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

Transformative Vertical Flight Workshops
- Building community & developing industry roadmap
- https://nari.arc.nasa.gov/wghome

Since 2014, annual series with NASA, etc.
2. Aug 2015, NASA Ames, California
4. Jun 2017, Denver, Colorado
5. Jan 2018, San Francisco, California
6. Jan 2019, Phoenix, Arizona
7. Jan 2020, Mountain View, California

Presentations, videos and links at
- http://www.vtol.org/transformative

Significant funding in electric VTOL >$1B+
- >100 companies developing electric and hybrid/electric VTOL aircraft

Uber Elevate
- Unveiled at 4th Workshop in Sep 2016
- White Paper in Oct 2016 / Summit in April 2017

Developing an “Ecosystem”
- Partnerships with cities, real estate companies, aircraft OEMs, EV charger manufacturers & cities
- Connecting innovators, investors, regulators, technical experts, standards organizations
Conventional Helicopters Today
Bell 505 JetRanger X – EIS 2017
Traditional Technology Development Path

- Military Research & Development
  - Engines
  - Systems
  - Airframes

- Research Organizations (NASA, etc.)
  - Aerodynamics and Modeling
  - Structures - Composite Airframes
  - Propulsion - Alternate Fuel Engines

- Company-Funded Innovation and R&D
  - Airliners, helicopters, tilt rotors, compound helicopters
  - Light aircraft Innovation - Burt Rutan, Cirrus, Diamond
  - New Aircraft classes – Regional Jets, single-engine turboprops, singleengine jets
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

Civil and Military Compound Helicopters
Civil and Military Tiltrotors
Unconventional Configurations
Winged eVTOL Flight Testing

... Enable a Transformation in Vertical Flight
Advancements in electric motors
+ Advancements in batteries
+ Advancements in computer modeling, simulation and AI
+ Advancements in composites
+ Low cost manufacturing
+ Change in FAR Part 23
+ Tech innovations
+ Tech investments > $1B

= Enabling new configurations and new innovations
Electric Helicopters?

- 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)
Opener Blackfly
Marcus Leng – Canada & USA

Skykar Rebel – Oct 5, 2011

Opener Blackfly V2 – March 2018
Disruptive Technology

▪ eVTOL is Revolution in aerospace technology
  – Electrification of Aviation – gliders, trainers, VTOL, Regional, Mainline
  – Cost reduction, “Green” technology
  – Highly integrated designs

▪ Key drivers
  – Advances in electric motors, batteries, controllers, autonomy, situational awareness and artificial intelligence
  – Leverage technologies from non-aviation sectors

▪ Key Motivations
  – Silent, agile, safe, autonomous, “on-demand” urban VTOL
  – Short term: trade performance for new mission / market (batteries not there yet)
  – Long term: gain performance through enabling technologies
Multi-“Rotor” Configurations

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

e-volo Volocopter VC200
(2013 tethered, 2016 manned)
e-volo 2x Multicopter
Now in pre-production

Photos courtesy of Volocopter GmbH
Lilium Aviation

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 Aviation
Garching, Germany
Joby Avation S4

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

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

- Unveiled at AHS Workshop in Sep 2016
- 1st 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

Smaller aircraft, but higher barriers
- Technical, regulatory, environmental, economic, infrastructural and cultural

Started www.eVTOL.news website
- 75 aircraft concepts detailed
- Many missions beyond Uber’s Elevate
Imagine the Future – Uber Skyport
NASA – a safe and efficient system for vehicles, pilots or not, to move passengers and cargo within a city

What is the market for an electric or hybrid electric VTOL aircraft?

– Urban Air Mobility
  • Recognize growing urban passenger demand and road congestion (value of time, connectivity)
  • Infrastructure Limitations – lack of investment in roads, surface transportation
  • Urban Origin and & Destination Megadata
    – Uber Passenger O&D Data, Cell Phone O&D Data & Google Map & Waze
  • High volume production & high demand utilizations (Uber 1,000 vehicles at DFW)
  • Revenue potential

New Value Proposition

• Short haul eVTOL flights to avoid congestion and save time
• Create Ecosystem – includes battery technology, ground infrastructure (skyports), charging technology, air corridors (ATC), autonomy, sense and avoid, APP’s
Market Disruption & Industry Disruption?

