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RESEARCH ON UAV AIR LAUNCH IN THE JSBSIM SOFTWARE ENVIRONMENT

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Abstract*—The article considers the scientific and practical aspects of unmanned aerial vehicle air launch, analyzes modern approaches and technologies, and also determines the advantages of this launch method compared to traditional methods. The method of studying unmanned aerial vehicle air launch using simulations in the JSBsim software environment is considered. The database of unmanned aerial vehicle air launch dynamics is presented, confirming the effectiveness of using unmanned aerial vehicle air launch simulation in the JSBsim software environment. The influence of unmanned aerial vehicle weight on the launch process and subsequent unmanned aerial vehicle flight is considered in detail. The scientific novelty lies in the development of a method for high-precision modeling of unmanned aerial vehicle air launch in a circuit with an autopilot, the creation of a high-precision database of unmanned aerial vehicle air launch dynamics.*

Keywords—Unmanned aerial vehicle air launch; flight dynamics model; unmanned aerial vehicle; database; autopilot.

I. INTRODUCTION

The modern development of unmanned aerial vehicles (UAVs) is accompanied by the search for new technologies that ensure the increase of the efficiency of their operation. One of the promising directions is the air launch of UAVs [1], which involves the separation of the device from the aircraft. Carrier or other platform with subsequent transition to autonomous flight. This approach allows to reduce energy costs for takeoff, ensure reaching the required altitude and speed, and increase the range and duration of the flight task.

Computer simulation of air launch is a very important tool for studying the flight dynamics process. A highly accurate model of air launch dynamics is the basis for developing an autopilot that provides effective control of such a complex phase of flight.

Thus, the problem of modeling UAV air launch is relevant both from the point of view of fundamental scientific research in the field of flight dynamics and control systems, and in the context of practical tasks related to increasing the efficiency, reliability, and safety of using unmanned aircraft systems.

The purpose of this work is to study the dynamics of UAV air launch through high-precision modeling in the JSBsim and SITL Ardupilot programs.

The process of air launch (detachment and initial flight of a UAV) is characterized by a high level of uncertainty and complexity of dynamic interactions. This stage is significantly influenced by: initial conditions (altitude, speed, angular parameters), aerodynamic characteristics, delays and errors in the operation of control systems.

The objectives of this work are: modeling of UAV air launch in the JSBsim environment [2], [3], creation of an air launch dynamics database. This database is capable of ensuring effective performance of the flight task by supporting the optimal initial parameters of the UAV for launch and informing operators about the influence of environmental parameters on launch characteristics.

To provide simulation in the circuit with an autopilot, we use the sitl ardupilot software [4], the use of which is described in [5], [6].

II. ANALYSIS OF THE ADVANTAGES OF UAV AIR LAUNCH OVER OTHER LAUNCH METHODS

Below we will consider the main advantages of air launch.

Energy efficiency and fuel economy. Starting from air carrier (aircraft, helicopter, multicopter) allows you to avoid energy consumption for gaining altitude from the ground. The UAV starts already at a certain altitude and speed, which reduces fuel (or electricity) consumption for the initial stage of the flight.

Increased flight range and duration. Since the launch occurs at optimal parameters (altitude, speed), the UAV's energy reserve is used only to complete the task, which increases the flight range and duration.

Reducing the load on the structure. During takeoff from the ground, the UAV is subjected to the greatest loads: acceleration, engine operation at maximum thrust, possible turbulent flows near the surface. Air launch reduces these factors, which extends the life of the engines and airframe.

Flexibility of use. Air launch allows the UAV to be used from any point in space, regardless of the availability of a runway or prepared site. This is especially important in military conditions or in areas with difficult terrain.

Ability to launch heavier or specialized vehicles. Some UAVs with large wingspans or high payloads cannot effectively launch from a short runway or catapult. Air launch solves this limitation.

Increasing efficiency. Carrier can quickly deliver UAVs to the operation area, which significantly reduces deployment time and allows for more rapid response to changing situations.

