

Engineering a low-cost Air Launch To Orbit (ALTO) system

Marco Capriz – Chief Technical Officer Indochina Space



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Abstract

The commercial micro-satellite sector remains fundamentally bottlenecked by the geographic and regulatory constraints of fixed ground-based launch infrastructure. Terrestrial spaceports impose rigid orbital insertion windows, complex downrange safety corridors, and narrow azimuth restrictions that frequently compromise mission architecture or delay operational deployment. This paper evaluates a low-cost, infrastructure-light alternative: an internal-carriage Air-Launch-to-Orbit architecture engineered around a nominal 110 kg payload to a 410 km polar low Earth orbit. It is based on the substantial work carried out by the School of Aerospace Engineering of Rome's Sapienza University that has been studying low cost methods for delivering small payloads to flexible low earth orbits.

By utilising standard, unmodified cargo transport aircraft—such as the C-130J platform—as a reusable first stage, this model establishes a framework of reversible integration. This bypasses the capital-intensive airframe modifications and complex aviation authority recertification pipelines that historically undermined the economic viability of air-launch systems. When paired with a lean, multi-stage solid-propellant booster, the system achieves substantially expanded azimuth freedom compared with fixed terrestrial launch sites. This architecture enables suitably licensed operators to conduct targeted orbital insertions from approved oceanic airspace, delivering a per-mission cost highly competitive with fixed terrestrial launch sites while providing unmatched operational flexibility and sovereign launch security.

System Concept and Baseline Assumptions

The baseline mass model presented in this paper is configured for a nominal 110 kg payload into a 410 km polar low Earth orbit. The launch vehicle has a total mass of 16.993 t, with a 1.9 t canister, keeping the extracted launch package within the 19t Type V platform extraction limit, subject to final verification of interface and restraint hardware masses. This mass margin is narrow and should be treated as a critical design constraint during sled, restraint, and separation-system qualification.

Azimuth Autonomy and Velocity Partitioning

Terrestrial launch infrastructures for small-satellite payloads are fundamentally bound by local geographic realities. A fixed ground-based launch pad introduces strict directional constraints driven by downrange flight corridors, stage-drop zones, and nearby populated landmasses. Rectifying a non-optimal initial launch location requires energy-intensive orbital manoeuvres, such as out-of-plane doglegs or inclination corrections, which degrade the net payload mass fraction delivered to orbit.

An Air-Launch-to-Orbit (ALTO) architecture achieves substantially expanded azimuth freedom by shifting the primary launch coordinate to international airspace. The carrier aircraft acts as an unconstrained, repositionable launch pad. By adjusting the flight heading over open ocean prior to payload deployment, the vehicle can inject directly into any targeted orbital plane—from equatorial to Sun-Synchronous Orbit (SSO)—without consuming onboard rocket propellant for out-of-plane steering.

The structural and mass advantages of this high-altitude mobility are mathematically quantified by mapping the physical benefits of the air-launch directly into the variables of the Tsiolkovsky rocket equation. The baseline capability of the rocket stack to achieve the final orbital velocity increment (Δv) is governed by the classic formulation:

$$\Delta v_{rocket} = \sum_{i=1}^3 I_{sp,i} \cdot g_0 \cdot \ln\left(\frac{m_{0,i}}{m_{f,i}}\right)$$

Where:

- i : number of rocket stages
- Δv : the rocket's velocity relative to its starting velocity
- I_{sp} : The rocket stage's specific impulse (determined by the engine manufacturer)

- g_0 : gravitational constant
- m_0 : initial stage mass
- m_f : final stage mass after fuel is spent

For a conventional ground-launched rocket, the vehicle itself must generate a total Δv that covers both the absolute horizontal orbital velocity (v_{orbit}) and the severe velocity losses imposed by the environment:

$$\Delta v_{ground_launcher} = v_{orbit} + v_{drag} + v_{gravity} + v_{steering}$$

An ALTO architecture fundamentally alters this velocity allocation. By partitioning the total energy requirement between the carrier aircraft and the multi-stage rocket stack, the net velocity increment the rocket must produce (Δv_{rocket}) is explicitly reduced by the mechanical states inherited at release:

$$\Delta v_{rocket} = \Delta v_{orbit} + \Delta v_{drag} + \Delta v_{gravity} + \Delta v_{steering} - v_{aircraft} \cdot \cos \theta$$

Releasing the vehicle at a nominal altitude of 7.0 km optimises the equation's variables via three distinct parameters:

