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Flight Transient Estimation of VTOL Aircraft with Propellers

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Abstract

Methodological issues associated with the determination of the vertical take-off and landing aerodynamic parameters equipped with two rotary propellers during take-off and hovering, descent and landing are studied in the proposed article. During the computer simulation process, kinematics parameters diagrams were made, aerodynamic coefficients and propellers thrust components at all stages of aircraft take-off were estimated. That numerical data can be used in a preliminary stage of aerodynamic design for the vertical take-off and landing aircraft and electric drones at the determination of control and equalization elements geometric and kinematic parameters.

Keywords

Vertical Take-Off and Landing (VTOL) Drone, Propeller, Transient, Thrust, Vector, Modeling, Kinematic, Aerodynamic Coefficient

1. Introduction

Unmanned Aerial Vehicles "UAVs are to be known as isolated and reusable powered aerial vehicles" [1]. These vehicles are remotely controlled, semi-autonomous, autonomous, or have a mixture of these capacities. So, the UAV is an acronym for Unmanned Aerial Vehicle, which is an aircraft with no pilot on board. Thus, UAVs can be remote controlled aircraft or can fly autonomously based on pre-programmed flight strategies or more complex dynamic automation systems.

Ref. [2] described that the acronym UAV has been expanded in some cases to UAVs (Unmanned Aircraft Vehicle System). The FAA has adopted the acronym UAS (Unmanned Aircraft System) to reflect the fact that these complex systems include ground stations and other elements besides the actual air vehicles [1].

The main goal in creating a new electric power vertical take-off and landing

(VTOL) heavy drone is to ensure stability and controllability during its vertical take-off and landing. We are interested in studying the process of the transient regime from the moment of hovering to reaching the speed at which the aerodynamic lift becomes equal to the take-off mass VTOL drone like American Dynamics AD-150 [3]. The Drone which is studied is equipped by two electric motors with 280 kW each, instead of one Pratt & Whitney Canada PW200 powerplant with 560 kW. In this case, the decision problem of finding the aerodynamic forces and moments acting on the VTOL drone is relevant (**Figure 1**).

2. Problem Statement

Calculation allows us to estimate the aerodynamic characteristics and VTOL drone electric propulsion system on transient modes during start and vertical transition to horizontal flight.

Calculation of aerodynamic characteristics of VTOL drone in horizontal flight performed using the "Electric Fighter" soft, developed by the method of Burago [4] and improved for contemporary applications. Characteristics transition take-off was found in MATLAB soft to the initial data obtained for horizontal flight, traction, and power characteristics VTOL drone electric propulsion system [5].

During take-off in transient mode without climb VTOL drone with a propeller, the length of the horizontal segment is figured out by the formula given in Ref. [6]:

$$L_{trans} = \frac{V_{trans}^2}{2\left(\frac{\mathrm{d}V_x}{\mathrm{d}t}\right)_{average}}. \tag{1}$$

In (1) the transient speed is:

$$V_{trans} = V_{trans\,0}\sqrt{1-\mu_{cruise}\sin(\Psi)-\mu_{trans}\cos(\Psi)} - 0.8V_2\sqrt{\frac{A'}{A}}, \tag{2}$$

where $V_{trans\,0}$ the speed of stable horizontal flight when $L_\Sigma = m_0 g$; $\mu_M = \frac{1}{K}$ — required cruise thrust-to-weight ratio; K—aerodynamic quality of the VTOL aircraft corresponding to the given flight speed; Ψ—the angle of inclination of the propeller thrust vectors; v_2—jet velocity behind the propeller; A—VTOL wing area; A'—propeller jet area.

Figure 1. American dynamics AD-150 VTOL drone [3].

Time laps during which VTOL drone accelerates from V_1 to VTOL speed $V_2 = V_{trans}$ was found from the next expression [4]:

$$t = \int_{V_1}^{V_2} \frac{1}{\frac{\mathrm{d}V}{\mathrm{d}t}} \mathrm{d}V. \tag{3}$$

3. Methodology

During applied calculations, the condition VTOL drone to enter level flight was fulfilled at $\Psi = 2\phi$ (where Ψ the angle of inclination of the thrust vector relative to the horizontal flight), when the sum of the projections on the Y-axis of the lift L and the propeller thrust T_L will be equal to the VTOL drone take-off weight:

$$L_\Sigma = P_y + L = m_0 g. \tag{4}$$

The main idea of the local angles of attack of the wings through the true angles of rotation of the VTOL drone thrust vector and the angle of attack could be reflects the essence of changes in aerodynamic forces and moments during transient modes throughout aircraft take-off and landing.

