BADA eVTOL Performance Model for UTM Traffic Simulation and Analysis

César Nieto Sánchez, Jorge Chorniqué Sánchez, Miguel Ángel Vilaplana Ruiz
Airbus UTM
{cesar.n.nieto-sanchez, jorge.chornique, miguel-angel.vilaplana-ruiz}@airbus.com

Vincent Mouillet, Angela Nuić
EUROCONTROL Innovation Hub
{vincent.mouillet, angela.nuic}@eurocontrol.int

***Abstract*— A new digital traffic management ecosystem, commonly referred to as UTM (Unmanned Aircraft Systems Traffic Management), is currently under development to enable autonomous operations at scale at low altitudes, including UAM (Urban Air Mobility). UTM is anticipated to provide services that will facilitate airspace integration of high-density operations involving passenger-carrying eVTOL (electric Vertical Take-off and Landing) vehicles in urban airspace. Concepts of operations, regulations and standards for UTM are being developed in different regions (such as the U-space and Advanced Air Mobility initiatives in Europe and the US, respectively), but much work still needs to be done in order to operationalize an UTM ecosystem that can cater for the anticipated requirements of UAM. In particular, advanced modelling and simulation tools are needed to analyze how UAM traffic can be safely integrated in the airspace. A cornerstone of such simulation tools will be an Aircraft Performance Model (APM) that is able to accurately reproduce the main performance variables of different eVTOLs and that allows realistic modelling and simulation of eVTOL trajectories in any condition. Such a model will allow the UTM and UAM communities to conduct the studies required to advance towards the operationalization of UTM and UAM. This paper proposes a generic APM that aims to fulfil those requirements. The proposed APM is based on the modelling approach of EUROCONTROL's Base of Aircraft Data (BADA). It provides a generic performance model that can be parameterized for different eVTOLs while protecting the manufacturers' proprietary performance data, and includes the performance variables needed to calculate the evolution of the vehicle's trajectory, including battery consumption.**

Keywords- aircraft performance model; eVTOL; UAM; UTM

I. INTRODUCTION

eVTOL vehicles are projected to be key enablers of future UAM. eVTOL operations are expected to require advanced traffic management services to enable their safe integration in the lower part of the urban airspace. Air traffic simulation will be a key enabler of the operationalization of UTM and UAM. Extensive simulation studies, both fast-time and real-time with hardware and human-in-the-loop, are needed to design and validate different solutions required to deploy UAM and UTM, including the vehicles and ground systems characteristics, the CNS (Communications, Navigations, Surveillance) capabilities or the requirements on the UTM services. Fast-time and real-time simulation tools will rely on performance models of the vehicles that operate in the scenarios considered in order to reproduce their trajectories in all the situations and under all the circumstances that need to be studied. For example, such an APM is needed to synthesize optimal trajectories created by the airspace users and to model how a tactical deconfliction UTM service would modify those trajectories to avoid conflicts. There is a need for an APM that can accurately reproduce the main performance variables of the different types of eVTOL vehicles that will be operated within the future UAM environment. Such a generic APM should have a structure that facilitates its integration with different trajectory computation tools and should be sufficiently accurate to be used in place of the vehicle manufacturer's proprietary data.

In this paper we present an eVTOL APM developed collaboratively by EUROCONTROL and Airbus that aims to fulfil the above requirements. The model is based on the BADA modelling approach and uses the technical demonstrator eVTOL 'Vahana' as a reference vehicle to develop and validate the model. The research leading to this APM has been conducted in the context of the DELOREAN project, which has received funding from the EU Agency for the Space Programme within the EU framework program Horizon 2020, and is led by PildoLabs with the additional participation of FADA-CATEC, GeoNumerics, Airbus, Correos, Bauhaus Luftfahrt, EUROCONTROL and Universitat Politècnica de València. The main objective of the DELOREAN project is the assessment and promotion of the use of EGNOS and Galileo as an enabler to urban air mobility services. To do so, it will demonstrate the viability of EGNSS as an enabler of future UAM in Air Taxi and Delivery scenarios. As part of the development of the Air Taxi scenario, a route optimization engine is envisioned, which – in order to be representative and provide realistic results – requires the use of aircraft performance models. Airbus and EUROCONTROL joined efforts to develop a generic BADA eVTOL model leveraging the existing BADA H model and the performance data from the Vahana vehicle.

The remainder of this paper is structured as follows. First, the Vahana experimental eVTOL vehicle used as a reference to design and validate the APM is described. Then, the different physical models included in the APM are described in detail, including their mathematical formulation and their connection to the BADA modelling framework. Each of the mathematical models in the APM is characterized by a set of coefficients that would assume different numerical values depending on the specific eVTOL being modelled (following the BADA modelling approach). Subsequently, the identification of the models' coefficients based on reference performance data from Vahana is presented and discussed. Finally, an example of how the resulting APM could be used for trajectory simulation is presented, before discussing some shortcomings of the models, future work and some preliminary conclusions.

