The Future of Vertical Flight: How Do We Get There?

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VTOL Innovators – Then and Now

1st AHS Banquet
1944

1st eVTOL Workshop
2014
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 (AHS)**
  - Everything from VTOL MAVs/UAS to helicopters, eVTOL, etc.

- **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

- **Brings together the community** — industry, academia and government agencies — to tackle the toughest challenges

Join us today: www.vtol.org
A 75+ Year Legacy

- VFS has a long history of advocacy and leadership
  - Helped establish NASA-Army Joint Office, Nat’l Rotorcraft Technology Center (NRTC), Centers of Excellence, RITA/VLC
  - Worked with NASA and DoD to save the NFAC wind tunnel
- Provided major support to transformative initiatives
  - Joint Strike Fighter/F-35B STOVL Lightning II
  - V-22 Osprey tiltrotor
- Providing major foundational support to new transformative initiatives
  - Future Vertical Lift (FVL)/Joint Multi-Role (JMR)
  - Electric and hybrid-electric VTOL (eVTOL)

VFS Works to Advance Vertical Flight!
Aging U.S. Military Fleet

- V-22 only new U.S. military rotorcraft design fielded in past 30 years; CH-53K in service in 2023-2024
- All other deployed designs are 30-50 years old
  - UH-1 Huey first flight 1956; Chinook 1961; Black Hawk 1975; Apache 1976
  - Many 1960s airframes are still flying!
  - CH-53K only new design in acquisition process
  - OH-58 Kiowas in service from 1969 to 2017
Rotorcraft Generations

**Investments in RDT&E Needed for Next Generation Capabilities**

1940-1960 (1st Gen)
- R-6, H-21
- Airspeed <100 kts
- Reciprocating Engines
- Wood Rotor Blades
- Mechanical Controls
- No Survivability

1960-1980 (2nd Gen)
- UH-1, AH-1
- Airspeed <130 kts
- Turboshaft Engines
- Metal Rotor Blades
- Improved Flight Controls
- Metal Structure
- Reduced Vulnerability
- Passive Survivability
- Countermeasures
- Crashworthiness
- Weapons Integration

1980-2000 (3rd Gen)
- UH-60, AH-64, CH-47
- Airspeed >150 kts
- Increase Engine Power
- Composite Rotor Blades
- Augmented Flight Controls
- Improved Avionics
- Reduced IR Signatures
- Active Survivability
- Countermeasures
- Improved Crash Safety

2000-2020 (4th Gen)
- RAH-66, CH-53K
- Airspeed >170 kts
- Efficient Engines
- Advanced Blade Design
- Fly-By-Wire Flight Controls
- Composite Structures
- Improved Survivability
- Limited Open Systems Architecture (OSA)

2020-2040 (5th Gen)
- FVL, MUX, FTUAS
- Airspeed >200 kts
- Multi-Speed Engines/Transmissions
- Fly-By-Wire Flight Controls
- Individual Blade Control
- Common, Resilient Digital Backbone (Modular Open Systems Architecture)
- Advanced MUM-T (supervised autonomy) and Optionally Crewed Vehicle
- Advanced ASE
- Active Crash Safety Systems
- Holistic Situational Awareness & Decision Aiding
- Degraded Visual Environment

Investments in RDT&E Needed for Next Generation Capabilities

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Future Vertical Lift (FVL)

- 5 Capability Sets from Light to Ultra Heavy
  - Plus advanced unmanned programs
- Joint Multi-Role (JMR) Technology
  Demonstrations – 30,000 lb-class (13.6 t)
  - Bell V-280 Valor and Sikorsky-Boeing SB>1 Defiant
  - *US industry has invested ~$1B in JMR at 4:1 government spending*
- Currently 3 Capability Sets in planning
  - **CS1** (Light): Army’s Future Attack Reconnaissance Aircraft (FARA) to replace Kiowa Warriors
  - **CS2** (Medium): Navy to replace Seahawks/Fire Scouts with FVL Maritime Strike
  - **CS3** (Medium heavy): Army’s Future Long-Range Assault Aircraft (FLRAA) to replace Black Hawks; Attack/Utility Replacement Aircraft (AURA)
Sikorsky Boeing SB>1 Defiant
JMR Demonstrator
Bell V-280 Valor JMR Demonstrator
Future Attack Reconnaissance Aircraft (FARA)

