The Electric VTOL Revolution

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Kitty Hawk Cora
Released March 2018
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
The Future of Vertical Flight

Military Developments  Distributed Electric VTOL  Advanced Civil Technologies  Urban Air Taxis

Disruptive Technologies and Approaches ...
The Future of Vertical Flight

Clean Sky 2 RACES FORWARD

Civil and Military Compound Helicopters

JMR Prepares for Takeoff

Civil and Military Tiltrotors

UrbanAero’s PancerCraft Transformation

Unconventional Configurations

Electric VTOL Takes Off

Winged eVTOL Flight Testing

…Enable a Transformation in Vertical Flight
Annual Forum attracts 1,250 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 is May 13-16, 2019 @ Philadelphia
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, and other

**Technical Experts Working to Help Shape the Future**
<table>
<thead>
<tr>
<th>Date</th>
<th>Event</th>
<th>Location</th>
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<tr>
<td>2018 Jan 16-19</td>
<td>Aeromechanics Design of Electric VTOL</td>
<td>San Francisco, Calif., USA</td>
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<tr>
<td>2018 Feb 21-22</td>
<td>Airworthiness and HUMS</td>
<td>Huntsville, Alabama, USA</td>
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<td>2018 May 14-17</td>
<td><strong>Forum 74</strong></td>
<td><strong>Phoenix, Arizona, USA</strong></td>
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<td>2018 Sep 4-6</td>
<td>3rd Australia Indo-Pacific Army Aviation*</td>
<td>Adelaide, Australia</td>
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<td>2018 Sep 18-21</td>
<td>European Rotorcraft Forum (ERF)*</td>
<td>Delft, The Netherlands</td>
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<td>2018 Oct 24-25</td>
<td>Helicopter Military Ops Tech (HELMOT)</td>
<td>Hampton, Virginia, USA</td>
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<td>2018 Oct 30-Nov 1</td>
<td>7th Asian-Australian Rotorcraft Forum*</td>
<td>Jeju Island, South Korea</td>
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<td>2018 Nov 13-15</td>
<td><strong>Intl Powered Lift Conference (IPLC)</strong>*</td>
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<td>2019 Jan 29-31</td>
<td><strong>Automomous VTOL/eVTOL</strong></td>
<td><strong>Mesa, Arizona, USA</strong></td>
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<td>2019 Feb 20-21</td>
<td>Development of Complex Systems (FVL)</td>
<td>Huntsville, Alabama, USA</td>
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<td>2019 Feb 27-28</td>
<td>10th Australian Pacific Vertiflite Conference</td>
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<td>2019 May 13-17</td>
<td><strong>Forum 75</strong></td>
<td><strong>Philadelphia, Pennsylvania, USA</strong></td>
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San Francisco, Jan. 16-19, 2018
    – www.vtol.org/TVF-2018 (slides and videos)

Watershed event with technologists from
    – Traditional: NASA, Army, OEMs, suppliers, etc.
    – eVTOL: Joby, Zee, Carter, Terrafugia, Aurora, etc.
    – New tech: Uber, Amazon, Honda, Toyota, Intel, etc.
    – Big OEMs: Embraer, Boeing, Bell, Airbus, etc.

Technical community has embraced the future of vertical flight

Vertical Flight Society provides forum for understanding and collaboration

VFS Recognized as a Leader in Electric VTOL
Uber Elevate

- Unveiled at AHS Workshop in Sep 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
- 90+ aircraft concepts detailed
- Many missions beyond Uber’s Elevate
Uber Elevate Aircraft Partners

- Aurora Flight Sciences
- Bell
- Pipistrel
- Karem Aircraft
- Embraer
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
The Electric VTOL Wheel of Fortune

Shown here are representative aircraft designs in major categorization of electric propulsion VTOL aircraft.
**Electric VTOL Categories**
*(80 aircraft a/o Jun 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
- AirisOne
- Aurora Flight Sciences LightningStrike
- Autonomous Flight Y6S
- Bartini Flying Car
- Bell Air Taxi
- Carter Aviation CarterCopter (probably)
- DeLorean Aerospace DR-7
- Digi Robotics DroFire
- Digi Robotics Droxi
- Dufour aEro2
- EVA X01
- HopFlyt Venturi
- JAXA Hornisse 2B
- Jetoptera J2000
- Joby Aviation S4
- Karem Butterfly
- KARI PAV
- Lilium Jet
- Moller Skycar M400
- Neoptera eOpter
- Piasecki eVTOL
- Pipistrel (unnamed)
- PteroDynamics Transwing
- Sabrewing Draco-2
- Sikorsky VERT
- SKYLYS Aircraft AO
- Starling Jet
- Supervolant Pegasus
- Terrafugia TF-2 (“Tiltrotor”)
- Transcend Air Vy 400
- VerdeGo Aero PAT200
- Vertiia
- Vickers WAVE eVTOL
- Vimana (unnamed)
- VTOL Aviation Abhiyaan
- XTI Aircraft Trifan 600
- Zenith Altitude EOPA

