ACADEMIE DE L'AIR ET DE L'ESPACE
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LES DOSSIERS

THE VIABILITY OF ELECTRIC URBAN TRANSPORT AIRCRAFT

AAE Dossier 53

2022

THE VIABILITY OF ELECTRIC URBAN TRANSPORT AIRCRAFT

AAE Dossier #53 **2022**

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1 FOREWORD

In 2018, the Air and Space Academy published its Dossier No. 44 covering the future of passenger transport by rotary wing aircraft by 2050, which mentioned the probable appearance of vehicles with electric and hybrid engines. AAE therefore decided to look in more detail at the viability of these aircraft with such innovative engines. To this end, a working group was set up, comprising AAE members as well as invited experts from industry and the research sector.

Indeed, over the last few years, we have witnessed an explosion of projects for small electrically powered aerial vehicles (e-VTOL) and Dossier No. 53, after identifying their general specifications, which basically respond to the commercial need expressed by the transport company UBER, analyses the state of the art and perspectives for propulsion chain technologies, their strong points as well as any obstacles to their development in terms of performance, noise, cost and safety. It then assesses the potential of these aircraft to perform intra-urban and inter-city passenger transport missions in the medium term.*

Regarding intra-urban transport, it is concluded that e-VTOLs can just about meet the target specifications in terms of performance, noise and safety, with inter-city transport still being out of reach. However, some big questions remain about their cost and all-weather capability, as well as the possibility of developing the necessary infrastructure. In addition, battery recharging is identified as a significant problem that will need to be addressed.

On the positive side, it should be noted that the electrification of VTOL aircraft offers the prospect of easing the introduction of new architectures which could prove to be more efficient, with significant developments in rotary wing technology. These new paradigms will make it simpler to meet the requirements for urban passenger transport and, in the longer term, inter-city transport.

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* *Electric Vertical Take-Off and Landing.*

Consequently, the dossier concludes that it is necessary to support research in this field of electrification and new architectures/airframes by taking advantage of new sources of funding that can advance VTOL technology. To this end, recommendations are made to all operational actors and funding providers.

Michel Wachenheim
President

Air and Space Academy
(AAE)

2 EXECUTIVE SUMMARY AND RECOMMENDATIONS

***We are currently witnessing an explosion of projects for small, electrically powered aircraft**, as well as a few hybrids with a fuel complement. Most of these projects are still at the development stage and doubts remain as to whether they will be able to evolve into a mass-market operational means of transport in large numbers as claimed by their promoters.*

All these aircraft are small (two to nine passengers) and have a restricted range (35 to 200 km) due to the limited performance of the batteries used to store electrical energy, whose weight becomes prohibitive as storage capacity and power output requirements increase. Hybrid and fuel cell aircraft projects face similar constraints.

***Such payload and range limitations effectively restrict these aircraft to intra-urban use** – in line with specifications proposed by the operator Uber[1], at the origin of this interest in Urban Air Mobility (UAM) – or, at the most, city centre to city centre (inter-city) transport between neighbouring metropolises, the majority of these projects being e-VTOL[2].*

The concept of intra-urban or inter-city VTOL is not a new one and has already been tested using helicopters, although with little success. The reasons for this were analysed in AAE Dossier No. 44 and include high costs, public unacceptability due to noise pollution and fears about flight safety, lack of infrastructure (heliports) and traffic restrictions over built-up areas.

Benefiting from distributed (redundant) electric propulsion technology, which is easy to implement, and enjoying a good ecological image, this proliferation in e-VTOL projects is leading to renewed interest in urban e-VTOLs, which could be an answer to worsening transport congestion in major cities, probably for a minority of

1 *Uber: this name refers to Uber's air mobility division, Uber Elevate.*

2 *e-VTOL: electrical Vertical Take-Off and Landing aircraft.*

passengers. Operational applications for mass transport will only follow on, however, if previously mentioned obstacles to the development of urban VTOLs are removed, whether in terms of the aircraft themselves (performance, noise, cost, safety) or the associated safe transport network (heliports with fast-charging capacity, routing, global real-time network management system).

Such transport networks cannot emerge without the support of the public authorities, itself contingent on acceptance by the public, who require environmental aspects to be dealt with satisfactorily and will not support a system seen as being reserved for too small an elite.

The dossier examines these various points, limiting itself to urban electric VTOLs. Hybrid solutions were ruled out because of their high costs, engendered by the combination of fuel and electric engines, and poor ecological image.

In conclusion, prospects for inter-city transport by e-VTOL are considered marginal at present because of their limited range (less than 100 km today) and market (too small to amortise the cost of the necessary helipads).

Intra-urban transport e-VTOLs would seem to just about meet the required performance, noise and safety specifications, although serious doubts remain as to their cost and all-weather capability. Battery recharging is also a significant problem that will need to be addressed.

In the UAM concept, e-VTOLs link helipads to hubs via travel corridors in a centrally managed transport network; fully automated operation with no onboard pilot is even considered a possibility in due time. The operational regulations governing such a system do not yet exist and the construction of helipads and allocation of routes will pose many problems, including that of public acceptance. Assuming these are resolved, the network will necessarily have limited capacity, unless we imagined that the congestion observed on the ground in large metropolises could be reproduced in the sky. This means that the numbers of urban e-VTOLs and passengers they carry will remain low (although significantly greater than for helicopters today). This solution is therefore unlikely to solve the problem of transport congestion in urban areas. The most likely outcome is that the system will be used mainly by business travellers, with no benefit for the average citizen who will have to suffer the impact (albeit less marked than with current helicopters).

Given the absence of public interest, let alone support, it would seem difficult for public authorities, at least in opinion-conscious Western European countries like France, to play a leading role in the deployment of UAM transport networks.

To sum up, small e-VTOLs are fast becoming capable of performing urban transport missions, a capability that should improve as battery performance improves, however the economic viability of the concept remains to be demonstrated since the technical solutions involved will be expensive. Deployment of the corresponding transport networks will represent a risky bet on return on investment and great determination will be required to overcome the many obstacles associated with any major land-use planning undertaking. These conditions may be found in countries *that are technologically driven and/or where rapid development is leading to a saturation of ground-based transport systems.*

This conclusion is based on the state-of-the-art in terms of technology, in particular battery technology and its evolution in the short/medium term, although given current research efforts in the fields of electrical energy production and storage, a breakthrough solution significantly improving e-VTOL performance might well emerge. With endurance expected to increase by a factor of two in the medium term, e-VTOLs could conceivably take over part of the small helicopter market for applications going beyond urban transport, such as VIP transport, medical evacuation, police, media, etc. Likewise, ecological pressure and the craze for electric propulsion could persuade users to accept reduced performance in exchange for an image combining ecological virtue with avant-garde modernity.

The electrification of VTOLs also makes it easier to develop new architectures that could prove more efficient and help drive innovations in rotary wing technology.

***Research in the field of electrification must therefore be pursued**, taking advantage of new sources of funding to advance VTOL technology.*

*We must bear in mind, however, that electricity, which will eventually be decarbonised, will only be available in limited quantities, giving rise to competition between its rapidly growing uses and probably leading to the definition of political priorities. **The social utility of these aircraft, possible newcomers to transport provision, will therefore have to be assessed**, by considering their impact on urban transport systems. If established, this social utility will help justify regulatory or even economic support from the public authorities to further their development.*

Key recommendations:

For UAM transport to develop, the following conditions must be met:

► *Recommendation No.1:*

Safety

Safety demonstrations (essential for the user) should cover:

S1: the aircraft itself (with the necessary redundancies, particularly in terms of lift, propulsion – availability of energy with the required margins – and above all piloting systems);

S2: traffic management (development of systems capable of managing conflicts in restricted spaces almost instantaneously);

S3: the availability of qualified pilots, until automated operating solutions are deployed (by which time cybersecurity will have progressed);

S4: the issue of all-weather flights for the safe availability of connections.

► ***Recommendation No.2:***

Noise

Noise perception (essential for the surrounding area), a prerequisite for UAM acceptability, requires:

B1: identifying the key criteria of human perception of noise;

B2: using noise and performance optimisation tools to confirm the possibilities of proposed projects;

B3: launching correlative studies of the noise emitted during landing and take-off phases in an urban environment, with anti-noise trajectories taking into account the presence of buildings.

► ***Recommendation No.3:***

Costs

The costs and prices advanced by e-VTOLs promoters (essential for operators) paint a confused picture that rules out any credible operational cost estimation. It is therefore necessary to ensure that:

C1: development costs of devices meeting certification requirements are properly assessed;

C2: unit manufacturing costs of aircraft are based on realistic production rates;

C3: infrastructure costs are included in assessments;

C4: periodic utilisation rates are correctly established (in particular the number of annual flights, taking into account the time required to recharge the batteries).

► ***Recommendation No.4:***

Support from European public authorities

Public authorities should encourage the development of UAM if real benefits to the population can be demonstrated. It is therefore necessary to:

P1: analyse the social utility of these aircraft, focusing on the main expected uses and the impact they may have on transport systems;

P2: encourage and financially support coordinated research to provide answers to the above conditions;

P3: monitor corresponding international developments in order to avoid the emergence of industrial and operational dependencies;

P4: participate in the development of regulatory texts, with as international a scope as possible, corresponding to this type of activity.

3 INTRODUCTION

The use of electrical energy for air transport is currently being envisaged with the main goal of limiting environmental impact and reducing the consumption of kerosene, soon expected to be in short supply. However, an analysis of such projects for conventional take-off and landing aircraft (CTOL), in the long-haul, medium-haul and even regional categories, indicates a lack of viability for the moment because of the excessive weight of the energy storage devices; according to forecast performance improvements, this conclusion will remain valid in the long term in the absence of any unexpected technological breakthrough.

It seems possible to use small electric CTOLs for very short or low endurance missions, but this use corresponds to a niche market such as recreational aviation.

It should be noted that these conclusions also apply to helicopters, whose range in the current fuel propulsion version is already limited (a few hundred kilometres) and would be reduced to a few dozen kilometres in the case of electric versions.

However, a number of multi-rotor electric VTOL projects are emerging and targeting the Urban Air Mobility (UAM) market. Their ambition is to use the simplicity of electric motorisation to develop multi-rotor configurations that could bring advantages in terms of safety (redundancy), performance and cost. Their VTOL characteristics and small size mean that they can be used either in urban environments or for short inter-city journeys, if they have sufficient range performance (the latter use of UAM was already identified as an opportunity for future development of VTOL passenger transport in AAE Dossier No. 44, published in 2019).

In terms of pure performance, electric VTOLs (e-VTOLs) could already be considered capable of carrying out intra-urban UAM missions, since they meet specifications issued by Uber, the operator at the origin of this air taxi concept. It is now a question of determining whether these missions could be carried out by aircraft that comply with the certification and operating regulations currently being finalised, under conditions that meet the requirements of this emerging market. One *could then examine how these conditions might evolve in the light of technological progress, particularly that of electrical energy storage devices.*

We therefore propose, in the first instance, to identify the requirements of the UAM market and its development, not by in-depth study but based on the results provided by Uber (at the origin of this eruption of activity in the area of urban air mobility) with regard to performance, economic aspects, safety, environmental impact, as well as operational aspects, infrastructures and, of course, regulatory issues (certification, operational rules of use).

After identifying the different configurations currently under development, an assessment will be made of their ability to meet market requirements today and up to 2050, anticipating the impact of technological progress. Conclusions will be drawn from this analysis, with recommendations for use by manufacturers, prospective operators and certification authorities.

Remarks

1) *The example of electrically powered road developments must be considered. While the development of all components of the electric propulsion chain for application to road transport can facilitate applications to air transport, specificities of use – in particular cycles, different power requirements, greater sensitivity to weight and safety aspects and reduced potential for environmental gains – do not allow for a transposition of the application of electric energy between these two modes of transport, especially as the market volumes justifying investment are not comparable.*

2) *In terms of implementation, experience provided by drones should not be underestimated. Indeed, the general sizes of medium or larger UAVs, which are similar to those considered here, lead to new, innovative, reusable technological solutions to meet the goals of weight and cost reductions. This is particularly true of military applications, which are already highly developed thanks to technological progress supported by significant research resources. Of course, robust system solutions will have to be devised that go well beyond those used by the military, since their known loss-of-control rates cannot meet requirements for civilian transport.*

   The proliferation of drone flights, with their various types of missions, is giving rise to highly reactive air traffic solutions in order to avoid collisions, especially when these aircraft must be inserted into airspace already occupied by traditional aviation; the trend for such aircraft is to seek full autonomy. For e-VTOL operations in dedicated sites, the problem is less acute, although unforeseen events must always be taken into account.

3) *At this point it is worth referring to AAE Dossier No. 42, that deals with transport aircraft automation and concludes that by 2050, passenger-carrying aircraft will continue to be flown by at least one onboard human pilot. Indeed, it indicates that to meet safety objectives – which are the same as those required for the*

"enhanced" category e-VTOLs (see section 7.1) considered in this study –, the presence of this onboard pilot will be required until automated systems have proved they are capable of appropriate action to deal with most "unforeseen" cases that arise during operations. Of course, work at design stage may plan for the eventual elimination of the single onboard pilot. Case simulations and experience with heavy lift drones will certainly help.

4 E-VTOL INTRA-URBAN AND INTER-CITY SPECIFICATIONS

Two types of aircraft and use are considered, responding to two different specifications: one for intra-urban traffic (air taxi) and the other, more ambitious, for longer distance, inter-city links.

4.1 Specification for intra-urban aircraft

Specifications for air taxis have been extensively detailed by the Uber organisation. Uber Elevate actually drove the whole concept by playing the dual role of future operator and "system builder", apprehending the full range of issues related to aircraft operations in urban environments. The Uber Elevate White Paper*, published in 2016, is the founding document for system development. This specification, ambitious in many areas, was chosen as the reference for definition of the "intra-urban" specification. It is supposed to cover the needs of about 50 megacities and is close to the conclusions of the analysis carried out in AAE Dossier No. 44 concerning passenger transport by VTOL by 2050. While performance aspects are well specified in it, they had to be refined and other parameters added for the purposes of an overall analysis of the projects. These intra-urban aircraft, of the e-VTOL type, would take off and land on vertiports on top of buildings (see section 7.2). They would carry up to four passengers (or 500 kg of cargo) over distances of at least 100 km (60 miles) at speeds well above those of land vehicles, in the order of 200 to 300 km/h at 300 m above ground level. They would be able to carry out a succession of shorter stages (40 km), with partial recharging of the batteries in masked time (during disembarking and reembarking at stations), for at least three continuous hours.*

To limit the size of vertiports, the overall dimensions of all aircraft, including any moving parts, must fit within a circle of 13.7 m diameter; motorised mobility on the *ground must be achieved with the rotors stopped. The vertiports must ensure a fast-charging capacity (600 kW).*

The maximum take-off weight (MTOM) must be less than 3,175 kg, which is the limit for "small" helicopters (see section 7.1).

Performance calculations will have to include minimum reserves to allow diversion to an alternative vertiport (a realistic value of 20 km was taken). Overall performance will necessarily be limited by battery performance, whose use as recommended by Uber, assessed with end-of-life battery characteristics, is very realistic, even if the specific energy level proposed is very ambitious (300 Wh/kg at pack level).

In an initial operating phase, onboard systems will provide automatic piloting, navigation and communications, with a pilot taking over if necessary. After this probationary period, during which the necessary data will be collected to demonstrate the safety of autonomous systems, the pilot will no longer be necessary.

The safety level referred to in the Uber specification will be ensured, on the one hand, by type certification (based on the EASA special condition and any other recognised foreign set of regulations) and, on the other hand, by operational regulations which remain to be established, covering this specific type of overflight of urban or densely populated areas.

Ambient conditions

The range of ground temperatures (between -10°C and +45°C) affecting battery operation and thermal conditioning must be specified.

Cabin air conditioning, limited to a minimum in view of the reduced duration of the flights, will be provided by pre-conditioning and/or heat pump to preserve the energy of the batteries, as for cars.

