Rise, Fly, Orbit

A Solar-Powered Electroaerodynamic Airship for Sustainable Access to Space

Vision and Physical Foundations

The dream of flight has always been a contest between patience and power. The early balloonists of the 18th century rose gently into the sky using buoyant gases, while the rocket engineers of the 20th century tore through it with fire. Both approaches share the same goal - escape the tyranny of gravity - but differ radically in philosophy. One uses the air as partner; the other treats it as obstacle. Between those two extremes lies a third way, one not yet realized in practice but no longer impossible in principle: a **solar-powered airship that can fly to orbit**, rising first by buoyancy, then by aerodynamic lift, and finally by centripetal support, all without chemical propellant.

At the heart of this concept is **electroaerodynamic (EAD) propulsion** - a form of electric thrust that uses electric fields to accelerate ions in air. The accelerated ions transfer momentum to neutral molecules, producing a bulk flow and a net thrust on the electrodes. In contrast to a rocket, which must carry reaction mass, or a propeller, which needs moving blades, electroaerodynamic propulsion operates with **no moving parts and no onboard exhaust**, only sunlight and air. When coupled to a high-efficiency solar array and mounted on a large, ultralight lifting body, it provides the missing ingredient for sustained acceleration in the upper atmosphere, where drag is small but air is still present.

The proposal is simple to describe but challenging to execute:

1. **Rise** - A buoyant airship filled with hydrogen or helium ascends passively to the stratosphere, far above weather and aviation traffic.
2. **Fly** - The airship accelerates horizontally using EAD thrust, slowly increasing velocity while climbing to thinner air to reduce drag.
3. **Orbit** - After weeks of continuous acceleration, centripetal force balances gravity; the vehicle no longer needs lift, having become a satellite by persistence rather than explosion.

The idea is not fantasy. Every step is rooted in known physics: buoyancy, solar power, electrostatics, and orbital mechanics. What changes is the timescale. Instead of minutes of combustion, we consider **weeks of sunlight**. Instead of tonnes of propellant, we rely on **fields and patience**.

The Energy of Orbit

Every discussion of spaceflight begins and ends with energy. The kinetic energy per kilogram of mass required to sustain a circular orbit around Earth is given by

$$E_k = \frac{1}{2}v^2$$

where v is the orbital speed. For low Earth orbit, $v \approx 7.8 \times 10^3\ \mathrm{m/s}$, so $E_k \approx 3.0 \times 10^7\ \mathrm{J/kg}$, or roughly **30 megajoules per kilogram**. That is the energy equivalent of burning about one kilogram of gasoline for every kilogram placed in orbit. It is a large number, but not astronomically large.

Now compare that to the continuous solar flux at the top of Earth's atmosphere: about **1,360 watts per square meter**. If we could convert even a small fraction of that into kinetic energy over days or weeks, we could, in principle, supply the required orbital energy. Modern high-performance photovoltaic arrays have specific powers on the order of several hundred watts per kilogram. At $P_{\mathrm{sp}} = 300\ \mathrm{W/kg}$, one kilogram of array produces 300 joules per second. Over a day (8.64×10^4 seconds), that is 2.6×10^7 joules - comparable to the orbital energy of one kilogram of mass.

That simple comparison shows the logic of this approach. The energy to orbit is available from the Sun in about **one day per kilogram of array**, if it can be efficiently turned into thrust. The practical challenge is that drag and inefficiencies absorb most of it. The solution is altitude and patience: work in the thin air where drag is low, and stretch the process over weeks instead of hours.

Trading Time for Propellant

Rockets solve the problem of drag by brute force - they go so fast that air is irrelevant. Airships, by contrast, work with the air; they can linger. If time is treated as an expendable resource, it can replace propellant mass. The airship's task is to maintain small but persistent acceleration over long periods, perhaps **on the order of** $10^{-3}\ \mathrm{m/s^2}$, until orbital velocity is achieved.

If the ascent to orbit takes three weeks, or roughly 1.8×10^6 seconds, the mean acceleration required is

$$\bar{a} = \frac{\Delta v}{t} = \frac{7.8\times10^3}{1.8\times10^6} \approx 4.3 \times 10^{-3}\ \mathrm{m/s^2}$$

- less than half a thousandth of Earth's gravity. Such accelerations are easily tolerable for an airship; they impose no structural strain. The only difficulty is **sustaining it**, given the small amount of thrust available per unit power.

If the vehicle has a mass of $10^3\ \mathrm{kg}$, an average acceleration of $4 \times 10^{-3}\ \mathrm{m/s^2}$ requires only about **4 newtons of net thrust** - less than the weight of an apple. The apparent absurdity of reaching orbit with the thrust of an apple vanishes when time is allowed to stretch to weeks.