In this paper, we propose a method for simulating the launch of an unmanned aerial vehicle from the air in the JSBsim environment. JSBSim is an open flight dynamics library used to simulate the movement of aircraft in a three-dimensional environment. It is used as a standalone tool or as a component in simulators (e.g., FlightGear, SITL ArduPilot, AirSim, etc.).

JSBSim implements mathematical models describing: the motion of the aircraft's center of mass (Newton's equation for translational motion), angular motion (Euler's equation for rotation around axes), aerodynamic forces and moments, forces and moments from engines, gravitational forces and atmospheric effects.

We have proposed a method for modeling air launch by obtaining a full set of aerodynamic coefficients of an unmanned aerial vehicle by performing complex aerodynamic calculations ("virtual purges") in the following software: PANSYM [7], [8], XFLR5 [9]. A set of coefficients for a real Mini Talon UAV, produced by X-UAV Company, was obtained. This set of coefficients allows us to create a high-precision model of UAV flight dynamics.

The proposed air launch method consists in developing a specified high-precision model of UAV motion dynamics and in modeling external forces that reproduce the impact air carrier on a UAV from the moment of takeoff to the moment of launch of the UAV.

The specified method using external forces allows to describe the real behavior carrier with UAVs and simulate not only the speed and altitude of the flight at launch, but also all angular velocities and accelerations.

To simulate the air launch of a UAV in a loop with an autopilot, it is proposed to use the SITL Ardupilot software. SITL (Software-In-The-Loop) is a software environment in which the ArduPilot firmware is compiled and executed as a regular program on a personal computer without a real controller. The dynamics of the device are simulated by the JSBSim, Gazebo, AirSim, etc. program. Exchange with ground stations is via MAVLink. We use Mission Planner as the ground station software. Figure 1 shows a block diagram of the air launch process using the SITL Ardupilot, JSBsim, and Mission Planner software.

Fig. 1. Simplified structural diagram of air launch simulation

III. UAV AIR LAUNCH DYNAMICS DATABASE

During the research, a UAV motion database was created, which is based on the results of numerous simulations in the JSBSim and SITL ArduPilot environments. The database is a unique tool that allows:

- save typical flight scenarios depending on launch conditions;
- compare the impact of different parameters on the behavior of the UAV after air launch;
- provide real-time trajectory prediction both at the ground station and in the on-board computer.

The base consists of two levels:

1) Parametric level (input parameters):

- launch altitude and speed;
- pitch angle;
- mass of the UAV;
- atmospheric parameters (temperature, air density, wind);
- characteristics of the power plant.

2) Resulting level (output parameters):

- loss of altitude;
- stabilization time;

- normal overload;
- angles of attack;
- angular positions;
- trajectory shape (model in the form of a set of trajectory points with timestamps).
- change in flight speeds.

Database formation consists of the following stages.

- *Simulation:* Thousands of launches were performed with variations in environmental parameters and UAV characteristics.
- *Normalization:* results are reduced to a unified record structure in the database;
- *Clustering:* Similar scenarios are grouped into “flight classes” (e.g., safe, marginal, critical).
- *Recording:* the database stores scenarios in a format suitable for both offline analysis and real-time access.

To use the database at the ground station, the operator selects launch parameters, the system accesses the database and offers a predicted trajectory with a risk assessment.

In addition, the on-board computer can download appropriate scenarios from the database during the flight and adapt the UAV trajectory in real time.

In addition, it is possible to perform a mission with many UAVs. The base can work as a collective intelligence – each UAV gets access to the learned behavior models.

Illustrative examples of filling the UAV movement database

In this section, we will consider an example of filling the database for different initial weights of the UAV. Weight directly affects lift and drag. If the weight increases, then more speed and engine power are required to maintain stable flight.

Consider a series of air launches of a Mini Talon UAV with the following weights: 5.5 kg, 5.6 kg, 5.7 kg, 5.8 kg, 5.9 kg, 6 kg. Launch speed 92 km/h, height 234 meters. No wind.

Figure 2 shows the dependence of flight altitude on time.

Figure 3 shows a diagram of height loss after launch for different initial values of the UAV weight.

Figure 4 shows the dependence of the pitch angle on time.

Figure 5 shows the dependence of flight speed on time.