Table 1 shows the results of approximate calculations for the kinematic and aerodynamic characteristics of electric VTOL drone. All that results could be used for kinematical simulations.

4. Results and Discussion

Kinematic parameters change $\alpha, \Psi = f(V)$, and the given laws of coefficients of lift c_{La}, drag c_{Da} and longitudinal moment m_z variation at all stages of electric VTOL drone take-off, up to speed V_{trans} are shown in Figures 2-6.

At the take-off stage with the known laws of aerodynamic coefficients change $c_{Da}, c_{La}, m_z = f(V)$, the corresponding dependences $D_a, L_a, M_z = f(V)$, were

Table 1. Kinematic and aerodynamic electric VTOL drone coefficients at the take-off stage.

V, m/sec	α^0	Ψ^0	c_{La}	c_{Da}	m_z
0	0	90	0	0	0
10	7.2	88	0.523	0.026	−0.048
15	10	87	0.727	0.08	−0.066
20	12.5	85	0.909	0.078	−0.083
25	14	78	1.018	0.097	−0.093
30	15	73	1.09	0.112	−0.1
35	16	66	1.166	0.127	−0.106
40	16	55	1.163	0.127	−0.106
47	15	35	1.02	0.098	−0.057
60	8.6	0	0.625	0.037	−0.057

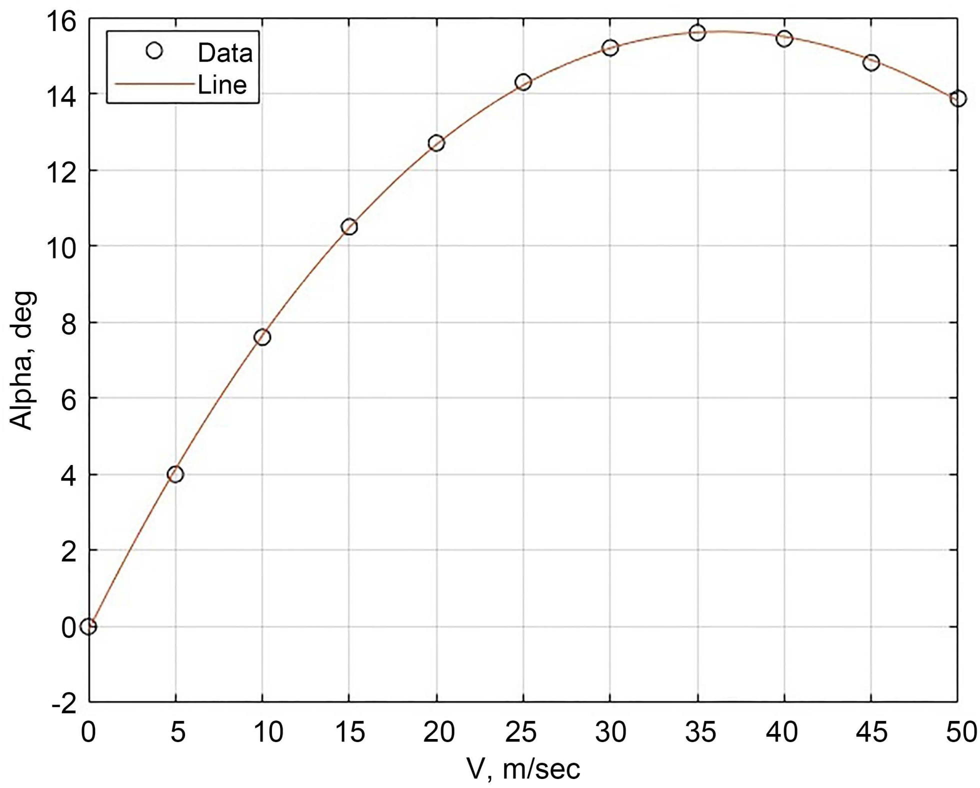

Figure 2. The law of change in the angle of attack in terms of take-off speed.

