Electric VTOL Wheel of Fortune

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Hirschberg in 2005 with the V/STOL Wheel behind him.

Twenty years ago, in the March/April 1997 issue of *Vertiflite*, I published my first article. The 20-page "V/STOL: The First Half-Century" included the wheel of "V/STOL Aircraft and Propulsion Concepts," which can now be found on the AHS Vertipedia site at **www.vtol.org/wheel**.

The article and the V/STOL Wheel catalogued the most prominent attempts to combine the vertical takeoff and landing capabilities of a helicopter with the high-speed forward flight of a fixed-wing aircraft. Of these 45 vertical and/or short takeoff and landing (V/STOL) aircraft types that were built and tested, only three were considered successful at the time: the British Aerospace Harrier, the Yakovlev Yak-38 and the Bell Boeing V-22 (little did we know that it would be another 10 years before the Osprey would be operationally deployed). In the 20 years since, only a single additional V/STOL aircraft has become operational: the F-35B.

In 1995, I began working in the Joint Strike Fighter (JSF) Program Office on the propulsion system development team. I was intrigued by the program's objective to develop the world's first operational supersonic V/STOL jet: at that time, the Advanced Short Take-Off and Vertical Landing (ASTOVL) program was being merged into the JSF Program.

The relatively fat subsonic Harrier had been designed in the late 1950s with a single-engine thrust vectoring propulsion system, and was successful because of its comparative simplicity. But ASTOVL studies and research in the 1980s and early 1990s indicated that the use of a remote lift fan (later employed on Lockheed's X-35B and today's F-35B) was the most promising way to achieve the slender airframe needed for a supersonic fighter/attack aircraft that was also capable of short takeoffs and vertical landings (STOVL). The lift fan augmented the thrust for STOVL and hover flights, and decoupled the engine location from the aircraft center of gravity by distributing the thrust fore and aft.

Mechanical V/STOL

The V/STOL Wheel was originally developed in the 1960s by McDonnell Aircraft to categorize the different propulsion schemes that were then being studied. One of my early tasks in the JSF Program Office was to research and update the V/STOL Wheel in order to ensure that the JSF Program would benefit from the lessons learned of past attempts … and not "reinvent the wheel," so to speak. Publishing my research as a *Vertiflite* article was my first introduction to writing for AHS, but over the next 15 years, I co-authored more than two dozen technical papers — most presented at AHS conferences — on the development of and lessons learned from V/STOL programs around the world.

My research documented the issues that impeded the successful development of V/STOL aircraft, including:

- A much greater thrust mismatch between vertical flight and cruise (compared to conventional takeoff and landing) — meaning either that the engines must be far more oversized for cruise, or that separate thrust devices are needed purely for the vertical flight regimes
- Distribution of the thrust around the center of gravity for hover — longitudinally and laterally
- Mechanical complexity to facilitate the above — such as numerous redundant independent engines or cross-shafting of multiple engines
- Fuel efficiency — powered lift is an inherently less efficient form of flight than aerodynamic lift; using more engines and shafts to drive more propulsors decreases efficiencies further

In addition, aircraft must maintain control in all six axes in hover, low-speed flight, transition and cruise. While cyclic-controlled rotors can generate moments for control, propellers and jets can only generate thrust. So, for non-rotorcraft, the need for low speed control often meant additional complexity with control thrusters or various thrust vectoring schemes (such as using high-pressure ducted gases).

The V/STOL Wheel has been often derided as the "V/STOL Wheel of Misfortune," a knock at the relatively low percentage of successful concepts. Sadly, it also reflects the relatively high number of lives lost in crashes, often caused by the failure of mechanical driveshafts, transmissions, gearboxes or engines.

The threat of engine failure in 20th century V/STOL aircraft was so high that the 1960s Bell Aircraft X-22 quad tilt-duct demonstrator had four engines for safety — and was 25% overpowered — plus 11 gearboxes. The Dornier Do 31 V/STOL cargo aircraft (about the same gross weight as today's V-22 Osprey but with little payload/range capability) used two of the Harrier's Pegasus lift/cruise engines plus eight more vertically mounted lift engines. The purpose of so many engines was to increase the chances of survivability in the all-too-likely event that one failed. But more engines didn't guarantee safety. All five prototypes of the four-engine/four-propeller XC-142 tilt-wing cargo plane crashed or were damaged.

Twenty-first century engine and mechanical reliability is a totally different realm than it was a half-century ago. The two latest V/STOL aircraft — the F-35B and the V-22 —

both have minimized the numbers of engines and shafts; nonetheless, the Osprey program has unfortunately demonstrated the hazards to powered-lift aircraft when flight critical lift systems fail (i.e., one of its two "lift posts").

