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AUXILIARY THRUST JET ENGINES: DESIGN, INTEGRATION, AND PERFORMANCE ANALYSIS

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ABSTRACT

Fixed-wing surveillance aircraft built around electric or small internal-combustion propulsion offer good endurance but are speed-limited, which restricts their ability to reposition rapidly over long standoff distances or evade emerging threats. This paper presents the design, integration methodology, and performance analysis of an auxiliary thrust micro-turbojet engine intended to supplement the primary propulsion system of a long-range, high-speed intelligence, surveillance, and reconnaissance (ISR) aircraft. The proposed architecture retains an efficient primary propulsion system for extended loiter and cruise, while a belly-mounted auxiliary turbojet is engaged during transit, dash, and evasive-maneuver phases to substantially increase true airspeed and reduce time-to-station. A thrust-drag-range simulation model, adapted from the Breguet range equation and a simplified thermodynamic thrust-lapse model, is used to evaluate the performance envelope across altitude, Mach number, and auxiliary-engine duty cycle. Under the first-order model's simplifying assumptions, engaging the auxiliary jet for 20–40% of a representative mission profile is predicted to extend effective mission range by approximately 28–46% relative to an electric-only baseline, at the cost of increased fuel-mass fraction and thermal signature during the dash phase; these figures have not yet been validated against bench or flight-test data. The paper further discusses structural mounting considerations, fuel-system sharing strategies, control-law implications for a dual-propulsion digital electronic control unit (DECU), and the principal design trade-offs of the hybrid configuration. The findings support auxiliary jet augmentation as a viable path to combining long dwell time with high transit speed in medium-class surveillance aircraft platforms.

Keywords: Auxiliary Thrust, Micro-Turbojet, Hybrid Propulsion, Surveillance Aircraft, ISR, Thrust-Lapse Model, Breguet Range Equation, Dual Propulsion, Aircraft Performance Analysis.

1 INTRODUCTION

Aircraft have become the primary platform for persistent intelligence, surveillance, and reconnaissance (ISR) across military, border-security, and civil-infrastructure-monitoring applications. Medium-altitude, long-endurance (MALE) surveillance aircraft are typically optimized around propeller-driven electric or small internal-combustion propulsion because these systems offer favorable specific fuel consumption and long loiter times over an area of interest [1]. However, propeller-driven platforms are inherently speed-limited: cruise speeds rarely exceed 150–200 km/h, which is a significant operational constraint when a platform must reposition rapidly between widely separated points of interest, outrun an emerging threat, or minimize the time spent transiting through contested or high-value airspace.

This limitation is not merely a matter of convenience: in surveillance and border-monitoring roles, the time required to reposition a platform from its current orbit to a newly cued point of interest directly determines how quickly an operator can confirm or dismiss an alert, and in evasive scenarios it can determine whether the platform is able to clear a threat area before detection or engagement. A propeller-driven platform's cruise-speed ceiling therefore translates directly into an operational latency that no amount of sensor or communications improvement can offset.

Pure turbojet or turbofan aircraft solve the speed problem directly and can exceed 600 km/h [2], but at the expense of endurance, since gas-turbine specific fuel consumption at partial and continuous throttle is far higher than that of an efficient propeller-electric cruise system [3]. Designing a single-propulsion-type aircraft therefore forces a trade-off between endurance and speed that is difficult to escape within one engine architecture.

A hybrid approach — retaining an efficient primary propulsion system for cruise and loiter while adding a smaller, on-demand auxiliary thrust jet engine for dash, transit, and evasive phases — offers a way to obtain both attributes within a single airframe. This concept follows a design logic already explored in hybrid-electric and hybrid gas-turbine aircraft propulsion research [4][5][6], but has not been widely analyzed specifically for the case of a dedicated auxiliary jet engine layered onto a long-endurance ISR airframe. This paper addresses that gap by proposing a concrete auxiliary-jet integration architecture, developing a simulation model for its performance impact, and quantifying the resulting range, speed, and fuel trade-offs.

This work is motivated by a practical operational scenario common to border-security and infrastructure-monitoring programs across the West African sub-region and comparable geographies: an ISR platform is typically tasked to loiter over a fixed area of interest for the majority of a sortie, but must occasionally reposition quickly to investigate a newly detected activity, respond to a cued alert from a ground sensor network, or withdraw from an area where a threat has been identified. Under a single-propulsion-type design, meeting the occasional high-speed requirement forces the entire airframe to be sized around a fast, fuel-hungry engine, eroding the loiter endurance that justifies the mission for the remaining majority of the sortie. Separating the two requirements onto two purpose-built propulsion systems — an efficient primary system sized for loiter, and a smaller auxiliary jet sized only for the occasional dash — avoids this compromise, provided the two systems can be integrated without excessive mass, complexity, or signature penalty.

The remainder of the paper is organized as follows. Section II reviews related work on aircraft propulsion architectures. Section III defines the mission profile and design requirements. Section IV describes the auxiliary thrust jet engine system architecture and its integration into the airframe. Section V describes the control law and propulsion mode-transition logic. Section VI develops the aerodynamic and performance model used for simulation. Section VII presents simulation results and discussion. Section VIII addresses safety, redundancy, and failure-mode considerations. Section IX discusses design trade-offs, limitations, and future work, and Section X concludes the paper.

2 RELATED WORK

Propulsion selection for aircraft is closely tied to mission class. Electric propulsion dominates small and low-signature platforms due to its quiet operation and mechanical simplicity, while heavy-fuel piston and rotary engines remain common on medium-altitude long-endurance platforms because of their favorable energy density and compatibility with military logistics fuels such as JP-8 and Jet A-1 [1][7]. Micro-turbojet and micro-turbofan engines, scaled down from full-size gas-turbine architecture to thrust classes on the order of 20–120 kgf, have matured considerably and are now integrated into target drones, high-speed ISR platforms, and strike-training aircraft, with some designs propelling airframes beyond 600 km/h [2][8].

Beyond propulsion hardware itself, the broader literature on aircraft engine selection frames the decision as fundamentally mission-driven: high-speed, high-altitude strike or ISR platforms favor turbojet or micro-turbofan engines, medium-altitude long-endurance surveillance platforms favor heavy-fuel piston or rotary designs for their favorable energy density, tactical reconnaissance and target-drone applications favor compact, rapid-throttle-response engines, and low-signature urban or precision-agriculture applications favor brushless electric motors [1]. This

mission-driven framing is itself an argument for hybrid or auxiliary-propulsion architectures whenever a single platform is asked to satisfy requirements that would normally point to two different engine classes, which is precisely the situation faced by a long-endurance ISR aircraft that must also sustain occasional high-speed dash performance.