II. Reference Vehicle Characteristics

Vahana was a single-passenger or cargo, all-electric, fully autonomous eVTOL demonstrator, developed by Acubed – Airbus' Innovation Center, in the Silicon Valley – focused on advancing self-piloted, electric VTOL flight for Urban Air Mobility (UAM) vehicles. The aircraft has a tilt wing and canard configuration that allows it to change the thrust direction of the eight fans driven by electric propulsion (see Fig.1). The main vehicle characteristics are listed in Table I.

Figure 1. General view of the vehicle

TABLE I. General data of the vehicle

Attribute	Vahana value
Cruise airspeed	100 knots / 51 m/s
MTOW	~ 1600 lb / 725 kg
Payload	~ 220 lb / 100 kg
Demonstrated range	50 km
Number of rotors	8
Rotor diameter	~ 5 ft / 1.524 m
Number of controls	22
Installed torque	1.7 x nominal hover

The vehicle is fully controlled by the Flight Control System (FCS) that fixes all the control variables: wing and canard tilt angle, elevators deflection angle, fan collective angle and angular speed. Wing and canard tilt angles are changing from a vertical position, in vertical climb or hover, to a horizontal position in cruise. The impact on the power required for steady level flight is depicted in Fig. 2, where the vertical scale has intentionally been removed from the plot to preserve the confidentiality of the reference performance data.

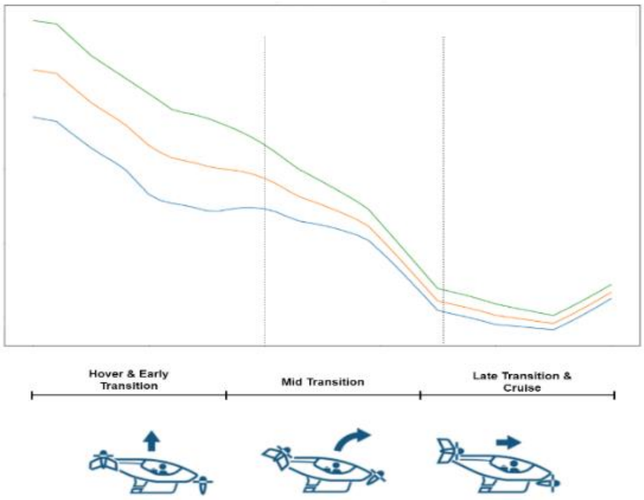

Figure 2. Flight regimes and impact on configuration

III. Design and Structure of the APM

The design of the eVTOL APM presented in this paper is derived from the design of the Base of Aircraft Data (BADA) Family H that was recently developed by EUROCONTROL to model helicopters [1]. The physical model is based on a kinetic approach, which considers the aircraft as a point and requires the modelling of underlying forces that cause aircraft motion. The APM is structured into four models: action, motion, operations and limitations.

A. Action model

The action model allows the computation of the forces acting on the aircraft via their associated powers. It includes three categories of actions: aerodynamic (power required), propulsive (engine power and energy consumption) and gravitational (weight).

1) Power required

The power required is defined as the amount of power to be provided to the aircraft for steady flight (constant speed and altitude). It is the sum of the power required by the rotor, the power required to run the auxiliary systems, and the calculated power loss. Since the power required model of BADA H has already been described in details in [1], this section will focus on the changes developed for the eVTOL model, and only the main BADA H formulas for power required P_{req} (1), power required coefficient C_{Preq} (2), thrust coefficient C_T (3) and advance ratio μ (4) are provided here for convenience:

$$P_{req} = \rho \pi R^2 (\Omega R)^3 C_{Preq} \quad (1)$$

$$C_{Preq} = C_1 + C_2\mu^2 + C_3 C_T \sqrt{\sqrt{\mu^4 + C_T^2} - \mu^2} + C_4\mu^3 + C_5 C_T^2 \mu^3 \quad (2)$$

$$C_T = \frac{mg_0}{\rho \pi R^2 (\Omega R)^2} \quad (3)$$

$$\mu = \frac{V}{\Omega R} \quad (4)$$

where ρ is the air density [kg/m^3], R is the main rotor diameter [m], Ω is the main rotor rotation speed [rad/s], m is the aircraft mass [kg], g_0 is the gravitational acceleration [m/s^2], V is the aircraft true airspeed [kt], and C_1 to C_5 are constant nondimensional values (specific to each aircraft).

Whereas BADA H currently models only helicopters equipped with a single main rotor, the configuration of Vahana is much more complex as it is equipped with 8 rotors mounted on tilt-wings. Since a detailed study of the complex physics of multi-rotor and tilt-wing aircraft was out of the scope of the DELOREAN project, several simplifications have been made to develop a power required model capable of reproducing the Vahana behavior with a minimum number of changes to the existing BADA H specifications.

