Meet hVTOL – a solid first step for The Urban Air Mobility Industry

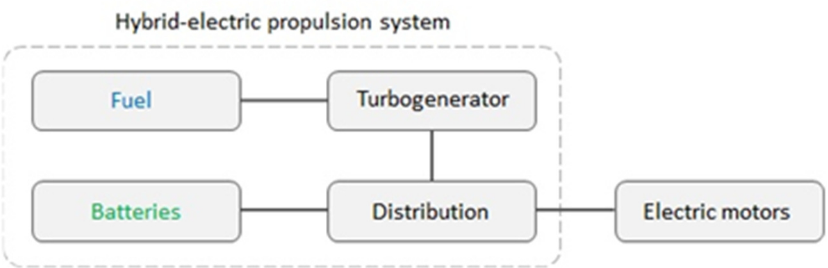
Compared to traditional VTOL aircraft, passenger vertical take-off and landing vehicles with electric powertrains (eVTOL) have several significant advantages; these lend weight to the forecasts of the emergence of an eVTOL- based industry worth over $1bn in the next two decades. One of the principal benefits is improved safety and this is achieved by redundancy of propulsion drivers, the powertrain's simplicity. Other key benefits, namely enhanced efficiency and reduced noise, result from the application of new aerodynamic designs.

The combination of these and other factors contribute to more sustainable vehicles that are better suited to use in cities. This will help Urban Air Mobility take market share from terrestrial means of transportation and increase the size of the overall passenger mobility pie. In addition, eVTOLs may substitute some regional aircraft and operate in other niche applications.

Currently one key industry bottleneck is the relatively low specific energy density of batteries available for airborne applications. Commercially available batteries with acceptable charge cycles have power densities of around 150-200 Wh/kg, steadily growing at 5-6% CAGR. This parameter affects flight range and payload, the pillars of flying vehicle economics.

The specific energy density of fossil fuel is 60-150 times greater than that of a battery; it is, therefore, worth studying hybrid-electric VTOLs: such aircraft combine the high levels of safety as electric vehicles with the substantial flight range of VTOLs with traditional engines.

A hybrid power unit here implies a system containing a microturbine with integrated electric generator, power electronics, batteries and fuel. Using a gas turbine as the foundation of a hybrid-electric system is considered by many as the most rational technology choice, due in large part to its high power-to-weight ratio, but also thanks to its reliability and the extensive knowledge of its maintenance in the industry.

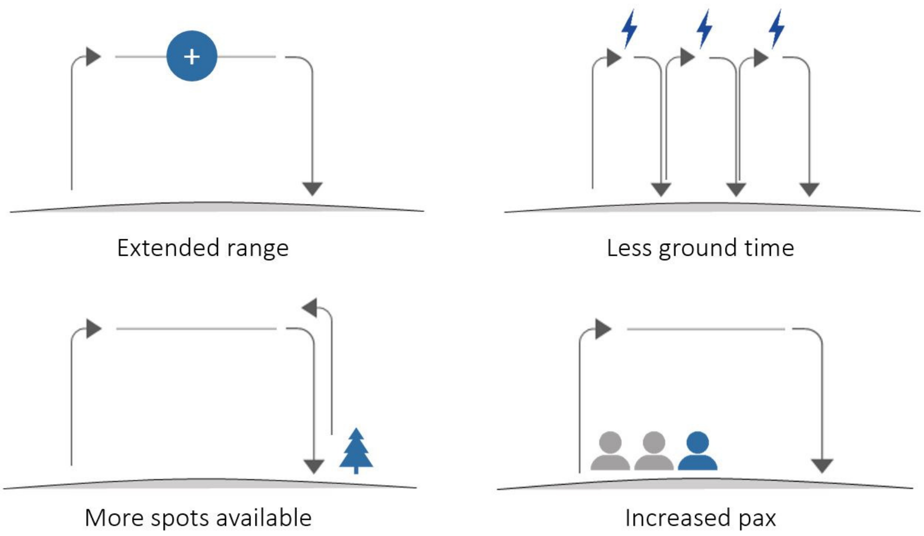


We consider jet fuel (kerosene) as a primary fuel. Despite hydrogen's higher heat capacity, storage issues complicate its use. Nevertheless, as light-weight cryogenic means of storage evolve, gas turbines can be adapted to run on hydrogen fuel without significant changes in design.