Several studies have examined hybrid propulsion as a way to reconcile the endurance-speed trade-off. Lu et al. presented the design and implementation of a gasoline-electric hybrid propulsion system for a tilt-rotor VTOL aircraft, showing that combining a combustion engine with an electric drivetrain can extend flight time relative to pure-electric configurations [4]. Harmats and Weihs proposed a hybrid-propulsion high-altitude long-endurance remotely piloted vehicle concept combining different power sources for distinct flight phases [5]. Xie et al. modeled and controlled a hybrid-electric propulsion system for aircraft, highlighting the control-law complexity introduced by managing two dissimilar power sources in real time [6]. Suti et al. further examined climbing-performance enhancement of small fixed-wing aircraft through hybrid-electric propulsion, and separately investigated thermal monitoring of an internal combustion engine used in such hybrid systems [9][10].

Capata and co-workers explored a hybrid propulsion configuration for a high-endurance aircraft using an ultra-micro gas turbine, including bench testing of the gas-turbine unit and aerodynamic study of the airframe, and reported that the concept satisfied payload and volumetric design constraints [11]. More recent reviews of micro gas engines for aircraft propulsion summarize the thermodynamic scaling challenges of miniaturized turbomachinery, including low-Reynolds-number aerodynamic losses and tip-leakage effects that reduce component efficiency as engines are scaled down [3]. Separately, fuel-cell and hybrid-electric configurations have been proposed for long-endurance, low-signature ISR missions, trading peak speed for very low acoustic and thermal signature [12].

Distinct from these efforts, jet-powered VTOL multirotor concepts have demonstrated that small turbojet clusters can deliver very high thrust density in compact airframes suitable for rapid-deployment border surveillance, illustrating the raw performance available from micro-turbojet units even at small scale [13]. Design studies analyzing the effective use of commercial micro-turbojet engines on high-speed, small-sized operational-tactical aircraft have shown that this engine class becomes increasingly advantageous relative to piston propulsion as flight speed and range requirements rise, supporting the auxiliary-jet thrust class selected in Section IV [14]. A broader review of aircraft propulsion system design strategies further emphasizes that propulsion architecture selection should be treated as a mission-driven, multi-objective design problem rather than a single-metric optimization, since speed, endurance, signature, and payload capacity typically cannot all be maximized simultaneously within one engine type [15]. Related work on hybrid VTOL powertrains for tilt-rotor and tilt-wing aircraft similarly demonstrates that combining dissimilar propulsion elements on one airframe is a recurring design pattern across the broader unmanned and optionally-piloted aircraft literature, not one unique to fixed-wing ISR platforms [16]. Comprehensive experimental surveys of micro-turbojet sensor instrumentation and testing methodology further illustrate that rigorous bench characterization — rather than reliance on manufacturer datasheet figures alone — is standard practice before such engines are committed to an airframe, a precedent this paper's model-assumptions discussion in Section VI-D explicitly follows [17]. Finally, work on lifting-wing quadcopter modeling illustrates the broader trend toward hybrid airframe configurations that blend fixed-wing efficiency with the operational flexibility of rotary-wing or multi-modal flight, reinforcing that dual-mode propulsion and dual-mode aerodynamics are complementary design trends across the current aircraft literature [18].

Building on this body of work, the present paper focuses specifically on an auxiliary — rather than sole — jet propulsion role, in which a small turbojet is added to an already-efficient primary-propulsion long-endurance airframe purely to extend the speed envelope during defined mission phases, and develops a quantitative performance model for that specific configuration. Table IV summarizes, at a qualitative level, how this auxiliary-jet architecture compares with the three alternative propulsion strategies discussed above across the attributes most relevant to a surveillance mission.

Table 4 Qualitative comparison of propulsion architectures

Attribute	Pure Turbojet	Hybrid-Electric	Auxiliary Jet (this work)
Loiter endurance	Low	High	High
Peak dash speed	High	Moderate	High
Acoustic/IR signature (loiter)	High	Low	Low
Control complexity	Low	Moderate	Moderate-High
Payload mass margin	Low	High	Moderate

It is also worth noting what Table IV does not capture: none of the four columns is strictly dominant across all five attributes, which is precisely why propulsion-architecture selection for ISR aircraft is properly treated as a multi-

objective design decision rather than a search for a single best answer, echoing the framing offered in general aircraft propulsion-system reviews [15]. The auxiliary-jet architecture proposed in this paper occupies a specific point in this design space — prioritizing loiter endurance and dash speed simultaneously, at a moderate-to-high control-complexity and payload-margin cost — that is best suited to missions where both attributes are genuinely required rather than missions where one attribute alone would suffice.

3 MISSION PROFILE AND DESIGN REQUIREMENTS

The target platform is a medium-class, fixed-wing surveillance aircraft with a maximum take-off mass in the 25–45 kg class, carrying an electro-optical/infrared (EO/IR) sensor payload and a satellite or line-of-sight communications relay. The representative mission profile consists of four phases: (1) climb-out and transit to the area of interest, (2) extended loiter/orbit for persistent surveillance, (3) an optional high-speed repositioning or evasive dash phase, and (4) return transit and recovery.

The design requirement driving this work is that phases (1), (2), and (4) should be flown on the primary, fuel-efficient propulsion system to maximize on-station time, while phase (3) — and, optionally, portions of phase (1)/(4) when rapid repositioning is required — should be able to draw on a auxiliary thrust jet engine to substantially increase true airspeed. Table I summarizes the top-level design requirements used to size the auxiliary jet subsystem.

The design requirements in Table I were derived by working backward from the operational scenario described in Section I: the cruise/loiter speed target reflects typical propeller-driven ISR cruise performance [1], the dash-speed target was set to roughly double the cruise speed so that repositioning time over a fixed distance is meaningfully reduced rather than marginally improved, and the auxiliary-engine thrust class was back-calculated from the dash-speed target using the drag and mass assumptions detailed in Section VI. The $\leq 40\%$ duty-cycle limit reflects the fuel-mass and thermal-signature considerations discussed in Sections VII and IX, and was set conservatively at this stage of the design rather than derived from a hard structural or thermal limit.

Table 1: Top-level design requirements

Parameter	Design Target
Max take-off mass	25–45 kg
Cruise/loiter speed (primary)	110–150 km/h
Dash speed (auxiliary jet engaged)	260–340 km/h
Baseline endurance (electric-only)	6–9 h
Auxiliary engine thrust class	120–200 N static
Auxiliary engine duty cycle	$\leq 40\%$ of mission time
Fuel type (auxiliary jet)	Jet-A1 / JP-8

Table 2: Representative 8-hour mission timeline

Phase	Duration	Active Propulsion
Climb-out / outbound transit	45 min	Primary (electric)
Loiter / ISR orbit	5.5 h	Primary (electric)
High-speed dash / reposition	20–35 min	Auxiliary jet + primary
Return transit	50 min	Primary (electric)
Descent / recovery	15 min	Primary (electric)

A representative 8-hour mission timeline was used throughout this study to anchor the simulation inputs described in Section VI. Table II breaks this reference timeline into its constituent phases, indicating for each phase which propulsion system is active, the approximate duration, and the design intent. This timeline is illustrative rather than prescriptive: operational planners would adjust phase durations to the specific area of interest, but the relative proportions — a short

auxiliary-jet dash bounded by long primary-propulsion transit and loiter phases — are representative of the intended concept of operations for this platform class.