1. **Reduction of the Required Velocity Increment (Δv_{rocket}):** The term $v_{aircraft}$ provides an immediate horizontal velocity contribution of 147m/s to 168m/s at launch, directly reducing the required orbital velocity deficit. Concurrently, by initiating flight above 75% of the dense lower atmosphere, the fluid resistance term (Δv_{drag}) is minimised. Because the vehicle does not need to fight through heavy sea-level air layers, the time spent climbing vertically is reduced, which significantly decreases the gravity losses ($+\Delta v_{gravity}$) accumulated during the ascent corridor. θ is the angle of the aircraft's velocity vector relative to the local horizontal plane at the moment of deployment. $\cos \theta$ is the geometric scaling factor that dictates how much of the carrier aircraft's forward speed contributes directly to the horizontal orbital plane. Because the aircraft executes a level drop ($\theta = 0^\circ$), $\cos(0^\circ) = 1$, ensuring that 100% of the aircraft's kinetic speed is inherited by the launcher as a direct credit, reducing the propulsive workload of the first stage.
2. **Maximisation of Specific Impulse (I_{sp}):** The specific impulse of a rocket motor is directly tied to the ambient atmospheric pressure (P_a) at the nozzle exit plane, expressed through the thrust equation relationship:

$$I_{sp} \propto [\dot{m}v_e + (P_e - P_a)A_e]$$

Where:

- $\dot{m}$ is the propellant mass flow rate, defining the mass of combustion gas exhausted through the nozzle per second (kg/s)
- v_e is the localised velocity of the supersonic exhaust gas as it crosses the nozzle exit plane
- P_e is the static exit pressure of the exhaust gas at the nozzle exit plane, determined by the nozzle's expansion ratio $\epsilon = A_e/A_t$
- At the 7.0 km ALTO release altitude, P_a is lower than at sea level, increasing the pressure-thrust contribution $(P_e - P_a)A_e$ and improving nozzle efficiency relative to sea-level ignition.
- A_e is the total cross-sectional area of the nozzle's exit plane.

Ground-launched first stages must compromise their expansion ratios to avoid destructive flow separation at sea level, which diminishes early engine efficiency. By igniting the first stage at 7.0 km where P_a is severely reduced, the exit-to-throat area ratio can be optimised closer to a vacuum profile. This maximises the pressure thrust term $(P_e - P_a)A_e$, raising the effective average I_{sp} across the stage 1 burn timeline to 285 seconds.

3. **Optimisation of the Mass Ratio ($\frac{m_0}{m_f}$):** Because the target Δv_{rocket} is lower and the linear multiplier I_{sp} is higher, the exponential mass ratio requirement is drastically reduced when the rocket equation is inverted to solve for structural allocation:

$$\frac{m_0}{m_f} = \exp\left(\frac{\Delta v_{rocket}}{I_{sp} \cdot g_0}\right)$$

The reduced dynamic pressure (q_{max}) experienced by the vehicle eliminates the need for heavy aerodynamic wings, complex thermal protection tiling, or thick reinforcing bulkheads required by externally slung systems (such as what is required in a Lockheed Martin Pegasus rocket). Stripped of these parasitic atmospheric structures, the airframe is optimised purely to contain internal combustion pressures, allowing the first-stage structural mass fraction ($\epsilon_1 = \frac{m_s}{m_0}$) to be reduced to a highly efficient 0.09. This optimisation ensures that a compact, low-mass solid booster can deliver competitive payload masses to orbit for a fraction of the capital cost of a ground-launched vehicle.

The initial conditions at deployment provide a significant atmospheric advantage:

- **Kinetic and Potential Energy Baseline:** The vehicle inherits an initial velocity vector (147m/s to 168m/s) and a potential energy baseline at an altitude of 7Km directly from the carrier aircraft.
- **Aerodynamic Drag Mitigation:** At 7 km, the vehicle is released above a large fraction of the densest lower atmosphere, reducing both dynamic pressure and nozzle backpressure compared with sea-level ignition. This lowers the maximum dynamic pressure q_{max} experienced by the vehicle, allowing for a lighter structural airframe design.
- **Thermodynamic Nozzle Expansion Efficiency:** Sea-level rocket nozzles suffer from plume under expansion losses due to atmospheric backpressure. Igniting the first stage in a reduced pressure environment allows the nozzle exit-to-throat area ratio to be optimised closer to a vacuum profile, maximising the average specific impulse I_{sp} throughout the first-stage burn.