Firstly, the 8 rotors of the real aircraft were replaced in the model by a single rotor whose area is equal to the sum of the 8 rotor areas.

Secondly, the original power required model from BADA H has been modified to manage a variable rotation speed of the rotor. While the original model was able to reproduce the power required behavior of Vahana in hover and cruise conditions, it could not reproduce the bump in power required that occurs at intermediate speeds during the transition between the tilt-wing configurations (Fig. 2). Considering that the rotation speed of the Vahana rotors varies during this transition [2], the constant rotor rotation speed of BADA H has been replaced by a variable rotation speed that is a function of the airspeed:

$$\Omega = \sum_{i=0}^{5} c_i \cdot V^i \quad (5)$$

where Ω is the rotor rotation speed [rad/s], V is the eVTOL true airspeed [kt], and c_1 to c_5 are constant nondimensional values (specific to each eVTOL).

Although it was inspired by one of the phenomena that occur in the real Vahana aircraft, the sole use of variable rotor rotation speed to reproduce the power required behavior of a tilt-wing aircraft shall only be seen as an artificial modelling choice, and not as an attempt to model the actual physics of tilt-wings. However, the results presented in section IV.A illustrate that this empirical modelling is sufficient to reproduce the main characteristics of the power required by Vahana during the transition between the tilt-wing configurations.

2) *Motor power and required energy consumption*

Vahana is equipped with eight direct current brushless motors. This type of motor needs an electronic speed control system and a motor controller in order to work in the required angular speed regime.

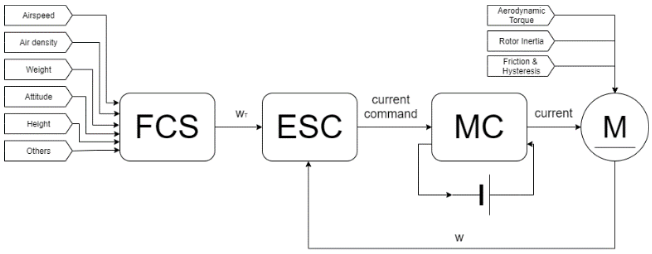

Figure 3. Electric motor control scheme

A schematic view of the system is shown in Fig. 3, which consists of the following sub-systems:

- **Flight Control System (FCS)**: System producing the command input for all the physical devices controlling the flight of the vehicle. From the electric motor point of view, the required input is the target angular speed (WT).
- **Electronic speed controller (ESC)**: Receives target angular speed, from FCS, and actual angular speed of the motor (W). A current command is sent to the motor controller in order to change the angular speed of the motor. This device only handles low power signals, so it is not taken into account in further calculations.
- **Motor controller (MC)**: Receives the current command and generates the power current that feeds the motor. This current is a three phase, square-shaped signal synchronized with the angular position of the motor shaft. The power to generate this signal is taken from the battery. Literature suggests a dependency of power losses with angular speed and current provided to the motor [5].
- **Motor (M)**: Receives the current from the motor controller and generates a torque in the motor shaft that must equilibrate aerodynamic torque, friction, hysteresis, and rotor inertia. The motor will rotate at an angular speed that is probably not equal to the target defined by the FCS, so this data is sent back to the ESC to close the control loop. Electric motor power losses have three sources: transformation from electrical to mechanical power that depends on the angular speed of the motor and the current [5], damping that is proportional to angular speed, and hysteresis.

The energy consumption from all the previous sources has to be taken into account, as it could be non-negligible. Nevertheless, a further simplification is applied in order to eliminate the dependencies of power losses with motor angular speed and position and current provided to the motor. These magnitudes are very dependent on the vehicle design and would lead to a more precise, but less general mathematical model. Therefore, a constant motor efficiency value η_{motor} is taken for the full system ESC+MC+M (6), where $P_{battery}$ is the power drained from the battery and P_{motor} is the motor output power delivered to the fans.

$$\eta_{motor} = \frac{P_{battery}}{P_{motor}} \quad (6)$$

The accuracy of this approximation has been verified using the Vahana dataset and software used during vehicle design. The motor system efficiency was calculated for a wide range of flight conditions: Fig. 4 presents the results in horizontal flight (in red) and the results in all flight conditions (in blue); mean values are marked as horizontal lines, and black dots represent the error. The zone of high speed for horizontal flight, where the vehicle is going to spend most of its flight time, shows little dispersion, therefore considering the motor efficiency as constant seems a reasonable approximation. Numerical values for motor efficiency can be taken from the manufacturer specifications sheet [6].