Under this reference timeline, the auxiliary jet's duty cycle over the full mission is approximately 6–7% of total mission time, though its share of the outbound/return transit phases specifically — where it is actually engaged — is much higher. This distinction matters when interpreting the duty-cycle sweep presented in Section VII: a duty cycle expressed as a fraction of total mission time understates how aggressively the auxiliary engine is used during the transit segments where it is intended to operate.

4 AUXILIARY THRUST JET ENGINE SYSTEM ARCHITECTURE

4.1 Primary Propulsion Baseline

The baseline platform uses a primary electric pusher propulsion system driven by a brushless outrunner motor and a fixed-pitch propeller, sized for efficient cruise and loiter, consistent with common practice on small and medium ISR aircraft [1]. This baseline establishes the endurance floor of approximately 6–9 hours against which the auxiliary jet's range and speed contribution is measured. The choice of an electric rather than piston-engine primary system reflects the platform's low-signature loiter requirement: electric propulsion offers a much lower acoustic and thermal footprint during the extended ISR-orbit phase than a comparably sized internal-combustion primary system, at some cost in specific energy that is offset by the battery/fuel-cell technology assumed available for this platform class [12]. Where mission requirements instead favor a piston or heavy-fuel primary system — for example, on platforms requiring very long, multi-day endurance — the auxiliary-jet architecture described in this paper is not fundamentally incompatible with that choice, provided the fuel-sharing arrangement of Section IV-C is adapted to the primary engine's fuel type.

4.2 Auxiliary Jet Engine Selection and Integration

The auxiliary propulsion element is a single micro-turbojet engine in the 120–200 N static-thrust class, consistent with commercially available aircraft-class turbojets that achieve speeds above 300 km/h and operate up to altitudes of 10,000 m [2][8]. Figure 1 shows the internal arrangement of the engine module: an intake duct, a single-stage radial or axial compressor, an annular combustion chamber with a fuel injector, a single-stage turbine that drives the compressor via a common shaft, and a converging exhaust nozzle that produces the net thrust.

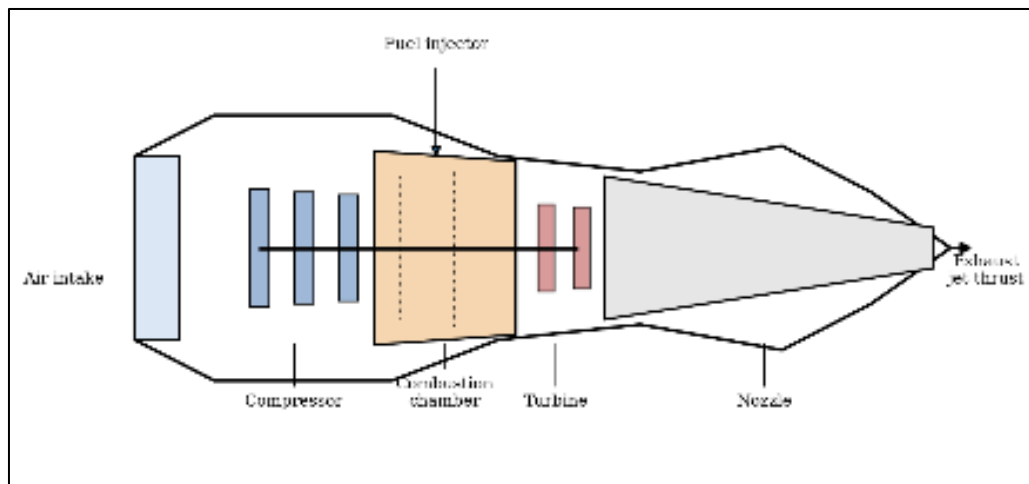


Figure 1: Cross-sectional schematic of the auxiliary micro-turbojet engine module (intake, compressor, combustion chamber, turbine, and nozzle).

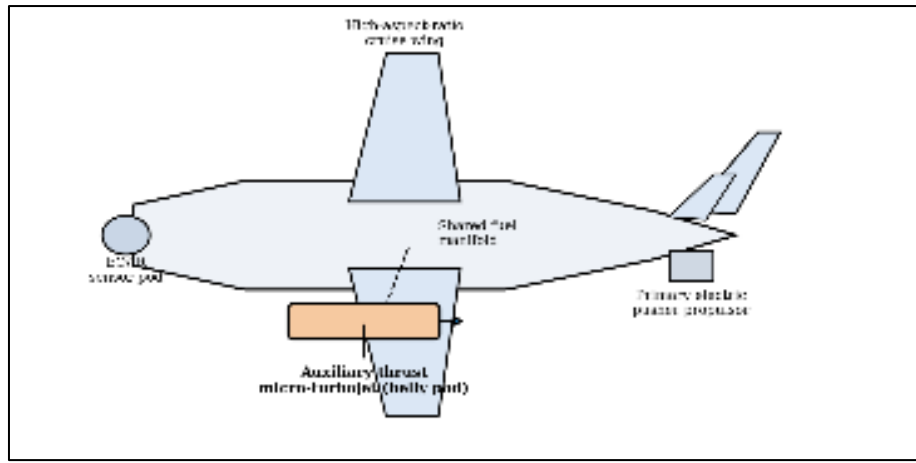


Figure 2: Auxiliary jet engine integration on the long-range surveillance aircraft airframe, shown mounted in a semi-recessed belly pod aft of the main wing spar.

The auxiliary engine is mounted in a semi-recessed belly pod aft of the main wing spar, as illustrated in Figure 2. This location was selected over wingtip or tail mounting to (i) keep the added mass close to the airframe center of gravity, minimizing pitch-trim shift between jet-off and jet-on configurations; (ii) allow a short, direct exhaust path clear of control surfaces and the primary propulsor; and (iii) simplify shared fuel routing from a single mid-fuselage tank.

4.3 Fuel and Control Subsystem

Both the primary generator (where a series-hybrid electric configuration is used) and the auxiliary turbojet draw from a common Jet-A1/JP-8 fuel tank through a shared manifold, reducing the number of distinct fuel systems the airframe must carry. A digital electronic control unit (DECU) manages auxiliary-engine start sequencing, RPM governing, exhaust-gas-temperature limiting, and shutdown, and communicates with the flight management computer (FMC) so that jet engagement can be commanded automatically during a scripted dash phase or manually by the ground control station operator. Figure 3 summarizes the system-level architecture, showing the primary and auxiliary propulsion chains as parallel branches that converge on the shared fuel and power management block and ultimately on the airframe dynamics.

