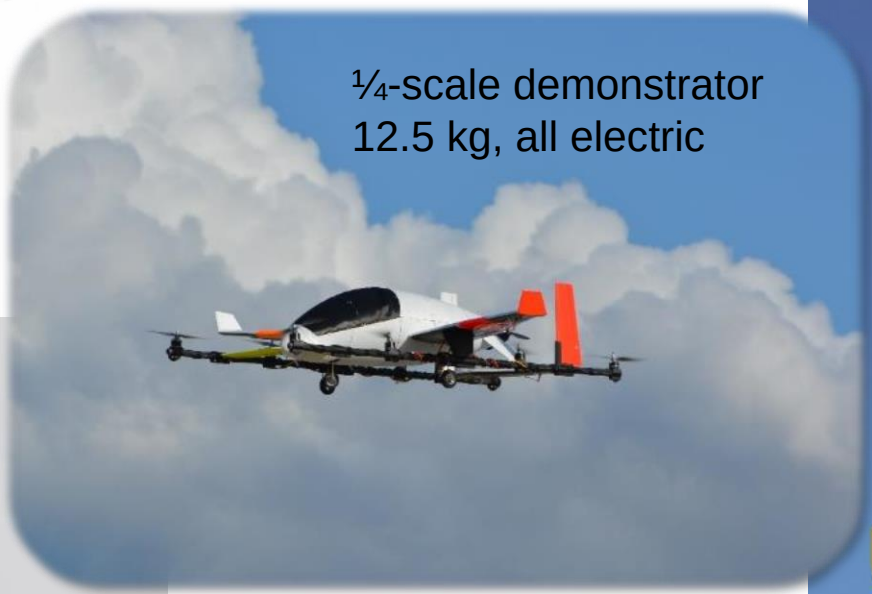
Aurora eVTOL

Full Scale eVTOL concept
800 kg, all electric

¼-scale demonstrator
12.5 kg, all electric



Graphics courtesy of Aurora
Manassas, Virginia, USA

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Uber Elevate

- Uber Elevate
  - Unveiled at eVTOL Workshop in Sep 2016
  - White Paper in Oct 2016
  - Summit in April 2017
- Developing an “Ecosystem”
  - Partnerships with cities, real estate companies, aircraft manufacturers, EV charger manufacturers and cities
  - Connecting innovators, investors, regulators, technical experts, media
- Small aircraft, but high barriers
  - Technical, regulatory, environmental, economic, infrastructural and cultural

- Started **www.eVTOL.news** website
  - 120+ aircraft concepts detailed
  - Many missions beyond Uber’s Elevate

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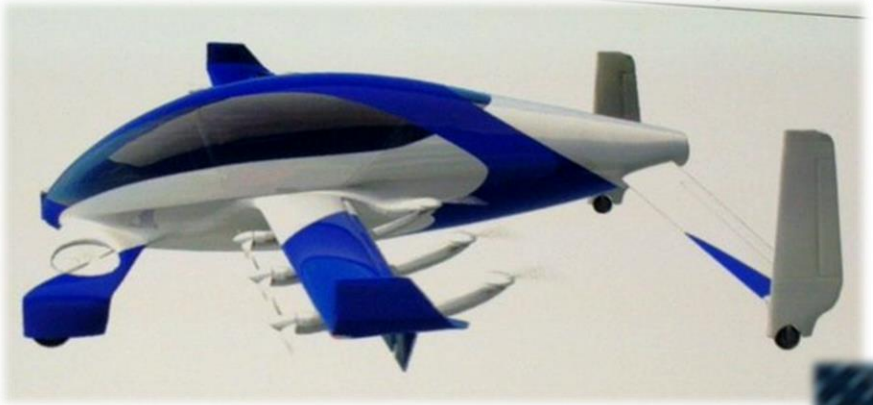
Uber Elevate Aircraft Partners



Aurora Flight Sciences

Bell

Pipistrel

Karem Aircraft

Embraer


GO FLY
SPONSORED BY
BOEING
www.goflyprize.com

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www.vtol.org

GoFly Prize

The GoFly Prize is a two-year, $2,000,000 USD competition to develop

safe, quiet, ultra-compact, near-VTOL personal flying devices

capable of flying twenty miles (32 km) while carrying a single person.