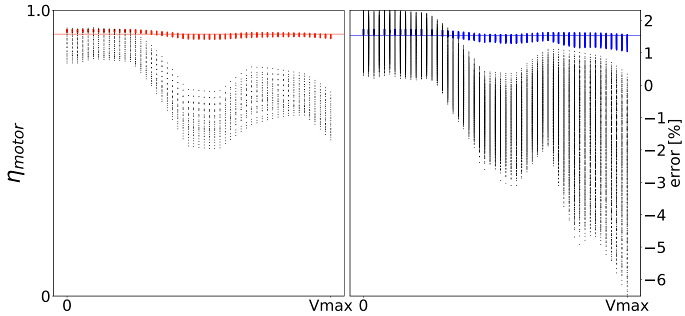

Figure 4. Electric motor efficiency for horizontal flight (left), all flight conditions (right)

3) Battery

The objective of the battery model is to be able to evaluate the battery consumption and to impose limits to the maximum deliverable instant power, due to battery and system limitations. A first approximation could be to assume that the battery energy consumption is equal to the power required by the system to work at each instant. Nonetheless, the battery dissipates some amount of energy into heat that is transferred to the surrounding environment. This energy dissipation can be calculated as the product of the internal resistance of the battery by the square of the current provided to the system. Once output voltage and internal resistance are modelled as functional relationships between current and State Of Charge (SOC), the power losses equation can be reshaped to be a function of required power and SOC. SOC is the ratio of actual stored energy in battery vs total energy that can be stored, measured as a percentage. The battery can be generically modelled using a simple scheme of a voltage generator V_g and serial resistor R_i, which is a simplification of the scheme proposed in [3].

V_g is a pure voltage generator that does not dissipate any power when working. As suggested by [4], the shape of the battery curves can be modelled with the following equations:

$$V_g = V_0 - R_0 \cdot I \qquad (7)$$

$$V_0 = v_0 + v_1 \cdot SOC^{v_2} + v_3 \cdot \frac{SOC}{SOC + 0.1} + \frac{v_4}{100.1 - SOC} \qquad (8)$$

$$R_0 = r_0 + r_1 \cdot SOC^{r_2} + r_3 \cdot \frac{SOC}{SOC + 0.1} + \frac{r_4}{100.1 - SOC} \qquad (9)$$

The resistor R_i is the only source of heat dissipation in the battery model. No dependence with battery temperature is included in the equations, as the normal battery working regime temperature must be controlled by the vehicle cooling system and set to be in the optimal temperature for battery performance. Therefore R_i is modelled as only dependent on the state of charge of the battery using a second degree polynomial.

$$R_i = r_{i0} + r_{i1} \cdot SOC + +r_{i2} \cdot SOC^2 \qquad (10)$$

Combining the equation of power P_{bat} delivered by the battery with the output voltage of the battery equivalent circuit, results in a second-degree equation that allows to compute output current as a function of required power and heat dissipation as the product of internal resistance by the square of current.

$$I = \frac{V_0 - \sqrt{V_0^2 - 4 \cdot R_t \cdot P_{bat}}}{2 \cdot R_t} \qquad (11)$$

$$V = V_0 - R_t \cdot \left(\frac{V_0 - \sqrt{V_0^2 - 4 \cdot R_t \cdot P_{bat}}}{2 \cdot R_t} \right) \qquad (12)$$

$$P_{loss} = R_i \left(\frac{V_0 - \sqrt{V_0^2 - 4 \cdot R_t \cdot P_{bat}}}{2 \cdot R_t} \right)^2 \qquad (13)$$

The equation governing the evolution of the total energy B stored in the battery (14) is obtained by adding P_{loss} to P_{bat}. Each one of the coefficients in these equations is only dependent on SOC, so the total energy consumed from the battery is only a function of SOC and the power transferred from the battery to the system.

$$P_{bat\,total} = -\frac{dB}{dt} = P_{bat} + R_i \left(\frac{V_0 - \sqrt{V_0^2 - 4 \cdot R_t \cdot P_{bat}}}{2 \cdot R_t} \right)^2 \qquad (14)$$

In addition to this equation, which allows to calculate the evolution of the battery internal charge along the flight, several limitations apply to the instant power that can be requested from the battery. The two main limitations to be imposed are the minimum voltage V_{min} (15) that the system requires to properly function, and the maximum current I_{max} (16) that the battery is able to produce.

$$P_{\max 1} = V_{min} \frac{V_0 - V_{min}}{R_t} \qquad (15)$$

$$P_{\max 2} = (V_0 - R_t \cdot I_{max}) \cdot I_{max} \qquad (16)$$

The coefficients V_0 and R_t are only dependent on SOC, so the maximum power that the battery can deliver can be predicted for any flight point (Fig. 5). It is important to remark that this could be a key information when simulating trajectories, because the vehicle may not be able to perform some high-energy manoeuvres when the battery SOC is reaching low values.