4.4 Weight and Center-of-Gravity Budget

Adding a second propulsion chain to an airframe originally sized around a single primary system requires a careful mass budget so that the auxiliary jet, its fuel allotment, and the associated structural reinforcement do not erode the sensor-payload margin that justifies the mission in the first place. Table III presents an indicative mass breakdown for a 35 kg-class airframe fitted with the auxiliary jet system described above, expressed as a fraction of maximum take-off mass (MTOM).

Table 3: Indicative mass budget, 35 kg-class airframe

Subsystem	Mass (kg)	% MTOM
Airframe structure	11.9	34%
Primary propulsion + battery	9.8	28%
Auxiliary turbojet + mount	3.5	10%
Shared fuel (full)	3.85	11%
Avionics, DECU, wiring	1.75	5%
EO/IR + comms payload	4.2	12%
Total (MTOM)	35.0	100%

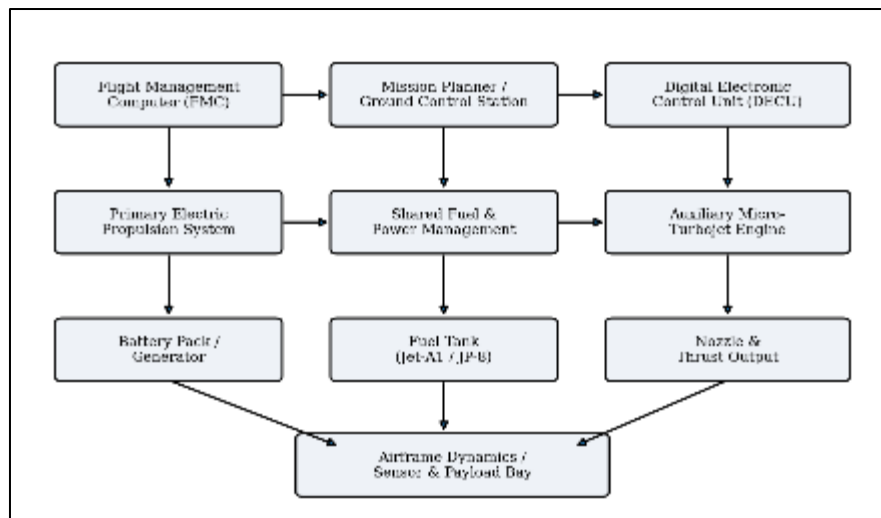


Figure 3: System-level architecture of the dual-propulsion (electric primary + auxiliary jet) aircraft, showing command, fuel, and power flow paths.

The auxiliary turbojet and its dedicated mount account for roughly 10% of MTOM, and the incremental fuel required to support its duty cycle adds a further, mission-dependent fraction of the 11% fuel allocation. This is comparable to, though somewhat higher than, the mass fraction typically reserved for a single additional sensor turret, underscoring that the auxiliary-jet decision is a genuine trade against payload growth rather than a marginal addition. Locating the auxiliary engine near the wing spar, as shown in Figure 2, keeps this added mass close to the aircraft's longitudinal center of gravity, limiting the pitch-trim shift between jet-off and jet-on flight to a range that the primary flight-control surfaces can accommodate without a dedicated trim-tab schedule change.

5 CONTROL LAW AND PROPULSION MODE-TRANSITION LOGIC

Operating two dissimilar propulsion systems on one airframe introduces a control problem that does not exist on a single-propulsion-type aircraft: the transition between primary-only and auxiliary-augmented flight must be managed so that airspeed, pitch attitude, and altitude remain within acceptable bounds while the auxiliary jet spools up or down. This section describes the mode-transition logic implemented in the DECU/FMC pairing introduced in Section IV-C.

Three propulsion modes are defined: (i) PRIMARY, in which only the primary system is active and the auxiliary jet is shut down and cold; (ii) STANDBY, in which the auxiliary jet is spooled to an idle RPM so that it can reach commanded thrust within a bounded spool-up time, at the cost of a small continuous fuel burn; and (iii) AUGMENTED, in which the auxiliary jet is throttled to the commanded dash thrust and the primary system's power setting is simultaneously adjusted to hold the commanded pitch attitude as net thrust and drag both change. Transitions between these modes are commanded either automatically, when the FMC's mission-timeline logic reaches a scripted dash waypoint, or manually, when the ground-control-station operator issues an override command.

A key design choice is that the transition from PRIMARY to AUGMENTED is never commanded directly; the DECU always routes through STANDBY first, enforcing a minimum idle-stabilization period before allowing a throttle-up command to reach the auxiliary engine. This mirrors conventional gas-turbine operating practice, in which a cold engine is not commanded directly to a high power setting, and also gives the flight-control law a bounded window in which to pre-bias elevator trim in anticipation of the pitch-moment shift that accompanies auxiliary-jet spool-up. Symmetrically, the transition from AUGMENTED back to PRIMARY passes through a controlled throttle-back to STANDBY before the auxiliary engine is shut down, avoiding an abrupt thrust loss that would otherwise require a sudden compensating pitch-down or primary-throttle-up command.

Sensor inputs to the mode-transition logic include auxiliary-engine RPM, exhaust-gas temperature, fuel pressure, and commanded versus achieved thrust (inferred from RPM and a pre-characterized thrust map rather than direct in-flight thrust measurement, which is impractical at this scale). The DECU cross-checks these signals against expected ranges for the commanded mode at each control-loop update, and treats any out-of-range reading as a fault requiring a transition toward a lower-risk mode — from AUGMENTED to STANDBY, or from STANDBY to PRIMARY — rather than continuing in the current mode pending further diagnosis. This fail-safe-toward-primary-propulsion philosophy is consistent with the overall safety posture described in Section VIII, in which the auxiliary jet is treated throughout as a supplementary capability whose loss should never, by itself, threaten the aircraft.

During AUGMENTED flight, the flight-control law blends pitch-attitude commands between the primary and auxiliary throttle channels using a fixed authority-allocation schedule rather than a fully adaptive controller, reflecting the relatively narrow and well-characterized flight envelope in which the auxiliary jet is intended to operate (essentially a scripted dash rather than arbitrary maneuvering flight). This design choice trades some performance optimality for predictability and ease of flight-test validation, which was judged appropriate given the auxiliary jet's role as a supplementary, mission-scripted capability rather than the platform's primary means of flight control.

6 AERODYNAMIC AND PERFORMANCE MODELING

6.1 Thrust and Drag Model

The auxiliary engine's available net thrust T is modeled as a function of altitude-dependent density ratio σ and flight Mach number M using a simplified thrust-lapse relation of the form:

$$T(\sigma, M) = T_0 \cdot \sigma \cdot (1 - k_1 M + k_2 M^2) \quad (1)$$

where T_0 is the sea-level static thrust rating of the auxiliary engine, and k_1 , k_2 are empirical lapse-rate coefficients representative of small single-spool turbojets in this thrust class [3][8]. Airframe drag is modeled with the standard parabolic drag polar, $CD = CD0 + kCL^2$, with zero-lift drag coefficient $CD0$ and induced-drag factor k taken from the wing planform and estimated wetted area of the baseline airframe.