Batteries in such a system function to provide peak power to the propellers during take-off, hover and landing, as well as holding emergency energy utilized in case of turbogenerator malfunction.

In the series of articles below, we review hybrid eVTOL,or hVTOL, evaluate other hybridization technologies, and look at the economics and opportunities that this technology brings to the Urban Air Mobility industry.

Hybrid power systems can become the enabler that drives VTOLs towards a mass market in the shortest time-frame. Hybrid concept can make vehicles versatile and viable for decades to come and offers the potential for hVTOL to operate in special environments long-term.



Study of hybrid-electric power plant use on the tilt-wing Airbus Vahana eVTOL

Vahana is one the leading projects committed to bring one- and two-seat all-electric tilt-wing eVTOL to life. At the time this article is issued, the first full-scale vehicle has performed a number of unmanned fully autonomous hover and cruise tests.

source: evtol.news

The Vahana team follows knowledge-sharing policy. The design process is outlined in detail in the company blog and there is an open source sizing tool used to run the trade-off study for aerodynamics, size, COGS and OPEX. Basing on the tool, we have estimated the hybridization potential using the original methodology criteria – lifetime **direct operating cost** per km.

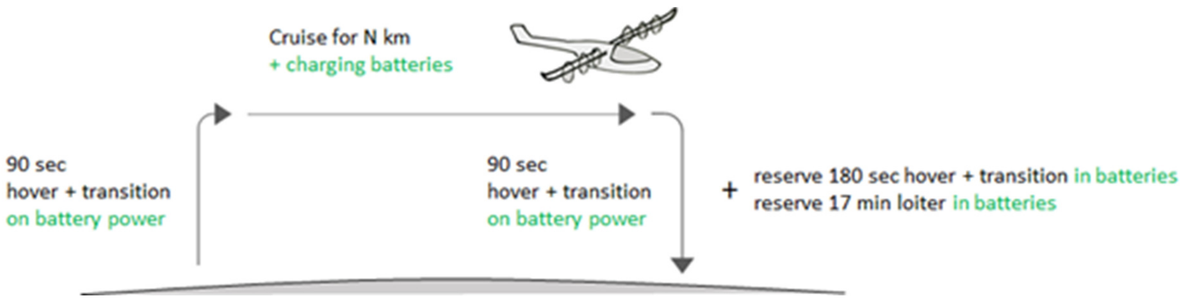
Technology
For this study, we have elaborated the basic hybrid system layout: a simple-cycle microturbine with integrated electric generator, power electronic and batteries.

Scenarios
To have more perspectives, we have created five scenarios of the energy storage distribution between fuel and batteries, as explained below. Initial all-electric vehicle parameters are the same as in the original source.

Scenario	Hover to climb up	Cruise	Hover to descend	Reserve		Redundancy	
				Loiter	Hover	¼ battery fail	Genset fail
1	Electric			Battery	Battery	Tolerate	-
2	Battery	Genset + charging battery	Battery	Battery	Battery	Tolerate	Tolerate
3	Battery	Genset	Battery	Battery	Battery	Tolerate	Tolerate
4	Genset & battery	Genset + charging battery	Genset & battery	Fuel	Battery	Tolerate	Tolerate
5	Genset & battery	Genset	Genset & battery	Fuel	Battery	Tolerate	Tolerate
6	2 x Genset			Fuel	Fuel	-	1 of 2 units

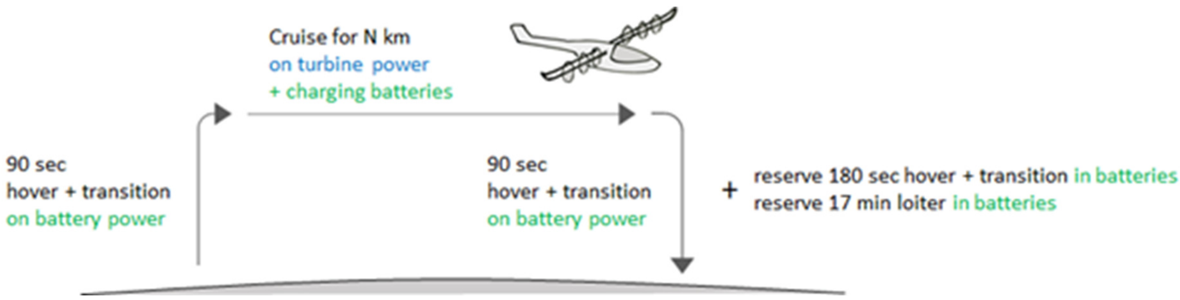
All scenarios imply the same emergency reserves: 3 minutes in the hover mode, 17 minutes of loiter at minimum power. Redundancy on battery side should mean safe landing in case 1 of 4 battery pack fail (25% less capacity, higher current). Failure of battery and genset were considered separately.