Night flights in the 10 p.m. - 6 a.m. time slot are not considered.

Flying in identified icing conditions is not required for inter-urban missions, although this may lead to a limitation of winter flights in temperate countries.

Noise pollution

There is consensus that e-VTOLs should have a noise level such that they blend in with the ambient noise of built-up areas, but the precise quantification of this target (difficult) and the conditions for measurement at the three conventional control points need to be specified. This could lead to a ground noise level of 65 dBA maximum at 150 m regardless of flight phase, with a target of 55 dBA in the future, since the objective in many countries is to reduce ambient noise in cities. To more accurately reflect the level of annoyance caused by e-VTOL operations, their operations will have to be measured continuously, site by site, to establish the actual level of "day-evening-night background noise" (LDEN, see section 6.3).

Cabin comfort needs to be clarified and significantly improved compared to helicopter cabins, in terms of noise (dBA and SIL) and vibration, which seems possible given the removal of the main gearbox (MGB).

Operating costs

One of the reasons given for the lack of success of passenger transport by helicopter is the high operating cost (purchase, crew, maintenance, energy, airport and traffic management charges). E-VTOLs therefore need to make a very significant improvement on this point: assumptions for a full realistic cost assessment are very uncertain. We will therefore limit ourselves to setting a target for the direct costs determined by the e-VTOL design in comparison with a helicopter of the same payload capacity, production volume and annual flying hours. The following assumptions are made: lower production cost, maintenance cost -50 %, energy cost -80 %.

The sensitivity of the results to changes in these assumptions is discussed in section 6.4.

Specification of inter-city aircraft

If battery performance allows it, the use of e-VTOLs for inter-city traffic can be considered. The requirements for this mission are the same as those for the intra-urban mission excepting:

- *a stage length of at least twice that of the Uber specification, i.e. 200 km with adapted diversion rules;*
- *a capacity ideally of nine passengers, the upper limit allowed by the EASA special condition;*
- *a flight altitude of below 3,000 m;*
- *a speed of at least 300 km/h to ensure that journey times are significantly shorter than those of land transport;*
- *operations from vertiports with the same noise objectives as intra-urban missions;*
- *a flight time that will probably require more elaborate cabin conditioning with the necessity of flight in certified icing conditions to ensure regularity of traffic. The impact on performance will need to be considered.*

5 COMPREHENSIVE REVIEW OF EXISTING PROJECTS

The choice of configuration can be justified by considering the main constraints: safety, performance at take-off (VTOL capability) and during cruise, weight and above all reduction in noise level, which can limit the marketability of an "air taxi" mission that meets specifications.

5.1 Constraints

Safety

Managing failures in the VTOL propulsion system calls for a high number of rotors and motors associated with battery power and with redundant, oversized control systems. The higher the number of rotors and motors, the lower the oversizing needed. The use of distributed power (over 4, 6, 8, 12, 18 and even 36 propellers) with the possibility of two independent motors per rotor – an undeniable advantage of electric motorisation – ensures adequate engine failure management. In addition, manoeuvrability must be ensured by differential control of the module and thrust orientation.

VTOL capacity

To limit power needs, which affect weight, noise, purchase and maintenance costs, the disc load must be reduced by increasing the diameter and number of rotors while remaining within the specified geometric envelope (wingspan less than 13.7 m, or 45 ft). However, the cumulative disc area will be much smaller than that of a conventional helicopter.

Cruise performance

The stage length depends directly on the value of the equivalent glide ratio in cruise, which for configurations with wings (e-VTOL A) requires large wingspans, limited *to 13.7 m. Configurations without wings (e-VTOL H) are strongly penalised and will offer glide ratios close to those of helicopters.*

Conflicting requirements can be noted for the cruise phase (maximum wingspan, wing surface allowing flight at near-maximum glide ratio, small diameter propulsion system) and the hover phase (minimum wingspan, large diameter propulsion systems). Unlike CTOLs, the e-VTOL wing will not be affected by take-off or landing considerations and will allow high glide ratios. For the transition phase, however, it will be necessary to procure reduced minimum speeds (of the order of 65 kt) by means of high lift devices (flaps).

Noise

Whatever the flight phase (take-off, overflight and landing), efforts to minimise noise pollution strongly impact propeller definition and speed of rotation, to the detriment of performance. The accumulation of rotors clearly has a negative effect, partly due to wake interactions.

Weight

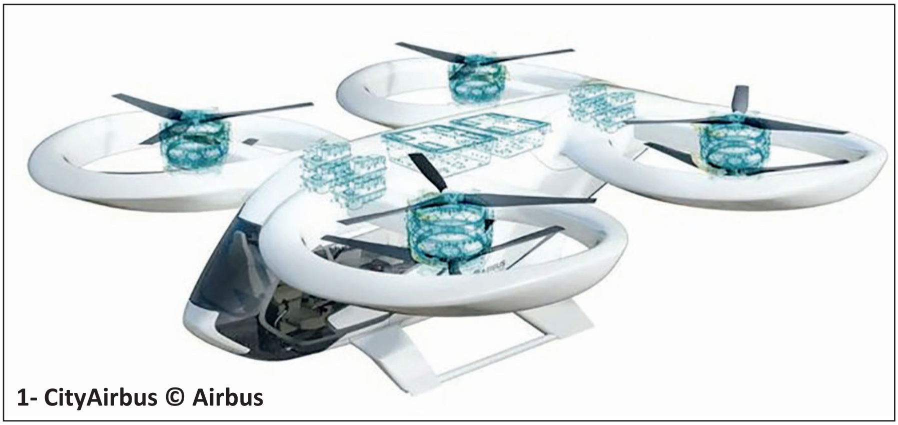
The regulatory limit of 3,175 kg for the Maximum Take Off Mass (MTOM) implies a greater effort to reduce the OWE (Operating Weight Empty) to be able to carry the highest possible battery weight, in addition to the imposed payload of 500 kg.

5.2 Configurations

Many different configurations have been proposed, sometimes very fanciful and often ephemeral. A selection of recent projects is illustrated in images 1 to 14 and the main published or estimated characteristics are given in the tables below.

A classification can be attempted, with the latest configurations all having a canopy and differing essentially in the number, type and arrangement of propulsion units.

e-VTOL H (helicopter types, with rotary wings only)



1- CityAirbus © Airbus

2- EHang216 © EHang

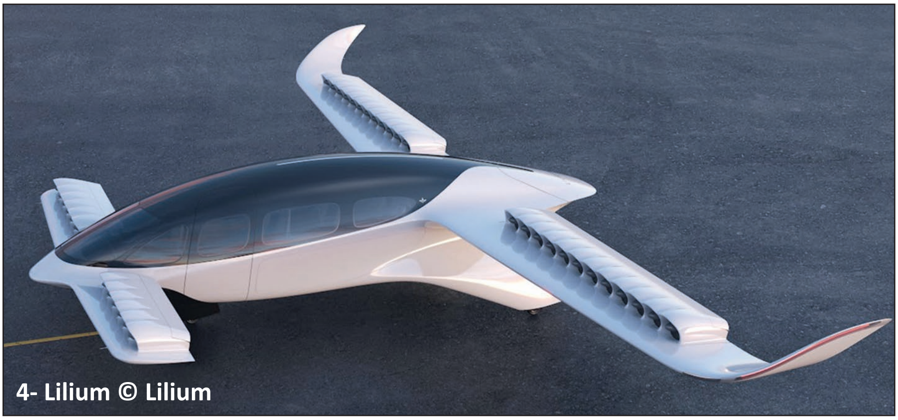
3- VoloCity © Volocopter

Projet / *Project*	CityAirbus	EHang 216	VoloCity	Specification
Constructeur / *Manufacturer*	Airbus	EHang	Volocopter	Uber
Capacité / *Capacity*	**4**	**2**	**2**	1+4
Type	VTOL H	VTOL H	VTOL H	
Contrôle / *Control*	Auto	Auto	Pilot	Pilot/Auto
Envergure / *Span* (m)	**8**	**5.6**	**11.3**	**13.7**
N moteurs / *N engines*	8	16	18	
N sustentation	**8**	16	18	
Type hélice / *Propeller type*	**contra rot DF**	**contra rot**	**single**	
D unit (m)	**2.8**	1.5	2.3	
A hover m² total	49.3	28.3	74.8	
N hélice croisière / *N cruise prop*	4	16	18	
Masses				
MTOM (kg)	**2 200**	**600**	**900**	**3 175**
OWE *wo bat* (kg)	1 408	240	495	
Batteries (k)g	**550**	140	205	
P/L (kg)	**250**	**220**	**200**	**500**
kOWE *wo bat*	**0.64**	**0.40**	**0.55**	
Energie / Energy				
N packs	4	8	9	
Energie kWh	**110**	31	45	
E* cell/Pack≈1C	200	220	220	**300**
P* cell/Pack 10C				
Aéro Finesse / *Lift / Drag*	4.5	4.5	4.5	
Performances				
Charge au disque / *Disk loading* (N/m²)	438	208	118	
Puissance / *Power hover Froude*	289	54	261	
K Duct	0.707	1	1	
Puissance / *Power* TO (kW)	**560**	**304**	335	
k Panne Puissance / *k failure power*	1.54	1.22	1.19	
k Panne batteries / *k failure pack*	1.33	1.14	1.13	
Puissance cruise aero / *Cruise power*	160	36	60	
Puissance cr bat / *Cr power pack*	**254**	**55**	**91**	
Z (m)		488		**300**
V cr (km/h)	**120**	**100**	**110**	**200<V<300**
Étape / *Mission* (km)	30	42	**35**	**96**
Durée / *Time* (min)	**15**	**25**	**19**	**29>T>19**
Bruit / *Noise* (dBA) TO/D m				**70/150**
Bruit / *Noise* (dBA) LDG /D m			**75/30***	
Bruit / *Noise* (dBA) survol / *fly over* / D m			**65/120***	

*measured

***Table 1: Analysis of different e-VTOL H projects** (manufacturer data **in bold**).*

e-VTOL A (aircraft types with fixed wings, whether compound or not)

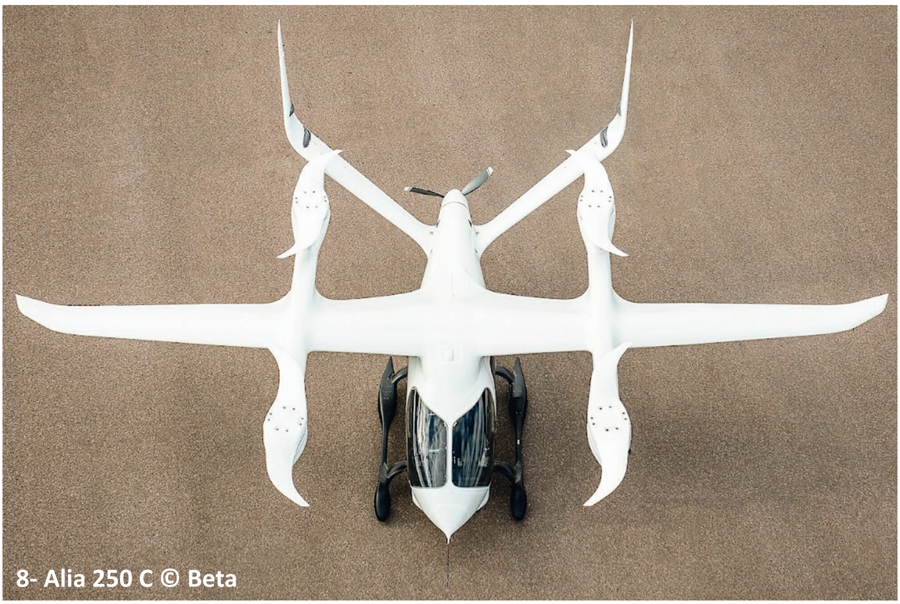


4- Lilium © Lilium

5- Maker © Archer Aviation

6- Cora © Wisk Aero LLC


7- Nexus 4EX © Bell / Textron


8- Alia 250 C © Beta

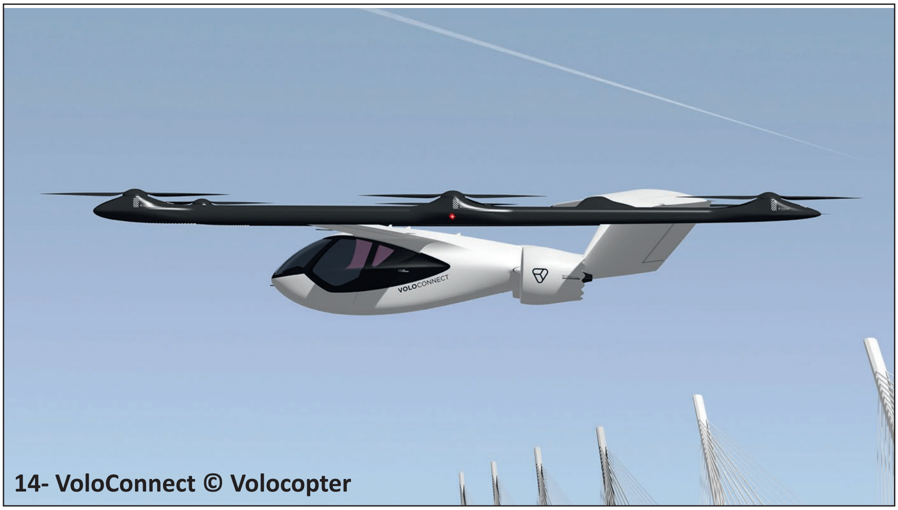

9- EVE © Embraer

10- Jaunt © Jaunt Air Mobility

11- Joby S4 © Joby / Toyota

12- Hyundai SA1 © Hyundai

13- VA-X4 © Vertical Aerospace



14- VoloConnect © Volocopter

Project	ALIA 250C	VA-X4	JOBY S4	Maker	Hyundai SA1	Cora	Nexus 4EX	Eve	Jaunt	VoloConnect	Lilium	Specification
Manufacturer	BETA	VA+RR	Joby / Toyota	Archer Aviation	Hyundai	Wisk / Boeing	Bell / Textron	Embraer		Volocopter		Uber
Capacity	**1+5**	**1+4**	**1+4**	**2**	**1+4**	**2**	**4/5**	**1+4**	**1+4**	**3/4**	**1+6**	1+4
Type	VTOL A	VTOL A	VTOL A	VTOL A	VTOL A	VTOL A	VTOL A	VTOL A	VTOL A	VTOL A	VTOL A	
Control	Pilot	Pilot	Pilot	Auto	Pilot/ Auto	Auto	Pilot/ Auto	Pilot/ Auto	?	Pilot/Auto	Pilot	Pilot/Auto
Span (m)	**15.24**	**15**	**11.6**	**12.19**	**15**	**11**	**12**	15	15		**13.9**	**13.7**
N engines	8	8	6	12	8	12	8	8	2	6	36	
Sustentation N	4	8	6	**12**	**8**	**12**	**4**	**8**	**1**	**6**	**36**	
Propeller type	proptor ?	**single**	**proptor**	**single**	**co rotative**	**single**	**single DF**	**single**	**rotor**	**single**	**single DF**	
Stowable	4	4		6	4	12		8				
Convertible	0	4	6	6	4		4				**36**	
D unit (m)	3.8 ?	3	2.90	1.8	3	1.3	2.5		12	3	**0.295**	
A hover m² total	45.4	56.5	39.5	30.5	56.5	15.9	19.6		113.1	42.4	2.5	
N cruise prop	1	4	6	6	4	1	4	**2 DF**	**4**	**2 DF**	**36**	
S ref m²	19.3	26.8	14.8	13	~19	11		~19	~16	~18	**18.7**	
Masses												
MTOM (kg)	**3175**	**3175**	**2177**	**1508**	3175	**1224**	**3175**				**3175**	**3175**
OWE *wo bat* (kg)	953	1746	958	829	1746	643	1746				**1523** 1143	
Batteries (kg)	1950 1543	979	**838**	429	979	400	694				**952**/1332	
P/L (kg)	**272/680**	**450**	**381**	**250**	**450**	**181**	**735**				**700**	**500**
kOWE *wo bat*	0.3	0.55	**0.44**	0.55	0.55	**0.53**	0.55				**0.48**/0.36	
Energie												
n packs	5	8	6	6	7	12	8	8			72	
Energie kWh	**330**	215	197	75		100	153				**305**	
E* cell/Pack≈1C	220	220	**235**	250/175	250/175	250 175	250/175				**320**/228	**- /300**
P* cell/Pack 10C	1500	1500	1500	1500	1500	1500	1500				**2700** 1928	
Lift:drag	16.8/1.2	15	**16**	**11.3**	15	**13.3**	13				**18.26**	
Performances												
Disk loading N/ m²	687	551	541	484	551	754	1586				**12658** 15179	
Power / Hover Froude	521	467	317	208	467	211	793				2239	
Power TO (kW)	**800**	719	**417**	**375**	719	277	1250				**2570**	
k failure power	1.54	1.54	1.84	1.31	1.54	1.31	1.54	1.54		1.84	1.09	
k failure batteries	1.25	1.14	1.20	1.20	1.17	1.09	1.14	1.14			1.01	
Cruise power kW	**100/-**	139	119	88	167	45	160				142	
Z (m)	**2438**			609							**3000**	**300**
V cr (km/h)	**195/268**	**241**	**322**	**241**	**290**	**180**	**240**	**241**	**130**	180	**300**	**200<V<300**
Mission (km)	**463/370**	**161**	**241**	**97**	**100**	**100**	**95**	**96**		**96**	**261**	**96**
Time (min)	104	40	45	24	21	33	24			32	52	**29>T>19**
Noise dBA (TO/D m)			**65/100**								**60/100**	**70/150**
Noise dBA (ldg /D m)												
Noise dBA survol Fly over /D m			**40/500**	45							**54.4/100**	

Table 2: Analysis of different e-VTOL A projects *(manufacturer data in **bold**).*

The following observations can be made: e-VTOL H models are more compact, especially the CityAirbus (8 m length/wingspan, with 2.8 m diameter blades), whereas e-VTOL A models, in search of maximum wingspan, can exceed the specified Uber value of 13.7 m but meet (with one exception) the regulatory limit of 15 m (50 ft). The difference in equivalent glide ratio (threefold) explains the abandonment of e-VTOL H models, whose cruise performances are even more marginal than the e-VTOL A.