VELOCITY COMPONENTS IN ALTO LAUNCH

Ground Launch vs. Air Launch: Velocity Budget and Partitioning

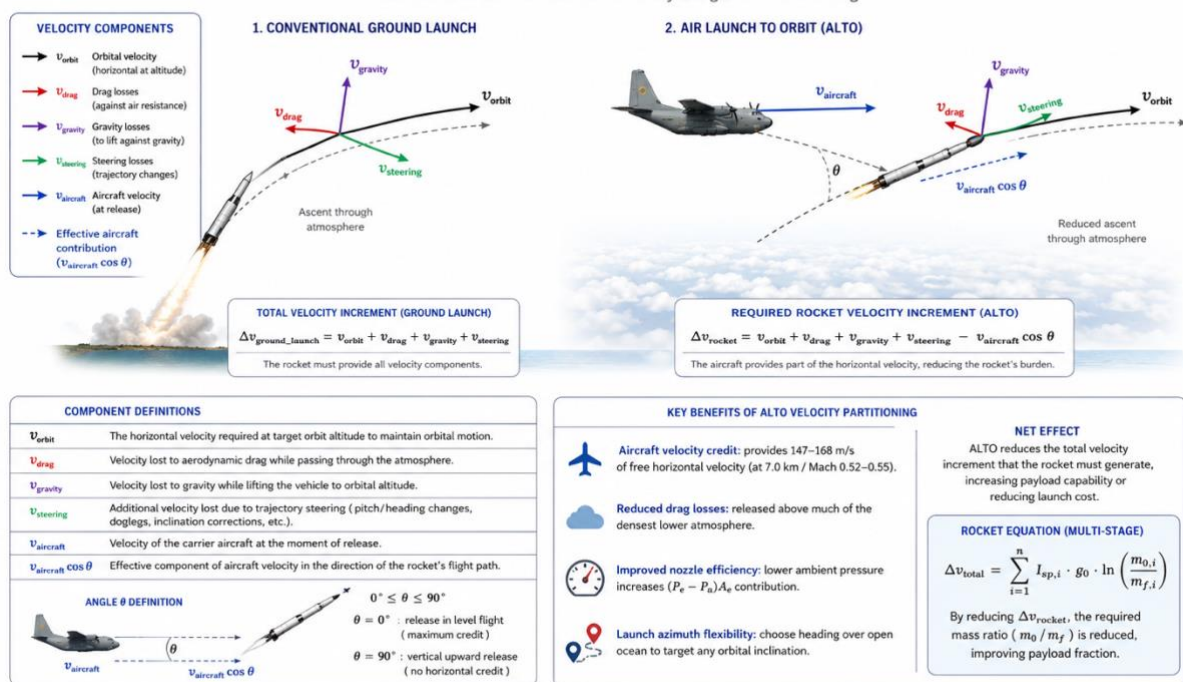


Figure 1: Velocity component comparison between ground and air launched rockets.

Δv budget table

Indicative Δv budget for nominal 110 kg / 410 km polar mission:

Component	Indicative value	Treatment
Orbital velocity at 410 km polar orbit	7,663 m/s	Required
Drag losses	+1,300 m/s	Add
Gravity losses	+800–1,000 m/s	Add
Steering / guidance losses	+300 m/s	Add
Aircraft velocity credit	–147 to –168 m/s	Subtract
Useful Earth-rotation contribution	~0 m/s	Negligible for polar insertion
Estimated rocket Δv requirement	9,895–10,116 m/s	Approximate
Working design value	~10.0 km/s	Preliminary

Table 1: Δv budget table

Trans-Ramp Kinematics and Aerodynamic Stabilisation

A core operational constraint an affordable ALTO programme is reversible aircraft integration: the deployment system must interface with a standard, unmodified commercial or military transport airframe. This approach avoids the high costs and long certification timelines associated with structural airframe modifications. The system we propose uses a standard roll-on/roll-off cargo configuration, utilising a C-130J Stretched aircraft as the baseline flight platform.