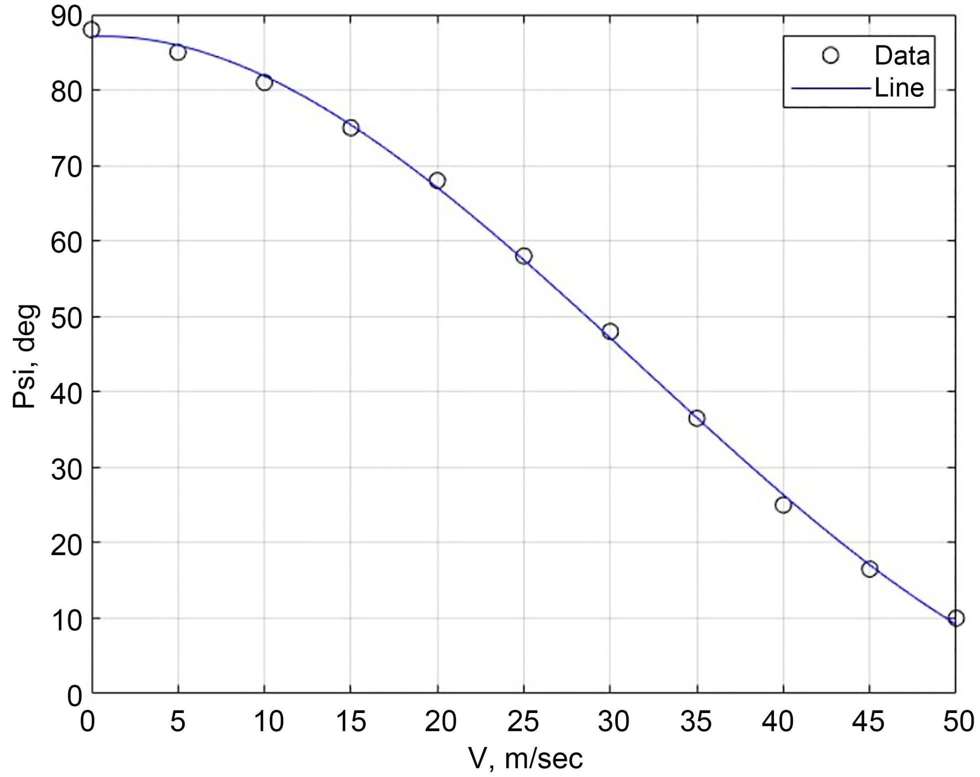

Figure 3. The law of variation of the angle Ψ of the rotary propeller thrust vector from the horizon electric VTOL drone in terms of speed.

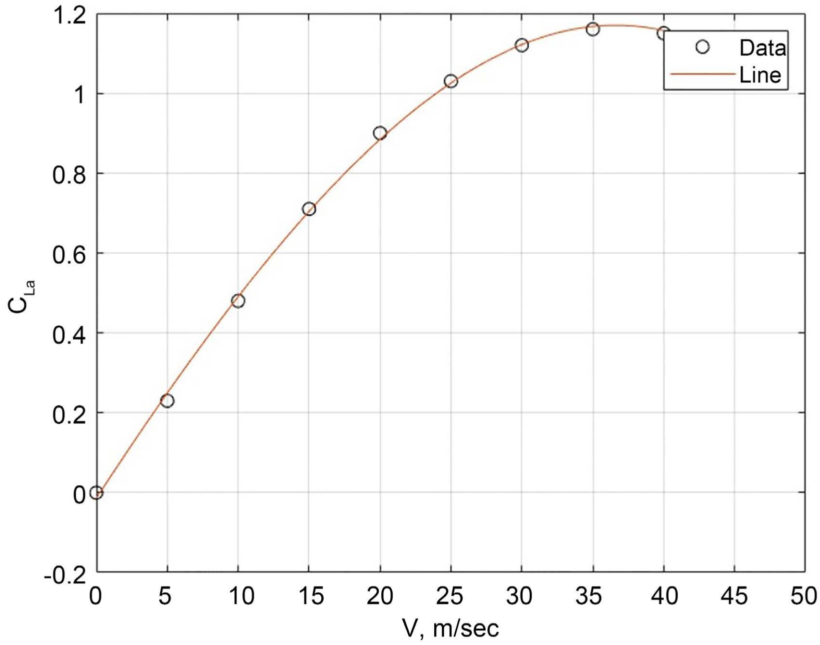

Figure 4. The law of variation of the lift coefficient $c_{La} = f(V)$ on take-off electric VTOL drone.