Convertible or compound

To manage the conflicting needs of the cruise and hover phases, the multiple propulsion units can be either identical and fixed (e-VTOL H: CityAirbus, EHang216, VoloCity), or identical and convertible – in these cases all pivoting to orient the thrust axes (e-VTOL A: Joby, Lilium, Bell) or different for each phase, thus partly retractable in cruise (compound e-VTOL A: Cora-Kitty Hawk, Eve, VoloConnect, Jaunt). Some configurations are complex compound/convertible combinations (AVX4, Archer).

It is likely that a patent application was filed for each configuration to block the competition, forcing it to copy (with the corresponding consequences) or to invent new concepts.

Propulsion systems

Lift and propulsion can be achieved either by freewheeling or by ducted propellers, each driven by one engine (or the equivalent of two for the four-pod configuration of the Bell and four rotor configuration of the Beta Alia).

Propellers, either free or ducted, can be single or combined in a co-rotating or contra-rotating doublet driven by two motors. Counter-rotating propellers provide better performance while co-rotating ones seem to be chosen for noise reduction.

Free propellers, with fixed, retractable or steerable axes of rotation, allow for larger diameters. Convertible propellers must ensure good performance and minimise noise in both configurations, and have acceptable performance during transitional phases.

Ducted fan nacelles, with their necessarily reduced diameter and therefore high disk load, have a drag penalty in cruise but offer a performance advantage in hover, combined with a likely reduction in noise emissions and improved safety in ground operations, which justifies their choice.

E-VTOL H propellers are extremely simple – two or three blades, fixed pitch, each associated with a motor – and can form counter-rotating doublets, favourable to performance.

E-VTOL A propellers dedicated solely to lift are also simple, two-bladed, acoustically optimised, fixed-pitch propellers that can form co-rotating, noise-friendly doublets.

Propellers providing propulsion or dual function are "conventional" and are critical from an acoustic point of view in the far field as well as in the near field (cabin). The

Eve project (Embraer) retains two "pusher" ducted fans, while the Joby project with 6 "conventional" propellers requires special solutions (patented, with cyclic control) to reduce acoustic nuisance

The performance and acoustic emissions of "free" propellers are directly related to the characteristics (geometry and peripheral speed) of the blade tips. The performance of the motors is related to the rotational speeds (revolutions per minute-t/min). Without a gearbox, a compromise will have to be made. The range of rpm announced goes from 950 for the Airbus City to more than 10,000 for the Lilium, which shows the possibility of electric motors, but the peripheral speed does not exceed 140 m/s for the CityAirbus propeller, which is strongly constrained by noise, compared with 158 m/s for a shrouded propeller. The latter value, largely subsonic, seems to be retained for all lifting propellers. Of the projects analysed, only the Jaunt would require a gearbox to drive its rotor.

The use of orientable propulsion nacelles (the case of convertibles) is a definite risk for certification, as no civilian convertible aircraft has passed this stage (ref. the AW609). However, the parallel with transport aircraft, which must ensure the symmetrical extension and retraction of slats and flaps and the secure control of the adjustable horizontal plane, would seem to indicate that certification could one day be obtained, with the necessary redundancies on the actuation devices, their energy sources and their control means.

Number of propulsion units

The use of distributed power (over 4, 6, 8, 12, 18 or even 36 propellers), with the possibility of two independent engines per propeller, ensures adequate engine failure management, but directly affects the configurations (in terms of total dimensions or aerodynamic and acoustic disturbances), all the more so since a large cumulative surface area of the discs must be sought.

5.3 Technical results

Disc load

Two extreme configurations in terms of disk load are the Jaunt pseudo gyrocopter, with a rotor diameter of almost 12 m, and the Lilium, with 36 ducted fans of 0.295 m diameter and a large hub, with a total surface ratio of over 45.

All configurations (except the Jaunt) have a cumulative disc area in hover mode that is significantly less than that of a helicopter of the same weight, which is a concern for the power level to be installed for hovering. In addition, rotor wash, which has been shown to be unfavourable for recent convertibles, may be of even greater concern. The difference in power between e-VTOL A models with neighbouring MTOMs ranges from 2,570 kW (Lilium) to 800 kW (Alia 250 C); power levels in cruise are closer and correspond to battery discharge in about one hour of flight, while the Lilium batteries will work very hard at take-off, during which the power will be more than ten times greater.

Aerodynamics

The search for a high glide ratio in cruise, which largely determines the corresponding power required, justifies the search for large wingspans by all e-VTOL A projects (e-VTOL H being at a strong disadvantage, being unable to better helicopters by this means). All their wingspans are therefore close to the limits imposed.

The Lilium project claims a glide ratio of 18.26. Its original configuration does not allow for comparisons, but the presence of 24 ducted fans on the wing and 12 on the canard tail should significantly disturb the flows on these lifting surfaces; despite a pre-project justification, this value is at the limit of credibility, with a glide ratio of between 16 and 17 for the Airbus CTOL e-FAN. Other e-VTOL A projects could claim a value close to 15 to 16 given the presence of numerous nacelles.

This value seems credible for large-scale e-VTOL A configurations with multiple nacelles.

Weight

For projects with a capacity of 4+1 occupants, which is proving to be the norm, the MTOM is close to the maximum allowed (3,175 kg), which is risky at this stage, except for the Joby, whose 2,177 kg is considered to be very ambitious.

OWE

For a first analysis, it is optimistically assumed that e-VTOLs should have empty weights close to those of fuel aircraft of the same MTOM and type.

Empty weight (without battery and pilot packs) should therefore be close to 0.55 MTOM (or a kOWE of 0.55) for the e-VTOL A and 0.50 MTOM for the e-VTOL H, compared to the statistics for combustion versions of the same type, with a five-point improvement to take into account the absence of landing gear (A) or gearbox (H), lighter engines and propellers, no cabin pressurisation and air conditioning, reduced flight speeds (for the A), simplified cabin layout (given flight duration) and the generalised use of composite structures.

Data is scarce and shows two extremes:

- *the Lilium project (e-VTOL A) claims a kOWE of 0.48, which includes part of the battery pack. If we exclude it to bring it in line with the other projects, the figure falls to 0.36, which cannot be justified by the 36-motor and variable-section nacelle configuration, which is inevitably heavier. The credibility of this project's performances is therefore highly questionable;*
- *the CityAirbus, which presents the advantage of having made its first flight with a kOWE of 0.64, heavily penalised by the use of existing oversized engines (8x204 kW certified, 8x100 kW installed, as opposed to the 8x70 kW required). Factoring in adapted engines, its kOWE would reach 0.53;*
- *based on published values, the kOWE of the EHang 216 is 0.40, which can be explained by the extreme simplicity of the configuration and is a minimum level value.*

The importance of the role of empty weight on the performance of VTOL projects with limited MTOM is recognised. In the context of this analysis of the various projects, it is impossible to be more precise, but kOWE values lower than those given above are difficult to credit, especially as they are associated with MTOMs that are already at the certifiable limit, and therefore have no margin.

Figure 1 illustrates the impact of kOWE and glide ratio on MTOM in accomplishing the reduced mission (60 km) to leave a domain of existence for helicopters within the 3,175 kg limit.

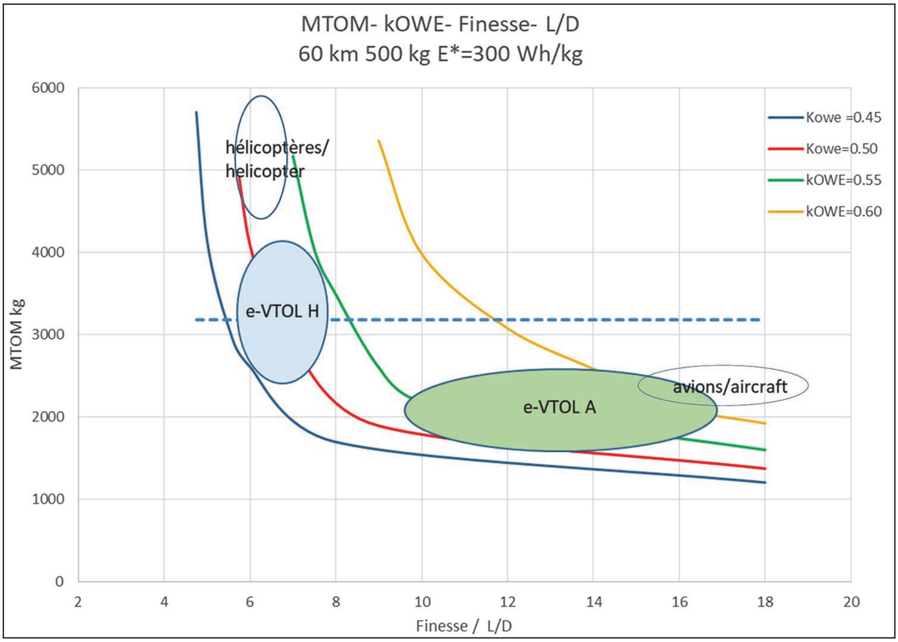


Figure 1: MTOM as a function of glide ratio and kOWE.

Performance

Claimed performances are heterogeneous, with e-VTOL H models not exceeding 35 km or 30 minutes of flight time at reduced speeds. They will therefore not be in a position to aim for Uber specifications.

For the e-VTOL A, the diversity (from 95 km to 463 km) is surprising, but may be the result of unspecified, optimistic battery specific data values and especially unrealistic kOWE and mission profile. Only one project, the Alia 250 C, clearly exceeds one hour of flight time (104 minutes, i.e. 463 km at 268 km/h), making it as implausible as the Lilium, while all the other projects fly for less than an hour. It should be noted that flight distance – obtained by dividing available on-board energy by drag – is the right criterion, with duration being deduced through speed, which is "arbitrary" within certain limits, hence the choice of high speeds to reduce this duration and fly at speeds above those corresponding to the maximum glide ratio, at acceptable incidences.

Noise

All configurations, especially their lifting propellers, result from acoustic optimisation to the detriment of performance. The detailed analysis presented by Lilium incorporating an attenuation of more than 5 dBA thanks to the acoustic treatments specific to ducted fans, arrives at a level of less than 60 dBA at 100 m for the most critical case for this configuration, take-off, despite a power level 3 to 4 times higher than those of the other projects. The doubt surrounding the technical data of the Lilium project would seem to cloud these values as well.

No mention is made of cabin noise in any of these projects. The removal of the main gearbox (MGB) in most cases is certainly propitious by eliminating vibrations but the proximity of the propeller blades, admittedly not heavily loaded and tending to rotate slowly, could be critical and would at least require an estimate, given that no acoustic treatment of the cabin can be envisaged.

5.4 Conclusion

Analysis of the main e-VTOL projects designed to meet the Uber specification, based on the limited and sometimes contradictory information published, shows that:

- *only e-VTOL A configurations could aim at the performances required by this specification;*
- *no publication presents a compliance analysis with the various points of this specification. Only the "maximum" stage is assessed;*
- *this evaluation leads to a dispersion of performances (from 95 km to 463 km) that is difficult to explain for similar payloads and configurations (excluding the Lilium, which is considered to be highly implausible). The credibility of the published performances is therefore doubtful, to say the least;*
- *to confirm or reject the potential of existing projects to meet Uber specifications, one cannot rely on published data. Therefore, only an independent and coherent analysis, of the pre-project type, can identify the conditions for success. This is the subject of section 6.1.*

6 ANALYSIS OF THE STATE OF THE ART AND PROSPECTS FOR ELECTRICAL ENERGY STORAGE TECHNIQUES AND COMPONENTS OF THE ELECTRICAL PROPULSION CHAIN

An essential component in ensuring aircraft mobility is the quality of energy storage since it ensures the safety and efficiency of propulsion systems. An analysis of the state of the art and prospects for electrical energy storage techniques indicates a proliferation of fundamental and industrial research, in all countries and regarding all storage modes, strongly motivated by the prevailing "green" mood and the huge market for road applications and reinforced with each announcement of a technology breakthrough. In the context of air transport use, the qualities sought for the storage mode are mainly safety, performance, operating costs and sustainability of energy sources. These properties have been analysed in detail in a review of the literature and the main results are summarised below.

6.1 Batteries

Batteries can store large amounts of energy and/or power per unit of mass or volume, and their performance is steadily improving as electrochemical technology changes. At present, lithium-ion technology is clearly the most efficient for use in transport, and this supremacy seems likely to continue, as its potential for improvement is still significant. The question is: can it be applied in a real way to air transport propulsion?

The name lithium-ion or Li-ion comes from the fact that the technology is based on the reversible insertion of lithium ions into the electrode materials which constitute the active materials of the electrochemical system and whose characteristics determine those of the cell, with the lithium element, initially contained in the electrolyte, being only a charge carrier.

This principle does not apply to batteries using lithium metal as the negative electrode, in which lithium is one of the active materials; not yet available, these offer the potential for a tenfold increase in performance.

Battery cell-module-pack (BMS)

The elementary battery is called a cell. It is made up of several superimposed thin sheets (from 10 to 75 µm) for a total of a few hundred µm. It is either cylindrical or prismatic with a rigid envelope or a flexible envelope known as a pouch.

The module is made up of an assembly of elementary cells, in series or in parallel depending on the goal. Several modules are assembled in a housing structure (pack) which includes the cell wiring, voltage, current and temperature sensors in the pack, junction box with the exterior and electronic box, known as the Battery Management System (BMS). For reasons of weight and cost, the trend is to eliminate the “module” stage. The BMS is an essential element for efficient, safe operation of the battery. In particular, it controls temperature level, which affects all aspects: safety (runaway), performance (capacity and power degradation) and economics (service life).