Bell 360 Invictus

Sikorsky Raider X

AVX/L3Harris CCH

Boeing

?
Sikorsky S-97 Raider for FARA
Compounds & Tiltrotors

Sikorsky-Boeing SB>1 Defiant™ (2019)
30,000 lb (13.6 t) class

Sikorsky S-97 Raider™ (2015)
11,000 lb (5 t)

Sikorsky X2 Technology™ Demonstrator (2008)
5,500 lb (2.5 t)

Bell Helicopter V-280 Valor (2017)
30,000 lb (13.6 t) class

Leonardo (with Bell) AW609 (2003)
16,800 lb (7.6 t)

Bell Boeing V-22 Osprey (1989)
52,600 lb (23.8 t)
Clean Sky 2:
Next Gen Civil Tiltrotor (NGCTR)
Clean Sky 2: Leonardo NGCTR Demonstrator

- New Wing (no dihedral and no swept) Integration (T-WING)
- Mast tilt for control improvement (LH)
- Advanced empennage configuration (LIFTT)
- Innovative fuel system (DigiFuel & DEFENDER)
- Distributed FCS system (LH)
- Flow through engine
- New control laws (LH)
- Splitted gearbox architecture to support non tilting engine (LH)
Clean Sky 2: Airbus RACER
Forecast International’s global Platinum Forecast database (does not include eVTOL):

Civil rotorcraft production is expected to dip again near term, but longer-term growth expected:

- 2019: $5.6B / 1,100 aircraft
- 2030: $8.6B / 1,400 aircraft
- +53% in production value
- +25% in units (more expensive civil rotorcraft)
Global Military Rotorcraft Production

Forecast International’s global Platinum Forecast database:

**Military rotorcraft production** expected to continue slow decline:
- 2019: $14.8B / 615 aircraft
- 2030: $12.3B / 448 aircraft
- -17% in production value
- +27% in units (more expensive military rotorcraft)
Electric & hybrid electric propulsion enable new possibilities for:

- Regional/Rural Air Mobility (RAM)
- Urban Air Mobility (UAM)/Air Taxis
- Urban Cargo Delivery/Disaster Relief
- Personal Air Vehicles
- Ultralights
- Personal Flying Devices
- Urban Package Delivery
Flight experience offerings

- Ultralights under FAR Part 103 do not require certification

- Less than 254 lb (115 kg) plus 30 lb per float plus parachutes, etc.

- Restricted in speed, overflights, etc.

- Opener and Kitty Hawk have made 20,000+ flight each!

*Like flying jet skis!*

- Kitty Hawk Flyer (<254 lb)
- Hoversurf Scorpion (<254 lb)
- Opener BlackFly (310 lb)
- LIFT Aircraft Hexa (462 lb)
Bell unveils all-electric Nexus 4EX at CES
Hyundai unveils S-A1 eVTOL concept at CES and pledges $1.5B for UAM
Joby Aviation’s Series C investment led by Toyota with $394M. Total = $720M overall.
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

- Sikorsky "Firefly" Project (2010)
  - Conversion of S-300C to electric power
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 > $2B

= Enabling new configurations and new innovations
“The Hype Cycle”

We are here

Peak of Inflated Expectations

Innovation Trigger

Trough of Disillusionment

Slope of Enlightenment

Plateau of Productivity

“The Hype Cycle”

ATTENTION:
The eVTOL Revolution Needs YOU!


www.eVTOL.news
Will the eVTOL Revolution Succeed?