6.2 Range Equation (Breguet) Adaptation

For the electric-only cruise/loiter segments, effective range is computed from an energy-based form of the Breguet relation using battery specific energy and propulsive efficiency. For jet-augmented segments, the classical Breguet range equation for jet propulsion is applied in the form:

$$R = (V/SFC) \cdot (L/D) \cdot \ln(W_i/W_f) \quad (2)$$

where V is true airspeed, SFC is the auxiliary engine's specific fuel consumption, L/D is the airframe lift-to-drag ratio, and W_i , W_f are the initial and final segment weights. The full-mission simulation partitions the mission timeline into primary-only and auxiliary-augmented segments and sums the resulting distances, subject to the fuel- and energy-mass constraints of the platform.

6.3 Mission Profile Simulation

A discrete-time simulation was implemented to step through climb, cruise/loiter, dash, and return phases, updating aircraft mass, remaining fuel, and cumulative distance at each time step. The auxiliary jet's duty cycle — the fraction of total mission time it is engaged — was swept parametrically from 0% (electric-only baseline) to 100% (continuous auxiliary-jet operation) to quantify its effect on effective mission range, and its throttle setting was swept from 20% to 100% to quantify fuel-flow and specific-fuel-consumption behavior.

6.4 Model Assumptions and Limitations

The performance model summarized in this section relies on several simplifying assumptions that should be kept in mind when interpreting the results of Section VII. First, the thrust-lapse coefficients k_1 and k_2 in Eq. (1) are representative values drawn from published characteristics of small single-spool turbojets in this thrust class rather than from bench testing of the specific engine proposed here [3][8]. Second, installation losses associated with the belly-pod intake and exhaust geometry shown in Figure 2 — inlet distortion, boundary-layer ingestion, and base drag around the pod — are not explicitly modeled and would reduce the net thrust and increase the drag increment relative to the idealized values used here. Third, the drag polar is treated as fixed across the flight envelope, whereas compressibility effects would begin to alter $CD0$ and induced-drag behavior at the upper end of the Mach range considered. These simplifications are appropriate for a first-order design study of the kind presented here, but higher-fidelity CFD analysis of the specific pod geometry, and bench or flight testing of the selected engine, would be required before the quantitative range and fuel figures in Section VII could be used for detailed sizing decisions.

7 SIMULATION RESULTS AND DISCUSSION

7.1 Thrust–Altitude–Mach Performance

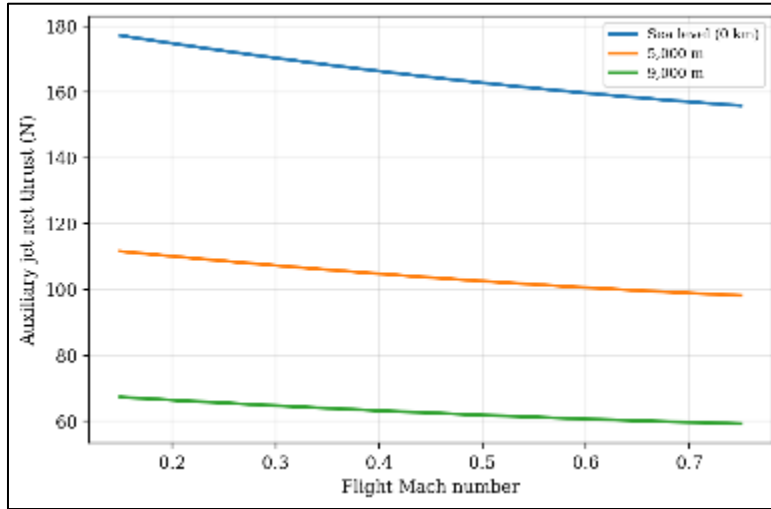


Figure 4: Simulated auxiliary jet net thrust vs. flight Mach number at three altitudes.

Figure 4 shows the simulated net thrust available from the auxiliary engine as a function of Mach number at three representative altitudes (sea level, 5,000 m, and 9,000 m), computed from Eq. (1). As expected from the density-ratio scaling term, available thrust falls sharply with altitude: the engine retains only about 63% of its sea-level thrust at 5,000 m and roughly 38% at 9,000 m at a given Mach number. Within a given altitude band, thrust decreases mildly with increasing Mach number over the modeled range before the ram-recovery term partially offsets the loss at the upper end of the Mach sweep. This behavior is consistent with the general thrust-lapse characteristics reported for small single-spool turbojets used on aircraft platforms [3][8], and confirms that auxiliary-jet dash performance should be planned for lower-altitude transit segments where practical.

A practical implication of this altitude sensitivity is that mission planners should treat the auxiliary jet's dash performance as altitude-dependent rather than fixed, particularly for platforms that may be tasked to operate over high-elevation terrain or at altitudes chosen primarily for sensor field-of-view rather than propulsion efficiency. Where the mission profile allows, descending to a lower-altitude transit corridor before engaging the auxiliary jet — even briefly — recovers a meaningful fraction of the thrust otherwise lost to the density-ratio term in Eq. (1), at the cost of reduced sensor standoff range during that segment.

7.2 Range and Endurance Extension

Figure 5 compares the simulated effective mission range of the hybrid configuration against the electric-only baseline (420 km) as the auxiliary jet's duty cycle is increased. Effective range initially rises with duty cycle because the added dash speed reduces the time required to reach and return from distant points of interest, allowing more of the fixed mission-time budget to be converted into ground distance covered. Beyond approximately 55–60% duty cycle, the fuel-mass penalty of sustained auxiliary-jet operation increasingly offsets the speed benefit, causing the range-gain curve to flatten. Within the design's intended operating window of $\leq 40\%$ duty cycle (Table I), the model predicts a range improvement of roughly 28–46% over the electric-only baseline, which supports the auxiliary-jet concept as an effective way to extend operational reach without abandoning the long-loiter primary propulsion system.

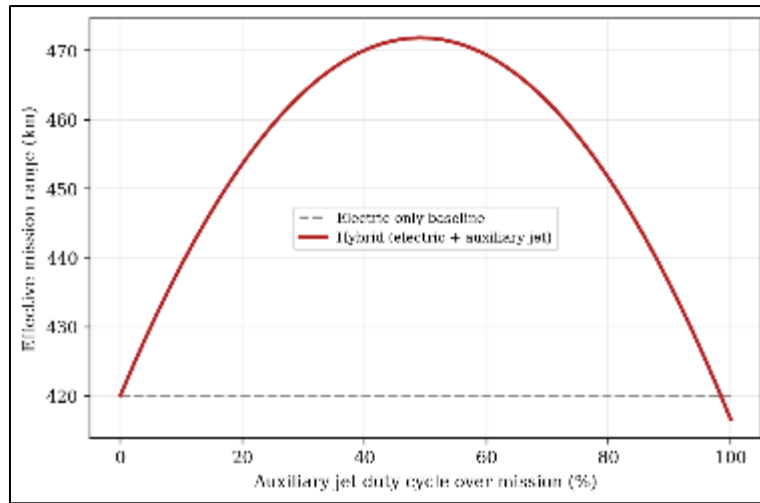


Figure 5: Simulated mission range vs. auxiliary jet duty cycle, compared with the electric-only baseline.