Scenarios analyzed:
Scenario 1.



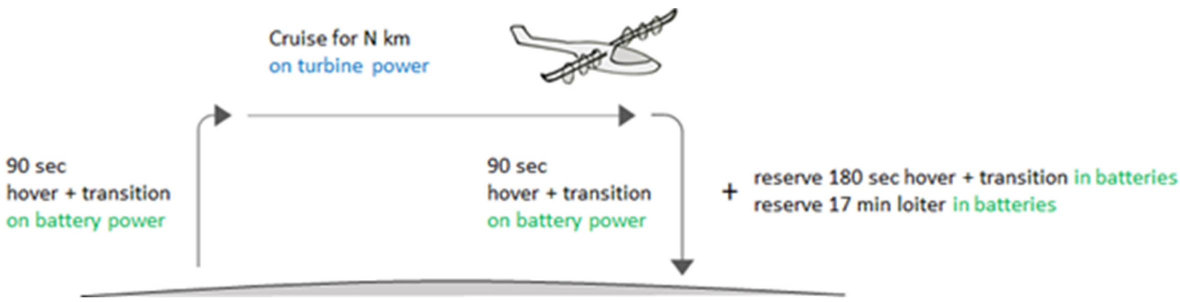
We have used the all-electric eVTOL as the reference point for comparison purposes. Take-off, flight and landing are performed using energy stored in batteries.

Scenario 2.



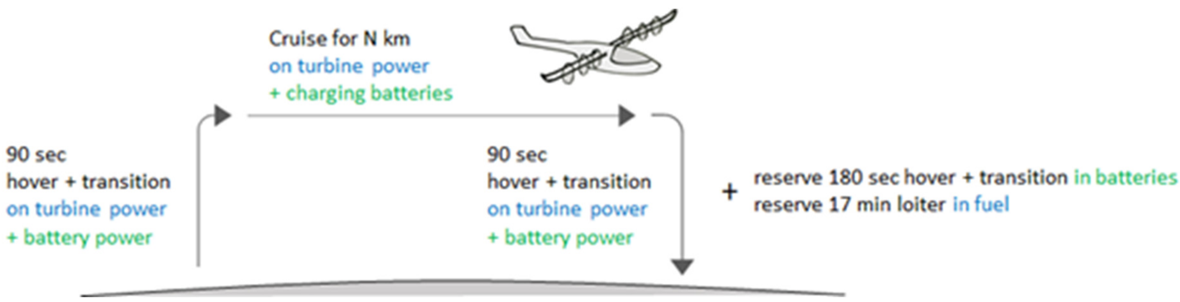
Hybrid VTOL. Fully electric take-off and landing is the key scenario feature, this avoids any additional noise close to ground infrastructure that would be emitted if the gas turbine was in operation. This scenario is the closest to the all-electric eVTOL from the emissions and sustainability perspectives. Genset charges batteries during the whole flight – this allows the vehicle to have less expensive ground infrastructure, expand the number of landing spots and increase the vehicle's availability time.

Scenario 3.



