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Research Progress on Short-Time Auxiliary Propulsion Technology for Micro Unmanned Aerial Vehicles

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Abstract. Micro unmanned aerial vehicles extend aerial sensing into spaces that are too small, dangerous or improvised for conventional aircraft. Their most vulnerable phase, however, is often the initial seconds of flight. Limited wing area, low-Reynolds-number aerodynamics and strict mass budgets make it difficult to combine efficient cruise with reliable launch acceleration. Short-time auxiliary propulsion addresses this mismatch by providing a brief, high-impulse launch stage while leaving the cruise system optimized for the mission. This review examines rocket-assisted take-off (RATO) as the most compact implementation of this concept, covering launch dynamics, booster-airframe integration, rail effects, separation reliability and system-level design. The literature shows a clear shift from isolated trajectory estimation towards coupled modelling of the aircraft, booster, launcher, and control system. Yet practical deployment remains constrained by mass penalties, thrust-line errors, centre-of-gravity migration, low-speed attitude sensitivity, separation safety, and regulation. Future progress will depend less on thrust magnitude alone than on predictable, modular and verifiable launch architectures.

Keywords: micro unmanned aerial vehicle, rocket-assisted take-off, short-time auxiliary propulsion, launch dynamics, solid rocket booster

1. Introduction

Micro unmanned aerial vehicles, often grouped with micro air vehicles (MAVs), have become an important class of aerial systems because they can be deployed quickly, operated at low cost and used in environments where larger aircraft are impractical. Bibliometric evidence shows that MAV research has expanded markedly since the late 1990s, spanning fixed-wing, rotary-wing, and flapping-wing designs, and propulsion and system integration have remained enduring technical concerns [1]. Miniaturization, however, creates a sharp propulsion dilemma. Small aircraft must reserve most of their mass and volume for structure, payload, battery or fuel, leaving little margin for a propulsion system that can deliver both efficient cruise and high launch acceleration [2].

The launch phase therefore represents more than an operational detail; it is a design bottleneck. A micro-UAV may require high thrust for only one to four seconds, after which a smaller cruise propulsion system is sufficient. Short-time auxiliary propulsion responds to this temporal mismatch by separating launch power from mission power. This review focuses on rocket-assisted take-off as the clearest embodiment of that approach, while considering its relationship with catapult and rail-

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guided launch methods. It asks three linked questions: how has short-time auxiliary propulsion for small unmanned aircraft developed, which constraints still hinder its use on micro-UAVs, and which design directions are most likely to ensure practical reliability.

2. From launch impulse to integrated RATO systems

Short-time auxiliary propulsion is commonly defined as a temporary energy source used during launch, initial climb, emergency acceleration or transition between flight modes. For fixed-wing micro-UAVs, the most direct form is rocket-assisted take-off (RATO), in which a small solid or hybrid rocket motor supplies high impulse before it is separated or becomes inactive. Unlike cruise propulsion, RATO is not governed primarily by endurance. Its key variables are impulse matching, thrust-line orientation, low-speed aerodynamic stability, and safe separation. For this reason, the most useful studies treat RATO as a coupled launch-system problem rather than as a simple motor-sizing exercise.

Early simulation work made this coupling visible. Liu, Fang, Li and Hao developed a nonlinear take-off model for a small UAV equipped with a single rocket booster. They reported that booster thrust could be an order of magnitude larger than the aircraft engine thrust; consequently, changes in total mass, centre-of-gravity, and inertia could not be ignored [3]. Their analysis also showed that booster installation angle has a tolerance band, not a single ideal value. This insight is especially relevant to micro-UAVs, where small assembly errors can become large attitude disturbances. Eymann and Martel extended the problem to the first 0.5 seconds of launch, showing that wind direction, centre-of-gravity position, and launch-rail effects can strongly shape the early trajectory [4]. Martel and Eymann then demonstrated that rail-induced forces and moments make the launcher an active element of the dynamics rather than a passive support [5].

