

A UAV Ejection Device Integrating Thermal and Compressed Air Coupled Launch

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Abstract

Aiming at the rapid take-off demand of small and medium-sized UAVs under restricted site conditions, a composite ejection device combining compressed air and gunpowder is proposed. The device combines the transient high-pressure characteristics of gunpowder gas with the controllable release characteristics of compressed air to achieve efficient acceleration of UAVs within a short stroke. Based on the LS-DYNA platform, a multi-physics field coupling numerical model including structure, gas and gas source is established, and the dynamic response characteristics under pure compressed air ejection and composite ejection are compared and analyzed. The simulation results show that under the same stroke condition, the maximum velocity and total system energy of the composite ejection scheme are significantly improved, with the maximum velocity increased by about 46% and the total system energy increased by about 5.9 times. Meanwhile, the structural stress of the UAV is lower than the allowable value of the material. The research results provide a theoretical basis for the engineering design and parameter optimization of composite energy UAV ejection devices.

Keywords

UAV Ejection; Compressed Air; Gunpowder Pressurization; Multi-Physics Coupling; Numerical Simulation.

1. Introduction

With the extensive application of small and medium-sized unmanned aerial vehicles (UAVs) in reconnaissance and surveillance, emergency rescue, tactical support and other fields, the demand for their rapid takeoff under complex terrain, shipborne platforms and narrow site conditions has become increasingly prominent. The traditional taxiing takeoff mode is highly dependent on the site and difficult to meet the requirements of mobile deployment. Therefore, catapult takeoff technology has become an important development direction. According to different power sources, UAV takeoff modes can be classified into rocket-assisted, compressed air, spring energy storage, electromagnetic drive and other types. Zheng Jiyuan et al. [1] systematically reviewed UAV takeoff modes with different power sources and pointed out that compressed air catapult has high engineering application value due to its relatively simple structure and good reusability. Starting from the development history of pneumatic catapult systems, Liu Xia et al. [2] summarized the advantages of gas-driven catapult in efficiency and safety as well as the existing pressure fluctuation problems.

Domestic scholars have carried out extensive theoretical and experimental research on the mechanism and system design of compressed air catapult. Chen Runzhe et al. [3] modeled and analyzed the interior ballistic process of UAV compressed air catapult devices, revealing the influence law of pressure variation on acceleration characteristics. Cong Longteng [4] established a numerical model based on the AUTODYN platform to simulate the interior ballistic process of compressed air catapult. Liu Xia [5] further conducted experimental and simulation comparative analysis of the compressed air catapult system combined with experimental data, improving the reliability of the model. At the structural and dynamic levels, Ji Henghuan [6] systematically studied the dynamic problems of UAV catapult; Liu Huinan [7] analyzed the structural strength and optimal design of the catapult; Lu Wei et al. [8] carried out dynamic simulation and parameter optimization for the pneumatic catapult process. In addition, Deng Donglei et al. [9–10] explored the engineering application of compressed air catapult systems from the perspectives of overall device design and portable application respectively. Zhang Zhao et al. [11] analyzed and optimized the dynamic characteristics of cold launch devices for folding-wing UAVs. Zhang Fenglin et al. [12] optimized the parameters of low-overload compressed air launch using the particle swarm optimization algorithm.

In addition to traditional compressed air, some studies have attempted to introduce other gases or special working conditions. Wang Zhifu et al. [13] conducted experimental and simulation analysis on tetrafluoroethane catapult for UAVs and discussed the influence of different gas media on catapult performance. Luo Xin et al. [14] studied a cold launch system scheme adopting compressed air catapult, providing a reference for the engineering implementation of gas catapult. Huang Qiang et al. [15] proposed a method for intercepting UAVs with damage sources based on compressed air launch, expanding the application scenarios of gas-driven technology.

In general, existing studies mostly focus on the interior ballistic characteristics, structural design and parameter optimization of a single gas power source, which is of positive significance for increasing catapult initial velocity and shortening stroke. However, limited by gas storage pressure and volume, a single compressed air system still has a bottleneck in achieving higher energy output within a short stroke. Based on this, this paper proposes a compressed air–propellant composite catapult scheme, which combines the transient high-pressure characteristics of propellant gas with the controllable release characteristics of compressed air. The dynamic response law is analyzed through multi-physics coupling simulation and compared with that of the pure compressed air condition, aiming to provide a new technical approach for the engineering design and parameter optimization of high-efficiency and miniaturized UAV catapult systems.

2. Structure and Principle of the Coupled Launch Mode

The structure and working principle of the launch device designed in this study are illustrated in Fig. 1. The system mainly consists of a UAV launch tube, a high-pressure gas storage pump, a gimbal platform, control valves, a tracked driving system, and a mobile power supply. The key structural parameters are as follows: the inner diameter of the launch tube is 100 mm, with a wall thickness of 5 mm and a total length of 0.65 m; the effective launch stroke inside the tube is 0.6 m. The UAV has a maximum take-off mass of 2 kg, a bottom diameter of 100 mm, and a total length of 230 mm in the folded state. The volume of the high-pressure gas tank is 15 L.