Buoyancy and the Path to Thin Air

The airship begins its journey as any lighter-than-air craft does: by displacing air with a lighter gas. The buoyant force is given by

$$F_b = (\rho_{\text{air}} - \rho_{\text{gas}})gV$$

where V is the gas volume and ρ the respective densities. Near sea level, $\rho_{\text{air}} \approx 1.2\ \text{kg/m}^3$, $\rho_{\text{He}} \approx 0.18\ \text{kg/m}^3$, and $\rho_{\text{H}_2} \approx 0.09\ \text{kg/m}^3$. Hydrogen provides slightly more lift, about **1.1 kg per cubic meter**, compared to **1.0 kg per cubic meter** for helium. The difference seems small but compounds over thousands of cubic meters.

Hydrogen thus offers a measurable performance edge, though at the cost of flammability. It requires strict electrical zoning and venting protocols, especially since the vehicle also carries high-voltage electrostatic systems. Helium offers lower lift but complete inertness. Both gases are viable; the choice depends on mission risk tolerance. In early public or populated-area tests, helium is preferable. For remote or orbital attempts, hydrogen may be justified.

As the vehicle rises, air density falls roughly exponentially with scale height $H \approx 7.5\ \text{km}$. At 30 km, the density is about $1/65$ of sea level; at 50 km, $1/300$. Buoyancy weakens correspondingly, but so does drag. The craft is designed to reach **neutral buoyancy** at an altitude where solar intensity remains high but dynamic pressure is minimal - roughly 30–40 km in the stratosphere. From there, it begins horizontal acceleration.

Lift, Drag, and Dynamic Pressure

To maintain altitude while accelerating, the airship may rely partly on **aerodynamic lift**. For a lifting-body hull, the lift and drag forces are

$$F_L = \tfrac{1}{2}\rho v^2 A C_L, \qquad F_D = \tfrac{1}{2}\rho v^2 A C_D$$

where A is the reference area, C_L and C_D the lift and drag coefficients. Because ρ is small at altitude, these forces are small; the vehicle compensates by having **a large area** and **low weight**.

The ratio $L/D = C_L/C_D$ sets the efficiency of aerodynamic flight. Modern gliders can exceed $L/D = 50$ in dense air. An ultralight airship designed with extreme smoothness and minimal appendages could plausibly maintain an effective L/D of 10–20 even in thin air. But as the air thins further, the transition to orbital flight is not limited by lift - it is governed by **drag power**.

The power needed to overcome drag is

$$P_D = F_D v = \tfrac{1}{2}\rho v^3 A C_D$$

and it scales with the cube of velocity. This is why rockets accelerate quickly: if they linger, drag consumes their energy exponentially. The airship takes the opposite route: it accelerates where ρ is so small that P_D remains bounded even at kilometers per second.

If, for instance, $\rho = 10^{-5}\ \text{kg/m}^3$ (typical near 60 km altitude), $A = 100\ \text{m}^2$, $C_D = 0.05$, and $v = 1,000\ \text{m/s}$, then

$$P_D = 0.5 \times 10^{-5} \times (10^3)^3 \times 100 \times 0.05 = 2.5 \times 10^4\ \text{W},$$

or 25 kW - easily within solar reach. By contrast, at sea level the same configuration would need 25 gigawatts.

The rule is simple: **thin air buys time**, and **time replaces propellant**.

The Electroaerodynamic Opportunity

In the early 20th century, physicists observed that strong electric fields near sharp electrodes in air produce a faint blue corona and a subtle airflow. This “electric wind” results from momentum transfer between ions and neutrals. It was treated mostly as a curiosity until high-voltage electronics matured. When properly arranged, the effect can produce measurable thrust.

Electroaerodynamic propulsion works by applying a high voltage between an **emitter**, a thin wire or edge that produces ions, and a **collector**, a broader electrode that receives them. The ions accelerate in the electric field, collide with neutral air molecules, and impart forward momentum to the gas. The device feels an equal and opposite thrust.

While early demonstrations were modest, recent experiments - including a fixed-wing **ion plane** flown by MIT in 2018 - proved that steady, silent flight is possible. Yet the idea predates that milestone. Years earlier, research into **Maxwell-tensor-based formulations** of electroaerodynamic thrust had shown how the same physics could scale to larger geometries and thinner air. In that formalism, the thrust arises not from “wind” but from **electromagnetic stress** integrated over the volume of the discharge region.