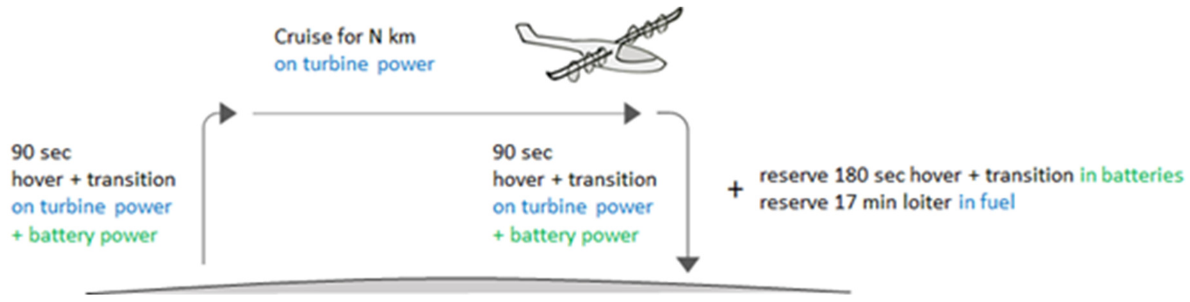
Hybrid VTOL. The scenario is the same as option 2 except that there is no airborne charging of the batteries. This option implies that there is ground electrical charging infrastructure at the landing spots. A lower maximum power output requirement for the genset leads to a smaller size and cost of the power unit, but the number of available landing options decreases.

Scenario 4.



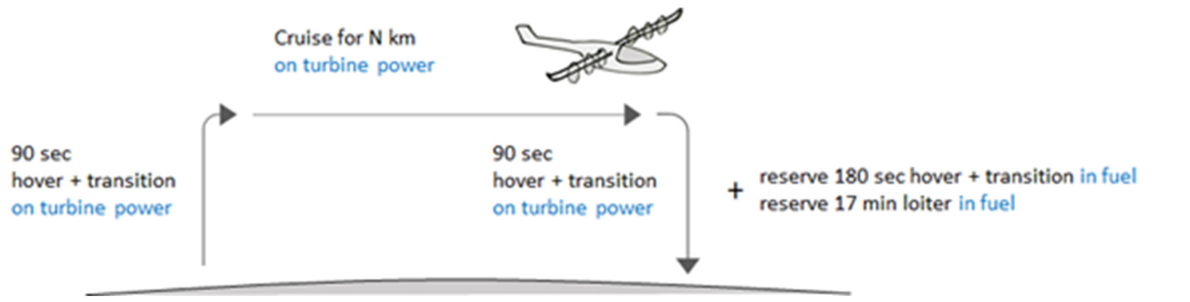
Hybrid VTOL. In this instance, the genset is operating during all the flight's phases, while batteries help to cover peak load for take-off and landing. The fuel holds part of the stored emergency energy.

Scenario 5.



Hybrid VTOL. Scenario 5 is similar to scenario 4 the difference being that batteries are charged exclusively with ground infrastructure.

Scenario 6.



VTOL with the electric powertrain between propellers and the gensets. Two turbogenerators operating in parallel provide 100% of the power for take-off, flight and landing phases as well as emergency cases. Since hovering power is substantially larger than that needed for horizontal flight, the micro turbine continuously operates on partial load, which reduces its efficiency.

Computation model

We used computation models of the VahanaTradeStudy tool and the trade study results, such as distribution of the batteries' mass, the propeller size and the costs of the vehicle, calculated for each range. Modelling has been performed by Mathcad.

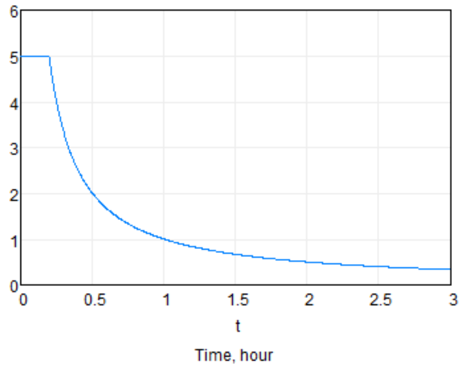
For each design point, the Vahana battery mass equates to the total weight of the hybrid system and the fuel. The model considers reduction of cruise power requirements as the weight of fuel decreases over the duration of the flight. Lifetime: 10 years, 600 flights per year. Range here stands for maximum range.

Direct operation costs of the default all-electric vehicle are lower than stated on the Vahana blog as a result of finding and fixing an inaccuracy on the blog after publication of the original article (check Vahana Configuration Trade Study Part II comments).

Batteries

The parameters set up by the original tool. Gravimetric density is 230 Wh/kg, which is stated to be an outrunning number. Specific cost – 161 $/kW, cycles until full replacement – 2000.