Based on an analysis of existing UAV launch devices, it is found that current systems generally suffer from limited mobility and a single launch mode. To address these issues, a tracked driving system is designed in this study, significantly enhancing the mobility and deployment flexibility of the system.

In terms of launch mode, conventional single-assist approaches (such as compressed-air launching or mechanical launching) typically rely on bulky and structurally complex devices to achieve high ejection velocities, and their deployment often requires considerable manual intervention. In contrast, this study proposes a hybrid launch scheme combining compressed air with explosive-driven impulse. Specifically, high-pressure gas in the external chamber is rapidly released into a low-pressure chamber, while the shock generated by explosive combustion is superimposed. A sealed buffer piston

is employed to effectively mitigate the adverse impact of the combined shock on the UAV, thereby enabling continuous acceleration of the UAV within the launch tube.

The proposed design achieves an ejection velocity comparable to that of traditional single-mode launch systems while significantly simplifying the overall structure. As a result, the system demonstrates substantial improvements in lightweight design, operational convenience, and mobility.

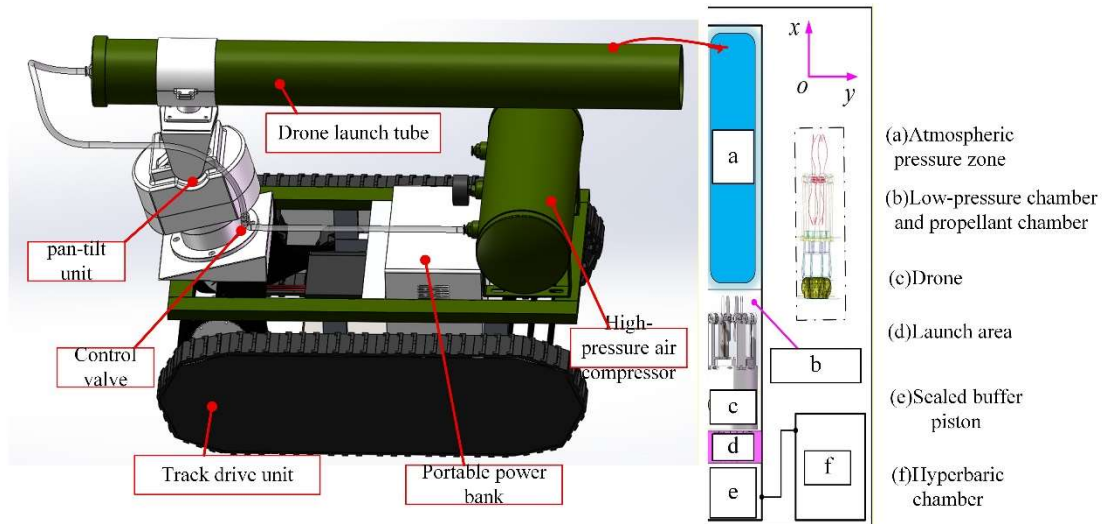


Fig. 1 Structure and Working Principle of the Launch Device

3. Development of the Hybrid Launch Model

3.1 UAV Launch Model

For the UAV launch model based on a hybrid gas–explosive scheme, the initial velocity calculation and gas charging design are conducted. The core idea is as follows: under ideal conditions, friction between the inner wall of the launch tube and the UAV is neglected, and due to the extremely short duration of the ejection process, the effect of gravity is considered negligible. The key formulas for energy conversion and velocity calculation are first established. Using simulation results of pure gas launching, the charging parameters of the main gas cylinder (compressed air tank) are determined. Then, the energy released by the explosive charge is calculated based on the propellant mass. Finally, the UAV’s final initial velocity under the hybrid launch mode is computed by combining the energy contributions and efficiency of both sources, ensuring that the entire calculation process is precisely consistent with the known structural parameters and simulation data[16].

The effective volume of the launch tube, V_{barrel} is calculated as $V_{barrel}=S \times L$, where S is the cross-sectional area of the tube and L is the effective launch stroke. Given the inner diameter of the launch tube $d=100\text{mm}=0.1\text{m}$, $S=\pi(d/2)^2=7.854 \times 10^{-3}\text{m}^2$, and the effective launch stroke is $L=0.6\text{m}$.

$$V_{barrel} = S \cdot L = 4.7124 \times 10^{-3} \text{m}^3 \quad (1)$$

The main gas cylinder is used to provide the energy for gas-driven launching, with an initial charging pressure of $p_{1-1}=13.8\text{bar}$.