The relevant equation is derived from the **Maxwell stress tensor** $\mathbf{T}$, which for an electrostatic field is

$$\mathbf{T} = \varepsilon \left(\mathbf{E}\mathbf{E} - \tfrac{1}{2}E^2\mathbf{I}\right)$$

where ε is the permittivity of the medium, $\mathbf{E}$ is the electric field vector, and $\mathbf{I}$ the identity tensor. The net electromagnetic force on a body is obtained by integrating this tensor over its surface:

$$\mathbf{F} * \mathrm{EM} = \oint *\partial V \mathbf{T} \cdot \mathbf{n}, dS.$$

Within the ionized region, this simplifies to a **volume force density**

$$\mathbf{f} = \rho_e \mathbf{E} - \tfrac{1}{2}E^2 \nabla \varepsilon,$$

where ρ_e is the local charge density. In a gas of roughly uniform permittivity, the second term vanishes, leaving the elegant **Coulomb body force**

$$\mathbf{f} \approx \rho_e \mathbf{E}.$$

This compact expression is the essence of electroaerodynamic propulsion: wherever an electric field and space charge coexist, a net body force acts on the medium.

The ions themselves are few, but their momentum is relayed to the neutrals through collisions. The mean free path λ between collisions determines how momentum diffuses; it scales inversely with pressure. At lower pressures, ions travel farther per collision, and the efficiency of momentum transfer changes. There exists an **optimal pressure band** where ions can still collide frequently enough to push the gas but not so frequently that they waste energy heating it. For Earth's atmosphere, that band lies roughly between a few torr and a few millitorr - exactly the range encountered between 40 and 80 kilometers altitude.

The airship's envelope thus becomes the ideal host for electroaerodynamic tiles operating in their natural environment. The atmosphere itself is the reaction mass.

The Physics of Electroaerodynamic Propulsion

At first glance, electroaerodynamic propulsion seems improbable. The idea that a silent, motionless set of electrodes could generate thrust strong enough to move an airship feels at odds with everyday experience. The absence of visible reaction mass or moving machinery challenges intuition. Yet every ion that drifts in an electric field carries momentum, and momentum is conserved. The field acts as an invisible lever, and the air as its working fluid.

The foundations of this phenomenon rest not in exotic plasma physics but in **Maxwell's equations** and their mechanical expression, the **Maxwell stress tensor**. This tensorial formulation makes clear that electric fields are not just patterns of potential - they store and transmit mechanical stress in the surrounding medium.

Field Stress and the Coulomb Body Force

The **Maxwell stress tensor** in electrostatics is

$$\mathbf{T} = \varepsilon \left(\mathbf{E}\mathbf{E} - \tfrac{1}{2}E^2\mathbf{I}\right)$$

where ε is the permittivity, $\mathbf{E}$ the electric field, and $\mathbf{I}$ the identity tensor. The first term represents the directional pressure along the field lines, and the second term the isotropic tension resisting field divergence.

The **net electromagnetic force** on a body immersed in such a field is the surface integral of this tensor:

$$\mathbf{F} * \mathrm{EM} = \oint * \partial V \mathbf{T} \cdot \mathbf{n}, dS.$$

Physically, this expression tells us that the electric field exerts a stress on the boundaries of any region containing charge or dielectric gradients. But it can be rewritten in a more local, volumetric form using the divergence theorem:

$$\mathbf{f} = \nabla \cdot \mathbf{T} = \rho_e \mathbf{E} - \tfrac{1}{2}E^2 \nabla \varepsilon.$$

The first term, $\rho_e \mathbf{E}$, is the familiar **Coulomb body force**: a charge density experiencing a field. The second term only matters where the medium's permittivity changes rapidly, such as at material boundaries. In air, ε is essentially uniform, so $\nabla\varepsilon \approx 0$, leaving

$\mathbf{f} = \rho_e \mathbf{E}$.

This deceptively simple equation encodes the entire principle of electroaerodynamic propulsion. If there exists a volume of gas in which ions (with density ρ_e) experience an electric field $\mathbf{E}$, then a **net force density** acts on that gas. The magnitude of the total thrust is the volume integral of $\rho_e \mathbf{E}$ over the discharge region:

$\mathbf{F} = \int_V \rho_e \mathbf{E}, dV$.

The electrodes feel the equal and opposite reaction, producing thrust.

Momentum Transfer and the Role of Collisions

Ions in air rarely travel far before colliding with neutral molecules. The **mean free path** λ is inversely proportional to the gas pressure p and cross-section σ:

$\lambda \approx \frac{kT}{\sqrt{2},\pi d^2 p}$

where d is the molecular diameter. At sea level, λ is tiny - on the order of tens of nanometers. In the mesosphere (around 70 km), λ stretches to millimeters or centimeters.

When an ion accelerates under the field, it transfers momentum to neutrals through collisions. Each collision shares a fraction of the ion's directed momentum; the cumulative effect is a **bulk neutral flow** - what experimenters call *ionic wind*. The gas moves from emitter to collector, and the electrodes experience an opposite reaction thrust.

In very dense air, ions collide too often; their drift velocity saturates, and energy is lost as heat. In extremely thin air, collisions are too rare; the ions fly freely but do not effectively drag the neutrals along. Between these extremes lies a **sweet spot** where the mean free path allows efficient momentum transfer - precisely the region the airship traverses on its way to space.