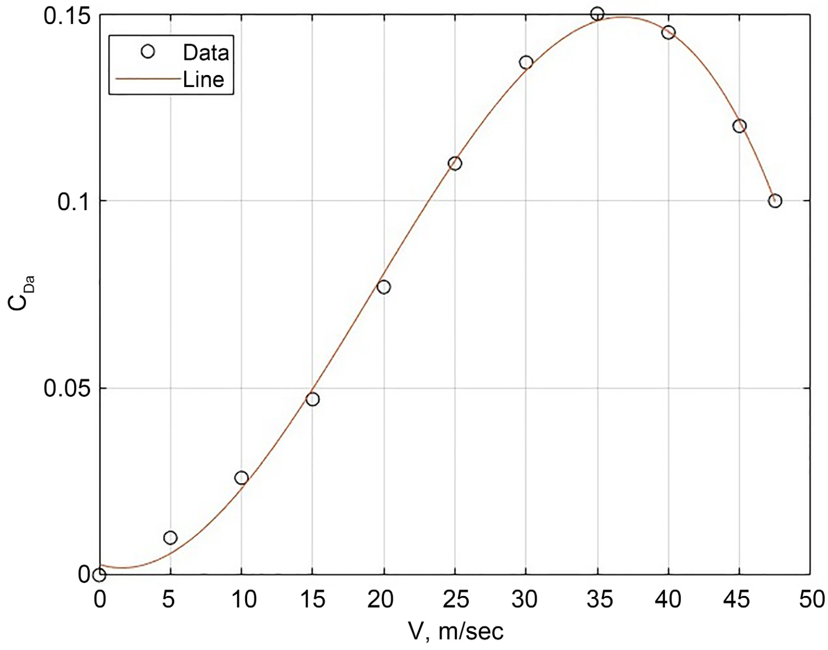

Figure 5. The law of variation of the drag coefficient $c_{Da} = f(V)$ on take-off electric VTOL drone.

calculated, and the components of the thrust vector of the tilt rotors electric power plant $T_a, T_x, P_y = f(V, \Psi)$ VTOL drone.

Figures 7-11 show the dependences of the vertical and horizontal components of the propeller thrust, lift, and drag of an electric VTOL drone in terms of speed during take-off.

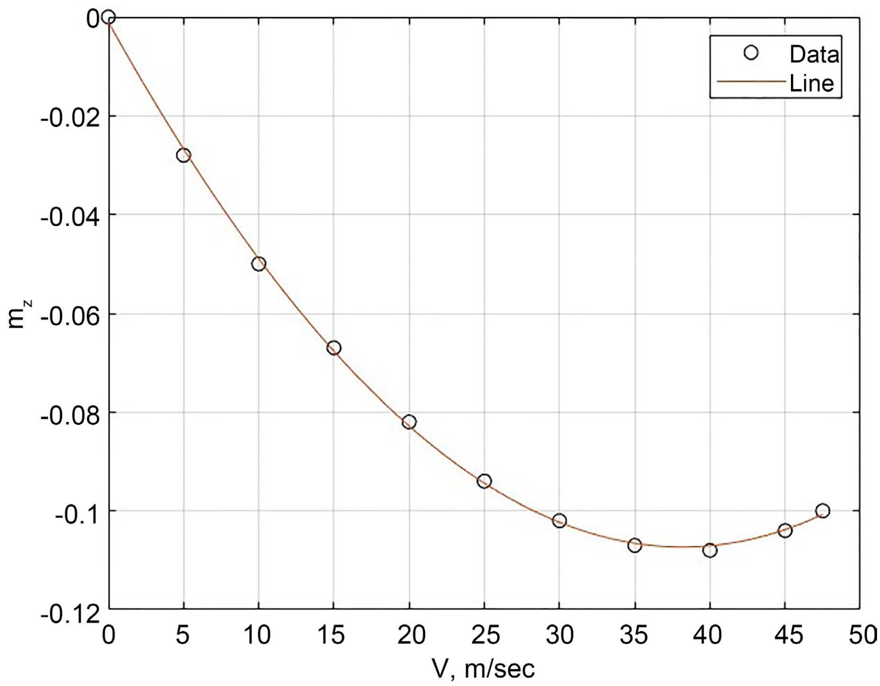

Figure 6. The law of variation of the coefficient $m_z = f(V)$ on take-off electric VTOL drone.