$$E_{kinetic} = \frac{1}{2} m v_0^2 \quad (2)$$

For pure gas launching, the energy released by the compressed air is given by:

$$E_{gas0} = \frac{E_{kinetic0}}{\eta} = \frac{mv_o^2}{2\eta} \quad (3)$$

Compressed air is stored in a sealed cylinder, and the energy release process can be approximated as an adiabatic expansion process. Due to the rapid launch process, heat transfer can be neglected. Therefore, the energy is calculated using the adiabatic expansion formulation. By incorporating parameters such as the cylinder volume and initial charging pressure, the expression can be written as:

$$E_{gas0} = \frac{p_{1-1}V_{1-1} - p_0V_{2-1}}{\gamma - 1} \quad (4)$$

The resulting expression is:

$$p_{1-1} = \frac{(\gamma - 1)E_{gas0} + p_0V_{2-1}}{V_{1-1}} \quad (5)$$

where p_{1-1} is the initial charging pressure inside the cylinder (Pa), which is the parameter to be determined; the volume of the main gas cylinder is given as $V_{1-1}=15L=0.015m^3$; p_0 is the pressure inside the cylinder after expansion (Pa), which is approximately equal to the atmospheric pressure, $p_0=1.113 \times 10^5 Pa$ (after launch, the cylinder pressure reaches equilibrium with the ambient environment); V_{2-1} is the gas volume after expansion (m^3), equal to the sum of the initial cylinder volume and the effective volume of the launch tube; and γ is the adiabatic index of air, taken as $\gamma=1.4$ (standard value for dry air at room temperature).

The energy released by the explosive is calculated as the product of its heat of explosion and the charge mass. The standard heat of explosion of TNT is $Q=4200J/g$ (under standard temperature and pressure conditions). Substituting the charge mass $m=0.1496g$ and $Q=4200J/g$, we obtain:

$$E_{powder} = m \cdot Q \quad (6)$$

In the hybrid launch mode, the energy released by the compressed air and the explosive, after accounting for efficiency losses, is entirely converted into the kinetic energy of the UAV. The corresponding expression can be written as:

$$E_{kinetic} = E_{total} = \eta \cdot (E_{gas1} + E_{powder}) \quad (7)$$

Where $E_{gas1}=E_{gas0}=412.86J$, $E_{powder}=628.32J$

Based on the kinetic energy of the UAV, the initial launch velocity can be obtained as:

$$v = \sqrt{\frac{2E_{kinetic}}{m}} = 26.99m / s \quad (8)$$

3.2 Establishment of the Simulation Model

A complete gas-driven launch system model is established based on a parametric feature-based modeling approach. Carbon fiber materials are adopted for both the UAV launch tube and the UAV body, achieving system lightweighting while ensuring sufficient structural strength.

According to the requirements of structural stress analysis, two-dimensional elements CQUAD4 and CTRIA3 are employed in the modeling process. The CQUAD4 element consists of four nodes, while the CTRIA3 element consists of three nodes, as shown in Fig. 2. For the UAV, air domain, and explosive, three-dimensional solid elements are used. The UAV is modeled using the Lagrangian formulation. Since the air domain and explosive exhibit significant flow behavior, involving large deformation and displacement, the Eulerian formulation is adopted for these regions.

To accurately capture the interaction between the shock wave generated by the explosive and the structural components, fluid–structure interaction (FSI) is considered. The air domain and explosive are therefore modeled using the Arbitrary Lagrangian–Eulerian (ALE) method. The element types and mesh models of each component are illustrated in the figure.

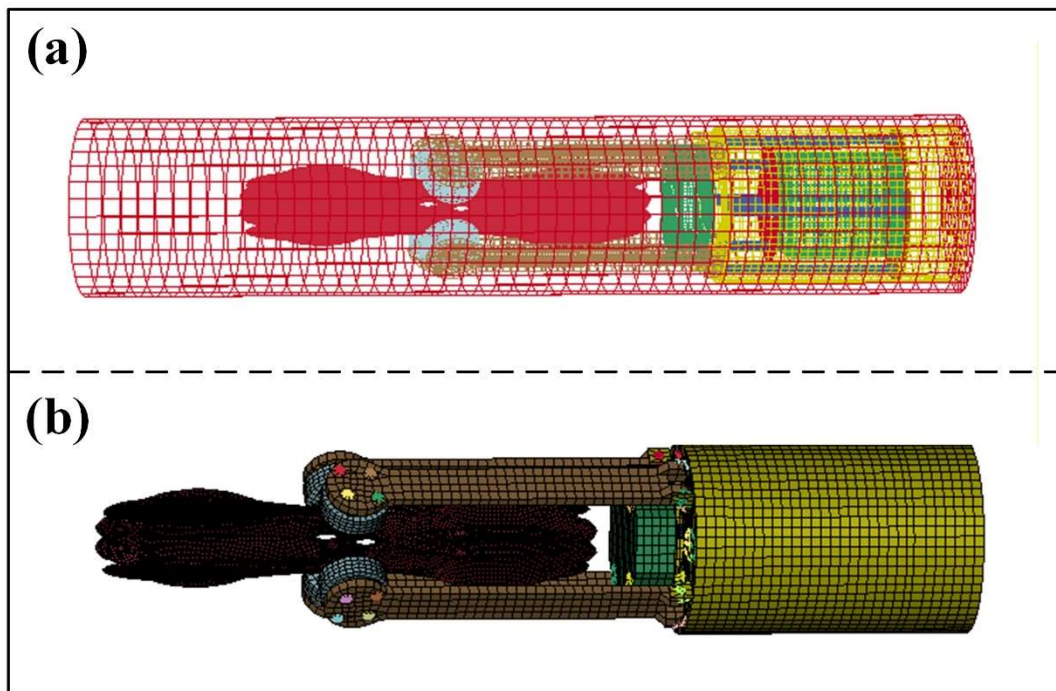


Fig. 2 Establishment of the Finite Element Model and Mesh Division: (a) Launch Tube and UAV; (b) UAV