- New eVTOL aircraft providing new urban air mobility services
- Silicon Valley investing in eVTOL platforms & sector development (Tesla, SpaceX)
- Silicon Valley seeks to be a major developers & operator of eVTOL aircraft
  - Uber Elevate – expand urban mobility options to include urban air mobility
  - Larry Page provided approx. $250M to Zee Aero / Kitty Hawk eVTOL programs
  - Joby Aviation – flight testing new eVTOL vehicle in secret for past two years
  - SkyKar/Opener BlackFly – first flight October 2011 in Canada; Moves to Silicon Valley 2014
- Disrupting Traditional OEMs – driving internal disruption of leading OEMs
  - Airbus, Embraer, Bell, Boeing, P&WC, Safran, Rolls Royce
- Promise of Significant reduction in operating and maintenance costs and noise
  - Expand urban market penetration – new Vertiports
  - Significant reduction in trip and seat mile costs
  - Facilitate new market applications
- Significant Airspace Integration, Development and Certification Challenges
Transformative Vertical Flight

- San Francisco, Jan. 16-19, 2018
  - www.vtol.org/TVF-2018
- 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, Airbus, etc.
- Technical community has embraced the future of vertical flight
- AHS provides the forum for understanding and collaboration

AHS Recognized as a Leader in Electric VTOL
Flight Global, Feb. 19, 2018
• “OPINION: Are air taxis on a ride to nowhere?”

AHS TVF5 Participant Survey
• Did the Conference and/or Workshop change your mind?
• Will eVTOL be operational in 5-10 years?

Unmanned air taxis? (Poll Closed)

- All hail (207 votes) 15.36%
- Fleeting gimmick (439 votes) 32.57%
- Rank stupidity (702 votes) 52.07%

Total Votes: 1,348

84% say won’t happen

59% say will happen in 5-10 years

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Uber Elevate Aircraft Partners

Aurora Flight Sciences

Bell

Pipistrel

Karem Aircraft

Embraer
Boeing Aurora eVTOL

- 8 VTOL electric props
- 1 pusher electric prop
- 97 kt (180 km/h)
- First Flight 2018

Full Scale eVTOL concept
800 kg, all electric

1/4-scale demonstrator
12.5 kg, all electric

Graphics courtesy of Aurora
Manassas, Virginia, USA
AeroVelo wins AHS Sikorsky Prize
Recruited by Google eVTOL Initiative
Kitty Hawk Flyer Prototype
Dr. Todd Reichert Pilot
Kitty Hawk Cora

Autonomous Lift+Cruise DEP
A³ By Airbus Vahana

Autonomous tandem electric tiltwing
XTI Aircraft TriFan 600 & Demonstrator

Advances in technologies overcome historical challenges
Result is greater performance and increased safety

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, 250 kw each
- Provide 1.30 thrust factor

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

60% prototype fan duct inlets
Aviation Comes to the Consumer @ CES 2018 – Las Vegas
Electric VTOL Categories
July 15, 2018