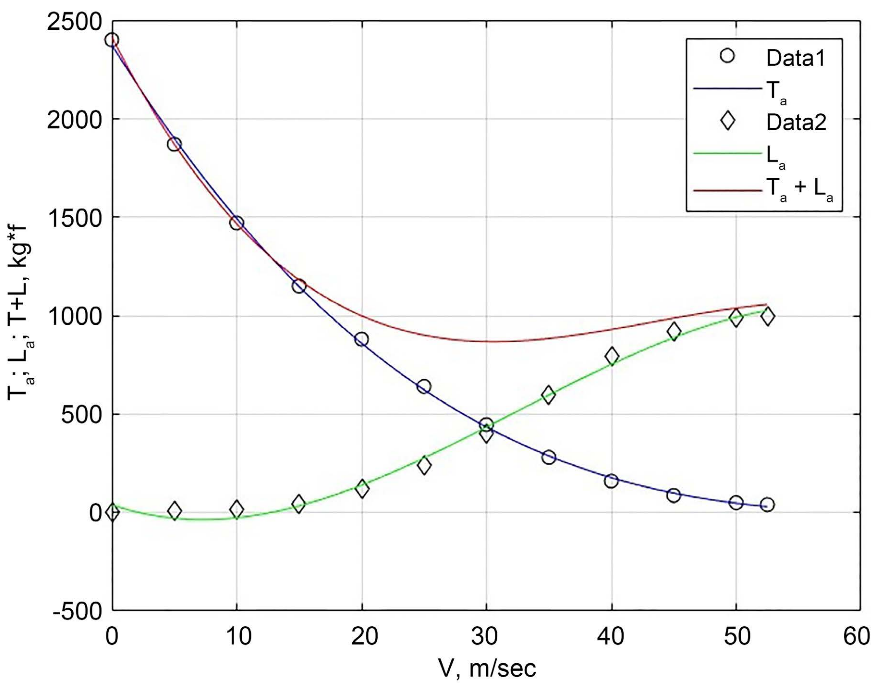

Figure 7. The variations of $T_L, L_a = f(V)$ on take-off electric VTOL drone.

Taking-off a VTOL drone is the most threatening in terms of flight safety. So, in case of failure of one of the engines in the vertical take-off mode or during the transient mode for a VTOL drone with heavily loaded rotary propellers ($P \geq$ 1000 N/m^2), the use of the propeller autorotation mode is excluded [6]. However,