New advances in vertical flight propulsion technology, however, promise to solve many of the problems of previously attempted V/STOL concepts. As electric motors and energy storage both improve, multi-thrust V/STOL configurations that were previously overly complex — and depended on multiple gearboxes — may now be feasible, at least at smaller scales.

Electric VTOL

As has been well-chronicled in *Vertiflite* over the past three years, there has been a groundswell of interest in electric and hybrid-electric-powered VTOL aircraft for personal air vehicles, urban air taxis and even military missions (see "Air Mobility Bonanza Beckons Electric VTOL developers," page 14). In 2014, AHS International started its series of joint Transformative Vertical Flight Workshops with NASA and technical societies AIAA and SAE to support these and similar technologies, with remarkable results (including supporting the progress discussed here).

Electric VTOL obviates the need for mechanical power transmission, allowing simpler, non-cyclical propellers to be more easily distributed around the lateral and longitudinal axes — particularly with distributed electric propulsion, demonstrated by NASA's Greased Lightning project. In addition, unlike turbine engines, electric motors are continuously variable, facilitating wide rpm variations between takeoff and cruise. These features mitigate a major Achilles' heel of V/STOL aircraft development based on mechanical systems: the much greater thrust required for vertical and hovering flight than for wing-borne flight.

There will doubtless be other challenges with electric VTOL that will have to be solved by the technical community. Even so, traditional vertical flight companies such as Airbus (Vahana), Aurora Flight Sciences (LightningStrike) and Leonardo (Project Zero) are known to have built — or to be developing — full-scale electric or electric-hybrid VTOL demonstrators, and at least a dozen new companies are aggressively exploring this novel market space.

Airbus Group CEO Tom Enders warned at a conference in January that "If we ignore these developments, we will be pushed out of important segments of the business." The company formed an Urban Air Mobility division last year, in addition to its Silicon Valley subsidiary, A^3.

In March 2016, MD Helicopters CEO Lynn Tilton, who also owns automotive supply companies, warned the rotorcraft community that, "We're living in a changing world…. We need to change how we work as an industry. We can't get comfortable with our [high] barriers to entry, that we can move slowly, that we can create at a slower pace than other industries. We've not yet had a Tesla come and rev our engines and show us who we need to be. I'd rather out-innovate myself than wait for someone to show me that."

The Electric Wheel of Fortune

After Tesla unveiled its all-electric Model 3 sedan in March 2016, more than 400,000 people put down $1,000 deposits for cars that they hope to receive in 2018. This number of orders is equivalent to as many all-electric automobiles sold globally in the previous five years combined. Analysts project that Tesla could generate annual revenues of $17B — with a 25% gross profit margin — from the Model 3 alone.

Tesla's founder, Elon Musk, of course, gained the capital to bankroll Tesla through his development of internet applications in the 1990s: Zip2 and X.com/PayPal. He is now using some of his $13B fortune to further the technological advances of Tesla, SpaceX and SolarCity, as well as projects such as the Hyperloop, the VTOL Musk Electric Jet, OpenAI and the colonization of Mars.

Uber Technologies similarly began as an information technology solution; it was founded as UberCab by Garrett Camp, the founder of StumbleUpon, and Travis Kalanick in 2009, and launched as a mobile phone app in 2011 in San Francisco. Bloomberg analyst Eric Newcomer forecast Uber's 2016 revenues to exceed $5.5B, with a valuation of $69B, "making it more valuable on paper than General Motors Co. and Twitter Inc. combined."

At the AHS co-sponsored International Powered Lift Conference (IPLC) in September, John Ballard of Capricorn Investment noted that a trillion dollars has been created by app-based services, and the recipients of those proceeds are looking for tangible investments, and often also for ways to advance technologies that will improve society.

Founders or CEOs of companies such as Google, Pinterest and Skype are now investing portions of their fortunes in electric VTOL aircraft projects. Uber is holding its global Elevate Summit this spring to "help to accelerate urban air transportation becoming a reality." In the same way that Tesla has revolutionized the electric car, and Uber has revolutionized ground transportation with an app, the company now hopes to do the same for air transportation.

The progress of electric VTOL aircraft to date is truly impressive, while the promise of completely "reinventing the Wheel" has nearly limitless potential. The fortunes of the vertical flight industry will surely be changing over the next decade. The technical community must embrace this change and take full advantage of the opportunities it affords. A new "Electric V/STOL Wheel of Fortune" may one day be populated by a plethora of innovative and transformative new flight concepts through novel propulsion and energy architectures.

What do you think? Please send your comments on our Commentaries to ***director@vtol.org***.

More information on electric VTOL can be found at **www.vtol.org/electric-VTOL**.