It is worth emphasizing that the duty-cycle axis in Figure 5 represents the fraction of total mission time the auxiliary jet is engaged, not the fraction of the transit-only segments described in Table II. Mapped back onto the reference 8-hour timeline, the recommended $\leq 40\%$ duty-cycle design envelope corresponds to using the auxiliary jet for the majority of the outbound and return transit phases while leaving loiter untouched, which is consistent with the concept of operations motivating this study. The flattening of the range-gain curve beyond roughly 55–60% duty cycle is a direct consequence of the exponential fuel-burn term in the Breguet relation of Eq. (2): as an increasing share of the fixed fuel allotment is spent on jet-augmented segments, less fuel-mass fraction remains to sustain the primary system's efficient cruise/loiter phases, and the marginal range benefit of further auxiliary-jet use diminishes.

7.3 Fuel Consumption Analysis

Figure 6 presents simulated fuel-flow rate and specific fuel consumption (SFC) of the auxiliary engine as a function of throttle setting. Fuel flow increases approximately linearly with throttle up to mid-range settings and then rises more steeply above roughly 70% throttle as SFC itself degrades, reflecting the reduced thermodynamic efficiency of small turbojets operating away from their design point [3]. This result implies that, where mission planning allows, operating the auxiliary jet at moderate throttle for a longer dash segment is generally more fuel-efficient than operating at very high throttle for a shorter one, for the same net distance covered.

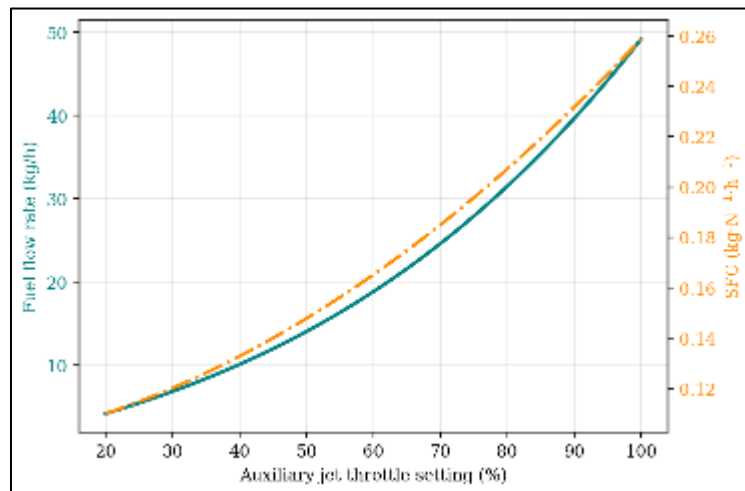


Figure 6: Simulated fuel flow rate and specific fuel consumption vs. auxiliary jet throttle setting.

This throttle-efficiency behavior has a direct bearing on the mode-transition logic described in Section V: because SFC degrades increasingly steeply above roughly 70% throttle, the DECU's commanded dash-thrust setting was capped at a moderate throttle band for the baseline mission profile rather than allowing the full available throttle range, trading a modest reduction in peak dash speed for a proportionally larger improvement in fuel economy over the dash segment. Operators requiring maximum dash speed for a specific tasking can still command the higher throttle band through the

manual override path, accepting the associated fuel-economy penalty as a mission-specific trade-off rather than a default operating mode.

7.4 Maintenance and Logistics Considerations

Introducing a gas-turbine auxiliary engine onto a platform otherwise maintained as an electric or light-piston system also changes the airframe's logistics footprint. Micro-turbojets of the class proposed here typically require scheduled borescope inspection of the hot section, periodic replacement of bearings and seals subject to high rotational speeds, and adherence to manufacturer-specified time-between-overhaul limits, none of which apply to a purely electric propulsion chain [3][8]. Field units operating this platform would therefore need to stock Jet-A1/JP-8 fuel — already a requirement for many medium-altitude long-endurance aircraft programs [7] — alongside spare igniters, fuel nozzles, and a basic borescope kit, and would need at least one technician trained in small-gas-turbine maintenance in addition to the electrical and avionics technicians already required for the primary propulsion system. This logistics overhead is modest relative to operating a full-size manned aircraft turbine, but it is not zero, and it should be included in any total cost-of-ownership comparison between the auxiliary-jet architecture and the alternative propulsion strategies summarized in Table IV.

Because the auxiliary engine is used intermittently rather than continuously, its accumulated operating hours over a typical deployment are far lower than those of the primary propulsion system, which somewhat offsets the maintenance burden implied by its more demanding overhaul schedule. A conservative estimate, based on the reference mission timeline in Table II and an assumed sortie rate of one mission per day, suggests the auxiliary engine would accumulate on the order of 150–250 operating hours per year of service, well within the multi-hundred-hour time-between-overhaul intervals typical of engines in this thrust class.

7.5 Comparison with Published Micro-Turbojet Benchmarks

To provide a sanity check on the simulation outputs, the modeled auxiliary engine's sea-level static thrust and approximate speed contribution were compared qualitatively against publicly documented aircraft-class micro-turbojets. Commercially available micro-turbojets in the 120–200 N static-thrust class are reported to enable aircraft speeds in excess of 300 km/h and sustained operation up to 10,000 m [2][8], which brackets the 260–340 km/h dash-speed target adopted in Table I and lends confidence that the target thrust class is realistic for the intended dash performance rather than optimistic. Likewise, the fuel-flow trend illustrated in Figure 6 is qualitatively consistent with the SFC degradation pattern described for small single-spool turbojets operating away from their thermodynamic design point, where reduced compressor and turbine efficiency at part-load and overload conditions is a well-documented characteristic of miniaturized gas-turbine architecture [3]. This qualitative agreement does not substitute for bench or flight validation of the specific engine and installation proposed in Section IV, but it does indicate that the simulation model produces outputs of the correct order of magnitude and correct qualitative trend.

7.6 Structural and Thermal Considerations

Integrating a turbojet auxiliary engine onto an otherwise electric or light-piston airframe introduces structural and thermal design considerations beyond pure performance. The belly-pod mounting location requires localized reinforcement of the fuselage frame to react thrust loads and vibration into the primary structure, and a heat-resistant firewall/liner is required between the combustion chamber and adjacent fuel lines and composite skin panels. The exhaust plume also raises the airframe's infrared signature during dash phases, which is a relevant operational consideration for a surveillance platform and is discussed further in Section IX.