Subsequent design studies connected these dynamic findings to complete launch architectures. A study designed and analysed a zero-length UAV launcher with a single rocket booster, incorporating aerodynamic correction of the combined UAV-booster body, centre-of-gravity variation, booster installation deviation, and flight-test validation [6]. The value of this work lies in its system view: the launcher, booster mount and airframe are treated as one coupled object. A more recent RATO retrofit for an existing jet-powered UAV reached a similar conclusion via a different approach. Greif and colleagues balanced launch speed, burn time, rail angle, reusability, cost and regulatory constraints in a single design process [7]. Although their vehicle was larger than a micro-UAV, the logic transfers directly: an auxiliary propulsion unit must expand the launch envelope without compromising the original mission system.

Research on small solid rocket boosters also informs micro-UAV launch assistance. Nowakowski and colleagues developed boosters for the ILR-33 sounding rocket, emphasizing composite cases, propellant mass fraction, ground and flight tests, stage integration and simultaneous booster operation [8]. The scale differs from that of a micro-UAV, but the governing trade-off is similar: high thrust must be produced inside a strict mass budget without creating destabilizing moments. Kierski, Pazik and Cieslinski later examined the booster separation system for the ILR-33 Amber 2K rocket and showed that separation design requires mechanical redesign, modelling, flight-dynamics simulation and ground testing as an integrated verification chain [9]. For micro-UAVs, the implication is clear. Booster separation is not a downstream packaging issue; it is part of the propulsion concept itself.

A broader shift is therefore emerging. RATO is no longer framed primarily as a permanent propulsion option, but rather as a mission-enabling launch stage. For a micro-UAV, the booster is justified only when it opens launch sites that would otherwise be inaccessible: a vehicle roof, a

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narrow ship deck, a forest clearing or a damaged road. The design target should consequently be minimum safe impulse rather than maximum acceleration. A smaller, better-guided booster may deliver more reliable field performance than a powerful motor that introduces excessive pitch moment, structural load or separation complexity.

3. Constraints limiting micro-UAV adoption

The first constraint is the mass-volume contradiction. A micro-UAV has little spare payload capacity, whereas a rocket booster requires propellant, casing, ignition hardware, mounting fixtures and sometimes recovery equipment. If the booster is too small, its impulse cannot overcome launch drag, gravity and low-speed instability. If it is too large, it shifts the centre of gravity and raises structural loads before the aircraft is airborne. The problem is intensified by low-Reynolds-number aerodynamics, which already leaves narrow stability margins. The booster must therefore be co-designed with the airframe, launcher and control law, not selected based on thrust alone.

The second constraint is attitude sensitivity. During launch, wings and control surfaces have not yet reached full authority. A small angular error in the booster axis can create a large pitch or yaw moment because thrust is high and burn time is short. Existing studies have repeatedly show that booster angle, rail geometry, crosswind and centre-of-gravity error can alter the initial flight path [3-6]. For micro-UAVs, flexible structures, field assembly and manufacturing tolerances make such errors more likely. Reliable launch therefore requires not only accurate fixtures but also launch-phase state estimation and robust control capable of absorbing uncertainty during the first seconds of flight.

The third constraint is interaction among the booster, launcher and airframe. RATO changes the shape and loading of the aircraft at precisely the moment when flight margins are smallest. The booster body can add drag and pitching moment, the exhaust plume can interact with the airframe or launcher, and a rail or cradle can impose asymmetric loads. These effects grow in relative importance as vehicle size decreases because small disturbances consume a larger fraction of the available aerodynamic and inertial margin. RATO research therefore emphasizes six-degree-of-freedom simulation, aerodynamic correction and rail-force modelling, rather than one-dimensional acceleration estimates [4-6].