The high-temperature and high-pressure gaseous products generated by the explosion rapidly expand into the surrounding medium, driving vigorous motion of the adjacent air. This leads to compression of the air and a sudden increase in density, forming a strongly compressed air region in the direction of expansion, i.e., the explosive shock wave. During propagation, the shock wave carries energy and continuously transfers it to the surrounding medium. Its parameters, including wave velocity, density, and overpressure, gradually decay with distance. When the shock wave pressure drops to the ambient atmospheric level, the high-temperature gaseous products no longer provide energy, and the two separate. The shock wave continues to propagate forward under inertia, entering a rarefaction wave phase and forming a negative pressure region. Subsequently, the wave gradually attenuates, and the pressure finally equilibrates with the surrounding atmosphere after repeated oscillations.

In this study, TNT explosive is selected to simulate the detonation process. The specific parameters are shown in Fig. 3. The MAT_HIGH_EXPLOSIVE_BURN material model parameters are defined

as follows: MID – material model identification number; RO – material density; D – detonation velocity; PCJ – Chapman–Jouguet pressure; and BETA – the β parameter, which can be set to 0.0, 1.0, or 2.0 depending on the case.

MID	RO	D	PCJ	BETA	K	G	SIGY
60	1.630e-09	9.930e+06	5.100e+04	0.0	0.0	0.0	0.0

Fig. 3 Selection of Parameters for the Explosive Model

In this study, TNT explosive is selected in the numerical simulation to model the detonation process, aiming to reproduce the dynamics of high-temperature and high-pressure gaseous product expansion as well as the formation and propagation of shock waves. The specific parameters are shown in Fig. 4.3. The explosive material is described using the MAT_HIGH_EXPLOSIVE_BURN model, whose main parameters include: MID (material model identification number), RO (material density), D (detonation velocity), PCJ (Chapman–Jouguet pressure), and BETA (expansion index). The BETA value can be set to 0.0, 1.0, or 2.0 depending on the operating conditions to reflect different expansion characteristics of the explosive products. By setting these parameters, the simulation can accurately reproduce the formation and propagation of explosive shock waves and their interaction with the surrounding air.

4. Simulation Results and Analysis

This study analyzes two propulsion schemes for the UAV launch system. The first is the pure gas-driven scheme, in which compressed air serves as the primary energy source. This approach features a relatively simple structure and good system controllability. Additionally, it offers advantages such as reusability, low maintenance cost, and high operational safety, making it widely applicable in small-scale UAV launch devices. However, due to the limited energy density of compressed air, the thrust provided often fails to achieve high initial velocities when the UAV mass is large or the launch acceleration distance is short. Consequently, this scheme has inherent limitations in high-performance launch applications.

The second scheme is a hybrid gas–explosive propulsion system. By combining compressed air with the high energy density released by solid propellant detonation, the system achieves a relatively smooth acceleration during the initial phase via compressed air, followed by a transient high-pressure pulse generated by the explosive in the later phase. This approach significantly enhances the overall energy output of the system. Compared with a single energy source, the hybrid propulsion scheme can increase both the energy density and peak thrust of the launch system without substantially increasing structural complexity. As a result, it effectively improves the UAV’s initial launch velocity and acceleration performance, providing a feasible technical solution for rapid UAV launches over short distances with high efficiency.

4.1 Simulation Results of Stress Variation Under Gas-Driven Propulsion

A numerical simulation of the UAV launch within the launch tube was conducted under the condition of an initial pressure of 13.8 bar in the high-pressure chamber. The stress distribution of the UAV launch body over time is shown in Fig. 4. Time-history analysis indicates that, during the acceleration process, the energy at the base of the launch body is gradually transmitted to the UAV main body, enabling it to gain kinetic energy. From the stress contour plots, the maximum stress of the launch body reaches 282.681 MPa. Considering the axial compressive strength of T700 carbon fiber and the cushioning effect of the buffer piston on impact, it can be concluded that the structural strength of the UAV launch body under this launch condition is sufficient to meet the design requirements.

Additionally, as the launch time increases, the energy absorbed by the launch body gradually rises, and its velocity shows a continuously increasing trend. The energy of the gas-pressure impact is effectively converted into the kinetic energy of the UAV, with the launch body reaching a kinetic energy of approximately 229 J at around 70 ms. This indicates that the hybrid launch system can provide sufficient acceleration to the UAV within a short time, achieving the desired initial launch velocity.