Choice of electrodes

There are many insertion materials for positive and negative electrodes, each pair determining both the reference open circuit potential, the OCV (Open Circuit Voltage) and the specific capacitance of the cell (by homographic composition of the theoretical capacities, with the lowest imposing its value. There is little point in increasing the capacity of the negative mass if the capacity of the positive remains limited and vice versa). The theoretical weight energy density is deduced from this, taking into account only the active materials of the electrodes.

Choice of electrolyte

The electrolyte is an essential element in batteries, as it allows the lithium ions to migrate from one electrode to the other.

A distinction is made between liquid electrolytes based on lithium salt and organic solvent, specific to Li-ion batteries, and electrolytes based on lithium salt inserted in a polymer structure, constituting a gel which also acts as a separator, specific to Li-Po batteries. Even solid electrolytes are being studied.

Features / Performance

Battery performance is directly related to the electrochemical characteristics of the electrode materials and the electrolyte, and is mainly characterised by the nominal practical mass energy density E (Wh/kg) and the nominal practical specific power P* (W/kg), both related to the complete mass of the pack. The curve of P* versus E* constitutes the Ragone diagram.*

Depending on the needs of the various applications, either “energy-type” or “power-type” batteries are developed. Figure 2 shows the Ragone diagram for three types of battery, whose envelope curve can be imagined.

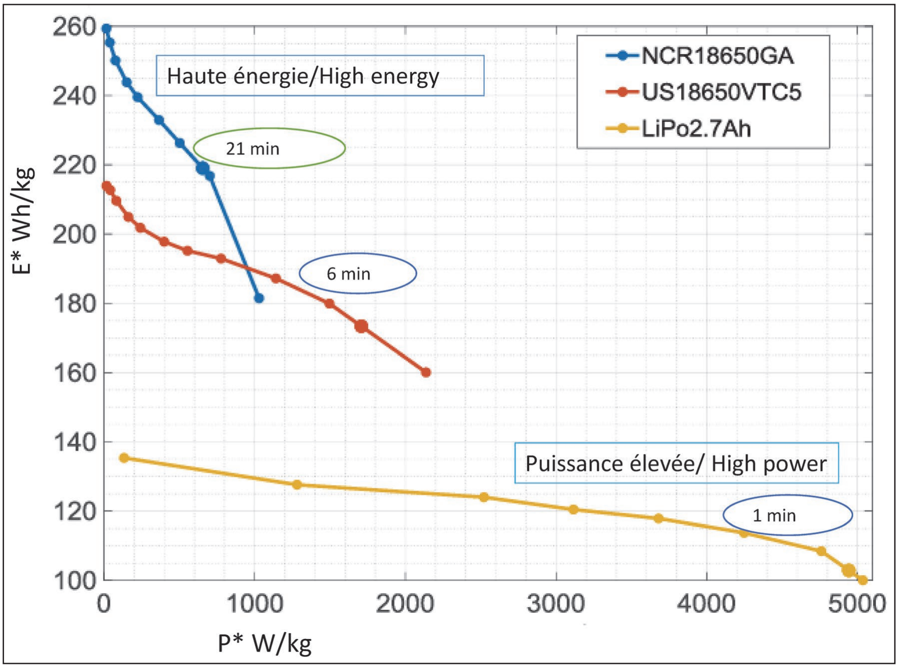


Figure 2: Choice of battery type. [3]

The published E and P* data are for new batteries, the effect of calendar ageing and wear and tear (in number of cycles) will degrade these values.*

Ageing, life span

Deterioration of performance with use, through a combination of calendar ageing and the cumulative effect of cycles, affecting both energy and power, limits operational life. It should be noted that a specific quality of lithium is the virtual absence of parasitic chemical reactions, other than very slow ageing reactions, resulting in a very low self-discharge rate, fundamental to energy storage. Highly sensitive to charge speed, this rate can be reduced to a few percent per year.

Determining the state of battery reserves

For the user, knowledge of the state of energy and power reserves until the end of operational life is fundamental for flight safety. Several parameters are used, with no universal definition:

- *SOC (state of charge) translates the evolution of consumption during a cycle; charge phase is monitored with the same parameter;*
- *SOH (state of health) reflects the ageing of the battery; it monitors the evolution of both energy and power reserves, the most critical determining the end of operational life.*

Recharge

The speed of the charging phase is even more important for air taxis than for road vehicles if they are to operate many flights per day. Provision of significant ground power is *necessary, with "fast" charging powers in excess of 500 kW; the charging current should not, however, exceed half the discharge current. The charging speed is limited by the phenomenon of lithium plating, where lithium ions form a deposit instead of being inserted. The charging law must be optimised.*

Costs

The price of active materials represented only 15% of costs in 2015, including 11% for lithium, with cell and pack production costs accounting for two thirds. The very rapid evolution (7.6-fold reduction in ten years, see Figure 3) can be explained by several parameters, the main one being the reduction in production costs, with the price of lithium contributing more and more. The trend is expected to reach below \$100/kWh by 2025, a turning point at which road electric vehicles will be almost on a par with current vehicles with internal combustion engines, facilitating the operation of electrically powered aircraft. The price of aeronautical batteries will inevitably be higher (increased safety constraints, mass optimisation, reduced market volume).

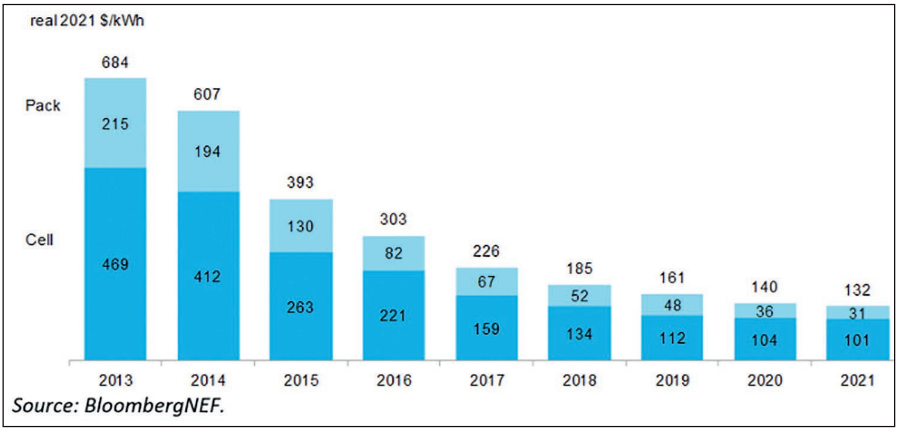


Figure 3: Volume-weighted average pack and cell split trend.

Lithium availability

Lithium as a raw material comes mainly from the crusts of salt lakes, the remainder from hard rock; research into extraction from sea water is underway. Demand is accelerating as a result of applications in road transport (a small electric car needs 4 kg; a small air vehicle is likely to need 20 times more). There is no question of a shortage yet, but prices are following the law of supply and demand. Recycling batteries for a second, non-aeronautical application would help the carbon and economic balance. The first step is to accumulate used batteries.

Operational safety

Lithium-ion cells have received bad press for the large number of highly publicised incidents that have occurred in recent years. It is mainly the flammability of the liquid electrolyte that poses safety issues and causes most of the damage. Practical mitigation of *these risks, particularly through the use of BMS, results in a limitation of battery performance and introduces installation constraints; the switch to solid electrolytes would provide a significant gain in this area.*

State of the art, innovations and perspectives

Tracking of continuous improvements in Li-ion battery performance (E) indicates a plateau in 2020 at around ≈300 Wh/kg, at the cell level, for NCR technologies (based on oxides of a mixture of manganese, nickel, cobalt and aluminium). The rapidly growing NMC technology (Ni rich), allowing to target a level of 350 Wh/kg by 2025, would represent a limit (?) for conventional insertion electrode technology: see Figure 4.*

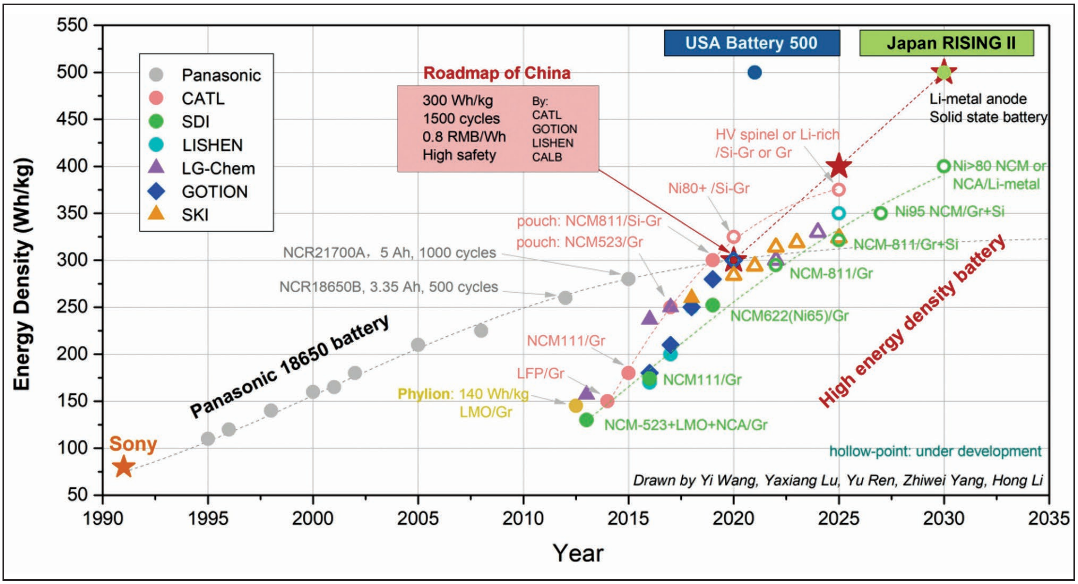


Figure 4: Comparison of specific performances of different batteries for application in electric cars. *Extract from the "European SET Plan (Battery 2030+ Roadmap)". This figure was provided by Professor Hong Li of the Chinese Academy of Sciences.*

These improvements will result firstly from work on the electrochemistry of the cells, but also on their mechanical design, to be optimised for aeronautical applications which are more sensitive to mass and power requirements, as well as on their manufacturing processes to continue to reduce costs.

Two additional potential improvements, constituting real breakthroughs, are envisaged, one with a lithium metal anode and a likely solid electrolyte, which is tricky to develop, the other, based on the concept of anionic redox reaction, with the appearance (2011) of Li-rich technology which is considered to be a revolution enabling the performance limits of insertion electrodes to be pushed back. This second approach seems more difficult to develop to an operational stage.

While the level of 500 Wh/kg at airframe level seems a feasible limit, the associated technology and the date of availability for batteries meeting aeronautical specifications cannot be specified; probably beyond 2030, which is the goal of research institutes.

6.2 Fuel cells

Fuel cells convert the chemical energy of the fuel (hydrogen) into electrical energy without combustion. For an aeronautical application, only the proton exchange membrane fuel cell (PEMFC), operating at moderate temperature (below 100°C), is considered. The energy available is linked to the quantity of hydrogen on board, but the mass of the complete system reduces the specific energy E, which can however be higher than that of Li-ion batteries. Their power P* is much lower than that of Li-ion batteries. They must be combined with a battery system in order to absorb power peaks. Despite being developed earlier than Li-ion batteries, PEMFCs are far from having reached the same level of maturity, with low-volume trial applications for road vehicles, especially for large transporters. Their potential is high but their prices are very high (platinum, membrane) and their life span limited; given the complexity of the complete system, many analyses conclude that fuel cells cannot be considered as a feasible energy source for the aeronautical applications under consideration (propulsion), at the envisaged timescale.*

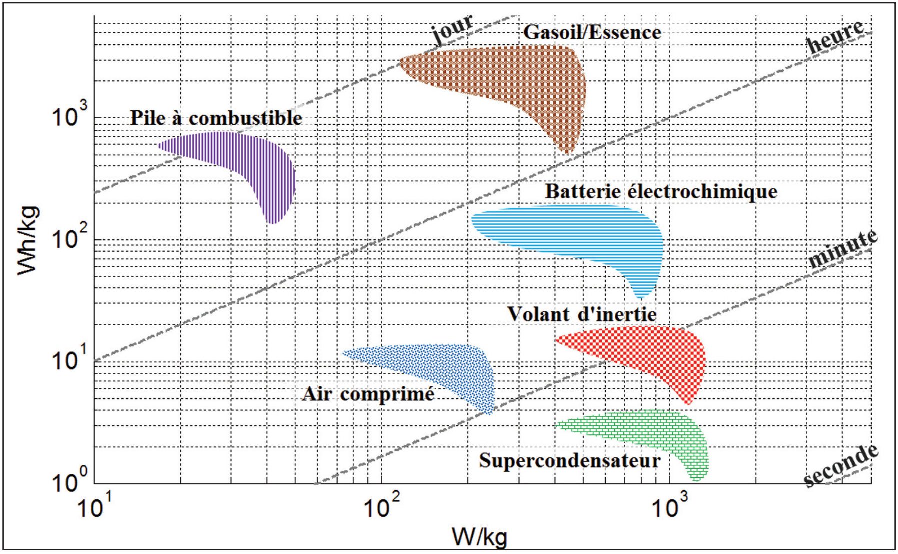


Figure 5: Ragone plot of different systems of energy stowages including corresponding engine mass. From top to bottom: Diesel/Petrol, Fuel cell, Electrochemical battery, Inertia flywheel, compressed air, supercapacitor.[4]

4 Crédits : Aurélien Lièvre, "Développement d'un système de gestion de batterie lithium-ion à destination de véhicules *"mild hybrid"* : détermination des indicateurs d'état (SoC, SoH et SoF). Énergie électrique. Université Claude Bernard, Lyon I, 2015.

6.3 Super capacitors

Energy is stored in a supercapacitor in the form of an electrostatic field within each electrode. The storage is done with a capacitor at each electrode connected by an electrolyte containing ions and a solvent (or polymer).

They offer high specific power but too low levels of specific energy, ruling out durations of more than a few seconds, which is incompatible with the envisaged use, except by hybridisation with batteries.

6.4 Evolution defined for E* and P*

Based on the review of battery developments at the cell level (E close to 300 Wh/kg in 2020+) and improvements to the complete system (mass increase coefficient between cell and complete pack between 1.3 and 1.5), we have chosen a reference value of E*=220 Wh/kg (1C) and a reference power P*=1,500 W/kg (10 C), which allows us to draw the Ragone plot (Figure 6), for a typical "high energy" aeronautic battery.*

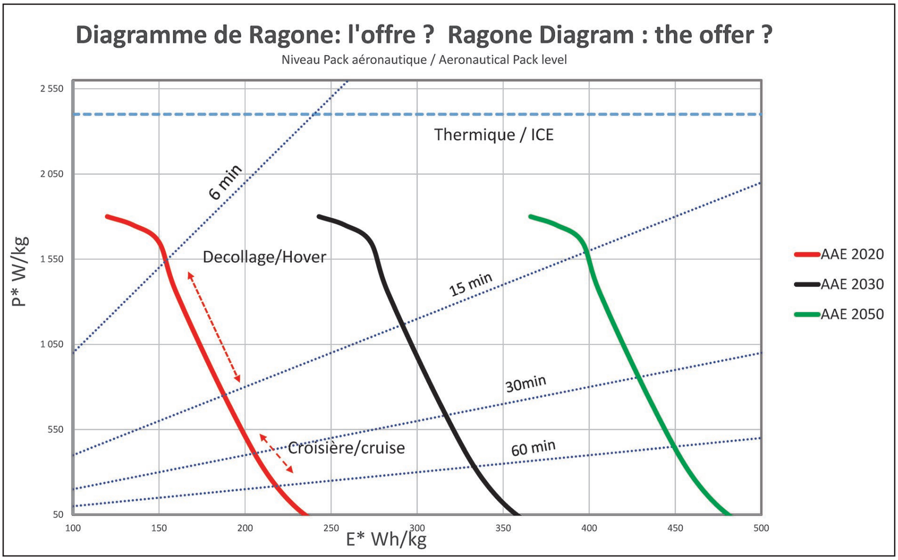


Figure 6: Ragone plot.