The launch phases are as follows:

[Level Cruise at 7.0 km] → [G11 Parachute Extraction] → [Evasion & Sled Jettison] → [Pitch Attenuation to 0°] → [First-Stage Ignition]

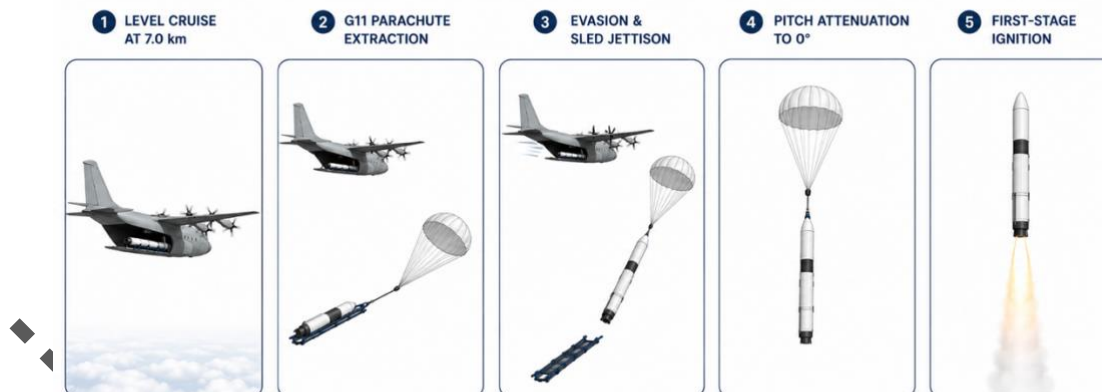


Figure 2: ALTO release, alignment, and ignition stages

The transition from internal cargo to stable, unpowered free-fall is modelled across three distinct physical phases:

Phase A: Parachute Extraction Dynamics

The launcher mass is 16.993 t, with an additional 1.9 t canister mass. The combined launcher-plus-canister extraction mass is therefore 18.893 t, compared with a stated Type V extraction limit of 19 t. This places the extraction sequence close to its allowable mass limit and makes snatch load, restraint release timing, sled friction, centre-of-gravity location, and parachute inflation transient loads critical qualification items.

The horizontal deployment sequence is initiated via a rear cargo ramp airdrop utilising a reusable Type V platform. A heavy-duty G11 parachute cluster pack is deployed into the trailing slipstream to extract the platform. Computational flight modelling by the School of Aerospace Engineering at Rome Sapienza University shows that the extraction sequence must account for complex transient fluid forces:

- **Snatch Forces:** High structural shock loads are generated during the initial inflation of the canopy line.
- **Added Mass and Porosity Effects:** The mass of the air column trapped within the canopy, combined with the geometric porosity of the fabric, governs the horizontal acceleration profile along the internal roller rails.
- **Shear and Structural Stresses:** High friction and shear loads are exerted on the Type V cradle interface, which must be absorbed without deforming the rocket airframe.

Phase B: Trans-Ramp Decoupling and Aircraft Evasion

The moment the Type V platform clears the cargo ramp, it enters the turbulent aerodynamic downwash of the carrier aircraft. To eliminate the risk of mechanical re-contact, the aircraft immediately executes an aggressive, pre-calculated climb-and-turn evasion profile. Simultaneously, pyrotechnic actuators on the extraction cradle trigger a clean separation event, jettisoning the high-drag Type V platform and parachute assembly away from the launcher.

Phase C: Aerodynamic Damping and Alignment

First-stage ignition occurs at approximately 7,000 m after clean separation from the carrier aircraft, following aerodynamic damping and attitude stabilisation.

Upon separation, the unpowered launcher enters a brief ballistic free-fall and experiences a significant pitch-up disturbance, reaching an initial pitch angle near 95° . The vehicle's mass distribution and aerodynamic centre cause it to behave like a heavy pendulum in the airflow. This geometric arrangement provides passive aerodynamic damping.

Flight simulations indicate that these high-amplitude pitch oscillations attenuate completely within 12 to 14 seconds after release. The vehicle's longitudinal axis aligns with a stable, forward-facing horizon profile (0° pitch relative to the relative wind). For a nominal release near 7.2 km, this stabilisation phase positions the vehicle for first-stage ignition at approximately 7,000 m.

These results should be treated as simulation-derived pre-test values and would require validation through instrumented drop tests before powered flight.

Solid Propulsion Synthesis and Thrust Vector Control

To achieve low development costs and eliminate the need for complex liquid-propellant turbopumps, plumbing, and active cargo-bay boil-off management, the launch vehicle uses a multi-stage stacked solid-propellant architecture. The preliminary mass distribution is driven by the canisterised internal-carriage configuration and the revised propellant allocation, although stage dry masses, interstage masses, avionics allocation, canister interface mass, and control-system consumables remain to be broken out.