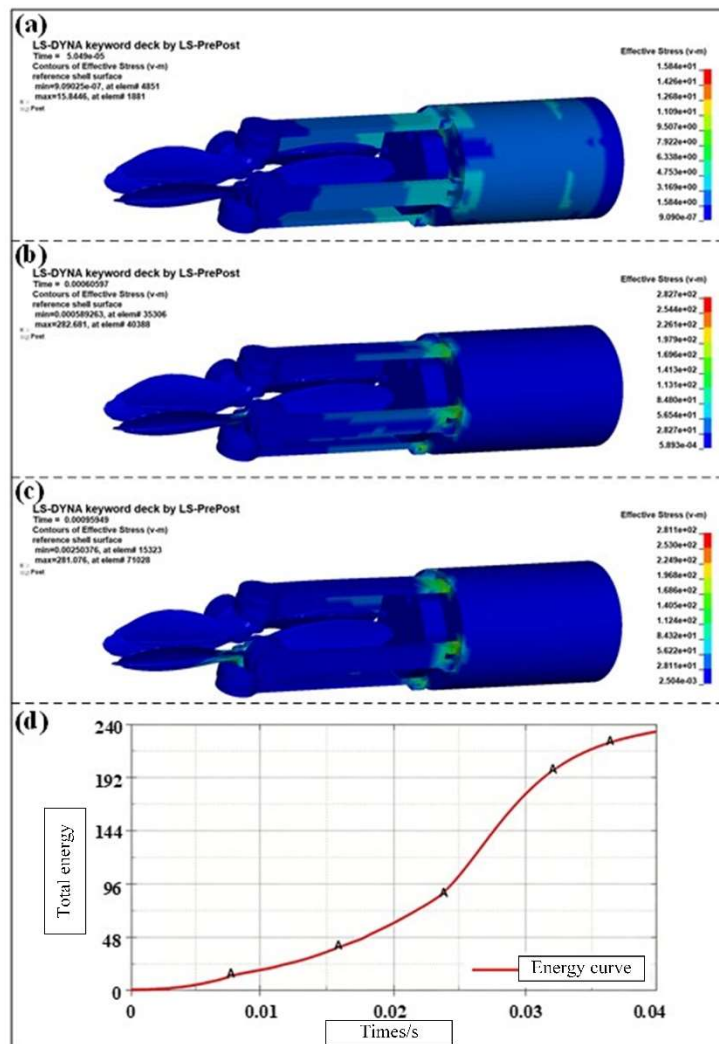


Fig. 4 Stress and energy variation of the UAV during simulation: (a–c) energy cloud maps; (d) component energy curves

4.2 Analysis of Velocity Variation in Gas-Driven Simulation

The UAV velocity versus time curve is shown in Fig. 5(a). As the launch time increases, the velocity exhibits a continuous upward trend, reaching a maximum of 17 m/s at approximately 70 ms. The

characteristics of the velocity curve indicate that the UAV undergoes a smooth acceleration process within the launch tube, without significant impact or oscillation. From the displacement data analysis, it can be observed that the UAV completes its exit from the tube near 70 ms, with an exit velocity of about 17 m/s, demonstrating that the compound ejection system can achieve a rapid and stable UAV launch within a short time.

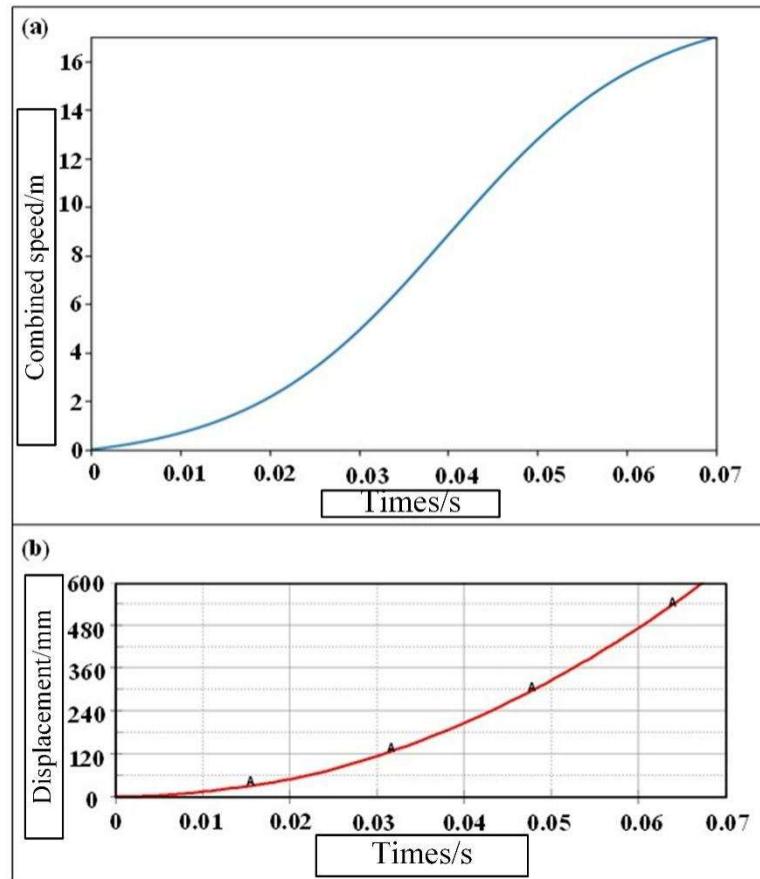


Fig. 5 UAV velocity variation curves: (a) rigid body velocity; (b) rigid body displacement

As shown in Fig. 5(b), during the initial launch stage (0–0.02 s), the UAV velocity increases relatively slowly, indicating that the initial release of high-pressure gas has not yet fully taken effect. After 0.02 s, the velocity curve steepens noticeably, showing that the high-pressure gas begins to continuously perform work on the UAV, achieving rapid acceleration. In the 0.04–0.07 s interval, the acceleration slightly decreases, and the acceleration process gradually approaches completion. Although the acceleration curve exhibits some fluctuations, the displacement curve consistently increases and reaches approximately 600 mm at 0.07 s, indicating that the UAV has completed its exit from the tube. The overall trends of velocity and displacement align with the characteristics of an ideal compressed-air launch, validating the compound ejection system’s ability to achieve sustained acceleration over a short travel distance.