In a medium-term prospective vision, towards 2030, taking into account the anticipated results of the work programmes of scientists and industrialists, we can propose an improvement of 50 % for the specific energy (330 Wh/kg), at constant specific power.

Considering the many research projects underway on batteries (lithium-air in particular), we can propose an identical gain by 2050, despite the uncertainties associated with such a distant projection. These quantitative hypotheses will make it possible to qualify the possible evolution of the performance of the e-VTOLs currently under development.

6.5 Electrical components

Power electronics are used for the many power converters (DC/DC – Direct current – or DC/AC – Alternative current) that allow energy transmission to be optimised and also for the control of electric motors. They are also being considered for the protection of distribution circuits. We can therefore expect a reduction in the masses linked to power electronics thanks to the use of new types of transistor (Si, then SiC – Silicon Carbide – then GaN – Gallium Nitride) with an effect on passive components.

6.6 Propulsion systems

Electric motors

The many motors with relatively low unit powers (below 100 kW) need to offer high specific power (kW/kg) to reduce the weight of the propulsion unit, and high efficiency to restrict losses and reduce cooling requirements. The competition was mainly between the asynchronous "squirrel cage" motor and the permanent magnet synchronous motor. It is worth mentioning the recent emergence of disc-shaped "axial flux" motor projects that claim a 2.5-fold power density. This competition should make it possible to achieve specific powers of the order of 5 kW/kg in the short term. Of note is the ability of these engines to offer good performance over a wide range of rpm, which is essential for e-VTOLs equipped with gearless propellers or rotors.

Propellers and duct fans (performance, mass, noise)

Propulsion systems (propeller, fan) associated with electric motors will offer the same performance as those for combustion engines unless their operating conditions (rpm range) allow them to be more efficient and less noisy. They could be shrouded if the overall balance (performance, noise, mass) is favourable. It should be noted that very sophisticated calculation methods are available to optimise the definition of these engines, taking into account performance, acoustics and structural aspects (with effects on mass).

7 POSSIBLE RESPONSES OF E-VTOL CONFIGURATIONS TO SPECIFICATIONS

7.1 Performance *(payload capacity, range, speed)*

The analysis of the performance of existing projects presented in Chapter 4 revealed a disparity in the published data without identifying the significant distinguishing parameters that could explain it (battery technology, mass specification, glide ratio (F), evaluation method and assumptions) for projects that are supposed to meet the same Uber specification and the MTOM limit of 3,175 kg.

In order to specify the technical viability of e-VTOL type aircraft, a pre-project study was carried out, focusing on the main definition parameters (kOWE, cruise glide ratio, cumulative surface area of the discs) as well as the specific characteristics of the batteries (E Wh/kg and P* W/kg); this study followed the mission modelling proposed in the Uber specification, with realistic reserves, targeting its mission objectives. The aim of the study was to specify the necessary values of these parameters and to qualify their feasibility.*

A cruise speed of 180 km/h is chosen. Without optimisation, this value does not affect distances but only mission times, given that it is likely to be low to aim for maximum glide ratio.

For the glide ratio parameter, the values from 13 to 17 cover a realistic range, incorporating the published values.

For kOWE, a wide range is used (0.45 to 0.6) to measure the impact of this parameter which is important but difficult to estimate.

The surface of the discs corresponds to four propeller ducts, 1.5 m in diameter, each driven by two motors. This parameter is used to assess the power required for *hovering and dictates the energy consumption in the climb and transition phases but has little effect on the energy balance of a mission.*

For batteries, two technologies are used: one corresponding to the state of the art identified for 2020 and the other proposed in the Uber specification. The end-of-life values are retained.

The graphical results of this analysis are given in Annex 6.1 and allow us to conclude that:

- ***2020 battery technology** does not meet the 100 km mission with realistic values of the "project" parameters and with the MTOM limit at 3,175 kg. Reducing capacity to four occupants, as considered in the specification, does not change this conclusion;*
- *this technology is also unable to meet the demand for 40 km multi-missions, with a five-minute recharge time that is too ambitious;*
- *a 75 km mission would be achievable with a specific power requirement P* of more than 1,400 W/kg, compatible with 2020 technology;*
- *the share of energy actually consumed is only about half of the energy on board. The need for recharging is therefore limited and the possibility of carrying out several "small" missions with more realistic partial recharging (10 min) in masked time seems possible;*
- ***the technology defined by the Uber specification** (300 Wh/kg) allows the 96 km mission to be largely achieved with realistic values of the "project" parameters, the study presented in Chapter 5 shows that this level should be reached around 2030;*
- *it also enables multi-missions of 40 km for three hours;*
- *P* must improve with E* because battery weight decreases while the power requirement remains;*
- *with this level of battery technology, the imposed limit of 3,175 kg appears to constrain any increase of range or capacity, which was not the case with the 2020 technology;*
- *to double the maximum range and consider inter-city journeys while respecting the 3,175 kg limit, it is necessary to reach E* values close to 400 Wh/kg, which pushes this use back towards 2050, the need for power remaining limited.*

7.2 Safety

Safety of operations

For e-VTOL transport within cities to develop, it is essential to ensure its objective safety as well as the perception of safety by users and those concerned by ground damage resulting from a possible crash in built-up areas.

The criterion of perceived safety is added to that of objective safety by factoring in whether configurations have a reassuring or worrying appearance, as well as *passengers' impressions as to the level of stability of platforms, or their perceived fragility or robustness. These aspects will not be the easiest to deal with given the unusual configurations envisaged and the conditions of use close to the ground in built-up environments.*

Objective safety takes into account all elements of the transport system: the aircraft (design, manufacture) and its operation (maintenance in operational condition, traffic management including breakdown situations), along with meteorological risks, pilot qualification and the prevention of terrorist activity. Operational safety is largely guaranteed by type certification of aircraft and the operational regulations discussed in Chapter 7.

The safety objective considered by EASA is that of passenger air transport and is based on design, manufacturing, maintenance and traffic management rules equivalent to those in force for mass air transport. This objective is justified by the frequency of flights envisaged and the overflight of built-up areas. The experience of passenger air transport shows that this level of safety can be achieved, provided that the necessary means are available to all the players concerned.

The first player is the manufacturer, and current projects are clearly being carried out by a disparate group of aircraft manufacturers and start-ups. The former undoubtedly have the capacity to achieve the safety objectives, while the latter must demonstrate this by acquiring the necessary resources (technical and financial). Obtaining the type certificate will guarantee that the safety level of the vehicle is achieved.

Operational safety cannot be achieved without ensuring the qualification level of pilots (during the initial phase when a pilot on board will be required), which will pose a recruitment and training problem if the number of e-VTOLs exceeds that of transport aircraft. The autonomy or remote control of e-VTOLs envisaged in the future could provide a solution to this problem.

Safety also depends on traffic management, especially if it reaches the level targeted by the promoters of the UAM concept. Most agglomerations are in air-traffic-controlled areas where all movements are monitored by air traffic controllers (ATM). The envisaged UAM would lead to saturation of the current ATM system and new solutions will have to be found and deployed, such as controller assistance by artificial intelligence and/or autonomous e-VTOL operation. Until such solutions are developed, traffic will remain limited.

Helicopter experience shows that a large proportion of accidents occur during operations close to the ground and its obstacles where the slightest pilot error often has catastrophic consequences. Landing and take-off phases in urban environments will be critical with difficult noise trajectories and turbulence generated by buildings. The automation of these phases and the use of obstacle detection and avoidance systems will probably prove indispensable to guarantee the targeted level of safety.

Finally, the risk of terrorism will have to be prevented without affecting ease of access to the transport system, which requires more effective solutions than those currently in place at airports.

In conclusion, certification of e-VTOLs will ensure the safe operation of the aircraft but will increase its complexity and cost. The safety of the transport system also relies on traffic management and the availability of qualified pilots; limitations on these two aspects will slow down the development of UAM until automated operating solutions are deployed.

7.3 Noise

The recommendations of Dossier No.44 published by AAE concerning helicopter noise in urban areas were based both on technological progress on noise sources (main and tail rotors, take-off weight, automation of descent and low altitude flight phases), and on heliport approach flight profiles and weight and size reduction for urban use (four to six passengers, reduction of onboard fuel). The limitation of the number of flight frequencies in dedicated areas should also be considered.

Noise nuisance emanating from urban air taxis or aerial city shuttles, as perceived by the public, is a tricky point in the acceptance of these aircraft since most trajectories consist of low-level flights and descending approaches to urban stations.

It should be recalled that the noise of VTOLs (conventional helicopters) is mainly due to aerodynamic phenomena related to the rotation of the rotors. The interactions of the blade wakes with the other main rotor blades (Blade Vortex Interactions – BVI) are the major source. Other lessor sources are interactions between wakes and other parts of the aircraft and the reflection of these noises by the fuselage. The noise emitted is directional, with maximum noise areas at the front and rear, and maximum noise in descent.

The e-VTOLs known to date have various configurations that are quite different from the classical main rotor helicopter concepts. They are multi-rotor (up to 36), their rotors can have different speeds, they can use blades or propulsive rotors in certain phases of flight. These elements lead to significant differences with what we know of today's certified rotary-wing aircraft. Each element influences both the spectrum of acoustic frequencies emitted and the tone of the sounds emitted by the turbulent interactions between the constituent parts of the aircraft, the blade/vortex interactions for each rotor (in several flight configurations, unlike conventional helicopters), the interactions of the rotors or propellers with the fuselage (which are very high for e-VTOLs given their small size), recirculation effects, interaction of the wakes with the rotor blades (between each other) and with the other constituent parts, including the wing, thrust elements, and fairings if the configuration includes them.

The multiplicity of rotors leads to an increase in aerodynamic interactions between parts and unsteady elements: this makes it difficult not only to identify the sources *but also to identify the noisiest[5] flight phases. Indeed, the unsteadiness created by the complex aerodynamics of multi-rotor designs causes load variations on the rotor blades or the lifting surfaces, corresponding to the passing frequency of the blades, creating additional noise sources. On conventional helicopters, there is a predominance of unsteady effects on the main rotor, whereas on multi-rotor designs the sources are more numerous and less discernible from each other. The noise emitted is therefore broadband, including frequencies due to the rotors (inter-rotor and intra-rotor), interactions between the constituent parts and those created by the effects of atmospheric turbulence. To these sources, we must add the vibrations and vibration couplings between the support and structures, and the fuselage.*

Engine noise is a component that is not considered in the case of electrically powered aircraft. On the other hand, electrical power sources can induce vibrations that contribute to noise. In the state of the art, specialists consider that this potential source of noise is not yet well identified in terms of frequency and sound level. Similarly, recent studies do not take into consideration the possible presence of a main gearbox, which is a major source of noise and vibration for fuel propulsion aircraft but rare in e-VTOLs.

Finally, noise depends on flight phase:

- ***level cruise flight** is not the most critical phase of flight; most of the reported noise figures are for this flight condition. For convertible configurations flying in aeroplane mode, the noise level should be considerably lower than that of a helicopter, especially with the low peripheral speeds of the blades and the absence of impulsive noise; for compound configurations and multi-rotor helicopter configurations, the noise will come mainly from the rotors and the same methods as used for helicopters should make it possible to reach acceptable noise levels, although it is important not to overlook the various interactions between the wakes and the multiple rotors (risk of BVI or couplings or flutter-induced vibrations). In the case of configurations using shrouded rotors, the noise should be lower than that of a helicopter due to the masking effect of the shrouds; however, this geometry creates interactions between the stators' support arms and the blades;*
- ***hovering**: this is a helicopter-like situation and the same methods (in particular by reducing the peripheral speed of the blades) should ensure a low noise level. However, the multiplicity of rotors is a critical element. Shrouded rotor configurations will have an advantage in terms of noise level (same reservation about support arm/blade interactions). The first flight tests of the Volocopter 2X two-seater at Pontoise airport in June 2021 in hovering flight showed a "wide band" hum;*
- ***in descent and approach flight**, as with conventional helicopters, all free-rotor e-VTOLs should also be subject to BVI, but in principle at higher descent rates due to higher disc loads than for helicopters. Multiple rotors could be a factor in reducing BVI, but this depends on how the rotors operate with each other (rpm, individual disc loads and phase shift from one rotor to another). Again, shrouded*

rotors will have an advantage due to the shroud mask. The positioning of the rotors together on multi-rotor aircraft must be carefully analysed to avoid BVI interactions between the rotors, the methods identified for helicopters are applicable but make the machine more complex (and more expensive).

In the referenced report (see note 4), NASA analyses the capacity of acoustic simulation models to correctly characterise noise levels. There are improvements to be made to existing tools but given recent progress, CFD and CAA[6] calculation methods and associated numerical tools are quite capable of calculating a noise level emitted by a complex aircraft; they require a description of the design and behaviour in flight. Such analyses will lead to recommendations for the designer who will have to implement solutions to reduce the impact on noise emission. Known and demonstrated solutions on helicopters[7] can of course be exploited.

With regard to noise propagation in the urban environment, noise is reflected off building surfaces or obstacles (depending on the urban area considered), which impacts the nature (frequency, pitch) of the noise.

Noise perception (auralisation: audibility) is assessed according to criteria based on variations in noise exposure over a short or long time (a fraction of a second to several seconds, the latter corresponding for example to noise exposure during manoeuvres). This necessary analysis is not currently possible for e-VTOLs due to lack of measured data. Priority is given by designers to demonstrations of flight and operational capabilities in the current phase.

FAA and ICAO regulations applicable to rotary wings in terms of noise cannot be applied directly to e-VTOLs because it is necessary to consider, in addition to the major sources of noise identified, the fact that operations take place in a context of complex environments and obstacles in urban areas (reflection and absorption/masking, relationship to ambient noise). Authorities will have to issue definitions of "standard cases" (environment, flight phases, measurement methods and processes) to ensure the noise emitted complies with certification rules. Finally, the subsequent move to autonomous flight will mean including radiated noise monitoring for near real-time optimisation of e-VTOL flights. Acceptable levels for flight conditions will have to be set, which are likely to be equally or more stringent than those imposed on helicopters with a main rotor and combustion engine.

A few figures emerge for e-VTOLs: the Airbus Vahana is reported to be 5-7 dBA lower in flight than the comparable Cabri G2 helicopter (75.7 dBA). The noise level of the EHang 216, an aircraft deploying eight pairs of horizontal propellers, measured in 2019 during flea-hopping flights, was 90 dBA, a lower threshold than that of a conventional helicopter but beyond the comfort zone. It has reportedly been

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6 *CFD: Computational Fluid Dynamics; CAA: Computational Aeroacoustics.*

7 *For example, recent work on aeroacoustics has resulted in an H160 that is 50% quieter than older aircraft of the same tonnage, and it has been shown that split descent trajectories reduce noise by -6 EPNdB (Bluecopter demonstrator vs. H135).*

reduced to 75 dBA, according to the project promoters. Lilium, an aircraft with wings carrying a "distributed electrical propulsion" system, has a level of 94 dBA at nacelle level on take-off, but is still aiming for 60 dBA on take-off at 100 m. Volocopter claims 75 dBA on approach (75 m) and 65 dBA on overflight for the VoloCity. Flights carried out (for which no measurements were made) show a broadband noise (humming that could approach 65 dBA). Joby for its 2.0 prototype announces 65 dBA at take-off at 100 m, and in flight 45 dBA at 100 m and 40 dBA at 500 m.

The conditions under which these measurements were made (or calculated?) are not detailed. The first available data estimates a noise level, depending on the manufacturer, of 75 dB on average at a distance of 15 m at take-off and 56 dB at a distance of 1,000 m during overflight, i.e. three to four times less noisy than a conventional helicopter and twice as quiet as a single-engine passenger aircraft, according to ADP, which included the VoloCity, the CityAirbus and the Lilium in its projections.

For psychoacoustic analysis, perception by an observer on the ground is characterised by two measurements: dose (level of exposure to noise) and response (average annoyance as assessed by the individual).