- eVTOL must have low direct operating costs and seat mile costs to be successful
- Batteries will continue to improve
  - Drones: 1.5M drones registered in US (Jan 2020) and 162,000+ registered drone operators.
  - EVs: Tesla Model S started in 2012, now all car companies have electric cars. Much lower operating costs vs. fuel-burning cars.
  - Look at your laptop or cell phone today compared to 10 & 20 years ago
- Cost: eVTOL aircraft will be much cheaper/easier to manufacture, for much higher production rates/reduced costs vs. helicopters (but cars?)
- Noise: much lower, allowing more operations in higher density locations

Potential for step-change in utilization by improved cost, noise & speed
Uber Elevate & VFS
- Unveiled at eVTOL Workshop in Sep 2016
- Summits April 2017, May 2018, June 2019

Developing an “Ecosystem”
- Partnerships with cities, real estate companies, aircraft manufacturers, and EV charger companies, etc.
- Connecting innovators, investors, regulators, technical experts, media

Small aircraft, but high barriers
- Technical, regulatory, environmental, economic, infrastructural and cultural

Uber plans test flights in 2020 and operational service in 2023!
1. **Technology**: batteries, motors, etc. for larger sizes, e.g. pilot + 4 pax
2. **Infrastructure**: physical and ATM/UTM
3. **Flying**: Pilot shortage vs. autonomy
4. **Standards & Regulations**: in development
5. **Public acceptance**: safety, noise, NIMBY

+ a rush for first mover advantage!

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**Gannett Fleming Skyport concept**

Airbus 1-seat Vahana (unmanned)

Boeing 2-seat Passenger Air Vehicle (unmanned)

Airbus 4-seat CityAirbus (unmanned)
The Electric VTOL News
www.eVTOL.news

- World eVTOL Aircraft Directory
  - Everything from the silly to the serious
- 253 aircraft (as of 4 Feb 2020)
  - 97 Vectored Thrust
  - 37 Lift + Cruise
  - 54 Wingless (multicopters)
  - 46 Hover Bikes/Flying Devices
  - 19 eHelos & eGyros
- 188 eVTOL companies/designers
- 230+ VFS articles on eVTOL
- Timeline, maps, company directory, educational videos, etc.
eVTOL Online Resources

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

- **Also**
  - Electric VTOL eNewsletter
  - eVTOL News videos
  - eVTOL video presentations (100+ hours)
  - eVTOL short course videos (20 hours)
VFS eVTOL Events

- **Transformative Vertical Flight 2020 @ San Jose, California, Jan. 21–23, 2020**
  - 7th Annual Electric VTOL Symposium
  - 500 attendees, 17 exhibitors, 11 sponsors, NASA tour

- **2nd Workshop on Electric VTOL Infrastructure**
  - Glassboro, NJ, March 17-19, 2020
  - Supporting FAA Tech Center, Atlantic City
  - City planners, architectural firms, utilities, etc.
  - www.vtol.org/information

- **76th Annual Forum, Montreal, May 19-21, 2020**
  - 1,400 rotorcraft & eVTOL engineers, scientists and leaders from industry, academia and governments
  - ~250 technical papers, ~75 panelists, ~75 exhibitors
  - www.vtol.org/forum
Final Fly Off
Feb 27-29th @ Moffett Federal Airfield
NASA Ames Research Center
Moffett Field, CA, USA
www.GoFlyPrize.com
Where We Are Now

First hover
- 1907 Cornu (Lisieux, France)
- 1938 Fw 61 Deutschlandhalle (Bremen)
- 1967 Bo 105 first flight (Ottobrun)
- 2015 H160 (Marignane)

First public demos
- 2011 e-Volo VC1 (Karlsruhe, Germany)
- 2019 Volocopter 2X Mercedes-Benz Museum (Stuttgart)

Capable product
- 2019 Concept Volocopter VoloCity

Advanced product
- TBD
eVTOL Supply Chain Challenges (1)