4.3 Simulation Results of the Compound Propulsion System

Based on the aforementioned pure gas ejection condition, 0.1496 g of TNT explosive was added to the low-pressure chamber to conduct a coupled driving simulation analysis. The simulation results are shown in Fig. 6. As time increases, the energy acquired by the UAV launcher continuously rises, and its velocity correspondingly increases. The pressure generated by the release of compressed air, together with the shock wave produced by the explosive detonation, acts jointly to enable the system to release higher energy within a short time and effectively convert it into the kinetic energy of the UAV.

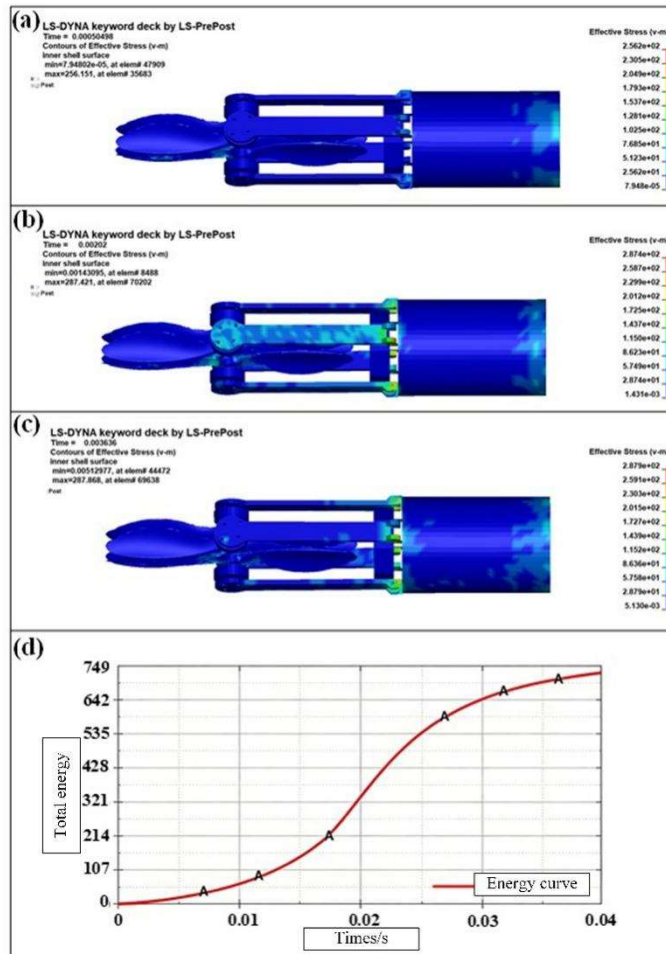


Fig. 6 UAV stress and energy variation: (a–c) energy cloud maps; (d) component energy curves

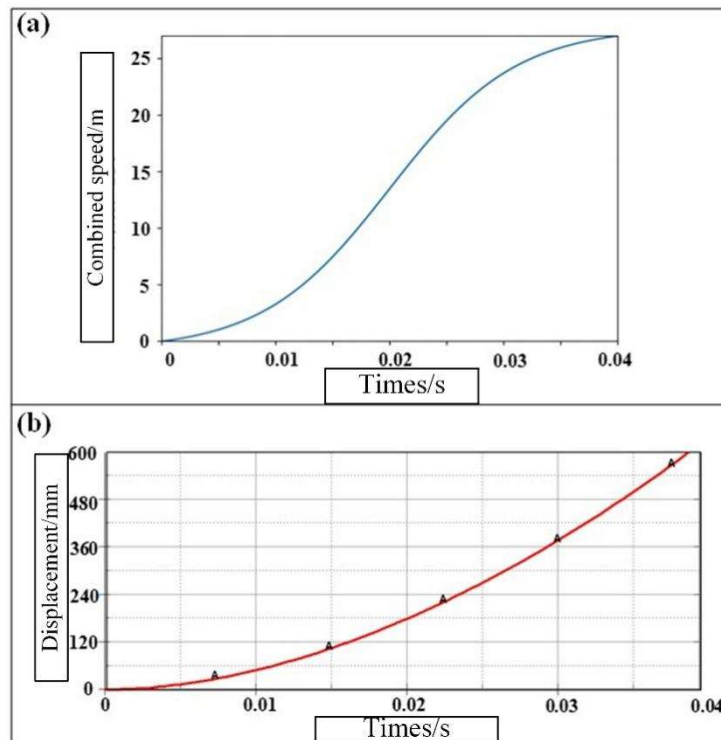


Fig. 7 UAV velocity variation during combined injection: (a) rigid body velocity; (b) rigid body displacement

The simulation results show that the total kinetic energy of the UAV launcher reaches 729 J at 40 ms, which is significantly higher than the 289 J obtained at 70 ms under the pure gas-driven condition. This indicates that, under the coupled effect of explosive energy and compressed air pressure, the system can deliver higher energy output within a shorter time, thereby markedly enhancing the UAV's acceleration capability and ejection performance.