The studies carried out with Eurocopter in the framework of Dossier No.44 showed that a 4/5-seat helicopter weighing less than two tonnes could (just) meet the LDEN criterion at 55 dB. The current status established by the NASA working group experts shows that no report on the psychoacoustic noise perception of UAMs has been published. There have been none since.

Most communications on the subject, including the recent EASA[8] communication, give information on the difference between identifiable noise level and ambient noise level, generally evaluated at 55 dB. However, it should be noted that this level is influenced by the transmission loss related to the personal environment and personal sensitivity to ambient noise (occupation, type of locale, season...) and the frequency of passage.

Mark Moore's[9] creation of Whisper Aero, a start-up company dedicated to designing quiet UAM devices, is also an interesting sign of the current state of noise pollution from existing UAM devices.

Finally, it should not be overlooked that human perception of noise is subjectively associated with the operational mission of the aircraft!

In conclusion, noise is an important criterion, it is the consequence of aircraft architecture, flight conditions, interactions with the surrounding environment and aerological conditions. Tools developed in the aeronautical world enable configurations to be optimised in terms of noise/performance trade-off although complementary tool development is necessary due to the variety of e-VTOL

8 *EASA: "Study on the societal acceptance of Urban Air Mobility in Europe", May 2021.*

9 *Mark Moore, former NASA engineer, writer of the "Uber Elevate paper, the driving force behind the Uber Summit". See Bloomberg article, 12 July 2021.*

configurations. Optimisation technologies have been demonstrated on helicopters, in addition to those specific to multi-rotors (modulation of the rotation speed and phase of the blades) as well as on aircraft and can be adapted. The problem, which has not been anticipated in many concepts, is not insoluble.

It is commonly accepted, without the figures to back this up, that e-VTOL aircraft could be quieter than helicopters of the same tonnage, but that their noise emission does not have the same frequency spectrum as a main rotor helicopter (their noise is said to be "broadband"). The goal of reducing noise is necessary in view of public sensitivity and authorities' priorities, but it is ambitious. It is costly in terms of computation and measurement time and has an impact on direct and operational costs.

Noise perception, an essential criterion for the acceptability of UAMs, is based on quasi-individual human behaviour for which metrics are being defined; at the very least the key criteria of human perception of noise are being identified.

Residents, public authorities and elected representatives are all concerned by these noise levels, which can have an impact on flight frequency if the aircraft does not have inherently satisfactory "silent" qualities.

It is generally accepted that the perception of noise should be considered as the difference with the average noise of an urban environment, usually considered to be 55 dBA.

And noise is one of the key elements of public acceptance!

7.4 Costs

Evaluating the cost of travel by e-VTOL is a difficult exercise as this means of transport differs from what exists in terms of the aircraft itself and its operation, with or without a pilot on board.

Today, a transfer from Issy-les-Moulineaux heliport to Charles de Gaulle airport by conventional helicopter costs between €4,000 (1 passenger) and €667 (6 passengers) for a 17-minute flight, with the requirement to arrive 30 minutes before the flight for boarding formalities (Helipass service). This value will have to be significantly reduced to develop this new traffic.

Compared to helicopters, the e-VTOL benefits from attributes such as its engine that make it mechanically simpler, but also from costly features such as batteries and a highly automated and redundant flight control system.

The costs of transport by e-VTOL are mainly composed of the following elements:

- *The cost of acquiring the vehicle: the propeller/electric motor systems of an e-VTOL are simpler and in principle less expensive than the rotor(s) and MGB associated with the piston engines or turbines of conventional helicopters. This cost is highly dependent on their rate of production, with each doubling of production leading to a 15 % reduction in cost. According to Joby Aviation, the production* *cost of their e-VTOL S4 would be $1.3M (USD) with a prospect of halving in the future. Lilium, presumably penalised by a 36-shaft propeller engine, has announced a price of $2.5 million per vehicle. Part of the acquisition cost of the vehicle concerns the batteries, which have a lifespan of between 600 and 800 flight hours (Volocopter White Paper 1.0). Mark Moore announced a battery depreciation cost of $76 to $90 per flight hour.*

- *The cost of the ground infrastructure: it will be composed of vertiports (landing, take-off and battery recharging sites), vertistops (landing and take-off sites without recharging, less costly in terms of investment and operations) and e-VTOL parking sites when they are not in use (at night for example). The costs of building and using this infrastructure will vary according to its nature, location (roof top, existing helipad, etc.) and use (traffic density, charger capacity). A cost of 4 to 5 million euros per vertiport is announced by ADP (Edward Arkright) while the L.E.K Consulting study forecasts a cost of between 3.5 and 12 million dollars for a large city.*
- *Direct operating costs will be kept low due to the low energy consumption of e-VTOLs thanks to the high efficiency provided by Distributed Electric Propulsion (DEP) technology and the potential improvement in cruise efficiency if a fixed wing is chosen.*
- *Operating expenditure: this notably includes the cost of piloting. Two phases should be considered: a phase during which a pilot remains necessary on board (pending the emergence of a transport and ATM infrastructure enabling autonomous flight), and a phase of autonomous flight. The duration of the first phase depends on the one hand on the maturing of the e-VTOL transport system itself (obtaining adequate levels of safety and security of aircraft and UAM operations at an acceptable cost) and on the other, on the environment in which e-VTOL will evolve (air traffic control automation, flight rules, social acceptability). Given the very slow integration of cargo drones into general air traffic, this timeframe can be estimated to be at least 15 years in Western Europe;*
  - *pilot cost: this may be lower than that for conventional helicopter pilots insofar as the e-VTOL is a vehicle with simplified operations (piloting through a touch-sensitive tablet for the VoloCity) whose piloting requires less extensive expertise and skills than those of a helicopter pilot. It is perhaps this point that leads Uber to put the cost of a pilot, including charges, at within a range of $50k to $90k per year (young engineer profile?) whereas other studies give an annual cost of $280k, to which must be added an annual cost of $90k to maintain skills;*
  - *air traffic control costs: e-VTOLs will have a pilot on board and will use conventional air traffic control services in the first instance. Eventually, a new dedicated air traffic control system, probably a private UTM (Unmanned aircraft system Traffic Management), will have to be added to the current ATM*

to manage this new automated traffic. Little information has been published on the cost of this system, which has yet to be defined;

- *charges and taxes: it should be noted that charges cover some of the costs explained above, such as ground infrastructure or air traffic control costs. These charges vary according to the location of flights and landings and take-offs, and are particularly high at major airports. Today for example, due to the scale of these charges, Battersea Helicopter advises its customers to travel to London Heathrow or Gatwick via other smaller airports with lower charges and to travel the last ten kilometres by land vehicle.*

- *Vehicle maintenance costs: maintenance costs per flight hour for e-VTOLs are expected to be comparatively lower than the maintenance costs of existing light helicopters; a reduction of about 50 % in overall maintenance costs can be expected.*
- *Indirect operating costs: these include non-vehicle specific costs such as commercial ground staff, insurance and other miscellaneous costs. These costs can add up to 50 % to the direct operating costs.*
- *The costs of longer flight times due to the density and complexity of air traffic in the vicinity of airports. An ideal situation would be for e-VTOLs to have no waiting time before taking off and landing, which seems difficult to achieve in the short and medium term with air traffic control and e-VTOL piloting relying heavily on human interaction.*

Costs for the e-VTOL service operator will additionally depend on two parameters:

- *vehicle utilisation rate: this could be high compared to conventional VTOLs thanks to the choice of routes where e-VTOLs offer a decisive advantage over ground transport (city-airport links where ground traffic is dense and rail links are impractical) and to the strategy of partial recharging on each landing to limit the downtime associated with a full charge;*
- *vehicle occupancy rate (average number of revenue-generating passengers occupying the vehicle): this will be high if aerial shuttle or metro type uses are favoured over on-demand taxis in order to limit, or even eliminate, empty vehicle repositioning.*

Attempts to reconcile the current costs of helicopter transfers between cities and airports with the ambitions of those who promote the use of e-VTOLs show that it is necessary to define many parameters before costs can be defined (piloted aircraft or not, fees and taxes included or not, e-VTOL parking costs when not in use, use of a road segment in the last few hundred metres, etc.). Today, the company Hélipass offers a transfer from Issy-Les-Moulineaux to Charles de Gaulle airport for €666.67 per person, assuming six people are on board, for an advertised flight time of 17 minutes and a journey of approximately 35 km (21.75 miles). The price per seat.km is therefore €19 (or €30.65 per seat.mile).

Joby Aviation, which acquired Uber Elevate and sized its S4 vehicle based on the 2015 Uber specification (four passengers, one pilot), presented its investors with an economic study taking into account the following assumptions:

- *production of 963 aircraft, 850 of which are in service;*
- *cost of $1.3 million per vehicle;*
- *50,000 flight hours, or more than 15 years of use.*

The performance indicators are calculated assuming that aircraft spend 7 hours in the air for 12 hours of operation per day, that the average distance of each leg is 24 miles, that an average of 2.3 passengers are carried per flight and that 12.4 million flights are made per year.

COGS (Cost of Good Sold, which includes pilot salaries, landing fees, customer service and maintenance), operating expenses, vehicle depreciation and loan interest are estimated at $1.2 million per aircraft.

These assumptions lead to a CASM (Cost per Available Seat Mile) of $0.86: for a total number of available seat miles of 1.188 million (Total Available Seat Miles).

A price of $3.00 per seat mile has been announced (for 2.3 persons carried per flight, which corresponds to $1.73 per seat mile when all four passenger seats are occupied).

Joby's assumptions of use and the resulting results appear to be very optimistic.

Lilium plans to offer its 1+6 seat vehicle with a price of $90 per person for a 10-minute flight from Palo Alto to San Francisco.

Volocopter offers two types of vehicle: the two-seater VoloCity equipped with 18 rotors and the four-seater VoloConnect equipped with a canopy, six rotors for lift and two enclosed electric fans for propulsion. In the White Paper *published at the beginning of 2021, it is stated that a price of 1 in 2023 (version with pilot on board) will be reduced to 2/3 in 2027 and then to 1/3 in 2032 when full autonomy is reached. A first flight experience in VoloCity has been proposed by Volocopter at $355 for a 15-minute flight ($24 per minute, September 2020).*

Archer quoted a price of $40 for the eight-minute flight between Santa Monica and Los Angeles, cities 15 miles apart, during the June 2021 presentation of its demonstrator.

South Korean conglomerate Hanwha Group plans to launch a commercial air taxi service by 2025. The cost of the vehicle being developed, called Butterfly, is $2.6 million.

The costs and prices quoted in these examples confirm that the current situation is still too confusing to estimate a generic cost of using e-VTOLs and to display a price per seat-passenger which will depend heavily on many parameters such as place of use, level of involvement of public authorities in the development of air mobility or societal acceptability of this new mode of transport. The Paris public transport group RATP's director of Strategy and Innovation gives an indication of how RATP will *perceive the use of e-VTOLs: by announcing that "*The right price will be the one that replies to a demand in which time has a value*," she indicates that the clientele will be mainly composed of VIPs. At the same time, French civil aviation authority DGAC indicates that it is premature to try to estimate taxes and fees before defining an economic operating model.*

8 CERTIFICATION AND OPERATIONAL REGULATIONS

8.1 Certification

The transport system's compliance with safety objectives is guaranteed by meeting all applicable certification specifications and operational regulations, imposed and enforced by certification bodies such as EASA in Europe, with delegation for application to national bodies such as the DGAC in France.

At present, there are no plans for a globally harmonised certification specification or operational regulation, and manufacturers face having to meet different requirements depending on the country/continent in which they wish to sell their product.

In July 2019, in response to needs expressed by manufacturers, EASA published a Special Condition – SC – for Small Category Vertical Take Off and Landing (VTOL) Aircraft *applicable from the beginning of 2021*[10] *as well as the* Proposed Means of Compliance with the Special Condition VTOL[11]. *This SC adopts part of the Certification Specification applicable to light helicopters and considers the same limits of carrying capacity (fewer than 9 passengers) and maximum mission weight (3,175 kg); however, these limits penalise e-VTOLs compared to helicopters because for a given carrying capacity and range, they are heavier due to the weight of the batteries.*

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10 Doc. No. SC-VTOL-01 – number 1, 2 July 2019.

*11 Doc. No. MOC SC-VTOL – number 1, 25 May 2020, from page 55. See also the EASA document: "CRI Consultation paper Special Condition Electric / Hybrid Propulsion System of 07/04/2021 and the EU Aviation safety agency **Terms of Reference** for rulemaking task RMT.0731 (Subtask 1)" of 09/09/2020.*

The SC VTOL considers two categories of use, "basic" and "enhanced"[12], the latter covering passenger transport, for which the safety level is set at that of passenger aircraft with a probability of less than 10^{-9} per flight hour for catastrophic consequences of combinations of failures (as well as no single failure with catastrophic consequences). This level is justified by the overflight of built-up areas and the risk of damage on the ground in the event of a multiple crash. This SC is designed to be compatible with future remote-control capability or different levels of autonomy, although these aspects are not covered at present. In the first phase of operation, a pilot is required on board, which has an impact on passenger capacity, cabin design and operating costs.

		Failure Condition Classifications			
	Maximum Passenger Seating Configuration	**Minor**	**Major**	**Hazardous**	**Catastrophic**
		Allowable Qualitative Probability			
		Probable	Remote	Extremely Remote	Extremely Improbable
		Allowable Quantitative Probability Development Assurance Level			
Category Enhanced	–	$\leq 10^{-3}$ FDAL D	$\leq 10^{-5}$ FDAL C	$\leq 10^{-7}$ FDAL B	$\leq 10^{-9}$ FDAL A
Category Basic	**7 to 9 passengers (Basic 3)**	$\leq 10^{-3}$ FDAL D	$\leq 10^{-5}$ FDAL C	$\leq 10^{-7}$ FDAL B	$\leq 10^{-9}$ FDAL A
	2 to 6 passengers (Basic 2)	$\leq 10^{-3}$ FDAL D	$\leq 10^{-5}$ FDAL C	$\leq 10^{-7}$ FDAL C	$\leq 10^{-8}$ FDAL B
	0 to 1 passenger (Basic 1)	$\leq 10^{-3}$ FDAL D	$\leq 10^{-5}$ FDAL C	$\leq 10^{-6}$ FDAL C	$\leq 10^{-7}$ FDAL C

(Quantitative safety objectives are expressed per flight hour)

Table 3: Safety goals by aircraft category and classification of failure conditions.[13]

From this phase onwards, the difficulty will be for manufacturers to demonstrate compliance with the safety constraint while controlling the repercussions on weight and costs, particularly for aircraft in the "enhanced" category, which is the only one considered here. The level of safety will require certain critical systems to be

12 *Page 5 of ref (1): Link to type of operations:* "VTOL aircraft that are certified in the Category Enhanced would have to meet requirements for continued safe flight and landing, and be able to continue to the original intended destination or a suitable alternate vertiport after a failure. Whereas for Category Basic only controlled emergency landing requirements would have to be met, in a similar manner to a controlled glide or autorotation". *See Table 3.*

13 *EASA: Doc. No. MOC SC-VTOL.*

redundant, with three-way architectures as on transport aircraft. Difficulties in designing and demonstrating safety features are to be expected particularly in areas of new technology or innovative propulsion configurations. These include demonstrating the following:

- *that battery packs:*
  a) *can contain cell fires and explosions as well as toxic fluid leaks that may occur, for example, during crashes, and*
  b) *provide segregation to prevent the propagation of a fault so as to ensure the required residual autonomy;*
- *resistance of often small propulsion systems to impact with birds;*
- *controllability, even in the event of failure and during convertible transitions. It should be noted that no civil convertibles have been certified to date. Where thrusters are used for both lift and control, the requirement that a single failure cannot lead to a catastrophic situation generally leads to a minimum number of independent thrusters of 6 (e.g. Joby, Beta's Alia 250 C has four propellers but eight engines), combined with a high overpower coefficient (1.84) in case of failure;*
- *safe operation in adverse weather conditions to ensure the continuity of the transport service, which is also a tricky issue (lightning and turbulence in stormy weather, blind flight, wind impacting performance and controllability particularly in hovering and low speed flight).*

Critical examination of the various projects underway and experience with the certification of transport aircraft with similar safety objectives raises doubts as to whether all the effects of these certification requirements are integrated into weight and performance estimates.