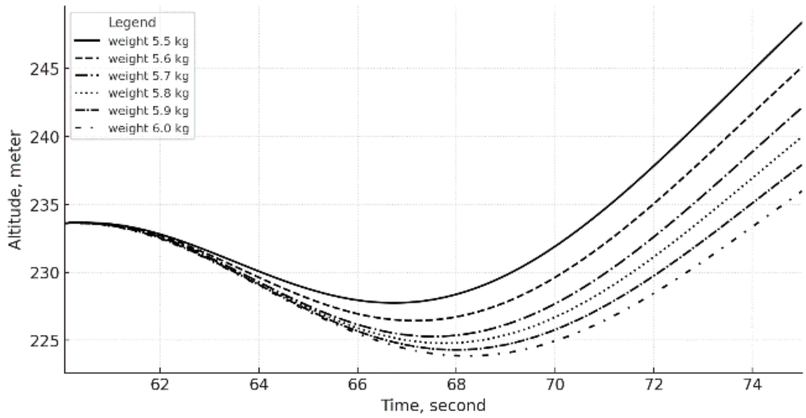

Fig. 2. Change in flight altitude after launch with different initial UAV weights

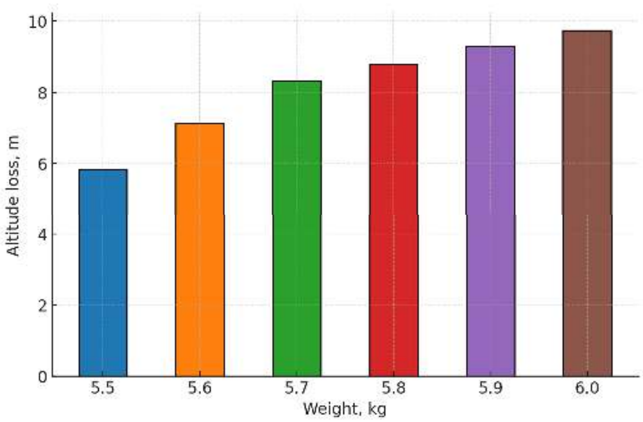

Fig. 3. Loss of altitude after air launch with different initial UAV weights

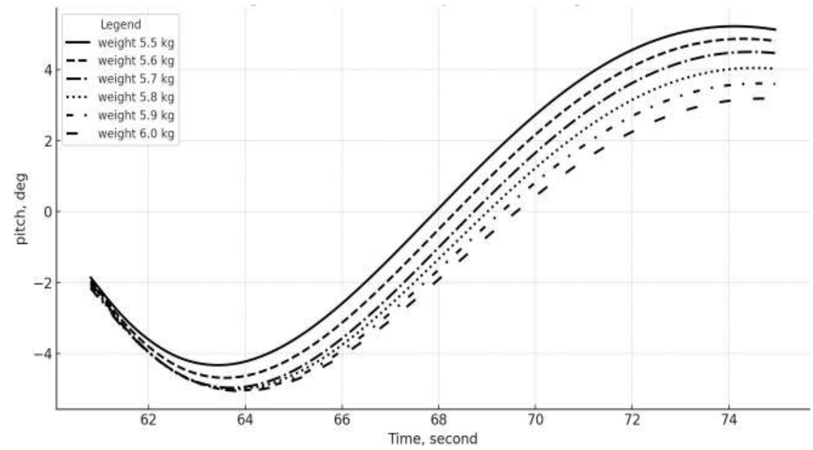

Fig. 4. Change in pitch angle after launch with different initial UAV weights

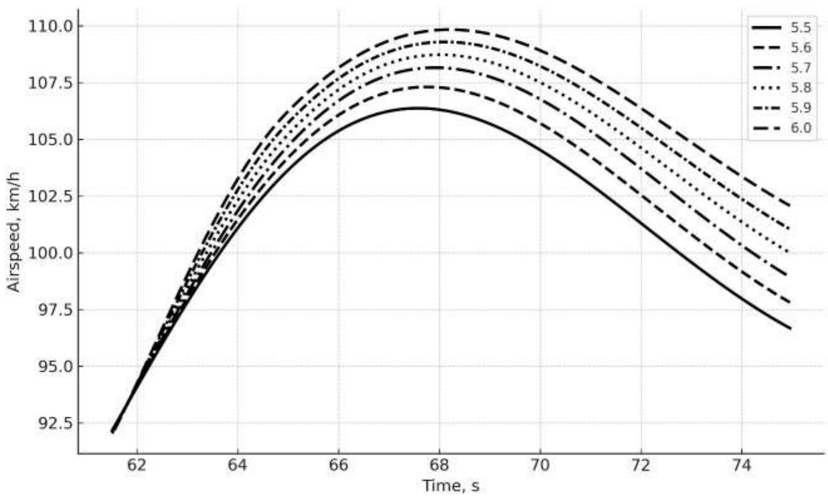

Fig. 5. Change in flight airspeed after takeoff with different initial UAV weights

The combination of JSBSim and SITL ArduPilot allows you to create a database with a full set of key flight parameters: separation height, initial speed, angle of attack, vehicle mass, wind characteristics, turbulence, control system response, overload, stabilization time and navigation errors. All these parameters are recorded with high accuracy thanks to the JSBSim aerodynamic model and real SITL autopilot algorithms, which ensures the maximum approximation of data to real conditions. The database is thus not limited to "ideal" models, but contains variable scenarios of UAV behavior in various modes, including critical ones.

The main advantage of this approach is that the database can be used as a forecasting and analysis tool. The ground station or UAV on-board computer accesses a set of verified trajectories with all flight parameters, compares them with current measurements and instantly assesses the level of risk. This provides not only high reliability, but also versatility. The database is easily scalable, enriched with new scenarios and used for planning, simulation and real flights.

IV. Conclusions

The article presents a comprehensive study of the process of air launch of unmanned aerial vehicles in the JSBSim software environment using SITL ArduPilot technology and the Mission Planner ground station. The proposed approach allowed obtaining a high-precision model of UAV flight dynamics during launch, taking into account both the aerodynamic characteristics of the vehicle and the influence of external environmental conditions and carrier.

The main results of the work are:

- development and testing of a method for modeling UAV air launch based on a set of aerodynamic coefficients obtained through virtual blowouts;
- creation of a database of air launch trajectories, which includes parametric and performance levels and allows analyzing the influence of initial conditions on flight characteristics;