- 45 vectored thrust aircraft
  - An eVTOL aircraft that uses any of its thrusters for lift and cruise
- 12 lift + cruise configuration
  - Completely independent thrusters used for cruise as for lift
- 24 wingless multicopter aircraft
  - No thruster for cruise – only for lift.
- 23 Hover Bikes/Personal Flying Devices.
  - Pilot sits on a saddle or is standing, or something similar. All are multi-copter-type wingless configurations.
<table>
<thead>
<tr>
<th>Electric VTOL Categories</th>
<th>Vectored Thrust</th>
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<tbody>
<tr>
<td>1. A³ Vahana</td>
<td>14. EVA X01</td>
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<td>2. aeroG Aviation aG-4</td>
<td>15. HopFlyt Venturi</td>
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<td>3. AirisOne</td>
<td>16. JAXA Hornisse 2B</td>
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<td>5. Aurora Flight Sciences</td>
<td>18. Joby Aviation S2 (defunct)</td>
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<td>Aurora LightningStrike (defunct)</td>
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<td>8. Bell Air Taxi</td>
<td>21. KARI PAV</td>
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<td>9. Carter Aviation</td>
<td>22. Lilium Jet</td>
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<td>CarterCopter</td>
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<td>10. DeLorean Aerospace DR-7</td>
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<td>12. Digi Robotics Droxi</td>
<td>26. Piasecki eVTOL</td>
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<td>13. Dufour aEro2</td>
<td>27. Pipistrel (unnamed)</td>
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<td>28. PteroDynamics Transwing</td>
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<td>34. Supervolant Pegasus</td>
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<td>35. Terrafugia TF-2 Lift + Push</td>
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<td>37. Terrafugia TF-X</td>
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<td>38. Transcend Air Vy 400</td>
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<td>39. VerdeGo Aero PAT200</td>
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<td>41. Vickers WAVE eVTOL</td>
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<td>42. Vimana (unnamed)</td>
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<td>43. VTOL Aviation Abhiyaan</td>
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<td>44. XTI Aircraft Trifan 600</td>
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<td>45. Zenith Altitude EOPA</td>
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<td>46. Trifan 600</td>
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</tbody>
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## Electric VTOL Categories

### Lift + Cruise
1. AeroMobil 5.0
2. Aerigility ATLIS
3. Aurora Flight Sciences eVTOL
4. EAC Whisper
5. Embraer (unnamed)
6. Flexcraft (unnamed)
7. HoverSurf Formula
8. Kitty Hawk Cora
9. Napoleon Aero VTOL
10. Ray Research VTOL Aircraft
11. Urban Aeronautics CityHawk
12. Zee Aero Z-P2

### Electric Helicopters
1. Sikorsky Firefly (SH300)
2. Solution F
3. Tier One Modified Robinson R44
4. Volta (Microcopter MC1)

### Wingless
1. Airbus Helicopters CityAirbus
2. Alauda Airspeeder
3. Astro AA360 (“Passenger Drone”)
4. Avianovations Hepard
5. Boeing Cargo Aerial Vehicle
6. Cartivator SkyDrive
7. chAIR Multicopter
8. Dekatone (unnamed)
9. EHang 184
10. EHang 216
11. Jetpack Aviation (unnamed)
12. Kármán XK-1
13. Kenyan Passenger Drone
14. Kitty Hawk Flyer
15. PAV-UL Ultralight
16. PAVX
17. Up Next
18. Skypod Aerospace Skypod
19. Sky-Hopper
20. Swarm Multicopter
21. Volocopter 2X
22. Volocopter VC200
23. VRCO NeoXCraft
24. Workhorse SureFly
### Electric VTOL Categories

#### Hover Bikes/Personal Flying Devices

1. Aeroxo ERA Aviabike*  
2. Bay Zoltán Flike  
3. Davinci ZeroG  
4. Flyt Aerospace FlytCycle  
5. Georgia TechHummingBuzz*  
6. Gravity X  
7. Hero Flyer  
8. HoverSurf Drone Taxi R-1  
9. HoverSurf Scorpion  
10. Kalashnikov (unnamed)  
11. Kitty Hawk Flyer (defunct prototype)  
12. Leap Vantage*  
13. Malloy Aeronautics Hoverbike  
14. NASA Puffin  
15. Neva Aerospace AirQuadOne  
16. Penn State University Blue Sparrow*  
17. Ray Research Dart Flyer  
18. Scoop Pegasus 1*  
19. Silverwing S1*  
20. teTra teTra 3*  
21. Texas A&M University Harmony*  
22. Trek Aerospace FlyKart 2*  
23. University of Kansas Mamba*  