In addition, one can expect gaps in the specifications for new technologies and configurations that may seriously lengthen the certification cycle of the first e-VTOLs to face these situations.

The first phase of commercial operations will certainly be carried out with a pilot on board. Indeed, the requirements of the safety objectives for the "enhanced" category of e-VTOLs we are considering here are the same as those applicable to large transport aircraft, so the conclusions of AAE Dossier No.42 hold good: an onboard pilot will be necessary until the automatic systems have proved they are capable of properly managing the vast majority of "unforeseen" cases arising during operations (machine learning should help, but millions of flights – both real and simulated – will be needed to accumulate a sufficient number of cases). This level of automation could lead to a reduction in the qualification level of pilots (Simplified Vehicle Operation – SVO – a concept studied in the United States by NASA and FAA). The experience of drones carrying objects will certainly help.

Of course, the original design of the aircraft may provide for the eventual elimination of the single onboard pilot. In this respect, two types of solutions are possible: remote human control with different degrees of automation/autonomy (the European *nEUROn drone is one such achievement), and complete autonomy. Following the reasoning above, they will probably follow each other chronologically. Of course, correlatively, strict preventive measures against cyber-attacks will have to set in place.*

Certification should take into account the overall transport system, including the segment outside the aircraft, and guarantee the safe operation of systems, certainly by using artificial intelligence.

Current operational regulations for the use of airspace over built-up areas are in many countries unsuitable for a UAM transport concept. It will take time to overhaul them, a process that will in many cases be hampered by the mistrust of urban populations regarding the nuisance that an urban air transport system could generate.

In conclusion, certification specifications and operational regulations are needed to ensure safe e-VTOL operations. These are currently being elaborated and the time required for this may slow down the deployment of UAM transport systems.

Compliance with certification specifications requires significant technical resources and heavy investment for newcomers with no aeronautical experience. This procedure enables safety objectives to be achieved but induces a complexity whose impact is probably not fully taken into account in the performance and cost forecasts of current projects, always assuming that a reasonable convergence can be achieved, technically speaking.

8.2 Operational aspects

Integration into air traffic and ATM (manned/unmanned)

Flying taxis belong to a category of aircraft – urban air mobility (UAM) – that is set to expand in the coming years. This category of aircraft aims to develop aerial applications over large cities where road travel is often very difficult. The e-VTOL flying taxis may be remotely piloted (from the ground) or even autonomous, but for the start of commercial operations, they will probably have a pilot on board in order to simplify certification, interface with existing traffic management systems and reassure potential passengers.

Flying taxis with an onboard pilot

In Europe, aircraft with a pilot on board must operate their flights in compliance with the Standardized European Rules of Air (SERA), which is in accordance with ICAO Annexes 2 and 11. SERA only covers flights with at least one pilot on board. These flights can be performed under either visual flight rules (VFR) or instrument flight rules (IFR). The difference between the two flight regimes relates in particular to weather conditions. In controlled airspace, the minimum visibility required for VFR flights is 5 km. In the controlled areas around major aerodromes, there is a special *type of VFR with less strict weather requirements: this is Special VFR. For helicopters, the minimum visibility required for Special VFR is 800 m.*

In France, most civil helicopter flights are conducted under VFR. Civil helicopters are rarely equipped to fly IFR. Moreover, pilots are not qualified for this regime. As opportunities to fly helicopters under IFR tend to be infrequent, operators do not consider the investment in aircraft equipment and pilot training to be sufficiently profitable. Flying taxis with a pilot on board are likely to operate under VFR.

In VFR, pilots must continuously monitor the airspace around their aircraft. The principle of avoiding collisions between aircraft in flight is called "see and avoid". In controlled airspace, ATC units are responsible for ensuring separation between IFR aircraft. For VFR aircraft, ATC generally only provides traffic information to pilots in controlled airspace (except in Class B airspace where VFR flights are treated the same as IFR flights).

To be able to fly in the control zones of aerodromes, it will be necessary to have a means of air-ground voice communication with ATC. An accurate navigation system will also be required to follow the trajectories imposed by controllers (Required Navigation Performance-1): GNSS (satellite navigation) is the most accurate system for light aircraft. For surveillance, a Mode S transponder is required, but carrying an ADS/B (Automatic Dependent Surveillance/Broadcast) system is highly recommended, making it possible to detect other ADS/B-equipped flights, and to be seen by other pilots.

Pilots will need to hold a commercial pilot licence. In the United States, NASA, with the support of the FAA and the General Aviation Manufacturers Association (GAMA), has launched a study on the definition of a pilot licence suitable for aircraft with simplified operations. This is the Simplified Vehicle Operations (SVO) project. Three levels of skills are envisaged: at level 1, these are the skills of an aeroplane (fixed-wing) pilot, with vertical flight management done automatically; at level 2, these are lighter skills for managing a highly automated aircraft; at level 3, no aeronautical skills are required since the aircraft is fully autonomous once the destination is entered in the flight computer.

Flying taxis without an onboard pilot

The European regulation applicable to aerial drones includes the possibility that drones may carry passengers, but the relevant texts are not yet available. Drone operations are classified by the European regulation into three categories: "Open", "Specific" and "Certified". Flying taxis fall into the Certified category, which is dedicated to high-risk operations, mainly because they carry passengers and fly over homes and inhabitants of large cities. The regulations applicable in Europe to Open and Specific category operations for flights in view of the remote pilot have been published. However, the regulations for certified operations are not yet available.

The European Commission has proposed to phase in a set of new services and operational procedures, called U-Space, to facilitate drone operations. The services *will be provided to drone operators by specialised U-Space Service Providers (USSPs) who will coordinate flights with air navigation service providers. The European Commission recently published three regulations on U-Space, to be implemented in 2022. The choice made in these regulations is to separate traffic: drones will operate in dynamic volumes of space possibly centred on cities or in dedicated areas around airports, accessible to piloted aircraft under certain conditions, when activated. These volumes may be defined within either controlled or uncontrolled airspace. They may be located over 120 m (400 ft) above ground level. An example of such volumes could be a corridor of reduced width and height protecting a dedicated drone route.*

For a drone performing a certified operation it will theoretically be possible to use both VFR and IFR manned aircraft regimes. The IFR flight regime poses less of a problem of compatibility with other manned aircraft than VFR, particularly when flying in areas where all VFR flights are subject to clearance or are prohibited. The VFR flight regime poses the problem of lack of awareness of other VFR flights in Class E to G airspace. There is therefore a risk of collision with piloted VFR flights, especially in the vicinity of large cities. To fly in these areas, it will be necessary to equip drones with a “detect and avoid” system that can perform the “see and avoid” function that is the rule in VFR. In VFR mode in controlled airspace classes B to D and in IFR mode whatever the class of airspace, there will also have to be a permanent link with ATC during flight, which is a major constraint on the drone; a remote pilot permanently connected to air traffic control would have to listen to and collate instructions issued by ATC and execute them rapidly. To fly under IFR, the drone will also need to be equipped with mandatory Communication-Navigation-Surveillance means. For the control-command of the drone and the relay of communications between the remote pilot and ATC, it will have to be equipped with a secure communication system with the remote pilot. The introduction of 5G mobile telephony should make it possible to provide certain air-ground links with drones flying at very low altitude. However, this possibility will have to be validated by the aviation safety authority, EASA. And the communication service will have to be secure.

Remote pilots controlling the flights of drones carrying out certified operations will need to hold a remote pilot licence. In the long term it is possible that flying taxis will become highly autonomous. They will then only need a supervisor who can monitor several aircraft simultaneously and who will intervene only when necessary. The supervisor will probably have to hold a licence which has yet to be defined.

Minimum flight altitude

The minimum altitude for flights with a pilot on board in France is defined in several texts: in the SERA regulation and in the decrees of 10 October 1957 and 17 November 1958 for overflight of inhabited areas. To carry out short flights between two authorised landing-take-off areas, flights will generally be made under VFR or even special VFR when the flights take place in a control zone (CTR).

Medical helicopter flights often take place at very low altitudes because the injured being transported do not tolerate altitude variations. In France, these flights benefit from a derogation granted by the DGAC, which is issued after submitting an application following a set format. In France, certain air routes between hospitals are reserved for medical helicopters in IFR flight with an altitude much lower than that of conventional IFR routes: these routes could serve as a model for the establishment of routes reserved for UAMs. The Eurocontrol organisation published two documents in 2019 concerning very low-level flight of IFR helicopters, which could be used as a reference for the publication of such routes in the Paris region.

Flying taxis over major cities will be subject to strict security and environmental protection constraints. For example, after the attacks of 11/09/2001, several helicopter flight routes in the Paris region were closed and have remained closed. Pilots must obtain a security clearance issued by the Ministry of the Interior. Once UAMs become drones, a major security threat is the risk of cyber-attacks, launched by hackers based anywhere in the world. Digital air-ground links and GNSS navigation signals are two vulnerabilities it will be important to protect. For air-ground links, it is possible to use several communication channels and to encrypt message exchanges. For GNSS signals, the simultaneous use of several satellite constellations (GPS, Galileo, Glonass, Beidou) on several frequencies will be necessary.

Noise pollution from rotary wings is very poorly accepted by the populations living under these flight paths and in the vicinity of the Paris-Issy-les-Moulineaux heliport, and this has led the DGAC to raise their altitude by 150 m (500 ft). The arrival of a large number of flying taxis on these routes is likely to provoke very strong reactions from local residents if the noise pollution is significant. In addition, the number of helicopter movements on the heliport is strictly limited and the arrival of additional flights could cause major problems with local residents if these aircraft are as noisy as the helicopters (see section 6.3).

The infrastructure and logistics of vertiports or vertistations

At first sight there is little difference between a heliport and a vertiport, unless one considers that vertiports should by design constitute focal points for multimodal transport ensuring the greatest possible satisfaction of the travellers.

Towards multi-modal infrastructures

If we look at the only air-to-air multi-modality theoretically available today, i.e. between planes and helicopters, it is in practice rendered impossible almost everywhere because of very inconvenient and even non-existent airport-to-helicopter transfers (with the exception in France of Nice-Côte d'Azur airport). Helicopter-aircraft cohabitation is not welcome at major airports and totally irrelevant at other airports, resulting in the virtual elimination of rotary wing aircraft from the mobility offer.

Tomorrow's passenger will indicate their points of departure A and arrival B and will expect to receive proposals meeting the criteria they have indicated, not limited by the *choice of a specific mode of transport, operator or company. Aeronautical transport and the full range of ground transport will be called up in a fully transparent manner.*

A fraction of the clientele will turn to offers allowing direct access to point B without loss of time. The time taken for the multi-modal transition to their remaining journey, of the order of one hour, should not exceed 15 minutes.

Air taxis will only be called if a relevant response can be provided to meet these criteria, both on departure from the airport and at the arrival point.

In terms of infrastructure, this means:

- *on the one hand, genuinely interconnected "vertiports" designed to avoid inconvenient breaks between air and ground modes; they would therefore have to be highly integrated at the very heart of the airports – or, failing that, easily and quickly accessible – and provide the same functions: reception and security, boarding and disembarkation, refuelling (including electrical), navigation, ground maintenance, etc., thus allowing changes of transport mode in around 10 to 15 minutes;*
- *on the other, a good spread of terminal landing and take-off points meeting the needs of the market. These may be intermediate hubs, with simpler functions but directly connected to the various means of land mobility – whether rail (regional trains, metro, tram) or road (coaches, minibuses, taxis, urban public transport, car-sharing centres, car parks) – which could be called multimodal ports or "multiports"; they can also be simple terminal points with disembarkation facilities alone, although including at least an electrical recharging capacity. They will be located in direct contact with urban centres, business centres, areas dedicated to major sporting and cultural events, commercial and leisure centres, and at the major current hubs for urban communications.*

These light terminal landing and take-off points could also spring out of redevelopment of local peri-urban airports, small ground installations or even platforms integrated into industrial and urban architecture, with ground or roof landing, backed up by carpooling points, and on-demand links.

Aerological constraints could prohibit the installation of vertiports on top of buildings, in which case it is necessary to provide dedicated constructions in locations allowing approaches with reasonable slopes (6°). The geometric constraints imposed on heliport landing and taxiing areas would be maintained, with possible adaptation to the dimensions of e-VTOLs.

Experimental vertiports

We are also witnessing a series of experimental initiatives on infrastructures, creating a turning point and driving the conditions needed for initiating personalised 3D mobility: this is reflected in initiatives in Switzerland, Finland, Dubai, China, the United States, London, and in France (ADP vertiport projects in partnership with RATP and Airbus).

Uncertainty about the capacity of the vertiports developed within the major airports is conditioning these projects. Each would seem to have integrated the time imperative *of modal transfer of passengers of future air taxis, which must be based on that of road taxis, i.e. almost instantaneous.*

In France, two concepts will first be tested on an airfield site in the Paris area (Pontoise) with a view to demonstrating transport services during the 2024 Olympic Games, prefiguring a commercial service on the scale of Île-de-France.

Multimodal operators

In addition to effective implementation of a genuine network of optimised infrastructures, multi-modality with an air taxi component also implies a real upheaval in the structure and missions of operators. This structural change is essential if we are to have groups or alliances of operators capable of meeting the optimised travel needs of tomorrow's users from point A to point B.

Concept of an intra-urban air transport network with its management

From the airport, if we use this starting point as an example, the aircraft will fly over the major rail and road routes, with small emergency landing areas along the way, which will not be problematic provided they are planned for. It will have access with no loss of time to a vertiport that is truly integrated (not just "tacked on") to the rail and bus station and to the connected large suburban car parks (provided they really are connected, both directly and instantaneously).

On arrival in a metropolis, aircraft will not fly over "urban areas", with scattered vertiports causing controversy, but rather mass air transport avenues such as ring roads at a certain altitude above their cousins on the ground, again with small emergency landings along the way; incursions could be made to selected focal points – major metro connections, ministries, police centres, hospitals, major tourist or sports centres, large-scale commercial or business points – and to a few "hubs" with a customised set of very fast, local connections linking directly to a few popular points: hotel complexes, radio stations, TV stations, theme parks, major sites, even maybe flyover visits to outstanding sites, privileged access to seasonal festivals, etc.

Routes dedicated to flying taxis will be able to be activated on demand by a U-Space Service Provider. They will be strategically separated from the routes followed by IFR flights in the terminal area. They may be crossed by VFR flights when no e-VTOL is present. USSPs will need to be connected to ANSPs managing general air traffic in the controlled airspace in which the dedicated routes for flying taxis are defined. USSPs will also have to manage access to vertiports, especially those without multiple landing areas, as flying taxis will not be able to hover in the same way as helicopters, due to their limited range. USSPs will only issue a take-off clearance when the entire route is clear and landing at destination is assured. They will ensure that the taxi flight proceeds in accordance with the initial flight plan, and that no serious event occurs during the flight that could lead to its interruption or even diversion to any vertiport other than the destination one.

9 PUBLIC ACCEPTABILITY

Public acceptability is a broad term. It can be considered to cover:

- *the user's perception of the means of transport in terms of safety (both in flight and on the ground), comfort and economic accessibility (efficiency, price of the seat);*
- *the perception of populations living in the vicinity of vertistations or vertiports in terms of noise pollution and safety at ground level;*
- *perception by the public authorities: requests for public services – state services, security services (fire brigade, ground control), possible intervention by air traffic control;*
- *perception in terms of a contribution to economic activity and employment seems too difficult to identify at this stage (although it is the subject of a question in the EASA survey).*

At the current stage, mid-2021, frontline manufacturers (Volocopter, Joby, Lilium...) and operators (ADP, Volocopter[14]) are working on operational demonstrations. The steps still to be completed for UAM implementation are a demonstration of operability in 2024-25 and an operational launch not before 2030.