- Need 10,000 eVTOLs/year. Aerospace supply chain not prepared for this!
  - Even with those quantities, the automotive supply chain will not be interested
  - Commercial vehicle (i.e. trucks) and military ground vehicle suppliers are more closely aligned in terms of volume and possibly reliability/environment

- Required electronics content will be a challenge
  - High volume (low cost) suppliers will struggle to meet aero requirements (energy density, power density, etc.)
  - Commonality and flexibility across platforms can provide some relief

- Electric motors, controllers & batteries all require “rare-earth” raw materials (Lithium, Cobalt, Neodymium, Samarium, etc.)
  - Limited sources ... from sometimes “undesirable” nations
  - Other industries are also increasing the use of these materials (automotive, industrial, power grid, etc.)
Novel materials / processes will be used in the development of the infrastructure
  - Current heliports typically do not see the volume of traffic anticipated by UAM
  - Lighting, surface treatment, etc. will require advancement to deal with this volume of traffic.
  - Substation required for charging demands ("grocery store" equivalent power for each aircraft)

Efficiency will be key in maintaining the fleet load factor and utilization
  - Delivery of electrical power to the aircraft (infrastructure design & Mfg.)
  - Charging of the aircraft (vertiport design/mfg.)
  - Passenger em-/deplaning (aircraft design/mfg.)
  - Optimization vs. commonality
Use of performance-based standards to show means of compliance will be effective in reducing the complexity of design/mfg.
  - Industry is still not sure how to achieve this

Getting AS9100 certified will be required
  - There are no shortcuts or comparable documentation sets in ground vehicle

Testing methodology is very different from ground vehicle

Crashworthiness:
  - Airplanes crash horizontally; rotorcraft crash vertically
  - What about unitized composite structures with lots of battery mass & distributed electric motor masses
  - New effort needed to understand eVTOL crash safety
Helicopter industry has a shortage of pilots, mechanics, etc.
- 2018 HAI/North Dakota study indicated a shortfall of 7,649 helicopter pilots and 40,613 mechanics in the U.S. between 2018 and 2036.

Rotorcraft industry needs more engineers
- Huge new military and civil rotorcraft development programs — need thousands of more rotorcraft engineers in the coming decade-plus
- Competition is fierce for rotorcraft grads and experienced professionals

eVTOL needs more pilots, engineers, mechanics, etc.
- US Army-Navy-NASA-funded Vertical Lift Research Centers of Excellence (VLRCOE) only producing dozens of grad students. Need more government & industry funding for university research/grads
- Need 500-1,000 engineers to develop each eVTOL to certification, then upgrades
- First generations of eVTOLs will be piloted. Need 50,000 pilots ... at least temporarily.
- Instead of A&P mechanics, do we need A&E’s?

Need a National eVTOL Strategy for workforce, infrastructure, batteries, etc.
The Electric VTOL Revolution is on track for 2023

“There are 1,000 reasons why eVTOL won’t work — we have to find solutions to all of them to find the path that does work”

eVTOL is the intersection of aerospace, automotive, electric, AI, drones, etc.

To invent to a new industry, it will take everyone’s efforts

VFS is leading eVTOL efforts
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VFS is leading eVTOL efforts

It takes a village
It takes a town
It takes a city
It takes a county
It takes a state
It takes a nation
It takes a society
It takes the world
It takes you

Join us!
VFS is the global Vertical Flight Society
- We are helping to shape the future of vertical flight!
- $Billions going into new military & civil high-speed/long range rotorcraft
- Find out more at www.vtol.org

Significant funds being invested in electric VTOL (>2.5B)
- 2nd Infrastructure Workshop: March 17-19 near Philly
- 250+ concepts — significant work in hybrid/electric VTOL aircraft
- The explosive interest in drones is being repeated with manned eVTOL
- The Electric VTOL Revolution is transformative like the turbine engine
- Find out more at www.eVTOL.news