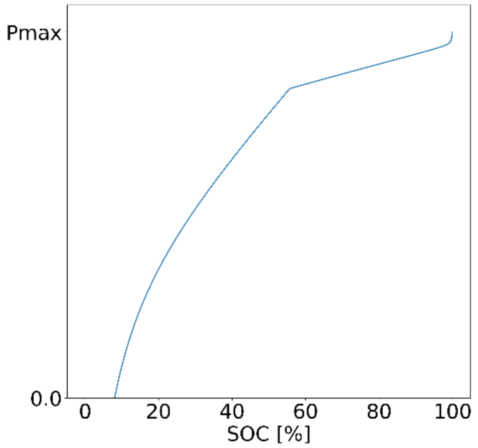

Figure 5. Maximum power delivered by the battery to the system vs SOC

B. Motion model

The motion model relates the geometric, kinematic and kinetic aspects of the aircraft motion, allowing the aircraft performances and trajectory to be calculated. The total-energy model used for this eVTOL model is the same as BADA H and equates the rate of work (i.e. power) done by forces acting on the aircraft to the rate of increase in potential and kinetic energy:

$$P_{eng} - P_{req} = mg_0 \frac{dh}{dt} + mV_{TAS} \frac{dV_{TAS}}{dt} \quad (17)$$

where P_{eng} is the all-engine power [W], P_{req} is the power required [W], m is the aircraft mass [kg], g_0 is the gravitational acceleration [m/s^2], h is the altitude [m], and V_{TAS} is the true airspeed [m/s].

Since eVTOL aircraft are battery-powered and do not burn fuel, the variation of mass and the fuel consumption are null:

$$-F = \frac{dm}{dt} = 0 \quad (18)$$

where F is the fuel flow [kg/s] and m is the aircraft mass [kg].

C. Operations model

In the present timeframe, there are many uncertainties in the definition of air taxis operations, as no meaningful solution is implemented. Therefore, instead of defining a highly customizable process, this model proposes a simple mission trajectory with a very strict definition of its phases as a starting point. A similar approach and typical values for distances, heights, speeds and accelerations can be found in [7] and [8].

Air taxis will fly along relatively short routes, very close to the ground and at lower speeds than conventional aircraft. These vehicles will also be tracked in position and altitude, as the urban environment will impose very strict position controls. All these conditions, very different from the classical way aircraft are operated, will also change the trajectory definition, from a trajectory based on speed and power settings to a more geometric trajectory.

Additionally, the following hypotheses have been made:

- Acceleration is limited to increase comfort of passengers, and the limit values are to be selected by the operator.
- Trajectory in vertiport has limitations in speed, height and distance, fixed by vertiport operator and regulation.
- The vehicle accelerates at constant acceleration value, till reaching the target speed.

Fig. 6, 7 and 8 provide summary schemes of the vertical trajectory of each phase, composed of segments of constant speed and constant flight path angle (gamma), segments of constant acceleration and constant gamma, and one segment (between points 1 and 1.1 in Fig. 6) of constant acceleration and constant rate of climb or descent..

D. Limitations model

The limitations model provides the boundaries within which the APM is valid. These boundaries limit the flight envelope in terms of weight (from operating empty weight OEW to maximum take-off weight MTOW), altitude (up to maximum operating altitude h_{MO}) and speed (up to never exceed speed V_{NE}).