Max dimension: 8.5 ft (2.6 m)
Max noise: 85 dBA @ 50 ft (15 m)
Max speed: >30 kt (56 km/h)

2886 registered “innovators”
716 teams
164 Phase 1 proposals

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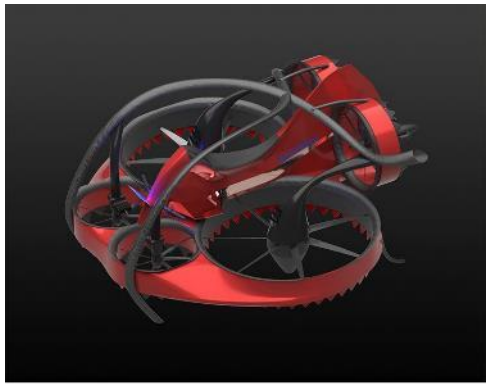
GoFly Prize Phase 1 Winners

10 winners announced 14 June @ $20k each

TEAM AEROXO LV | DEVICE ERA AVIABIKE

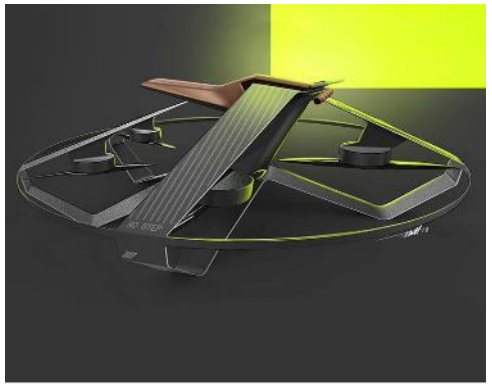


TEAM MAMBA | DEVICE MAMBA

TEAM TETRA | DEVICE TETRA 3

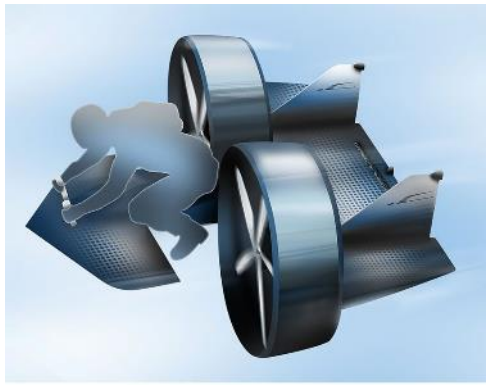
TEAM TEXAS A&M UNIVERSITY | DEVICE HARMONY