At pressures of about 10^{-2} to 10^{-4} bar (corresponding to 40–80 km altitude), ions can accelerate over macroscopic distances before colliding, yet collisions still occur frequently enough to produce thrust. The **electroaerodynamic coupling** between field and gas is at its most favorable.

The Power–Thrust Relationship

The electrical power delivered to a discharge is $P = \int_V \mathbf{J} \cdot \mathbf{E}, dV$, which is approximately IV for steady current I and voltage V. The useful mechanical output is the thrust times velocity of the accelerated air mass, but in steady-state propulsion we are mostly interested in the **thrust-to-power ratio**, T/P.

Empirical studies have reported T/P values ranging from a few millinewtons per watt ($\mathrm{mN/W}$) to nearly $0.1\ \mathrm{N/W}$ under optimized conditions. In atmospheric air at standard pressure, EAD is inefficient; but at reduced pressures, ion mobility increases and current density can be sustained at lower voltages, improving T/P.

A simple dimensional argument links the body-force density $f = \rho_e E$ to the current density $J = \rho_e \mu E$, where μ is the ion mobility. Then

$$f = \frac{J}{\mu},$$

so for a given current density, a higher mobility (achieved at lower pressure) yields more thrust per current. The total electrical power is $P = JEV$, so the **thrust-to-power** scales as

$$\frac{T}{P} \approx \frac{1}{E\mu},$$

implying that lower electric fields or higher ion mobility increase efficiency. But lower E also reduces current and thus total thrust, so there is again an optimum regime.

These relations are not theoretical curiosities - they determine the design of each EAD tile. At a given altitude, the voltage, gap distance, and emitter geometry must be tuned so that the **Paschen curve** (which relates breakdown voltage to pressure–distance product) is satisfied but not exceeded.

Paschen's law for air may be expressed approximately as

$$V_b = \frac{Bpd}{\ln(Apd) - \ln[\ln(1 + 1/\gamma_{\mathrm{se}})]}$$

where A and B are empirical constants and γ_{se} is the secondary electron emission coefficient. The airship's variable geometry allows d, the electrode spacing, to be adjusted dynamically to maintain efficient corona discharge without arcing as the ambient pressure falls during ascent.

Field Geometry and Stress Topology

Early "lifter" demonstrations used a thin wire as emitter and a flat foil as collector. The field lines were strongly curved, and most energy went into maintaining the corona rather than producing useful thrust. Efficiency was poor because the **Maxwell stress field** was not aligned with the desired thrust direction.

The key insight - developed in theoretical work preceding MIT's ionoplane - was to treat the electric field not as a byproduct but as the primary design variable. The thrust arises from the **integral of electromagnetic stress** along the field lines, so the goal is to shape those lines to be parallel and consistent across a wide region. The analogy is aerodynamic: just as smooth laminar flow minimizes drag, smooth electrostatic field topology maximizes directed stress.

This "field-topology engineering" reframes the device as an *electrostatic actuator* rather than a plasma toy. By controlling electrode curvature, guard potentials, and dielectric layers, one can make $\mathbf{E}$ nearly uniform across the acceleration path, producing quasi-linear stress and avoiding the destructive self-focus that causes arcing.

The consequence is scalability. When electrodes are tessellated into square-meter tiles, each with its own high-voltage converter and control logic, the entire airship envelope can be turned into a giant distributed EAD array. There are no moving parts to synchronize, only fields to coordinate.

Thrust Density and the Path to Scalability

The volumetric body-force density is $f = \rho_e E$. The charge density in a typical corona discharge at atmospheric pressure is on the order of 10^{-5} to $10^{-3}\ \mathrm{C/m^3}$. At reduced pressure, it can fall somewhat, but the electric field E can be increased safely to tens of kilovolts per centimeter without breakdown.

If $\rho_e = 10^{-4}\ \mathrm{C/m^3}$ and $E = 10^5\ \mathrm{V/m}$, the force density is $f = 10\ \mathrm{N/m^3}$. Spread over a $1\ \mathrm{m}$-thick active region, that gives a surface pressure of $10\ \mathrm{N/m^2}$ - equivalent to a few millipascals. That may sound small, but over thousands of square meters it becomes significant. A 1000 m^2 surface with $10\ \mathrm{N/m^2}$ stress produces $10,000\ \mathrm{N}$ of thrust, enough to accelerate a multi-ton vehicle at milligee levels - precisely the regime required for weeks-long orbit raising.

Such estimates illustrate why EAD, despite its low power density, becomes feasible for **large, lightweight structures** in thin air. Unlike a rocket nozzle, which gains efficiency only when power density is high, EAD gains advantage from area. The airship's envelope provides abundant area; turning it into an active surface is a natural match.