The fourth constraint is separation and safety. After burnout, the auxiliary propulsion unit becomes dead mass and an aerodynamic disturbance. Early separation may occur before the aircraft reaches a safe speed, whereas late separation reduces climb performance and may degrade stability. Separation also introduces collision risk, especially for underslung or rear-mounted boosters. Pyrotechnic ignition, hot exhaust, noise, fire risk and local regulations further narrow the feasible operating envelope. Compared with reusable pneumatic catapult systems for UAV launch, RATO is more compact but carries higher handling and safety burdens [10]. This trade-off defines the practical boundary of rocket assistance.

4. Design outlook

Future work should first emphasize modular, low-mass auxiliary propulsion units. Rather than designing a unique booster for each airframe, micro-UAV platforms would benefit from standardized modules specified by impulse class, burn time, mounting geometry and separation interface. Such modules would let designers select a booster much as they select a battery or propeller, while designers still need to perform vehicle-specific checks of centre-of-gravity shift and

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thrust-line alignment. Lightweight composite cases, safer propellant formulations and reusable brackets can improve utility more than a simple increase in peak thrust.

Second, launch design needs to be model-based and uncertainty-aware. Nonlinear simulation is already central to RATO research, but micro-UAV applications require tighter links among aerodynamic data, structural flexibility, launch-fixture geometry, motor thrust curves and control logic. A robust workflow should combine ground thrust testing, digital launch simulation, Monte Carlo analysis of installation errors and wind, and staged flight testing. The key design output would then be not a single nominal trajectory but an envelope of safe launch conditions.

Third, auxiliary propulsion should be combined with other launch technologies rather than treated as a universal substitute. A short rail, spring or pneumatic pre-accelerator and a small rocket cartridge can divide the launch task: the launcher provides initial guidance and kinetic energy, while the booster supplies compact impulse after release. This hybrid architecture may reduce booster size and improve attitude stability. It is particularly attractive for shipboard, vehicle-mounted and rough-terrain deployment, where a full runway is unavailable but fully free zero-length launch is too risky.

Finally, future systems must be designed around repeatability and regulation. Auxiliary propulsion will gain acceptance only when the ability to demonstrate ignition, burnout, separation and post-launch flight repeatedly with low risk is established. Reusable booster mounts, passive mechanical separation, onboard launch-event recording and clear operating procedures should become part of the technology definition. The next stage is therefore not simply more thrust for smaller aircraft. It is a propulsion ecosystem defined by safety, modularity and auditability.

5. Conclusion

Short-time auxiliary propulsion addresses a central contradiction in micro unmanned aviation. A small aircraft needs a burst of thrust at launch, but it cannot afford to carry an oversized propulsion system throughout the mission. Rocket-assisted take-off offers the most compact, high-impulse version of this solution. The literature reviewed here shows a field moving from basic trajectory estimation to coupled analysis of the booster, airframe, launcher, rail, control system and separation mechanism. The central lesson is that RATO should be treated as an integrated launch architecture, not as an external motor attached to a small aircraft.

The path to micro-UAV deployment remains constrained by mass penalty, centre-of-gravity migration, thrust-vector error, low-speed attitude sensitivity, rail and plume interference, safe separation and regulatory acceptance. These barriers are amplified at the micro scale because aerodynamic and structural margins are small. Future research should therefore prioritize modular booster design, lightweight and safer materials, uncertainty-aware simulation, robust launch-phase control, reusable separation mechanisms and hybrid launch architectures that combine RATO with rail or catapult guidance. The main limitation of this review is its reliance on publicly available literature; detailed micro-scale flight-test data remain scarce. Future studies should build open experimental datasets and compare rocket-assisted, pneumatic, elastic and hybrid launch methods under common micro-UAV mission requirements.

Because the field links airframe design, rocket-motor design and launch operations, progress should be judged by repeatability as much as by peak performance. Useful benchmarks would report launch success rate, attitude deviation at rail exit, minimum safe speed, separation clearance and post-launch climb margin under wind effects and installation errors. Such measures would move short-time auxiliary propulsion from promising concept towards dependable launch technology.

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