* GoFly Phase I winner
Postwar Helicopter Boom

- Bell Aircraft bought 500 Franklin engines in 1946 for the “boom”
- Bell finally sold its 500th Bell 47 after the US Army ordered the Bell 47 to serve in the Korean War in 1950 – took 5 years
- Other Bell programs sustained the Bell 47 production until military orders

American Helicopter Society – 1953

- The civil helicopter had its greatest success when it did the impossible
  - Offshore Oil Rig Crew Transport
  - Topographic and mineral survey in Northern Canada
  - Powerline construction over mountain ranges
  - Benefit measured in labour and project cost and time savings
Okanagan Helicopters
Kemano Project 1949-1953
Flight Lessons from Aviation History


- Thousands of people a month were commuting by helicopter in the early 1960s Los Angeles, New York, Chicago and San Francisco
  - Extensive heliport infrastructure and subsidized by mail contracts & subsidies
  - Chicago Airways folded after subsidies cancelled
  - LA Airways became a fixed-wing DHC-6 Twin Otter STOL operator
  - SFO Airways sold its S-61L/Ns to North Sea for a Profit
  - New York Airways subsidized by airlines; folded after NYC and Newark crashes

- Most successful when geographic obstacles, e.g. water, mountains

- Helijet Airways in BC most successful helicopter airline today
  - 59 mile overwater route with right clientele, right heliports and environment
Trump Air to British Columbia
Subsidized by NJ Casino Revenues
Utility Operations
Demand Driven by Commodity Prices
New York Airways to Columbia
Vertol 107 from Pax to Logging
Flight Lessons from Aviation History

Short Take Off & Landing

- de Havilland Canada invested several decades in the development of Urban STOL ports
  - Aircraft optimized for STOL ops and quiet airport operations
- London City Airport a Success
- STOL demand eclipsed by airline deregulation and major push for lower operating costs
Flight Lessons from Aviation History

Urban Operations

- Regulatory environment – single vs. twin engine requirements
- Urban customers – Mostly EMS, ENG and law enforcement
- Heliport Development
  - New York City – 3 heliports, 4th closed, restrictions on sightseeing ops
    - Corporate commuting & On-demand
  - Baltimore – Marina businesses expanded in helicopters, created heliport
  - Chicago – opened couple years ago
  - British Columbia – Downtown Vancouver, Victoria, Nanaimo & Whistler
  - Sao Paulo & Mexico City
    - Extensive corporate use, rooftop
Vancouver Harbour Heliport
Multimodal Hub – Opened December 1986
Direct Route Competition - 1986
Point to Point
Helijet International
32 Years of Schedule Operations
Seaplane Competition Also Matured
14 Pax DHC-3T Turbo Otter
• Significant funds being invested in electric VTOL (>1B)
  – 75+ companies investing heavily in electric and hybrid/electric VTOL aircraft
  – The explosive interest in drones is being repeated with manned eVTOL
  – Natural synergies between eVTOL and eCTOL — they can help make each other more successful
  – For more info, see www.eVTOL.news

• The Vertical Flight Society
  – Find out more at www.vtol.org
  – 75th Annual Forum is May 13-16, 2019 in Philadelphia
eVTOL News:
- Vertiflite magazine
- www.facebook.com/electricVTOL
- www.twitter.com/electricVTOL
- www.eVTOL.news

Uber Elevate white paper and Summit
- www.uber.com/elevate or www.vtol.org/uber

Transformative VTOL
- www.vtol.org/TVF

Roadmap — Four Working Groups
- Private Intra-city (Short range ~ 5 – 50 miles)
- Commercial Intra-city (Short range ~ 5 – 50 miles)
- Commercial Inter-city (Longer range ~ 50 – 150 miles)
- Public Services (Medical, fire, disaster, enforcement)

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Also
- Email newsletter
- eVTOL News videos
- eVTOL video proceedings
- Analytical report (Jan. 2018)