The baseline vehicle parameters are defined by the optimised engineering matrix and are listed in the table that follows.

Parameter	Value
Total launcher mass	16.993 t
Canister mass	1.9 t
Launcher + canister mass	18.893 t
Type V extraction limit	19 t
Extraction mass margin	0.107 t
Stage 1 propellant	8,400 kg
Stage 2 propellant	2,500 kg
Stage 3 propellant	1,603 kg
Total propellant	12,503 kg
Non-propellant launcher mass	4,490 kg
Nominal payload	110 kg
Launcher length	11.957 m
Launcher diameter	1.6 m
Nominal orbit	410 km polar LEO
First-stage ignition altitude	~7,000 m

Table 2: Stage characteristics

Stage dry masses, interstage masses, avionics allocation, canister interface mass, and control-system consumables remain to be broken out in the next mass model revision.

This mass allocation is derived from numerical optimisation algorithms evaluating a database of 263 existing, off-the-shelf rocket motors to maximise total velocity capability. References are cited below.

The direction control architecture is based on a simple stage-specific control scheme. The first stage is controlled by jet vanes placed in the exhaust stream. Jet vanes provide robust thrust-vector authority during the dense-atmosphere early burn and avoid the mechanical complexity of gimbaling a large solid motor. Their penalty is a loss of nozzle efficiency and additional thermal loading, which must be accounted for in the first-stage performance model.

The second and third stages use cold-gas reaction control jets. At higher altitude, aerodynamic control authority is limited, and thrust-vectoring demands are lower. Cold-gas jets provide attitude control during upper-stage coast, pointing, separation, and ignition events without requiring flexible nozzle joints or liquid injection into the exhaust plume. The sizing of the cold-gas system must be included in the upper-stage dry mass and performance budget.

ALTO LAUNCH VEHICLE – DIRECTION CONTROL ARCHITECTURE

Stage-Specific Control Scheme: Jet Vanes (Stage 1) and Cold-Gas Jets (Stages 2 & 3)

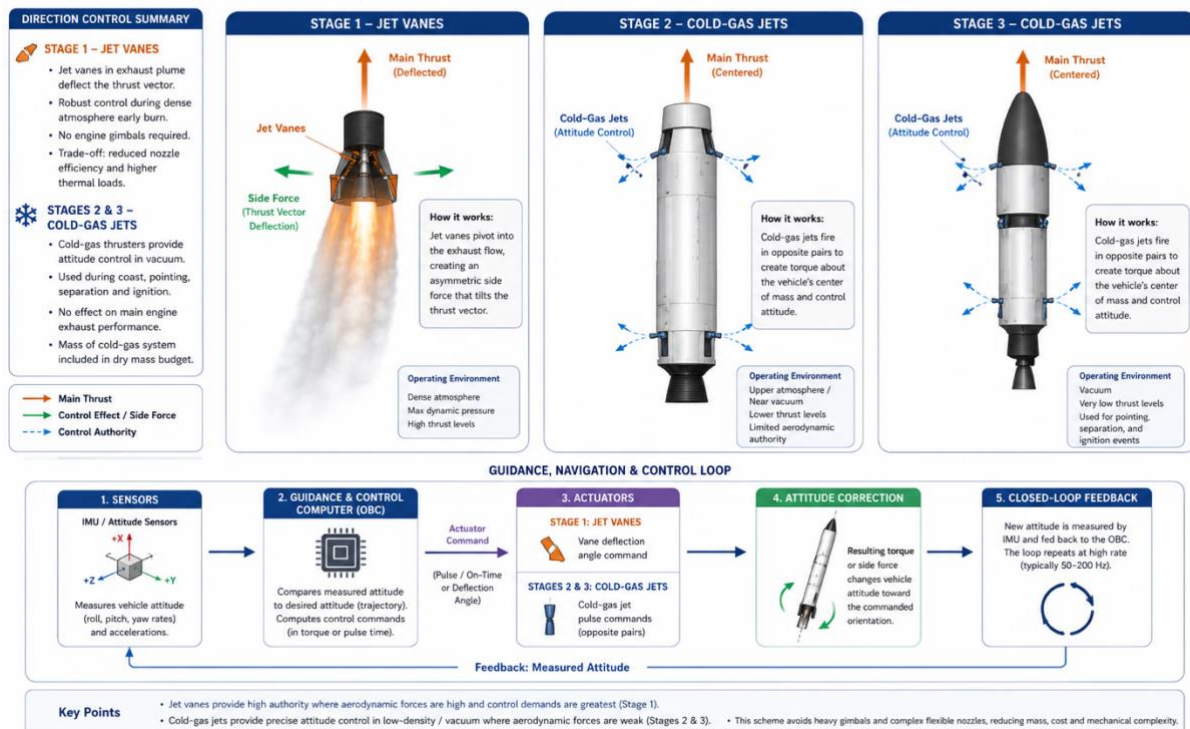


Figure 3: Stage thrust vector control options.