TEAM GEORGIA TECH | DEVICE HUMMINGBUZZ



TEAM LEAP | DEVICE VANTAGE

TEAM SCOOP | DEVICE PEGASUS 1



TEAM SILVERWING | DEVICE S1

TEAM BLUE SPARROW | DEVICE BLUE SPARROW

TEAM TREK AEROSPACE | DEVICE FLYKART 2

www.goflyprize.com

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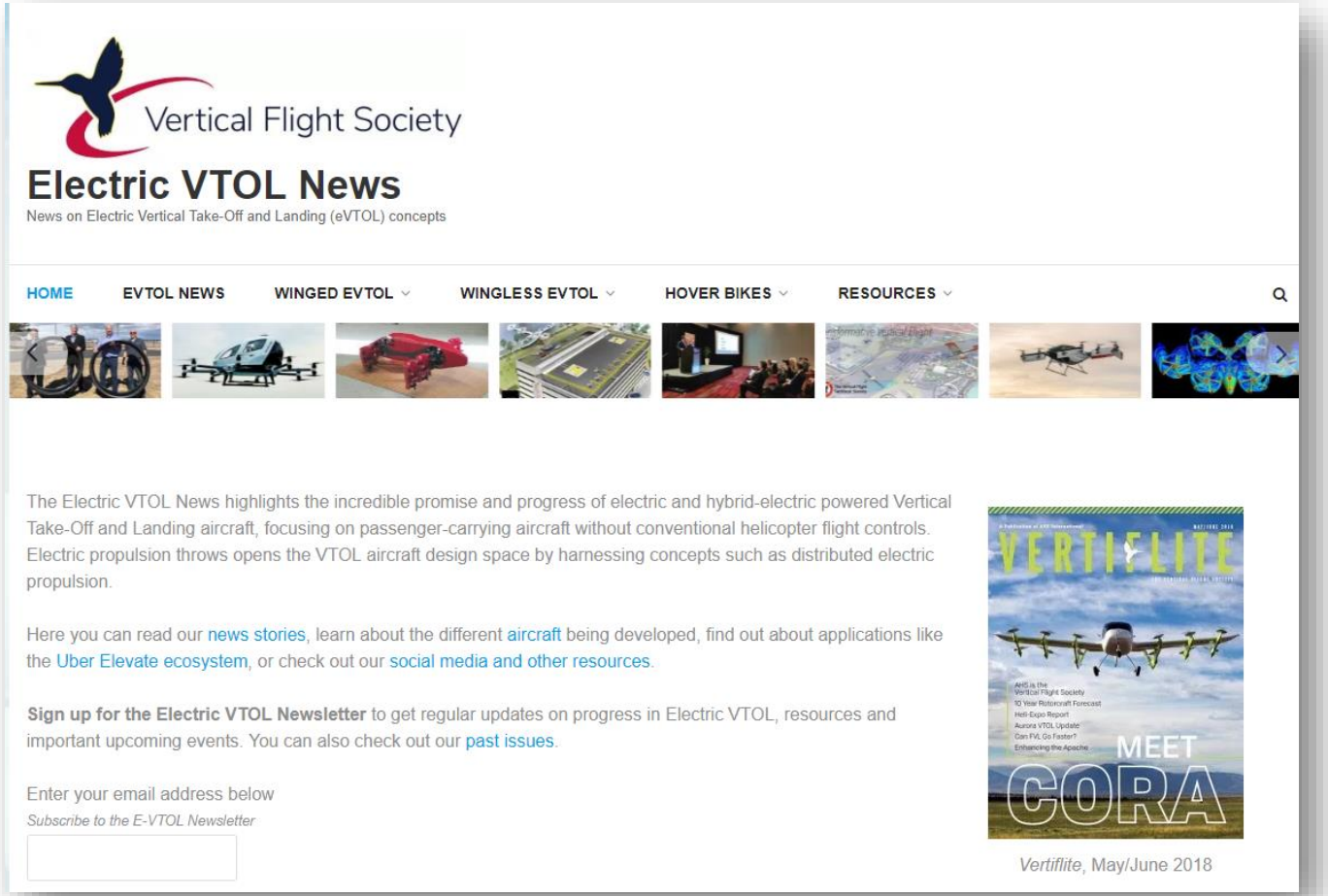
eVTOL Online Resources

- Electric VTOL News
  - **www.eVTOL.news**
  - **www.facebook.com/electricVTOL**
  - **www.twitter.com/electricVTOL**
  - **www.youtube.com/VTOLsociety**
  - **www.vimeo.com/VTOLsociety**

- Also
  - Email newsletter
  - eVTOL News videos
  - eVTOL video proceedings



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Summary

- VFS is the global Vertical Flight Society
  - If you are interested in VTOL, become a member!
  - 75th Annual Forum is May 13-16, 2019 in Philadelphia, Pennsylvania, USA
  - 6th Annual Electric VTOL Symposium: Jan. 29-31 in Mesa, Arizona, USA
  - Find out more at **www.vtol.org**

- Significant funds being invested in electric VTOL (>>$1B)
  - 120 companies investing heavily in electric and hybrid/electric VTOL aircraft
  - The explosive interest in drones is being repeated with manned eVTOL
  - The eVTOL community needs our help — many new to aviation
  - Find out more at **www.eVTOL.news**