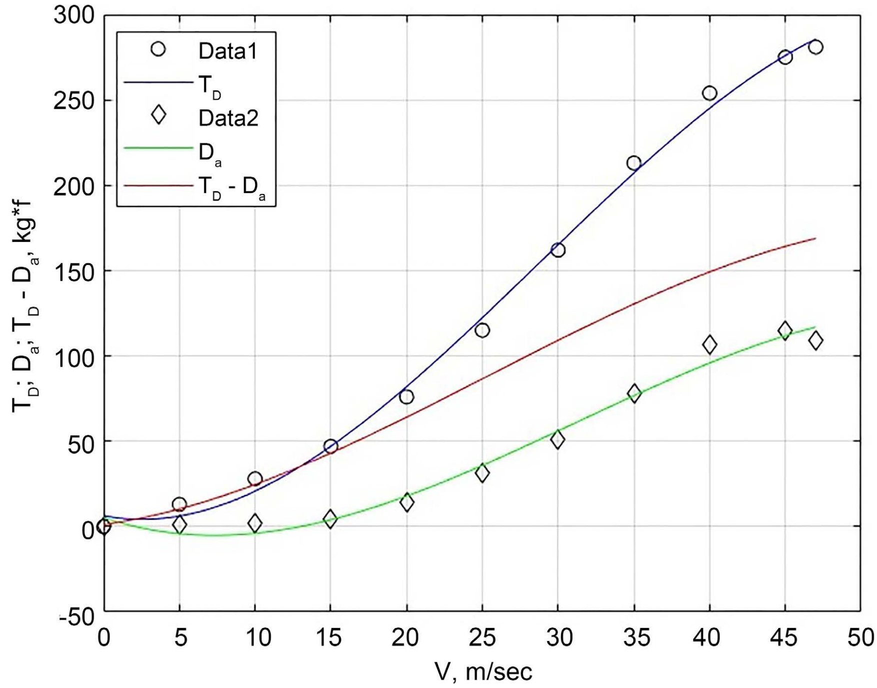

Figure 8. The variations of $T_X, D_a = f(V)$ on take-off electric VTOL drone.

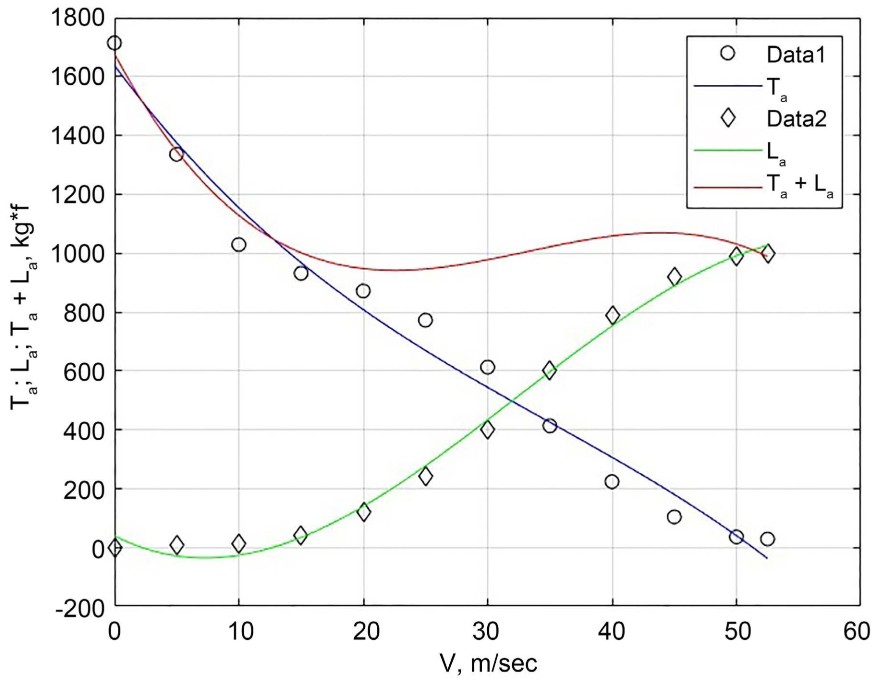

Figure 9. The variations of $T_a, L_a = f(V)$ if only one electric motor failure during VTOL (2 × 165 kW) take-off. Here, a 40% increase in propeller thrust is considered in case of a single engine failure.

it is known that when the electric power of the drone power plant drops by 50%, the thrust of the rotary propellers decreases by about 40%. This slows down the VTOL drone descent rate. To continue take-off in case of one engine failure, it is