The guidance, navigation, and control (GNC) firmware operates via an On-Board Computer (OBC) validated using a high-fidelity Hardware-in-the-Loop (HIL) laboratory environment. The HIL test architecture utilises laboratory-grade accelerometers, gyroscopes, and a triaxial motion table to simulate actual flight trajectories. It integrates a full-length electrical power distribution system and real motor control actuators to model physical response latencies.

At the point of ignition, the first-stage motor fires at a 0° angle of attack to preserve the inherited horizontal airspeed vector. Immediately after ignition, the TVC system commands a gradual, automated Gravity Turn. The thrust vector slowly rotates upward, allowing downrange gravitational pull to naturally curve the ascent profile into an optimal, low-drag flight path that maximises payload capacity.

Financial Feasibility and Cost Comparison

To assess the commercial viability of an Air-Launch-to-Orbit (ALTO) programme, its capital requirements must be benchmarked directly against conventional fixed land-based micro-launchers. The financial comparison isolates fixed infrastructure expenses, vehicle integration methods, and non-recurring propulsion development capital.

Land-Based Spaceport Infrastructure vs. Reversible Airframe Integration

Terrestrial spaceports configured for small-lift vertical launch vehicles, such as the Rocket Lab Electron or Firefly Alpha class, carry a significant [non-recurring infrastructure cost](#).

- Fixed Ground Infrastructure:** Establishing a dedicated land-based pad, launch mount, structural integration tower, cleanrooms, lightning arrestor networks, fuel farms, and localised tracking arrays typically demands between US\$ 45 million per operational site.
- Capital Diversion:** Public financial data indicates that out of Rocket Lab's early cumulative expenditure of approximately US\$180 million, a substantial portion was diverted into permanent ground footprints. This included funding three independent launch pads (LC-1A, LC-1B, and LC-2), dual mission control rooms, and extensive acres of production facilities to support vertical launch operations.

Conversely, the ALTO architecture bypasses land-based capital expenditure through a framework of **reversible integration**.

- **Low Airframe Alteration Costs:** By treating the launch system as standard roll-on/roll-off cargo deployed via a C-130J Stretched airframe, the structural cost to modify the transport aircraft is effectively negligible. The aircraft undergoes no permanent structural, electronic, or aerodynamic alteration, remaining a standard cargo asset throughout its service life.
- **Platform Capital Expenditure Shift:** The infrastructure budget shifts entirely to heavy-drop hardware: the fabrication of the reusable Type V deployment sled, cradle separation mechanics, and COTS G11 extraction parachute assemblies. This hardware can be developed and qualified for under US\$ 1-2M, allowing an operational military or civil cargo asset to be temporarily drafted into launch services and returned to normal transport duties immediately after deployment.

Vehicle R&D Economics: Liquid Bipropellant vs. Stacked COTS Solid Motors

Developing a clean-sheet, liquid-bipropellant ground-launched rocket optimised for a 100-200 kg payload introduces complex engineering hurdles.

- **Liquid Vehicle Development Capital:** Developing liquid micro-launchers (such as Electron) tracking toward functional status requires approximately US\$200 million in dedicated R&D capital. This high financial barrier is driven by the close-tolerance complexities of 3D-printed electric-pump turbomachinery, cryogenic liquid oxygen plumbing, carbon-composite tanks, and automated active boil-off mitigation systems.
- **Solid Stack Cost Reduction:** The ALTO architecture drops vehicle development costs by utilising a stacked multi-stage configuration built around pre-certified solid rocket motors. Eliminating liquid pumps, complex valving, and cryogenic ground-support loops could lower the development entry barrier, with preliminary estimates around US\$150M depending on qualification scope, motor availability, range-safety requirements, and launch cadence.