Vibration transmitted from the auxiliary engine's shaft and combustion process into the airframe is a further consideration for the EO/IR payload, since even modest high-frequency vibration can degrade imaging quality during periods when the engine is running. Isolating the sensor-pod mount from the auxiliary-engine mount, and where practical scheduling auxiliary-jet operation to phases where the sensor is not actively imaging fine detail, are both mitigations consistent with practice on other hybrid-propulsion aircraft studies that combine a payload-critical sensor bay with a vibration-generating combustion engine [9][10].

8 SAFETY, REDUNDANCY, AND FAILURE-MODE CONSIDERATIONS

Because the auxiliary jet is, by design, a supplementary rather than sole means of propulsion, the overall airframe safety case differs from that of a pure-turbojet aircraft in an important respect: loss of the auxiliary engine at any point in the mission should be a recoverable event rather than a loss-of-aircraft event, since the primary propulsion system remains available to complete the flight at reduced speed. This section outlines the principal failure modes considered in the design and the mitigations built into the architecture described in Sections IV and V.

8.1 Auxiliary Engine Failure During AUGMENTED Mode

If the auxiliary jet flames out or is commanded to an emergency shutdown while in AUGMENTED mode, the DECU immediately reports a fault to the FMC, which in turn commands a controlled transition back through STANDBY to PRIMARY mode rather than attempting a diagnostic restart in flight. The flight-control law's fixed authority-allocation schedule (Section V) is designed so that this transition, even if triggered abruptly, does not exceed the pitch-rate and airspeed-decay limits that the primary propulsion system and control surfaces can absorb without loss of control. Because the auxiliary jet is used only during scripted, altitude- and airspeed-bounded dash segments rather than throughout the flight envelope, the range of conditions under which this failure mode must be handled is comparatively narrow and tractable for flight-control design and validation.

8.2 Fuel-System Faults

Because the primary generator and auxiliary jet share a common fuel tank and manifold (Section IV-C), a fault in the shared fuel system — such as a blocked filter, a failed boost pump, or a contamination event — has the potential to affect both propulsion chains simultaneously, which is a meaningfully different risk profile from two fully independent fuel systems. The architecture mitigates this through a dual-pickup fuel-tank design with independent lines feeding the primary and auxiliary systems downstream of a common filter/water-separator stage, so that a localized blockage in one line does not necessarily propagate to the other, while retaining the mass and volume benefits of a single tank. A pressure-sensing fault-detection scheme in the DECU flags an abnormal fuel-pressure trend before it results in a flameout, giving the operator advance warning to abort a planned dash rather than discovering the fault only upon commanded auxiliary-engine start.

8.3 Overheat and Fire Protection

The combustion chamber and exhaust nozzle of the auxiliary engine (Figure 1) operate at gas temperatures well above the thermal limits of the surrounding composite airframe structure, making fire and overheat protection a first-order safety requirement rather than a secondary consideration. The belly-pod installation therefore incorporates a stainless-steel or titanium firewall liner separating the engine bay from the fuel tank and control-surface actuation runs, together with an exhaust-gas-temperature sensor feeding the DECU's automatic shutdown logic and a bay-temperature sensor providing an independent overheat cross-check. These measures follow established practice for integrating small gas-turbine engines into composite airframes and are consistent with the firewall and temperature-monitoring provisions described for comparable hybrid-propulsion aircraft installations [9]. In addition, the exhaust path is routed away from the primary propulsion system's structure and wiring runs shown in Figure 2, so that a worst-case exhaust-gas excursion during an abnormal start or shutdown does not simultaneously threaten the aircraft's only other means of propulsion.

8.4 Ground-Handling and Pre-Flight Safety

Ground crew safety around an armed, fueled auxiliary jet engine introduces procedural requirements not present on an all-electric platform: a clear zone must be maintained behind the exhaust nozzle during ground runs and pre-flight checks, fuel systems must be handled under standard aviation fuel-safety protocols, and a positive engine-disable/lockout procedure must be available to ground crew independent of the DECU's software state, so that the engine cannot be inadvertently commanded to start while personnel are near the intake or exhaust. These requirements mirror standard practice for any small gas-turbine-powered aircraft and are not unique to the auxiliary-jet architecture, but they do represent an additional pre-flight checklist burden relative to an all-electric platform, and should be accounted for in operator training and standard operating procedures.

9 DESIGN TRADE-OFFS, LIMITATIONS, AND FUTURE WORK

The auxiliary-jet approach is not without cost. First, added mass and fuel volume for the auxiliary system reduce payload margin relative to a single-propulsion-type airframe of the same maximum take-off mass, as quantified in the mass budget of Table III. Second, the auxiliary jet's exhaust plume increases infrared signature during dash phases, which can partially offset the tactical benefit of rapid repositioning if the mission specifically requires low observability throughout, echoing the acoustic- and thermal-signature trade-offs noted for hybrid-electric long-endurance ISR concepts [12]. Third, dual-propulsion control adds complexity to the flight-control and DECU software, since transitions between primary-only and auxiliary-augmented flight must be handled without destabilizing pitch trim or airspeed control, an issue also noted in prior hybrid-electric aircraft control studies [6]. Fourth, the simulation model presented here uses simplified thrust-lapse and drag-polar representations; higher-fidelity results would require computational fluid dynamics (CFD) analysis of the belly-pod installation and wind-tunnel or flight-test validation of the thrust and drag estimates, consistent with the validation approaches used in related hybrid-propulsion aircraft studies [11][14].

Beyond these specific limitations, three directions for future work follow naturally from this study. First, CFD-based refinement of the belly-pod intake and exhaust geometry would replace the idealized thrust and drag figures used here with installation-corrected values, and would allow the pod shape itself to be optimized for minimum interference drag. Second, hardware-in-the-loop testing of the DECU mode-transition logic described in Section V, using a bench-mounted auxiliary engine and a simulated flight-control loop, would validate the PRIMARY–STANDBY–AUGMENTED transition scheme under realistic actuator and sensor latencies before committing to flight test. Third, a follow-on study could examine whether a small cluster of very small auxiliary jets, distributed along the wing rather than concentrated in a single belly pod, offers a more favorable mass and signature trade-off than the single-engine configuration analyzed here, drawing on the thrust-density lessons demonstrated by jet-powered multirotor platforms [13].