The Upper-Atmosphere Sweet Zone

Every physical system has an operating niche. For EAD propulsion, the best regime is where the gas pressure is low enough to permit high voltages and long ion mean free paths, but not so low that the plasma becomes collisionless.

Below about 20 km, the atmosphere is too dense: ion mobility is low, breakdown voltages are high, and energy is wasted heating the gas. Above roughly 100 km, the air becomes too rarefied: ionization cannot be maintained continuously, and the neutral reaction mass vanishes. Between about 40 and 80 km lies a **transitional band** - the lower mesosphere - where EAD propulsion can produce its best thrust-to-power ratios.

Conveniently, this is also the altitude range where solar power remains nearly unattenuated and aerodynamic drag is orders of magnitude smaller than at sea level. It is a narrow but forgiving window, a natural corridor for a new kind of vehicle: neither airplane nor rocket, but something that lives in the overlap between them.

Efficiency and Energy Flow

At any instant, the electrical power input P is divided among:

1. **Useful mechanical thrust power** $P_T = Tv_{\text{eff}}$, where v_{eff} is the effective exhaust velocity of the air flow.
2. **Ionization losses** P_i, the energy required to sustain the plasma.
3. **Resistive losses** P_r, due to ohmic heating and leakage.
4. **Radiative losses** P_γ, emitted as light (the familiar corona glow).

The overall efficiency is $\eta = P_T/P$. Experiments suggest η can reach a few percent in dense air and potentially tens of percent in optimized low-pressure operation. While modest, these numbers are adequate for a solar-powered system operating over long durations, where efficiency can be traded against time.

Unlike chemical propulsion, which must reach high efficiency per second to minimize fuel, a solar EAD airship can afford inefficiency if it can **operate indefinitely**. The metric of success is not specific impulse but **specific patience**: joules accumulated over days.

From Maxwell Stress to Macroscopic Thrust

To illustrate the connection between field theory and everyday experience, consider the parallel-plate capacitor in a vacuum. The pressure between the plates is $p = \frac{1}{2}\varepsilon_0 E^2$. If $E = 10^6\ \mathrm{V/m}$, then $p \approx 4.4\ \mathrm{N/m^2}$. Multiply by area, and you get the mechanical force required to separate the plates. Electrostatic stress is literally mechanical pressure.

EAD propulsion replaces one plate with the atmosphere itself. The ions are the medium through which the field's stress is transmitted. Instead of static pressure, we get directional flow. The equation $\mathbf{f} = \rho_e \mathbf{E}$ is the dynamic analog of that static capacitor pressure.

When summed over the surface of the airship, the integrated stress becomes a net thrust vector, just as the integrated pressure over a wing's surface yields lift. The analogy is deep: aerodynamic lift is the momentum flux of air deflected by a surface; EAD thrust is the momentum flux of ions accelerated by a field.

The MIT Ionoplane and Experimental Proof

For decades, skeptics dismissed EAD as a laboratory curiosity. Then, in 2018, a small fixed-wing aircraft built by MIT demonstrated **steady, propellerless flight** powered solely by electroaerodynamic thrust. The "ionoplane" weighed about 2.5 kilograms and flew tens of meters under battery power. Its thrust-to-weight ratio was small, but the achievement was historic: the first heavier-than-air vehicle sustained in flight by ionic propulsion.

Crucially, the theory and conceptual groundwork that led to that demonstration were already independently under development. The theoretical framework presented in *Electroaerodynamic Propulsion* (see https://farid.ps/articles/electroaerodynamic_propulsion/en.html) had described the same mechanism in terms of **Maxwell stress** and **Coulomb body force** years earlier, emphasizing field topology and scalability rather than corona chemistry.

The MIT ionoplane proved the effect's practicality in dense air. The Rise–Fly–Orbit project aims to extend it into thin air, where the physics become even more favorable. If a small airplane can fly at 1 bar, a solar airship can fly to orbit at microbars, given enough patience and sunlight.

The Virtue of Simplicity

EAD propulsion is conceptually elegant: no moving parts, no combustion, no high-speed exhaust, no cryogenics. Its components are robust by nature - electrodes, dielectrics, power converters, and photovoltaic skins. The system scales naturally with area, not mass.

The technical challenge shifts from thermodynamics to **electrical engineering and materials science**: preventing corona erosion, managing charge leakage, and maintaining high-voltage isolation in varying pressures. These are solvable with modern materials and microelectronics.

Because the EAD mechanism depends only on field geometry and ion mobility, it is **inherently modular**. Each square meter of the airship's skin can be treated as a tile with known T/P and voltage characteristics. The vehicle's total thrust is the vector sum of thousands of independent tiles. This modularity allows graceful degradation - failure of a few modules does not compromise the whole craft.