By using indexed databases of existing sounding rocket motors and solid boosters, full operational vehicle qualification can be executed at a significant reduction from the cost required for custom liquid propellant architectures.

Operational Economics: Marginal Cost-per-Kilogram Analysis

To evaluate the commercial disruption of an internal-carriage Air-Launch-to-Orbit (ALTO) system, the recurring mission economics must be benchmarked directly against the modern industry standard for dedicated small-satellite launch: Rocket Lab's Electron. This analysis establishes an economic comparison based on a demanding, high-altitude mission profile: injecting a nominal 110 kg satellite into a 410 km polar low Earth orbit.

The Terrestrial Baseline: Dedicated Electron Mission Profile

Rocket Lab's Electron is a highly optimised vertical-launch vehicle utilising carbon-composite structures and liquid oxygen/RP-1 electric-turbopump Rutherford engines. To assess its cost-per-kilogram metric for this specific mission, the analysis applies public baseline parameters:

- **Dedicated Launch Pricing:** According to Rocket Lab's standard commercial pricing and public financial filings, the baseline cost for a dedicated Electron mission is US\$7.5 million (frequently scaling up to US\$8.5 million depending on bespoke orbital insertion requirements or custom payload integration).
- **Mass Performance to 700 km SSO:** While Electron can deliver up to 300 kg to a low-altitude, low-inclination orbit, its lift capacity degrades as altitude and inclination increase. For a high-altitude 700 km SSO, its payload performance capability is up to 200 kg.
- **The Dedicated Launch Premium:** If an operator requires a dedicated orbital path for a 100 kg satellite (to secure an exact insertion timeline or protect classified sovereign instruments), they must

purchase the entire vehicle capacity. Under this dedicated mission profile, the realised cost-per-kilogram is:

$$\text{Cost per Kg}_{\text{Electron dedicated}} = \frac{\$7,500,000}{100} = \$75,000/\text{Kg}$$

Even if the operator maximises Electron's full capacity for that specific orbit by flying a 200 kg co-manifested payload, the baseline efficiency is bound by fixed land-spaceport overheads, and the cost will still be \$37,500/kg.

The ALTO Cost Model: Parametric Assumptions

The ALTO economic framework eliminates the permanent capital amortisations built into terrestrial spaceport pricing. Because the carrier aircraft is an unmodified logistics asset, its fixed capital costs are distributed across global air cargo markets rather than being extracted solely from launch revenues.

To determine the marginal cost of a single ALTO mission launching a nominal 110 kg payload to a 410 km polar orbit, the model relies on three explicit, preliminary modelling assumptions:

1. **Assumption 1: Aircraft Wet-Lease and Flight Operations Overhead.** The system uses an un-modified civil L-100-30 or military C-130J aircraft. Based on heavy-cargo commercial charter flight rates, a complete wet-lease block (including standard flight-crew allocation, aviation fuel, hull insurance, and airspace clear-zone management over international waters) is budgeted at US\$25,000 per flight hour. Assuming a standard 4-hour mission profile (encompassing runway taxi, transit to the marine launch corridor, high-altitude drop sequence, and return to base), the total recurring aviation operations cost is US\$100,000 per launch.
2. **Assumption 2: Multi-Stage Rocket Stack Manufacturing Cost.** The three-stage solid-propellant launch vehicle is constructed around commercial off-the-shelf (COTS) solid rocket motors integrated with a carbon-phenolic flexible nozzle or a bolt-on Liquid Injection Thrust Vector Control (LITVC) assembly. Drawing from standard defence industrial manufacturing data for tactical solid motors of this scale (~12-tonne gross liftoff weight), the marginal unit production cost for the complete, integrated booster stack is scoped at US\$3.5 million per vehicle.
3. **Assumption 3: Range Operations and Payload Integration.** Because the launch is executed over open maritime sectors, ground support requirements are localised to standard cleanroom payload encapsulation and mechanical integration of the Type V drop pallet. Mobile telemetry tracking packs and regulatory range safety coordination are budgeted at a flat US\$200,000 per mission.