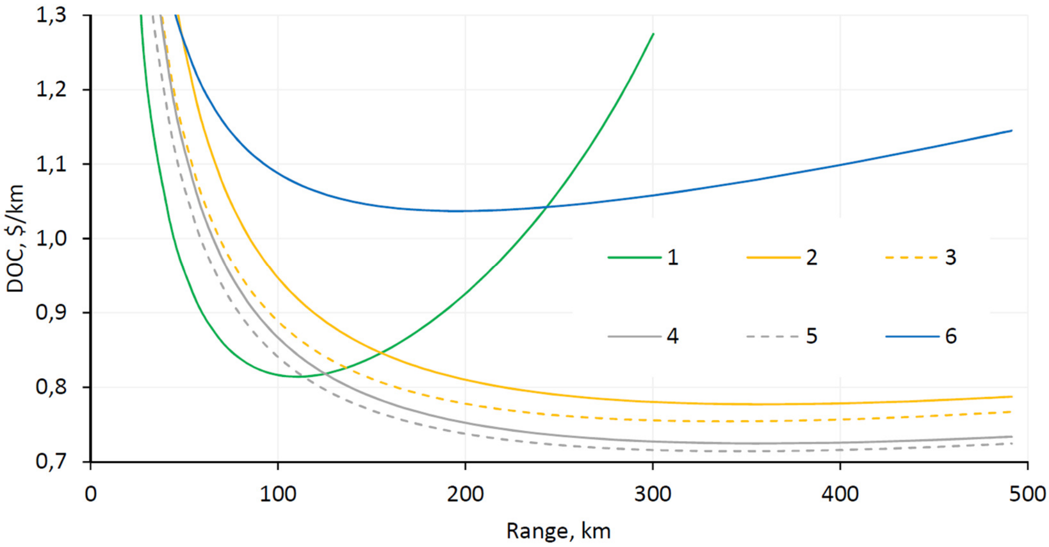
For the study, we set up charge/discharge C-rate limits as follows:



Turbogenerator
Applied total specific power of the genset is 2 kW/kg, specific fuel consumption – 0,5 kg/kWh, which are the actual average parameters for simple-cycle gas turbines without heat exchanger of the 40-100 kW range. The model considers a reduction of efficiency on partial loads. For emergency cases, the genset is able to bear 20% overload short-term.

Specific cost of the genset is 1500 $/kW, which we believe is an approximate target cost for such products. Fuel cost is 1 $/kg. Although average stock price for the aviation jet fuel is close to be 2x time lower, we have considered a higher end-user price due to the relatively small amounts of fuel being delivered to landing spots by, for example, car transport.

Hybridization study results
The main study objective is to compare the lifetime direct operating costs per km of an all-electric vehicle with that of a hybrid vehicle, according to the hybridization scenarios. The graph below summarizes the outputs:



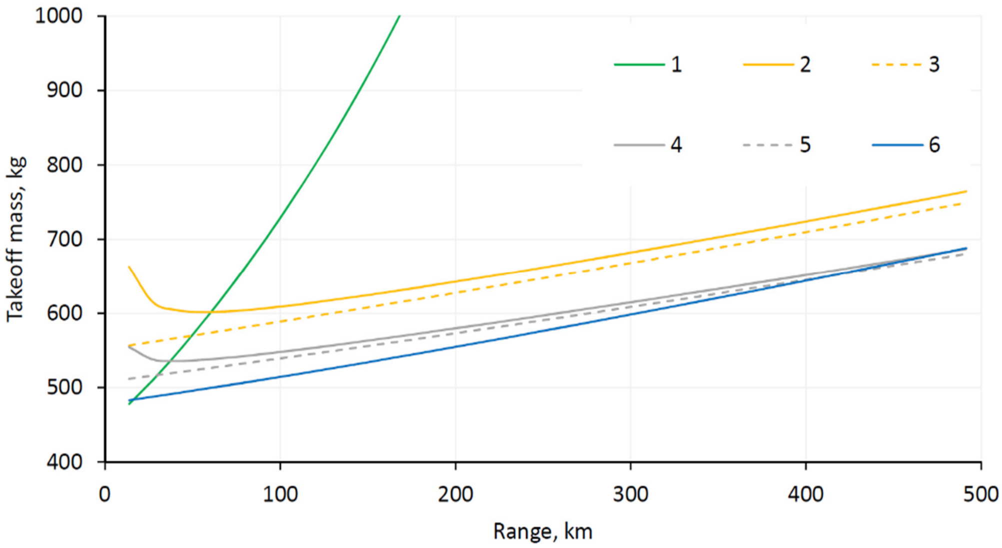
The data shows that use of a hybrid-electric system to power a vehicle that takes-off and lands solely on batteries (scenarios 2,3) is more economically viable than an all-electric type if the design maximum range is greater than 130-150 km.