### Lift + Cruise
Completely independent thrusters used for cruise as for lift:
- AeroMobil 5.0
- Aurora Flight Sciences eVTOL
- EAC Whisper
- Embraer (unnamed)
- Flexcraft (unnamed)
- HoverSurf Formula
- Kitty Hawk Cora
- Napoleon Aero VTOL
- Ray Research VTOL Aircraft
- Urban Aeronautics CityHawk
- Zee Aero Z-P2

### Wingless (Multicopter)
No thruster for cruise – only for lift.
- Airbus Helicopters CityAirbus
- Alauda Airspeeder
- Astro AA360 (“Passenger Drone”)
- Avianovations Heperd
- Avianovations Hepard
- Boeing Cargo Aerial Vehicle
- Cartivator SkyDrive
- Dekatone (unnamed)
- EHang 184
- Jetpack Aviation (unnamed)
- Kármán XK-1
- Kitty Hawk Flyer
- Neva Aerospace AirQuadOne
- Passenger Drone
- PAV-UL Ultralight
- PAVX
- Pop.Up Next
- Skypad Aerospace Skypad
- Terrafugia TF-2 (“Lift + Push”)
- Volocopter VC200 / 2X
- VRCO NeoXCraft
- Workhorse SureFly
“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?
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
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

Not this!
- Cars were not buggies with mechanical horses
Pre-Historic eVTOL


AgustaWestland Project Zero Unmanned (July 2011)

Solution F Electric VTOL flight By Pascal Chretien (Aug. 2011)

e-volo Electric VTOL Volocopter VC1 (Oct. 2011)
Multi-“Rotor” Distributed Electric Propulsion

NASA GL-10 Greased Lightning (2014 tethered, 2015 transition)

Volocopter VC200 (2013 tethered, 2016 manned)
Kitty Hawk Flyer

Prototype

Production

Electric Ultralight (Part 103 <254 lb)
e-volo 2x Multicopter
Now in pre-production

Photos courtesy of Volocopter GmbH
Aviation Comes to the Consumer @ CES 2018

Volocopter

Workhorse

Bell

Bell
**A³ By Airbus Vahana**

Autonomous tandem electric tiltwing
Aurora eVTOL

Full Scale eVTOL concept
800 kg, all electric

1/4-scale demonstrator
12.5 kg, all electric

Graphics courtesy of Aurora
Manassas, Virginia, USA
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

Joby S4
4-Seat all-electric
6-propeller tiltrotor
Ultra-quiet
200 mph

Robinson R44
4-Seat piston
Single-main rotor
135 mph

“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.”
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
Lilium Jet

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

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

New 5-seat LiliumJet concept

Graphics courtesy of Lilium Garching, Germany
1 Passenger
8 Propellers
4 Arms
Unveiled at CES 2016

2 Passengers
16 Propellers
8 Arms
Unveiled Feb. 2018

Graphics courtesy of EHang
XTI Aircraft: TriFan 600
Hybrid-electric concept

Three Generators
- Drive the electric motors
- Redundant system

Three 6 Foot Diameter Ducted Fans
- Forward Pivoting Fans for VTOL
- Closing body fan door for efficient forward flight

1,100 SHP Engine
- More Power, Lighter Weight
- More Reliable
- More Fuel Efficient

Dual Electric Motors
- Two per fan, 260 kW each
- Provide 1.30 thrust factor

Advanced Flight Controls
- Easier to Fly
- Stability Enhancement

Design Technology
- Computational Fluid Dynamics (CFD)
- Finite Element Analysis (FEA)
- Computer Aided Design (CAD)
- Enhances confidence and schedule

Carbon Fiber & Epoxy Structure
- Lighter weight
- Greater design flexibility

www.eVTOL.news
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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
GoFly Prize Phase 1 Winners
10 winners announced 14 June @ $20k each

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
  - Analytical report (Jan. 2018)
Summary

- AHS 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
  - 7th Annual Electric VTOL Symposium: Jan. 2020 in San Jose?
  - Find out more at www.vtol.org

- Significant funds being invested in electric VTOL (>$1B)
  - 90+ companies investing heavily in electric and hybrid/electric VTOL aircraft
  - The explosive interest in drones is being repeated with manned eVTOL
  - Find out more at www.eVTOL.news