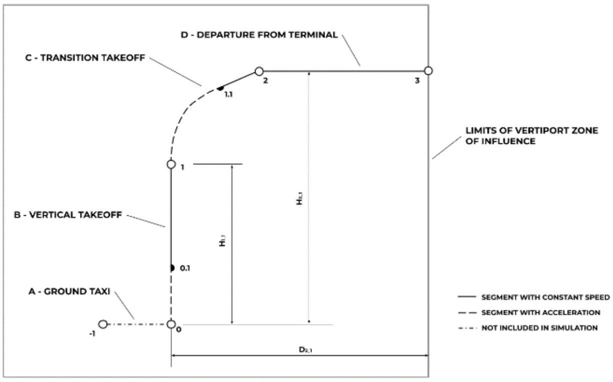

Figure 6. Trajectory scheme of take-off from vertiport

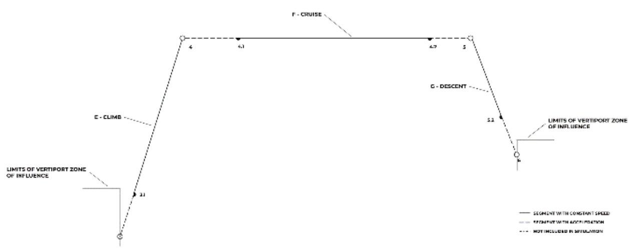

Figure 7. Cruise trajectory scheme

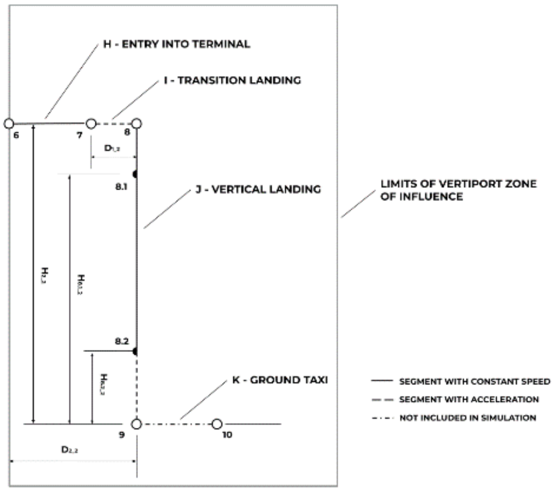

Figure 8. Trajectory scheme of landing at vertiport

IV. IDENTIFICATION OF THE MODEL COEFFICIENTS

Each aircraft model (representing a specific eVTOL aircraft type) is described via a set of coefficients that are used by the APM mathematical formulas. The generation of a specific aircraft model instance aims at identifying the values of the coefficients that achieve the best fit between calculated and reference aircraft performance parameters. The identification process of this eVTOL model follows a different approach from the identification process of other BADA families [1,9]. The reference performance data typically available for airplanes and helicopters relate to the whole aircraft and combine the aerodynamic and propulsive aspects, for instance in the form of rate of climb data. Therefore, the BADA identification process for these categories of aircraft determines the best coefficients simultaneously for both the aerodynamic and propulsive models. The identification process for Vahana, however, had to be adapted since no classical performance charts were available for the purpose of model development. Instead, a dedicated Vahana software, which had been developed to support the design of the vehicle, was used to produce the necessary reference data. This software package allowed calculation of all physical magnitudes (e.g. power required and electric motor/battery) for any flight condition, so a database of simulated flight points was developed, and a dedicated identification process was designed to identify separately the power required coefficients and the motor/battery coefficients.

A. Power required coefficients

Taking as input a set of reference power required values generated using the Vahana performance software for a variety of aircraft weight, airspeed and altitude conditions, the coefficients of the power required equations (1,2) and rotor speed equation (5) are selected as the ones that minimize the sum of the square errors (SSE) between the reference power required values and those estimated by the model in the same conditions.

Fig. 9 presents a comparison between the reference Vahana power required values (full lines) and the eVTOL model estimations (dashed lines) for various aircraft weights and airspeeds when flying at sea level in the International Standard Atmosphere (ISA) conditions. The model provides a good fit in hover and cruise conditions, which represent the major part of the expected eVTOL operations, and it is able to capture the general trends of the reference behavior at intermediate speeds corresponding to the transition between tilt-wing configurations.

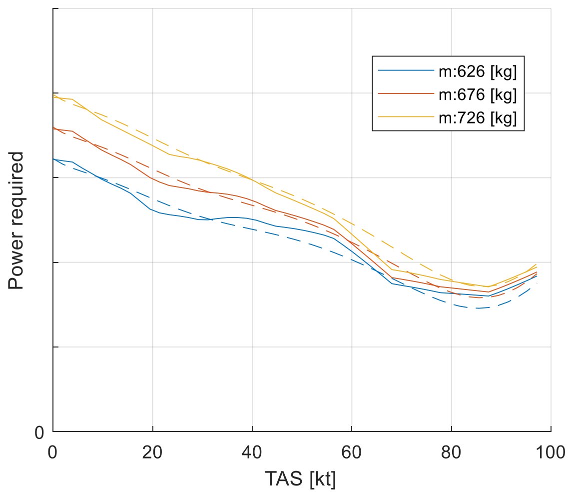

Figure 9. Power required comparison (ISA, sea level)

Fig. 10 illustrates the variations in rotation speed of the equivalent rotor used in the eVTOL model of Vahana. When compared to the variations in rotation speed of the actual rotors in Vahana [2], the amplitude of the variations is similar, but the increases and decreases occur at different speeds. As explained in section III.A.1, these differences can be explained by the fact that the rotor speed variations in the eVTOL model are used in an empirical way to obtain the desired variations in power required at intermediate airspeeds, and do not attempt to capture the real physics phenomena occurring during the transition between tilt-wing configurations.

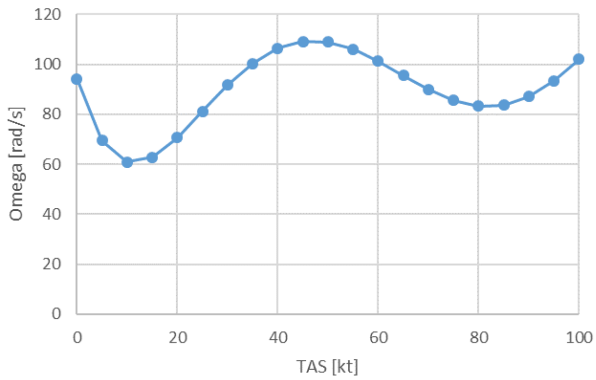

Figure 10. Variations in rotor rotation speed with aircraft speed

B. Battery coefficients

Taking as input the battery data used for the Vahana design, the coefficients of equations (8), (9) and (10) are selected as the ones that minimize the SSE between the reference battery voltage and current values and those estimated by the model in the same conditions. Once these coefficients are obtained, the goodness of fit is verified by calculating output voltage V_g (12), and total power drained from battery $P_{bat\ total}$ (14), as functions of the power P_{bat} delivered from the battery to the system. All calculations are performed for a constant temperature. As can be seen in Fig. 11 and 12, the shapes of V_g and $P_{bat\ total}$ as a function of P_{bat} are very well captured over a wide range of SOC.