Combined battery-and-fuel-powered take-off and landing (scenarios 4 and 5) have lower DOC and starts to be more viable than all-electric from a 110 km range. As mentioned above, battery charge during the flight increases dramatically availability of the vehicle, reduces the need for ground infrastructure and its corresponding CAPEX, but the model does not consider this assumption.

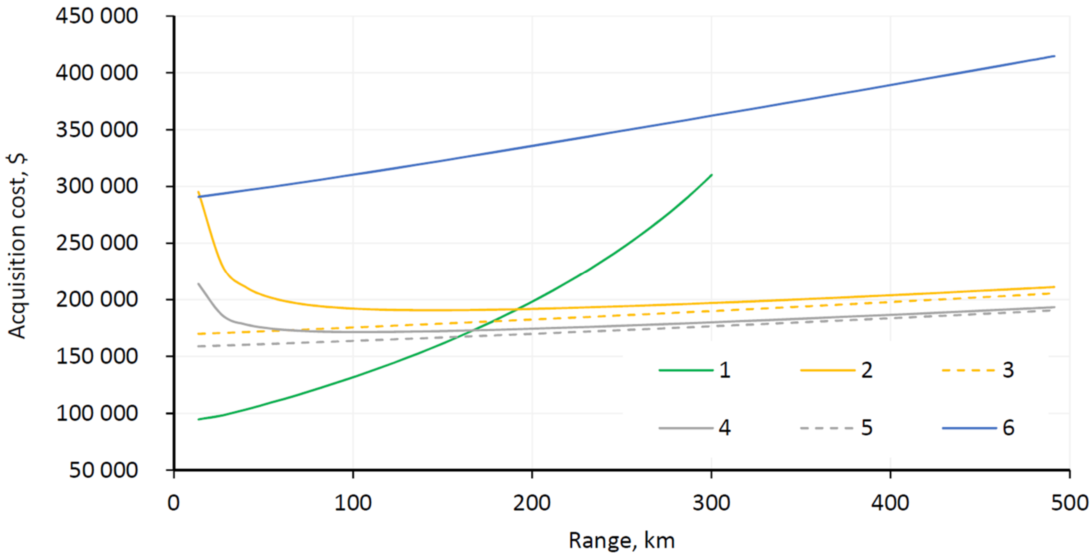
A vehicle without batteries with two turbogenerators and electric powertrain (scenario 6) is clearly less viable than any of the other hybrid options. The reason for this is the higher genset costs with higher power required for take-off and hover, and suboptimal efficiency on partial loads during horizontal flight, as the power requirement of cruise mode for Vahana is approximately 3 times less than when in hover.

A hybrid vehicle designed to have the maximum range of 200-700 km has the lowest direct operating costs per km.

At some extend, the mass is a proxy for overall aircraft noise estimation. The mass of hVTOL is lower than the all-electric vehicle for almost any range and every scenario
In comparison with the current Vahana, which has an MTOW of 815 kg, the hybrid Vahana of this size could have a range over 700 km. For the 4th, 5nd and 6th scenarios the mass is almost equal and is the lowest for almost any given range.



Acquisition costs of vehicles, designed for range over 200 km, are lower for hVTOLs with hybrid systems.