The Electroaerodynamic Airship as a System

When coupled to solar power, EAD propulsion becomes not just a thrust source but a **climate system** for the vehicle. The same fields that generate thrust also ionize trace gases, reduce surface charging, and potentially influence boundary-layer properties. The electric field can even serve as a tunable "electrostatic sail," interacting weakly with Earth's magnetic field or the ambient plasma in the upper atmosphere.

In the long term, one can imagine active control of drag by manipulating surface charge distributions - an **electrodynamic drag shield** that varies local field stress to trim flight path without mechanical control surfaces.

These possibilities move EAD propulsion beyond a curiosity and into the realm of a general-purpose, solid-state flight control technology - applicable wherever gases or plasmas can be polarized and accelerated by electric fields.

Engineering Architecture and Flight Dynamics

The fundamental advantage of the Rise–Fly–Orbit concept lies not in exotic materials or revolutionary physics, but in the **reordering of familiar principles**. Buoyancy, solar power, and electrostatics are all well-understood. What is new is the way they are sequenced into a single continuum: *an ascent without a moment of discontinuity*.

Rockets pass through distinct regimes - launch, burnout, coast, orbit. The electroaerodynamic airship, by contrast, experiences only gradual transitions. It rises by lightness, flies by lift, and orbits by inertia. Every stage blends into the next, governed by the same steady interplay of buoyant, aerodynamic, and electrostatic forces.

The Envelope: Structure as Atmosphere

The envelope of the airship must satisfy contradictory demands: it must be both **light and strong**, **conductive and insulating**, **transparent to sunlight but resistant to radiation**. These are reconcilable through layered construction.

The outermost layer can be a **metalized polymer** - for example, a thin film of aluminized Kapton or polyethylene terephthalate. This layer provides UV shielding and serves as a partial electrode surface for the EAD tiles. Beneath it lies a **dielectric layer** that prevents unwanted discharge and defines the gap to the inner collector electrode. The inner structure is a network of tensioned membranes and spars that maintain the overall geometry at a small internal overpressure, on the order of $\Delta p \approx 300\ \mathrm{Pa}$ - only a few thousandths of atmospheric pressure.

That overpressure is enough to keep the envelope taut but not enough to cause significant structural mass. In effect, the entire vehicle is an enormous, lightweight capacitor, its skin charged and alive with field lines.

The internal volume is filled with a lifting gas - hydrogen or helium. Because the required overpressure is small, the load-bearing demands on the material are modest. The main challenge is gas permeability and UV degradation over long missions, both addressable with modern coatings and layered films.

Hydrogen or Helium

The gas choice shapes the personality of the vehicle.

Hydrogen offers the highest lift, providing roughly 10% more buoyancy than helium. That difference becomes substantial when total volume reaches millions of cubic meters. Hydrogen is also easier to source and can even be generated in situ by solar-powered electrolysis of water. Its disadvantage, of course, is flammability.

The presence of high-voltage electrostatics makes hydrogen management nontrivial. Safety depends on meticulous compartmentalization, electrostatic shielding, and ventilation. The EAD modules themselves are sealed and separated from the gas cells by dielectric barriers, and potential differences across the hull are minimized by symmetrical charge distribution.

Helium, in contrast, is inert and safe but provides less lift and higher cost. Its main drawback is scarcity; large-scale use could strain supply. For early test vehicles and public demonstration flights, helium is the prudent choice. For operational orbital attempts in remote corridors, hydrogen may be justified by performance and cost.

Either way, the envelope design is largely compatible; only the gas-handling and safety systems differ.

Solar Power and Energy Management

The Sun is the craft's engine. Every watt of electrical energy begins as sunlight absorbed by the photovoltaic skin.

High-efficiency, ultralight photovoltaics - thin-film gallium-arsenide or perovskite composites laminated onto the airship surface - can achieve specific powers approaching **300–400 W/kg**. The arrays are arranged conformally to maintain aerodynamic smoothness. Power management is distributed: each panel section feeds a local maximum power point tracker (MPPT) that regulates voltage to the high-voltage bus supplying the EAD tiles.

Because the vehicle experiences day–night cycles, it carries a modest **energy buffer** - lightweight batteries or supercapacitors - to sustain low-level operations through darkness. But these are not large; the system's design philosophy is **direct solar drive**, not stored energy. At orbital altitudes, the craft can chase sunlight almost continuously, dipping into eclipse only briefly.

Thermal control is handled radiatively. With negligible convection at high altitude, heat rejection relies on **high-emissivity surfaces** and conduction paths to radiators. Fortunately, the EAD process is relatively cool - there is no combustion - and the main thermal load is from absorbed sunlight.

The Electroaerodynamic Tiles

Each square meter of the envelope functions as an **EAD tile** - a self-contained propulsion cell comprising an emitter, a collector, and a small control circuit. The emitter may be a fine grid of sharp points or wires at high positive potential, while the collector is a broad mesh held near ground or at negative potential. The space between is a controlled discharge region.