A comprehensive analysis reveals that, compared with single compressed-air driving, the gas-explosion coupled driving mode possesses higher energy density and stronger transient thrust capability, effectively increasing the initial launch velocity of the UAV.

The velocity-time curve of the launcher is shown in Fig. 7(a), and the displacement-time curve is presented in Fig. 7(b). As time progresses, the acceleration of the launcher undergoes significant variation, reaching its maximum at approximately 20 ms and then gradually decaying. Throughout the process, the UAV launcher experiences continuous acceleration, with its velocity steadily increasing.

From the comparison of the displacement curves, it can be observed that within the same time interval, the displacement of the launcher under the combined launch condition is significantly greater than that under the pure gas-driven condition. When the time reaches 40 ms, the displacement of the launcher attains 600 mm, completing its separation from the launch tube, while the velocity reaches 27.08 m/s.

An analysis of the slope of the velocity curves shows that the acceleration process of the combined launch mode is steeper than that of the pure gas-driven launch, indicating that the gas-explosion coupled driving can provide higher instantaneous acceleration to the UAV within a shorter time, which is significantly superior to the single compressed-air launch method. This result verifies the advantage of the combined launch scheme in improving the initial velocity and launch efficiency of the UAV.

4.4 Validation and Analysis of Results

After completing the construction of all physical components, a UAV remote launch and precise positioning system was established, with a tracked mobile platform as its core. The overall workflow can be summarized into three sequential stages: remote deployment - attitude fine adjustment - pneumatic launch.

First, the operator remotely controls the tracked vehicle via a wireless communication link, enabling it to move flexibly to the designated launch position. Once the vehicle reaches the target location and completes positioning, the system enters the attitude adjustment stage. A high-precision gimbal mounted on the vehicle is remotely actuated to continuously and finely adjust the elevation and azimuth angles of the launch tube according to mission requirements, until the spatial attitude of the launch tube fully meets the initial launch conditions of the UAV, ensuring that the launch trajectory aligns with the intended flight path. After attitude calibration is completed, the launch execution mechanism is activated. The cylinder is remotely controlled to perform rapid work, generating instantaneous thrust to accelerate the UAV inside the launch tube, thereby achieving reliable launch and deployment.

For launch performance validation, two sets of comparative experiments were conducted using a pneumatic launch approach. In the first test, a pure gas-driven mode was adopted, in which high-pressure gas directly performed work to launch the UAV. In the second test, a hybrid launch mode was employed, where an auxiliary cylinder partially replaced TNT-assisted propulsion, enabling coordinated work between the main cylinder and the auxiliary cylinder. To accurately measure the UAV exit velocity, a velocity sensor was used for real-time acquisition and validation of launch speed during the experiments. The measured results were then compared and analyzed to evaluate the performance differences between the two launch schemes, providing an experimental basis for optimizing the launch system parameters.

Due to the inability to conduct explosive experiments, a 12.5 L equivalent cylinder was used to simulate the explosive energy of TNT. Based on the principle of energy equivalence, the charging pressure of the equivalent cylinder was determined.

The energy of the equivalent cylinder, E_{gas2} , is assumed to be equal to the explosive energy of the propellant, $E_{gas2} = E_{powder} = 628.32J$

where energy losses during the equivalence process are neglected, and the overall energy efficiency is taken as $\eta=0.7$.

$$V_{2-2} = V_{1-2} + V_{barrel} = 0.0125 + 4.7124 \times 10^{-3} m^3 = 0.0172124 m^3 \quad (9)$$

Based on the adiabatic expansion energy equation, the initial charging pressure of the equivalent cylinder can be derived as:

$$p_{1-2} = \frac{(\gamma - 1)E_{gas2} + p_0 V_{2-2}}{V_{1-2}} \approx 1.82 \times 10^6 Pa = 18.2 bar \quad (10)$$

That is, the equivalent cylinder (12.5 L) needs to be charged with compressed air at a pressure of approximately 18.2 bar, which can effectively substitute for the explosive energy of 0.1496 g of TNT. After completing the structural assembly of the UAV and the launch vehicle, a series of functional validation experiments were conducted to verify the actual working performance and the rationality of the structural design. The tests covered launch mode validation and UAV attitude adjustment verification. The specific procedures and results are as follows.

First, a pure gas-driven launch mode validation test was carried out to evaluate the launch capability of the system and the initial launch state of the UAV under pure gas propulsion. During the experiment, a velocity sensor was used to measure the UAV launch speed in real time. After multiple repeated measurements, the UAV launch velocity under pure gas conditions was determined to be stable at 16.45 m/s. The launch process was smooth, with no jamming, abnormal noise, or other irregular phenomena, indicating that the pure gas-driven system of the launch vehicle operates reliably and can provide stable initial launch power for the UAV. The results of the pure gas launch are shown in the figure.