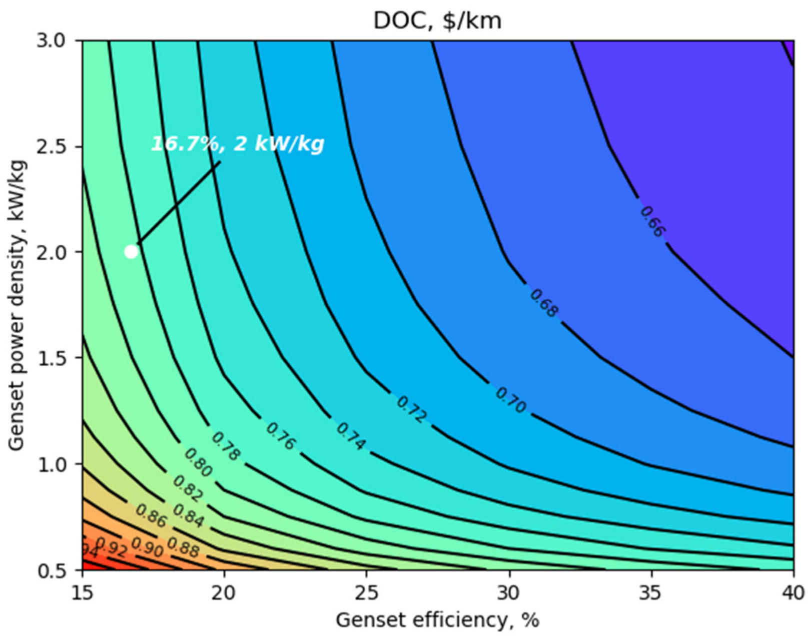


Sensitivity analysis

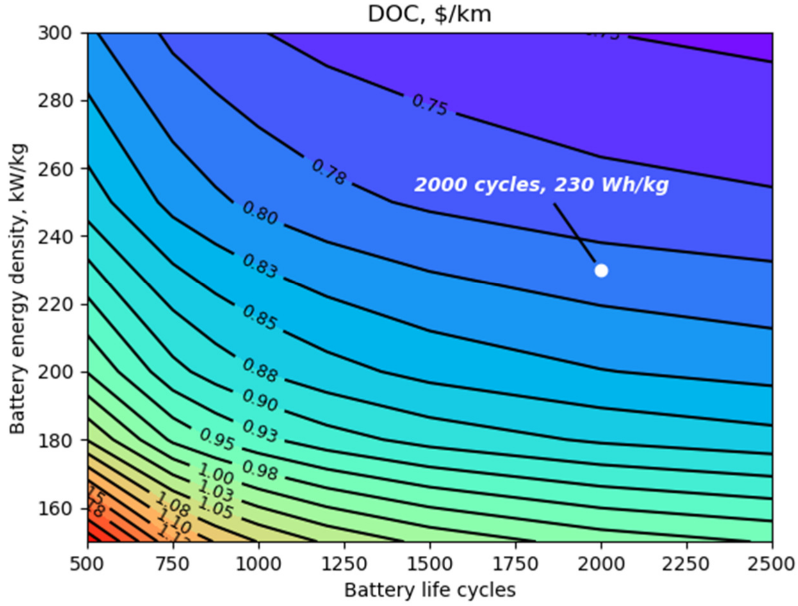
To estimate sensitivity of DOC for some assumptions made in hybrid vehicle model, we chose Scenario 2 with a 300 km range for the basis of comparison.

Genset's total performance ratio range, considering a 95% energy conversion ratio for both electric generator and power electronics, is limited to 40%. Such efficiency is obtainable by large gas turbines with high compression ratios and high gas temperature, or gas turbines with complex heat cycles, while the efficiency of small RC turboshaft engines is close to 5%

Specific power of the genset has slight effect on DOC when above 2 kW/kg, while DOC is sensitive for hybrid systems with specific power less than 1 kW/kg.



For scenario 2 at 300 km range, with fully electric take-off and landing as well as required emergency and redundancy options, the weight of the batteries is substantial - more than 50% from the total hybrid system weight. That is why battery parameters affect rather strongly.



Summary

Having in mind ongoing battery development, it is economically viable to design hybrid-electric tilt-wing VTOL with Vahana parameters for ranges from 200 to 700 km.

In hVTOL, long range is accompanied by uncompromised safety of landing on batteries in case of turbogenerator malfunction. Scenarios 2 and 3 add no additional noise close to ground infrastructure; scenarios 4 and 5 provide the lowest transportation costs among reviewed scenarios.