When energized, the tile establishes an electric field E, generates a charge density ρ_e, and produces a local thrust $f = \rho_e E$ directed tangentially along the surface. By modulating the voltages on different tiles, the airship can steer, pitch, and roll without moving parts.

Adaptive geometry is key. As ambient pressure falls with altitude, the mean free path increases. To maintain efficient discharge, the effective gap distance d between emitter and collector must increase roughly in proportion to $1/p$. This can be achieved with **flexible, inflatable dielectric spacers** that expand slightly as the external pressure drops, or with **electronic modulation** of potential gradients to emulate larger gaps.

Every tile reports telemetry - current, voltage, arc counts - to a central controller. If a tile experiences arcing or degradation, it is shut down and bypassed. The modular design means the loss of individual tiles barely affects total thrust.

From Buoyancy to Thrust

The flight begins gently. At launch, the airship rises buoyantly to the stratosphere. During ascent, the EAD system operates in low-power mode, providing minor thrust for stabilization and drift control.

At about 30–40 km altitude, where the air is thin but still collisional, the main acceleration begins. The airship turns gradually to horizontal flight, orienting its long axis in the direction of intended orbital motion.

Initially, thrust is balanced between horizontal acceleration and lift augmentation. The vehicle's residual buoyancy offsets much of its weight; the EAD thrust provides both forward and slightly upward components. As velocity increases, dynamic lift grows and buoyancy becomes negligible. The transition is smooth - there is no “takeoff moment” because the airship was never sitting on a runway to begin with.

The Three-Week Climb

Consider a representative vehicle mass of $m = 2000\ \mathrm{kg}$. To achieve orbital velocity of $v = 7.8 \times 10^3\ \mathrm{m/s}$ in $t = 1.8 \times 10^6\ \mathrm{s}$ (three weeks), the required average thrust is

$$T = m\frac{v}{t} = 2000 \times \frac{7.8\times10^3}{1.8\times10^6} \approx 8.7\ \mathrm{N}.$$

Eight newtons - the weight of a small orange - is the total thrust needed to reach orbit if applied continuously for three weeks.

If the system's T/P is $0.03\ \mathrm{N/W}$, typical of efficient EAD operation at low pressure, then producing 8.7 N requires only about **290 W** of power. This seems astonishingly small, and in practice, additional drag losses will raise the requirement to tens of kilowatts. But solar panels covering a few hundred square meters can easily provide that.

Let's include a safety factor of 100 for inefficiencies and drag: about **30 kW** of electrical power. With 15% overall efficiency from sunlight to thrust, the vehicle must harvest around **200 kW of solar power**. That corresponds to about 700 square meters of active solar area at 300 W/m^2 output - an area smaller than a football field, easily integrated onto an airship of 100 meters length.

This simple arithmetic demonstrates that the **energy flow is plausible**. What rockets achieve through power density, the airship achieves through patience and area.

Drag and the High-Altitude Corridor

Drag remains the principal energy sink. The drag force is $F_D = \frac{1}{2}\rho v^2 A C_D$, and the corresponding power is $P_D = F_D v = \frac{1}{2}\rho v^3 A C_D$.

At 50 km, $\rho \approx 10^{-3}\ \mathrm{kg/m^3}$. If $A = 100\ \mathrm{m^2}$, $C_D = 0.05$, and $v = 1000\ \mathrm{m/s}$, then

$$P_D = 0.5 \times 10^{-3} \times (10^3)^3 \times 100 \times 0.05 = 2.5 \times 10^6\ \mathrm{W}.$$

That's 2.5 megawatts - too high. But at 70 km, where $\rho = 10^{-5}\ \mathrm{kg/m^3}$, the same configuration yields only 25 kW of drag power. Hence the strategy: **climb as you accelerate**, staying on a trajectory where ρv^3 remains roughly constant.

The optimal corridor is one of steadily thinning air, perhaps 40–80 km altitude, where the atmosphere provides just enough neutral density for EAD to function but little enough to keep drag manageable.

Vehicle Control and Stability

Without propellers or fins, stability comes from field symmetry. Differential activation of tiles provides torque. If the forward tiles on the left produce slightly more thrust than those on the right, the craft yaws gently. Pitch control is achieved by biasing top and bottom tiles. Because the thrust per tile is small, response is slow, but the craft operates in a regime where agility is unnecessary.

Attitude sensors - gyroscopes, accelerometers, star trackers - feed a digital control system that maintains orientation for maximum solar incidence and correct flight path. The vast size of the vehicle and the slow flight regime make it remarkably stable.