A survey at European[15] level into two types of intra-urban and inter-city drone operations – delivery and air taxi – shows that the public (city dwellers of large EU capitals) links acceptability in order of priority to:

1) *flight safety (based on the guarantee of certification);*
2) *noise, taking into account distance (of aircraft and vertiports), duration of exposure and frequency of flights;*
3) *environmental impact, but this point is fairly "balanced" given the positive aspects of a smaller ground footprint due to reduced road traffic, and controlling pollution from these aircraft by means of electric or alternative energy;*
4) *security and, in particular, protection from cyber-attacks from such autonomous machines;*

5) management of the airspace above cities (including insects and birds) by incorporating site protection.

This survey shows a favourable opinion and curiosity for UAM aircraft, seen as highly innovative and offering positive technological challenges, in contrast to "classic" helicopters. 71 % of the panel considers these flights positively, although only 30 % express an interest in air taxi missions. The primary use is for deliveries, with peopled flights concerning first and foremost emergency medical transport; when it comes to point-to-point transport of people, a more favourable orientation can be found towards city-airport links.

In terms of safety, aircraft compliance with EASA and FAA regulations provides a framework to ensure the safety of flights, operations and passengers. It also implies regular audits, oversight by the relevant authorities and guarantees the initial and ongoing airworthiness of aircraft and the services operating them.

It is therefore by obtaining the certificate of airworthiness that air mobility devices will demonstrate the safety of passenger transport operations, with or without a pilot if they ask to be certified for autonomous operations. To this must be added the integration of these aircraft into an area subject to low-level traffic management (public or private), and in an urban, peri-urban or airport environment.

However, despite the regular acquisition of certification and airworthiness certificates, prejudices will remain and demonstration and persuasion will need to be carried out with all the above-mentioned audiences. This is not to overlook the impact of noise and visual pollution (point introduced by ADP).

It is increasingly apparent that low and medium altitude overflights of populated areas are perceived as a threat, hence the strong focus on the vulnerability to cyber-attack of these aircraft systems and controls.

On the economic side, public perception will also be based on the price of the service offered by future operators of UAM devices. Seat prices as presented today range from less than €100 (RATP ADP) to €300 or €400 (ADP target for the 2024 Olympics). The profitability horizon of an air mobility service when announced is quite distant (after 2050).

It should also be noted that health restrictions or anti-terrorism conditions may increase the need for ground services and thus remain a burden, part of which will affect ticket price (see section 6.4).

Finally, user acceptability will be based on the quality of the service (regularity, reliability, preparation for autonomous flight without a pilot, the feeling of safety and comfort: seat, volume, internal noise, stability of the cabin in flight, and the positive perception of an aircraft that is not too complex (no overly apparent mechanical elements), even if the technologies used are in themselves innovative, based on totally autonomous systems.

In conclusion, the acceptability of UAM aircraft is mainly based on public and user opinions. The public will be focused on any disturbance to their environment, whether it be noise or the perception of an unknown danger overhead. They will *probably remain curious about the technology, with a more favourable perception for health and safety operations than for the use of VIP transport.*

Users will judge the flying machine in terms of mission effectiveness, compliance and quality of service, price and seat comfort. Local authorities will judge the operations according to "minimum disruption" or on the contrary in terms of increased activity. The future remains open to the designers and operators of these aircraft to argue their case by carrying out the proper demonstrations, like the one underway at Pontoise airport by ADP and its partners or in China by EHang.

10 ANNEXES

Annex to §6.1: "Specifications for an aeronautical package"

- *Mass/weight: the reference mass of the pack, which is used to determine the specific performances – Specific Energy (E*) and Specific Power (P*) – incorporates all the elements of the pack ready to be installed in the vehicle (cells, support structure, sensors, BMS, thermal regulation):*
  - *E* Wh/kg, for a new battery, value associated with a temperature of 25°C and for a discharge at 1 C up to the cut-off voltage specified by the manufacturer: greater than 220 Wh/kg;*
  - *P* W/kg, for a new battery, value associated with a temperature of 25°C and for a discharge at 10 C up to the cut-off voltage specified by the manufacturer: greater than 1500 W/kg (the associated specific energy shall be specified).*
- *Specific gravity: over 600 Wh/l.*
- *Charging capacity: Compatible with 500 kW "ultra-fast" charger.*
- *Reference cycle: (25°C)*
  - *Discharge:*
    10 C for 60 s
    1 C for 45 min.
- *Number of cycles resulting in the deposit of packs: 1,500.*
- *Calendar life leading to the deposit: 1 year.*
- *Area of use:*
  - *altitude: from 0 to 3,000 m*
  - *temperature: ISA+15°C.*
- *Price: less than €200/kWh.*

Annex to §7.1: "Uber performance specifications"

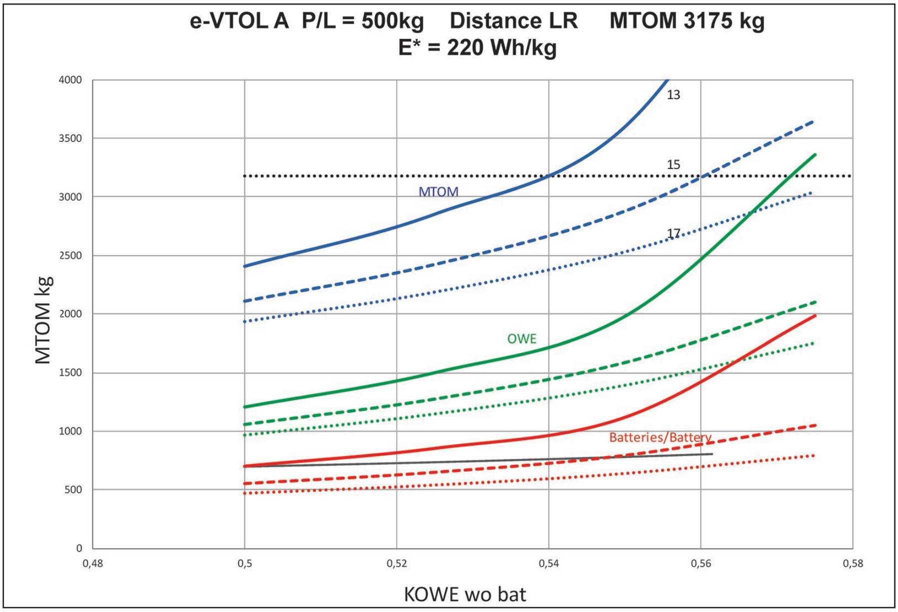

Figure 7: 2020 battery technology enables only 75 km mission with realistic aircraft parameters values.

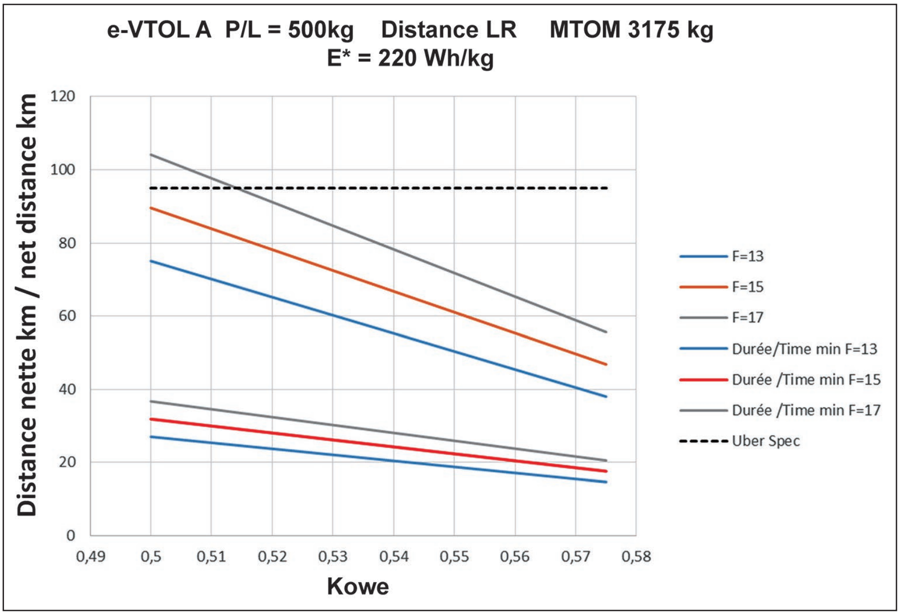

Figure 8: 2020 battery technology does not enable 96 km mission with realistic aircraft parameters values.

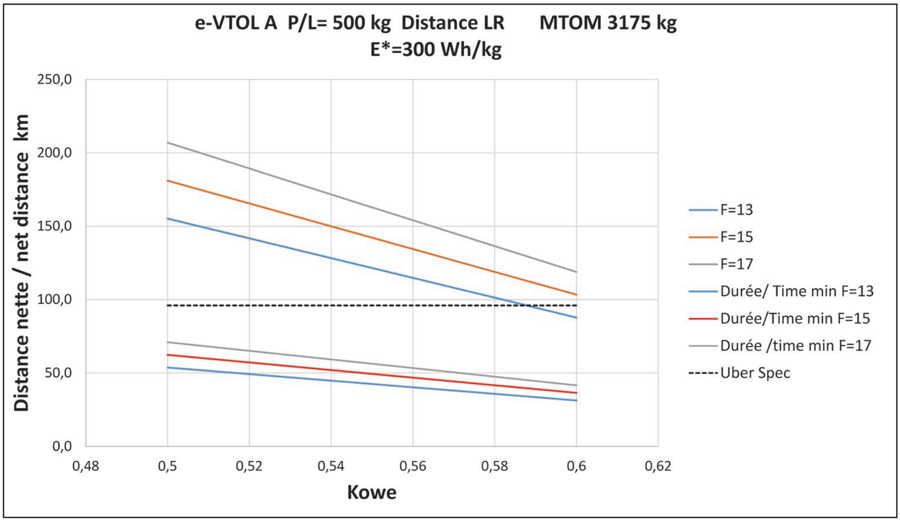

Figure 9: 2030 battery technology enables 96 km mission with realistic aircraft parameters values.

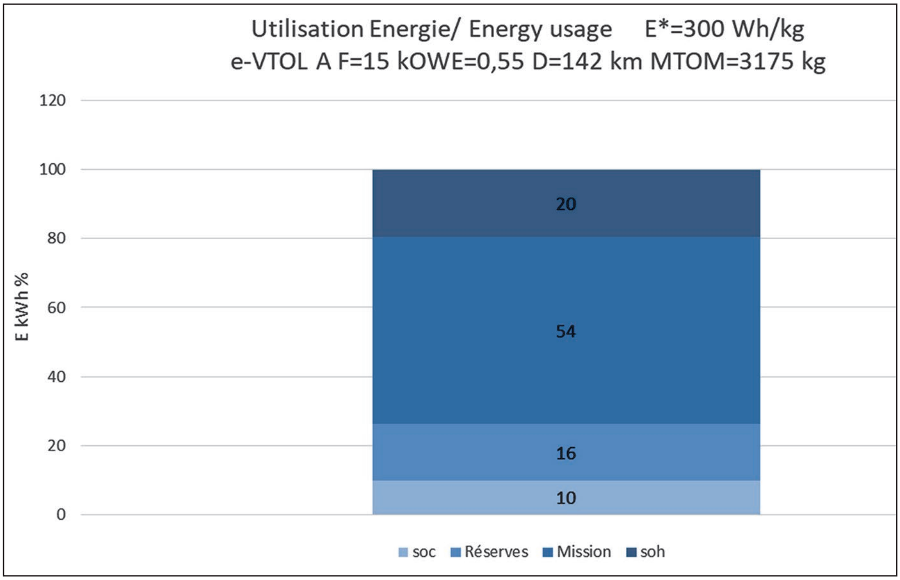

Figure 10: With end of life batteries, only 54 % of the loaded energy is dedicated to the mission.

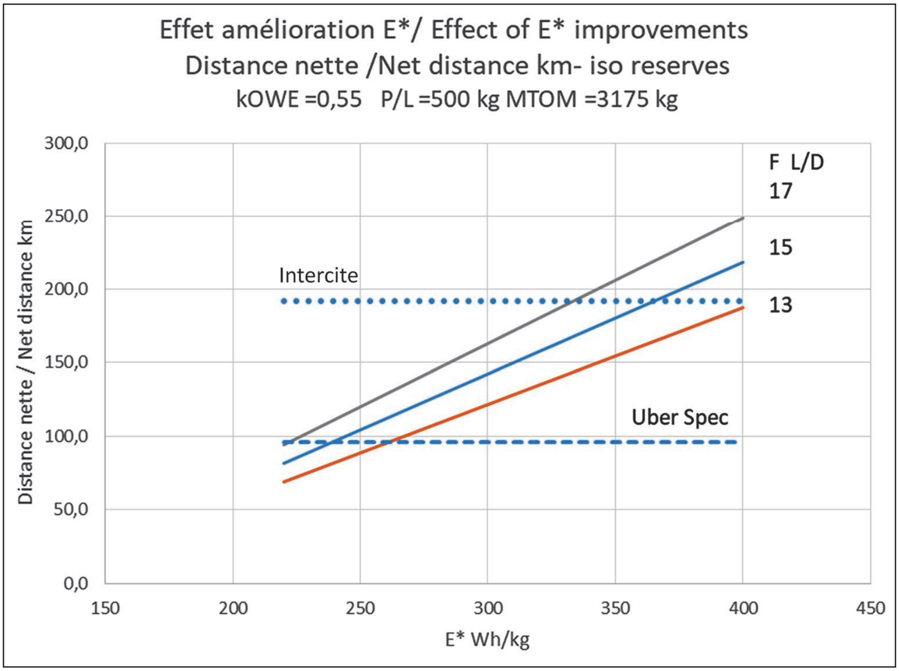

Figure 11: In order to double the mission and to enable inter-city links, large battery improvements are necessary, resulting from a new battery technology.

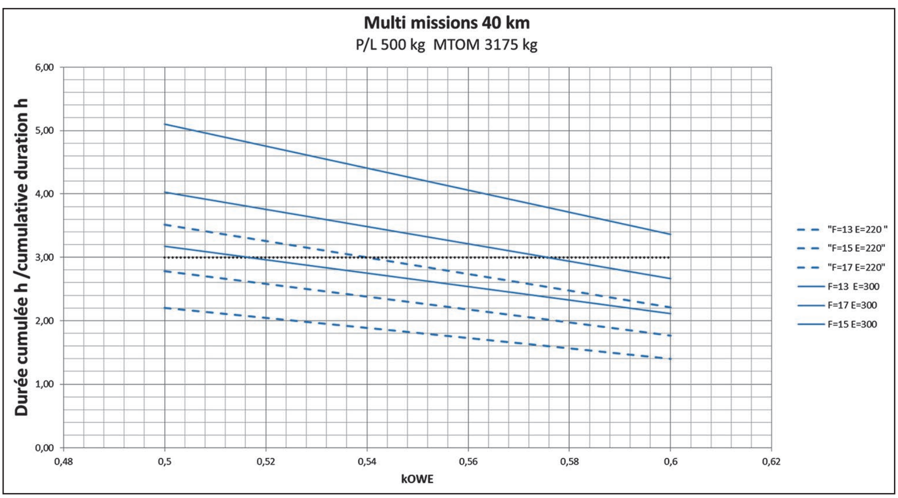

Figure 12: With a five minute partial recharge, multimissions will be achievable only with 2030 technology.

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We are currently witnessing an explosion of projects for small, transport market and meeting the specification proposed by Uber Elevate. Most of these projects are still at the development stage and doubts remain as to whether they will be able to evolve into a mass-market operational means of transport in large numbers as claimed by their promoters. Such transport networks cannot emerge without the support of the authorities and a favourable reception by the general public, which requires environmental aspects to be dealt with satisfactorily and the system not to be seen as being reserved for an elite.

This report identifies the strengths of the various projects as well as the obstacles to their development in terms of performance, noise, cost and safety, and assesses the potential of eVTOLs to fulfil intra-urban and inter-city passenger transport missions in the medium term.

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