The Economic Inversion: Dedicated Efficiency Analysis

By mapping these parameters into the target 110 kg to 410 km SSO mission profile, the economic comparison demonstrates a major efficiency inversion for dedicated satellite operators:

$$\text{Cost per kg}_{\text{ALTO dedicated}} = \frac{\$3,800,000}{100} = \$38,000/\text{kg}$$

Economic Indicator	Rocket Lab Electron (Dedicated)	Reversible ALTO System (C-130 Baseline)
Total Per-Launch Cost	US\$7,500,000	US\$3,800,000
Max Capacity to 700 km SSO	200 kg	100 kg
Cost-per-Kg (At Max Orbit Capacity)	US\$37,500 / kg	US\$38,000 / kg
Realized Cost-per-Kg (For 100 kg Payload)	US\$75,000 / kg	US\$38,000 / kg

Table 3: ALTO launch cost/kg comparison

The common industry critique of air-launch systems—that they cannot compete with the mass-optimised efficiency of advanced liquid-propellant ground rockets—holds true only when evaluating a launcher that is consistently filled to maximum capacity.

However, for tactical defence assets, urgent replacement constellations, or institutional research payloads weighing ≤ 100 kg, the primary commercial metric is the absolute cost to clear the pad on a dedicated timeline.

When an operator requires a dedicated orbit, Electron's high performance cannot overcome the structural cost of its unutilised capacity, resulting in an expensive US\$ 75,000/kg. By substituting permanent ground infrastructure with an asset class transport aircraft, the ALTO architecture cuts the total mission costs nearly in half. It delivers dedicated, on-demand orbital access to high inclination orbits for US\$ 38,000/kg matching the ideal pricing efficiency of a fully loaded ground rocket while providing complete geographical, launch timing, and azimuth freedom.

Conclusion

Air Launch To Orbit offers a credible alternative to conventional small-launch infrastructure by shifting part of the launch system from a fixed terrestrial site to a mobile airborne release platform. The engineering case presented in this paper shows that a rear-ramp cargo aircraft, a roll-on/roll-off deployment sled, parachute extraction, canisterised launch-vehicle carriage, aerodynamic alignment, and a three-stage solid booster can form the basis of an infrastructure-light launch architecture for small payloads. The baseline model is centred on a 110 kg payload to a 410 km polar low Earth orbit, using a 16.993 t launcher and a 1.9 t canister, with first-stage ignition at approximately 7,000 m after separation from the carrier aircraft. Because the launcher-plus-canister mass approaches the Type V extraction limit, extraction loads, canister separation, mass-property control, aircraft clearance, jet-vane thermal loading, and upper-stage cold-gas control authority become primary qualification drivers.

The principal advantage of ALTO is not the aircraft's velocity contribution alone, which remains modest against the total orbital velocity requirement. Its stronger value lies in the combination of launch azimuth flexibility, reduced exposure to the densest lower atmosphere, improved nozzle operating conditions at first-stage ignition, and lower dependence on fixed launch-pad infrastructure. These factors can reduce operational rigidity and provide countries without established spaceports with a more flexible route toward sovereign small-satellite launch capability.

The proposed architecture also has practical constraints. Rear-ramp extraction, sled separation, aircraft evasion, passive pitch attenuation, solid-motor staging, thrust vector control, and range-safety compliance must all be validated through a disciplined qualification sequence. The simulation-derived deployment behaviour described in this paper should therefore be treated as the basis for staged testing, beginning with ground extraction trials, captive-carry assessment, unpowered drop testing, inert separation tests, and eventually suborbital propulsion demonstrations.

From an economic perspective, ALTO changes where the major costs occur. It reduces dependence on permanent ground infrastructure and avoids permanent modification of the carrier aircraft, but it does not remove the need for rigorous vehicle qualification, safety certification, operational control, telemetry, and regulatory approval. Its financial case is strongest where an operator already has access to suitable cargo aircraft, oceanic launch corridors, technical integration capability, and a national requirement for responsive small-payload access.

In summary, ALTO should be viewed as a technically plausible and strategically valuable small-launch architecture rather than a finished launch system. Its promise lies in combining existing airlift capability, mature heavy-drop techniques, and solid-propellant staging into a system that can be developed progressively and tested incrementally. With careful qualification, conservative safety margins, and transparent cost modelling, it could become a practical pathway toward lower-cost, sovereign, and operationally flexible access to low Earth orbit.

Acknowledgements and Reference Documents

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New perspectives in space launch activities (Technical presentation on air-launch dynamics, parachute extraction physics, and solid-motor stage optimisation by Prof. Paolo Teofilatto, Scuola di Ingegneria Aerospaziale, Sapienza Università di Roma).

MALMISAT proposal (Formal PNRM defence research proposal text outlining work packages, TRL progression, and COTS system integration strategy by Datasel s.r.l.)

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