- demonstration of the advantages of air launch compared to traditional methods (energy saving, increased range, increased flexibility of application and reliability);
- confirmation of the possibility of using the database both on board the UAV and in ground control stations for predicting and optimizing trajectories in real time.

The scientific novelty of the work lies in the development of a method for high-precision modeling of UAV air launch in a closed loop with an autopilot and the formation of a unique database of trajectories, which can become the basis for further research and practical applications.

The practical significance of the results obtained lies in the possibility of using the developed database and modeling methods to increase the efficiency of UAV mission performance, reduce preparation time, and reduce risks at the launch stage.

Further research may be aimed at: integrating the air launch model with adaptive control algorithms, experimental verification of results in field conditions, expanding the database for different classes of UAVs, and carriers.

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В. В. Власик, О. М. Коршунова. Дослідження повітряного старту БпЛА в програмному середовищі JSBsim

У статті розглянуто науково-практичні аспекти повітряного старту безпілотного літального апарату, проаналізовано сучасні підходи та технології, а також визначено переваги даного методу запуску порівняно з традиційними способами. Розглянуто метод дослідження повітряного старту безпілотного літального апарату за

допомогою моделювань у програмному середовищі JSBsim. Представлено базу даних динаміки повітряного старту безпілотного літального апарату, що підтверджують ефективність застосування моделювання повітряного старту безпілотного літального апарату в програмному середовищі JSBsim Детально розглядається вплив ваги безпілотного літального апарата на процес старту та подальшого польоту безпілотного літального апарату. Наукова новизна полягає у розроблені метода високоточного моделювання повітряного старту безпілотного літального апарату в контурі з автопілотом, створенні високоточної бази даних динаміки повітряного старту безпілотного літального апарату.
Ключові слова: запуск безпілотного літального апарату з повітря; модель динаміки польоту; безпілотний літальний апарат; база даних; автопілот.

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