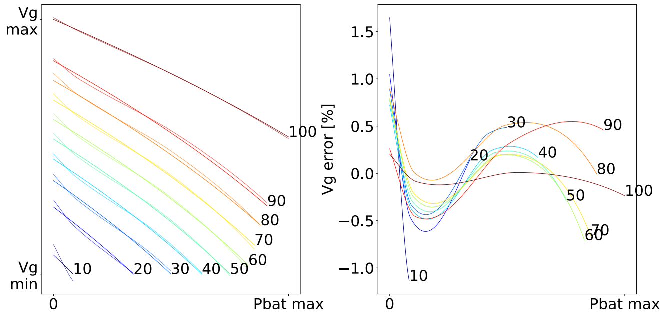

Figure 11. Comparison of calculated V_g vs original data

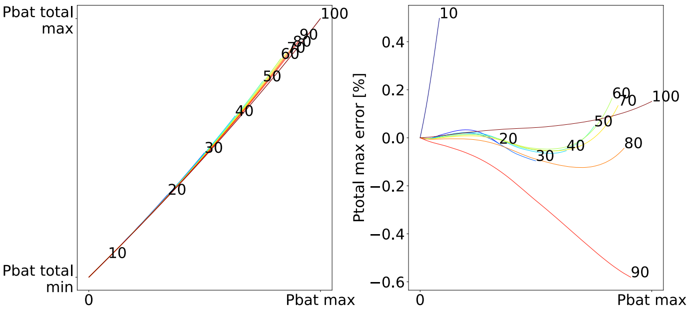

Figure 12. Comparison of calculated $P_{bat\ total}$ vs original data

V. EXAMPLE OF APPLICATION

In order to demonstrate some of the capabilities of the proposed APM, a sample trajectory was computed with the Vahana model flying a procedure based on the operations model described in section III.C. The pressure altitude (in red) and true airspeed (in blue) are presented in Fig. 13; the mechanical power required (in blue), electrical power delivered by the battery (in red), and SOC (in grey) are presented in Fig. 14.

Fig. 15 and 16 present the same data but only for the departure phase, so as to provide more details on the different segments that compose this phase, namely:

- Vertical take-off (constant ROC)
- Transition acceleration (constant ROC)
- Transition climb (constant ROC)
- Departure from terminal (level flight)
- Acceleration to climb speed (constant slope)
- Climb (constant slope).

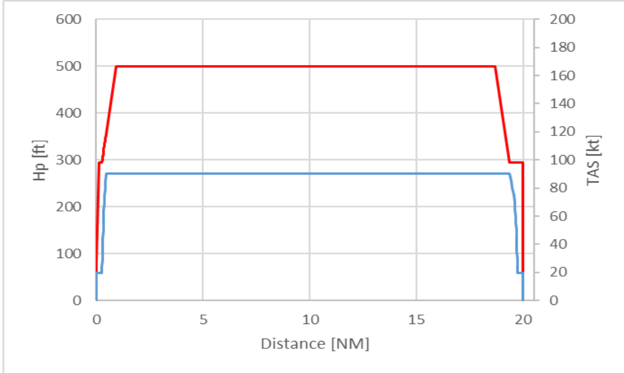

Figure 13. Altitude and true airspeed (full trajectory)

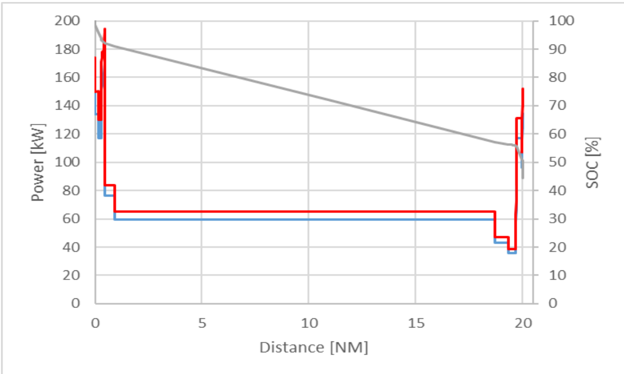

Figure 14. Mechanical and electrical power, SOC (full trajectory)