Subsequently, a hybrid launch mode validation test was conducted. To avoid the safety risks and environmental impacts associated with explosive-based launching, an auxiliary cylinder was used to replace the explosive as an auxiliary driving source, simulating the hybrid launch effect. The UAV launch velocity was accurately measured using a velocity sensor. Figure 8 presents a comparison between the experimentally measured velocity curve and the simulation results. As shown in the figure, the experimental data and simulation predictions are in good agreement in terms of overall trend and peak velocity. The UAV launch velocity under the hybrid mode reached 26.77 m/s, and the deviation between the two remains within a reasonable range, thereby verifying the reliability of the established compound ejection simulation model.

The results of the emission process for pure gases are shown in Fig. 8. This figure compares the actual velocity with the simulation results.

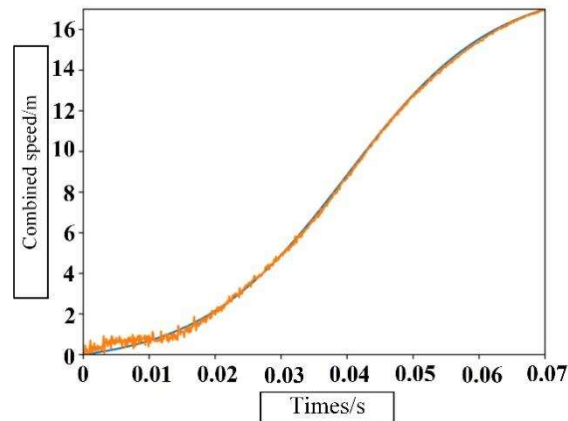


Fig. 8 Experimental validation curves

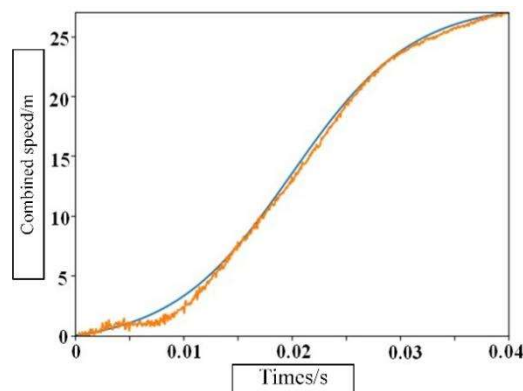


Fig. 9 Experimental validation curves

Finally, the autonomous attitude adjustment function of the UAV after launch was verified, with a focus on evaluating the deployment performance of the wings and the responsiveness of the attitude control system. The experimental results, as shown in the figure, indicate that after successful launch, all deployable components of the UAV can unfold smoothly according to the preset program. The deployment process is continuous and complete, without any jamming or damage. After deployment, the UAV's attitude control system responds rapidly, autonomously adjusting the body attitude and enabling the UAV to quickly enter a stable flight state, with attitude control accuracy meeting the design requirements.

In summary, the series of functional validation tests demonstrate that the launch systems of the UAV and the launch vehicle (both pure gas mode and hybrid mode) operate reliably. The UAV launch velocity meets the design specifications and shows high consistency with the simulation results. Furthermore, the performance of the deployable components and the autonomous attitude adjustment function after launch both satisfy the design requirements.

5. Conclusion

This study addresses the requirement for rapid takeoff of small and medium-sized UAVs in constrained environments by designing a compressed air–explosive coupled ejection device. Numerical simulations were conducted using the LS-DYNA platform, combined with equivalent experimental validation. The main conclusions are as follows:

The proposed ejection device integrates the advantages of controllable compressed air release and the transient high pressure generated by explosive gases. Together with a tracked mobile platform, sealing buffer piston, and other structural features, it overcomes the limitations of traditional systems,

such as poor mobility and excessive launch impact, achieving a balance of lightweight design, portability, and high launch performance.

Under the same effective launch stroke of 0.6 m, the composite ejection method increases the UAV's maximum velocity by approximately 46% and the total system energy by about 5.9 times compared with pure compressed-air ejection. Meanwhile, the structural stress of the UAV remains below the allowable material limits, ensuring both high launch efficiency and structural safety.

Validation experiments using a 12.5 L equivalent cylinder to replace the explosive show strong agreement between experimental data and simulation results. The launch velocity under pure gas conditions is stable at 16.45 m/s, while the hybrid mode reaches 26.77 m/s. These results verify the reliability of the simulation model and the engineering feasibility of the proposed scheme. In addition, post-launch functions such as attitude adjustment and component deployment meet the design requirements.

The composite ejection scheme overcomes the energy output limitations of single compressed-air systems. Without significantly increasing structural complexity, it enhances system energy density and transient thrust capability, providing a new approach for efficient short-stroke UAV launching. The findings of this study offer a theoretical basis for the engineering design and parameter optimization of composite-energy UAV ejection systems. Future work may focus on optimizing power parameter matching, reducing overload impact, and extending applicability to different UAV types.

Acknowledgments

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