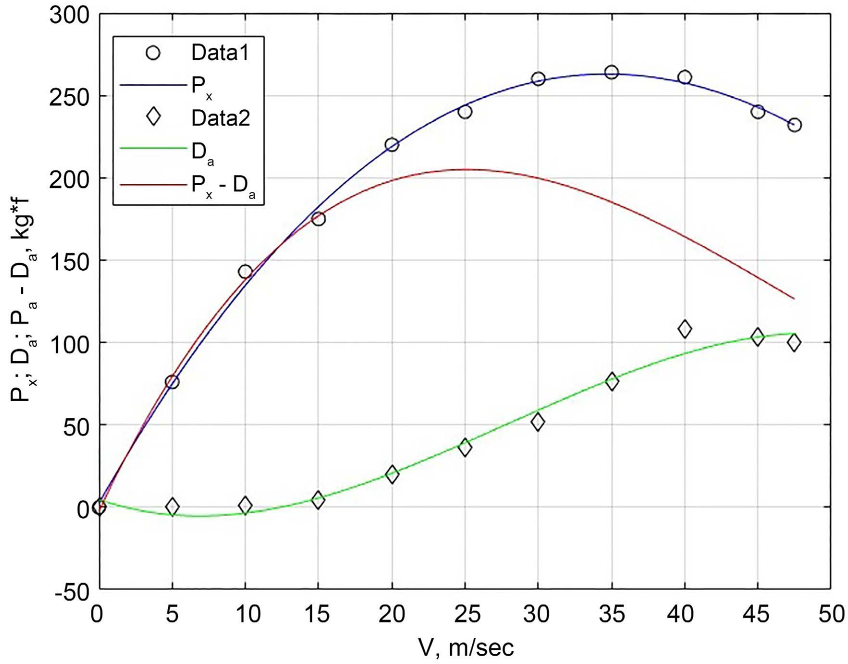

Figure 10. The variations of $T_x, D_a = f(V)$ on take-off VTOL (2 × 280 kW) with one engine failure.

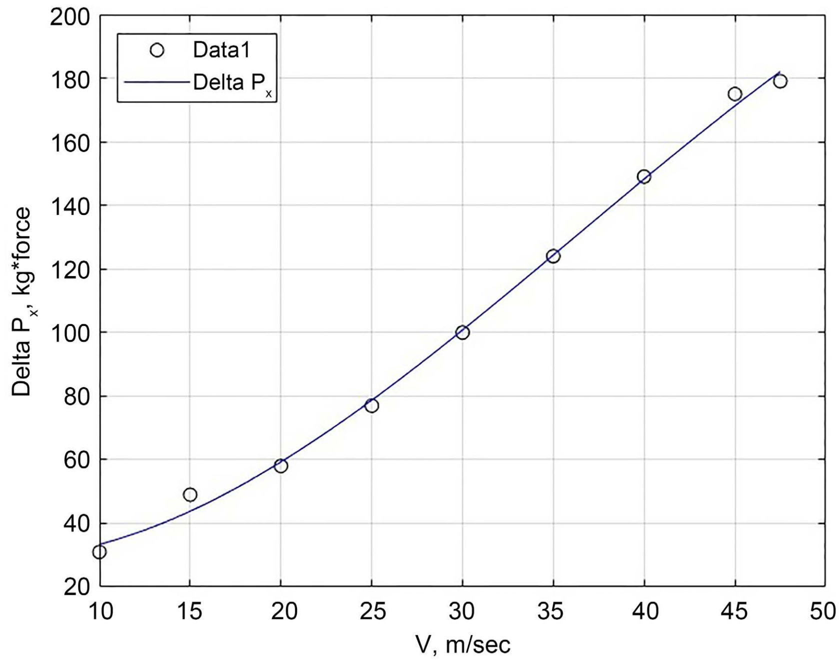

Figure 11. The variation of $\Delta P_x = f(V)$ during VTOL drone take-off.

necessary to have that power of an electric propulsion system, which supplies the VTOL drone to accelerate to the required horizontal speed (**Figure 9**, **Figure 10**).

As can be seen from the above dependences, the use of the proposed laws of change in kinematic parameters and laws of change in aerodynamic coefficients and thrust characteristics of an electric VTOL drone during take-off allows vertical take-off and the achievement of horizontal speed corresponding to the speed of the transient process V_{trans}. At this speed, there is an excess of thrust ΔT_x which is necessary for further VTOL drone acceleration, up to the maximum flight speed (**Figure 10**).

Reducing the target load (consumed mass) at the end of the flight reduces the required lifting thrust-to-weight ratio during VTOL drone landing. Calculations show that the available lifting thrust-to-weight ratio at the end of the mission is increased for electric propeller VTOL by 14% ... 15% on average [4]. Thus, even with an available thrust decrease significant because of the failure of one of the engines at the end of the mission, the possibility of a VTOL drone safe vertical landing is still.

Figure 11 shows the dependence of the excess propeller thrust in the transient mode during VTOL drone take-off.

The length of the horizontal section of VTOL drone acceleration and the time needed for the transient mode are determined by the following method.