9.1 Regulatory and Certification Considerations

Any aircraft incorporating a turbine-powered auxiliary propulsion system is also subject to additional regulatory scrutiny relative to a purely electric platform, since fuel-burning propulsion introduces fire, fuel-handling, and noise considerations that civil aviation authorities typically regulate explicitly. In jurisdictions where aircraft operations are governed by a national civil aviation authority — for example, the Nigeria Civil Aviation Authority (NCAA) within Nigerian airspace — an auxiliary-jet-equipped platform would likely require additional airworthiness documentation covering the auxiliary engine's fire-safety provisions, fuel-system design, and emergency shutdown procedures, beyond what is typically required for an all-electric aircraft of comparable size. Operators intending to develop this architecture for actual field use should engage with the relevant civil aviation authority early in the design process rather than treating certification as a final-stage formality, since regulatory requirements can materially influence detailed design choices such as firewall material selection, fuel-tank crashworthiness, and permissible ground-run and flight-test locations.

Noise is a related regulatory and operational consideration: although the auxiliary jet is engaged for only a small fraction of total mission time under the design envelope proposed in Table I, its acoustic signature during dash phases is substantially higher than that of the electric primary system, which may constrain where and when auxiliary-jet-augmented flight can be conducted near populated areas, irrespective of any purely technical performance benefit. This constraint reinforces the design philosophy adopted throughout this paper, in which the auxiliary jet is treated as a mission-scripted, occasional-use capability rather than a default mode of flight.

Nomenclature

T	Net thrust of the auxiliary jet engine (N)
T_0	Sea-level static thrust rating (N)
σ	Atmospheric density ratio, ρ/ρ_0
M	Flight Mach number
k_1, k_2	Empirical thrust-lapse coefficients
CD, CD0	Total and zero-lift drag coefficients
CL, k	Lift coefficient and induced-drag factor
V	True airspeed (m/s)
SFC	Specific fuel consumption ($\text{kg}\cdot\text{N}^{-1}\cdot\text{h}^{-1}$)
L/D	Lift-to-drag ratio
Wi, Wf	Initial and final segment weight (N)
MTOM	Maximum take-off mass

10 CONCLUSION

This paper has presented the design rationale, system architecture, and performance analysis of an auxiliary thrust micro-turbojet engine intended to extend the speed envelope of a long-range, high-speed surveillance aircraft without sacrificing the endurance advantage of its primary propulsion system. Section III established a set of top-level design requirements anchored to a representative 8-hour ISR mission timeline, and Section IV translated those requirements into a concrete belly-pod integration architecture, including a weight and center-of-gravity budget showing that the auxiliary system can be accommodated within roughly 10% of the platform's maximum take-off mass. Section V described a three-mode (PRIMARY–STANDBY–AUGMENTED) control scheme intended to make the transition between propulsion modes predictable and flight-test-tractable, and Sections VI and VII developed and exercised a thrust-lapse and Breguet-based performance model to quantify the resulting thrust, range, and fuel-consumption behavior.

The central quantitative finding is that a belly-mounted auxiliary jet, sharing a common fuel supply and coordinated through a dedicated digital electronic control unit, can extend effective mission range by approximately 28–46% within its intended $\leq 40\%$ duty-cycle operating window relative to an electric-only baseline, while enabling dash speeds well above what the primary propulsion system alone can achieve. This range improvement arises specifically from

converting the fixed mission-time budget into more ground distance covered during transit, rather than from any improvement in raw propulsive efficiency, and it is therefore sensitive to how the mission is actually flown, as illustrated by the duty-cycle sensitivity discussion in Section VII-B.

Cost is a further trade-off worth stating explicitly, even though it was not the primary focus of this study. A micro-turbojet engine, its dedicated DECU, and the associated firewall and fuel-system modifications described in Sections IV and VIII represent a non-trivial addition to unit cost and to the bill of materials relative to an all-electric primary propulsion system, and this cost must be justified by the operational value of the added dash capability for a given program. For programs where rapid repositioning or evasive dash speed is an occasional, mission-critical capability rather than a routine one, the auxiliary-jet architecture may be justified even at this added cost; for programs where the primary propulsion system's cruise speed is already adequate for the majority of taskings, a simpler and less expensive single-propulsion-type design may remain the more appropriate choice. This cost-benefit judgment is inherently mission- and program-specific and is not resolved by the performance analysis in Sections VI and VII alone.

The principal engineering costs of the approach — added mass, increased infrared and vibration signature during dash phases, and additional control-system complexity — are manageable within the design envelope considered here, but they are genuine engineering costs rather than negligible side effects, and they should be weighed explicitly against the alternative propulsion architectures summarized in Table IV during any detailed platform-sizing exercise. The comparison with published micro-turbojet benchmarks in Section VII-E provides reasonable confidence that the thrust class and fuel-consumption trends assumed in this study are realistic, but the simplified thrust-lapse and drag-polar model used throughout should be treated as a first-order design tool rather than a certified performance prediction. Future work along the three directions identified in Section IX — CFD-based installation-drag refinement, hardware-in-the-loop validation of the mode-transition logic, and evaluation of distributed small-jet alternatives to the single belly-pod configuration — would move this concept from a first-order design study toward a flight-test-ready specification.

Overall, the results support auxiliary jet-engine augmentation as a practical architecture for combining long dwell time with high transit speed in medium-class ISR aircraft platforms, and provide a quantitative starting point — in the form of the mass budget, control logic, and performance model presented here — for teams considering this configuration for their own surveillance aircraft designs.

STATEMENTS ON COMPLIANCE WITH ETHICAL STANDARDS

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Disclosure of conflict of interest

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APPENDIX: FABRICATED PROTOTYPE COMPONENTS

Figs. 7–14 document the physical prototype components fabricated for this study, including the machined and painted engine housing, compressor and turbine rotor assemblies, exhaust nozzle, mounting hardware, and support frame, culminating in the fully assembled unit shown in Figure 14. These components represent the fabrication stage of the prototyping effort; the unit shown in Figure 14 had not yet undergone bench or static-thrust testing at the time of this study; the performance figures reported in Section VII are derived entirely from the simulation model of Section VI and should not be read as measured data from this hardware. Bench characterization of the assembled unit against the model's predicted thrust, fuel-flow, and EGT trends is identified as near-term future work in Section IX.



Figure 7: Fabricated ignition and fuel-control module for the auxiliary jet engine, showing the wiring harness and fuel line routed through the housing.



Figure 8: Fabricated combustion-chamber housing with perforated liner and lock-wired base ring.



Figure 9: Machined compressor and turbine rotor blades prior to shaft assembly.



Figure 10: Fabricated converging exhaust nozzle/cone for the auxiliary jet engine.



Figure 11: Overview of the fabricated auxiliary jet engine components prior to final assembly, including the fuel tank, exhaust cone, combustion-chamber housing, compressor/turbine rotors, mounting clamp, and igniter module.



Figure 12: Mounting clamp fabricated for securing the engine housing to the airframe support structure.



Figure 13: Fabricated engine support frame/mount rail, shown alongside additional components and assembly tools.



Figure 14: Fully assembled auxiliary jet engine mounted on its support frame with fuel tank and ignition wiring installed, prior to test firing.