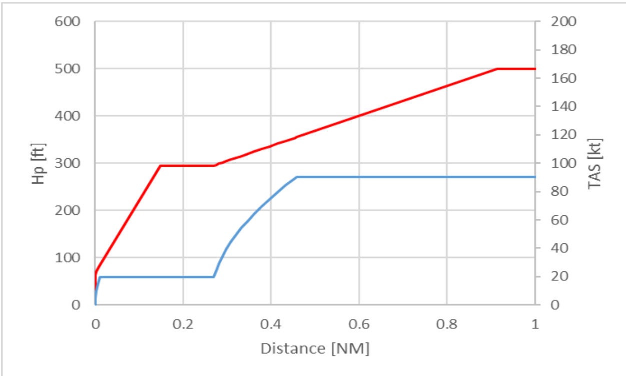

Figure 15. Altitude and true airspeed (departure)

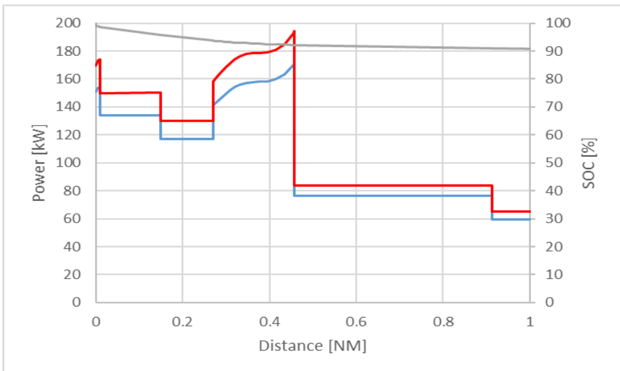

Figure 16. Mechanical and electrical power, SOC (departure)

VI. Known Limitations and Future Work

As only one vehicle was used to define and evaluate the power required model for eVTOL, its goodness of fit cannot be assured yet for other vehicles. The model is based on BADA H, and is therefore expected to behave correctly for eVTOL using a standard rotorcraft configuration, but further evaluation is necessary using data from other vehicles. If eVTOLs deploying a tilt-wing configuration become standard in UAM operations, further work will also be required to improve the physical modelling of tilt-wing aircraft.

The proposed battery model formulation enables reproducing non-linearities in the zones of high and low SOC. However, as with the power required model, only one battery type was used to derive the model. Further work will be needed to evaluate the model with other battery technologies.

The biggest unknown remains the vehicle operating procedures. No eVTOL is currently operational, therefore only hypotheses can be made. Nevertheless, the simple approach implemented in the proposed model provides a starting point to research activities, and more features could be added to the operations model once more information becomes available about the standard operating procedures of UAM vehicles.

Regarding the usability of the APM presented in this paper, it is important to note that the model coefficients have been derived from proprietary reference performance data, However, Airbus and EUROCONTROL may provide the coefficients to third parties under the BADA licensing framework for research and development purposes. We also invite other manufacturers to experiment with the proposed modelling framework.

VII. Conclusion

BADA eVTOL is a simple aircraft performance model based on the BADA H model already available for helicopters. This eVTOL model has been derived using detailed performance data from an actual flying urban air vehicle demonstrator, Airbus Vahana, and it provides representative estimates of both the power required to operate this aircraft, and the associated battery consumption. It is expected that the availability of an APM for an eVTOL based on real data will foster the development of UTM applications and provide a good starting point for future research.

Acknowledgment

This project has received funding from the European Union Agency for the Space Programme under the European Union's Horizon 2020 research and innovation programme under grant agreement No 870251.

References

[1] V. Mouillet and D. Phu, "BADA Family H - A Simple Helicopter Performance Model for ATM Applications", IEEE/AIAA 37th Digital Avionics Systems Conference (DASC), 2018.

[2] G. Droandi, M. Syal, and G. Bower, "Tiltwing Multi-Rotor Aerodynamic Modeling in Hover, Transition and Cruise Flight Condition", AHS International 74th Annual Forum and Technology Display, 2018.

[3] T. Bruen and J. Marco, "Modelling and experimental evaluation of parallel connected lithium ion cells for an electric vehicle battery system", Journal of Power Sources, Vol. 310, 2016.

[4] A. Reuben Gnadt, "Technical and Environmental Assessment of All-Electric 180-Passenger Commercial Aircraft", Massachusetts Institute of Technology, 2018.

[5] F. Settele and M. Bittner, "Energy optimal guidance of a battery electrically driven airplane", CEAS Aeronautical Journal, Vol. 11, 2019.

[6] MAGiDRIVE Integrated Motor Controller Specifications.

[7] Uber Elevate, "Uber Air Vehicle Requirements and Missions", 2018.

[8] M. D. Patterson, K. R. Antcliff and L. W. Kohlman, "A Proposed Approach to Studying Urban Air Mobility Missions Including an Initial Exploration of Mission Requirements", 75th Annual Forum and Technology Display, 2018.

[9] A. Nuic, D. Poles, and V. Mouillet, "BADA: An advanced aircraft performance model for present and future ATM systems", International Journal of Adaptive Control and Signal Processing, Vol. 24, No. 10, 2010.