Knowing the excess thrust increment with increasing speed from V_1 to V_2, the average acceleration can be written as:

$$\left(\frac{\mathrm{d}V_x}{\mathrm{d}t}\right)_{average} = \frac{g\Delta P_{x_{excess}}}{m_0 g} = j_{average},$$

where $j_{average}$ is VTOL drone average acceleration in fractions of gravity g [2].

Further, having determined the transient mode speed according to formula (2), we obtain the horizontal section length on which the transient take-off mode is performed:

$$L_{trans} = \frac{V_{trans}^2}{2\, j_{average}} = 294 \text{ m}.$$

Time during which VTOL drone accelerates from speed V_1 to $V_2 = V_{trans}$ $t_{trans} = \frac{V_{trans}}{j_{average}} \approx 34 \text{ sec}$. The transient mode during VTOL drone landing is calculated in the same way as during take-off, with the only difference that the landing weight of the aircraft is less than the take-off weight by the value of the target load (consumed weight) and the average acceleration $j_{average}$ has the opposite sign.

Using the proposed laws of kinematic parameters changing and the laws of change in aerodynamic coefficients and VTOL drone thrust characteristics during take-off allows vertical take-off and achievement of horizontal speed V_{trans}. At this speed, there is an excess of thrust P_x, required for further VTOL drone acceleration, up to the maximum flight speed. Considering the true angle of rotation of the propeller thrust vector $\Psi_{true} = \Psi - \alpha$ slightly increases the length of the horizontal section and the time of the transient mode [7].

5. Conclusions

The idea of the local angles of attack of the wings through the true angles of rotation of the VTOL drone thrust vector and the angle of attack only approximately reflects the essence of changes in aerodynamic forces and moments during transient modes throughout aircraft take-off and landing. Therefore, the refinement of local angles of attack on VTOL drone elements and special definitions of aerodynamic power and moment characteristics in vertical take-off and acceleration of VTOL drone up to the speed at which condition (4) is realized. The correctness of the solution to this problem can be confirmed during flight experiments.

Despite the evaluative nature, the results obtained in the calculations can be used at the preliminary stage of VTOL drone aerodynamic design while deciding the geometric and kinematic parameters of aerodynamic controls and stabilization. In addition, they must evaluate VTOL drone performance at an early stage of design.

Declarations

All stages were performed personally by author.

Code Availability

Matlab license number: 968398.

Authors' Contributions

All research, analysis and text were made exclusively by author.

Ethics Approval

According to human's social ethics.

Consent to Participate

Yes.

Consent for Publication

Yes.

Availability of Data and Material

Yes.

Conflicts of Interest

No conflicts of interest.

References

[1] Doumit, J.A. (2018) Scientific Edition Polygraph. Kuban State University, Krasnodar, 112 p.

[2] Karkera, Y., Siddalingappa, P.K., Mascarenhas, S, Dsora, C. and Bali, H (2017) The Design and Development of Transitional UAV Configuration. *International Journal of Mechanical and Production Engineering Research and Development*, **9**.

https://www.academia.edu/40182250/THE_DESIGN_AND_DEVELOPMENT_OF_TRANSITIONAL_UAV_CONFIGURATION

[3] Wikipedia (2013) American Dynamics AD-150. https://en.wikipedia.org/wiki/American_Dynamics_AD-150

[4] Burago, S.G. (1989) Vybor aerodinamicheskoy komponovki dozvukovyh I sverhzvukovyh letatelnyh apparatov. MAI Publisher, Moscow, 108 p.

[5] Ifikhar, B.A. (2019) Computer Modeling in the Aerospace Industry. Wiley, Scrivener Publishing, L.L.C., 173 p.

[6] Kurochkin, F.P. (1970) Osnovy proektirovaniya samolyotov s vertikalnym vzletom I posadkoy. Mashinostroeniye, Moscow, 224 p. (In Russian)

[7] Kumar, V., Sharma, R., Sharma, S., Chandel, S. and Kumar, S. (2021) A Review on Design Methods of Vertical Take-Off and Landing UAV Aircraft. In: *Proceedings of International Conference on Materials Science and Engineering*, Mathura, 18th-19th December 2020, Article No. 012142. https://www.researchgate.net/publication/351892893_A_Review_on_Design_Methods_of_Vertical_take-off_and_landing_UAV_aircraft