Thermal and Electrical Safety

EAD operation involves tens to hundreds of kilovolts at low current. In the thin, dry air of the stratosphere, insulation behaves differently: arcs can propagate long distances across surfaces. The airship's electrical design thus treats the entire structure as a controlled potential system. Conductive paths are redundant, with isolation layers separating gas cells from HV lines.

Arcing is not catastrophic - it tends to be local and self-quenching - but it can damage electrodes. Each tile monitors its current waveform; if a discharge spikes, the controller reduces voltage or switches off the affected module for several seconds.

Thermally, the absence of convection means any local heating must be spread by conduction to radiative panels. The materials are chosen for high emissivity and low absorption in the infrared, allowing excess heat to radiate into space.

Scaling and Modularity

The system scales by tiling, not by increasing voltage. Doubling the number of tiles doubles the thrust; there is no need for larger discharges. This makes the architecture **linearly scalable** from laboratory models to orbital vehicles.

A practical prototype might begin as a small, helium-filled platform with a dozen square meters of EAD surface, generating millinewton thrusts measured over hours. Larger demonstrators could follow, each expanding in area and power. The final orbital version may span hundreds of meters, with thousands of independently controlled tiles, operating under full solar power for months at a time.

Because all components are solid-state, the system has an inherently long service life. There are no turbine bearings or combustion cycles to wear out - only gradual electrode erosion and material aging. With careful design, mean time between failures could reach years.

Ascent Profiles and Altitude Transitions

The complete mission can be visualized as a smooth spiral in the (v, ρ) plane: as velocity increases, density decreases. The path is chosen so that the product ρv^3 - which determines drag power - remains below a threshold the solar system can supply.

1. **Buoyant climb** to 30–40 km.
2. **Acceleration phase**: maintain roughly constant $P_D \approx 20\text{–}50\ \mathrm{kW}$ by adjusting pitch and altitude.
3. **Transition to orbital regime**: above 70 km, lift and buoyancy vanish, and the airship effectively becomes a satellite still grazing the atmosphere.

The transition from “flight” to “orbit” is not a sharp boundary. The atmosphere fades gradually; thrust compensates for drag until drag ceases to matter. The vehicle’s path becomes circular rather than ballistic, and it remains aloft indefinitely.

Energy Balance and Endurance

Integrating over the full ascent, the total energy input from the Sun is vast compared to what is needed. Even at a modest collection rate of 100 kW, three weeks of continuous operation accumulates

$$E = 100{,}000 \times 1.8 \times 10^6 = 1.8 \times 10^{11}\ \mathrm{J}.$$

For a 2000 kg vehicle, that is **90 MJ/kg** - three times the orbital kinetic energy requirement. Most of this energy will be lost to drag and inefficiencies, but the margin is generous.

This is the quiet magic of solar patience: when time is allowed to stretch, energy abundance replaces power scarcity.

Maintenance, Return, and Reuse

After completing its orbital mission, the airship can decelerate gradually by reversing its EAD field polarity. Drag increases as it descends; the same mechanism that lifted it now acts as a brake. The vehicle can re-enter the stratosphere and float down under residual buoyancy.

Because no expendable stages are discarded, the system is **fully reusable**. The envelope may be serviced, re-gassed, and relaunched. Maintenance involves replacing degraded tiles or films rather than rebuilding engines.

In contrast to chemical rockets, where every launch consumes tanks and propellants, the EAD airship is an **energy-recycling spacecraft**. The Sun refuels it continuously; only wear and tear require human intervention.

The Broader Engineering Significance

The same technologies enabling a solar EAD airship - lightweight photovoltaics, high-voltage power electronics, thin-film dielectrics - have immediate terrestrial applications. Stratospheric communications platforms, high-altitude climate sensors, and long-endurance drones all benefit from the same developments.

By pursuing a system capable of reaching orbit without fuel, we also invent a new class of **solid-state aerial vehicles** - machines that fly not by combustion but by field manipulation.

In this sense, the Rise–Fly–Orbit project sits in a lineage that includes the Wright Flyer and the first liquid-fueled rockets: not a perfected technology, but a **proof of principle** that transforms what “flight” can mean.

Regulation, Strategy, and the Philosophy of Slow Ascent

The physics of a solar electroaerodynamic airship are permissive; the law is not. Today’s flight rules divide the sky into neatly bounded domains: **airspace** governed by aviation law, and **outer space** governed by space law. Between them lies a gray region - too high for aircraft certification, too low for orbital registration. The airship to orbit lives squarely in that gray, moving continuously through altitudes that, on paper, belong to no category at all.

Why It’s “Impossible”

Airspace statutes assume vehicles that take off and land within hours. They require certified engines, aerodynamic control surfaces, and the ability to yield to traffic. None of those assumptions fit an autonomous, solar-driven balloon that may loiter for weeks above 60 km.

Launch-vehicle regulations begin where rockets fire: a discrete ignition, a launch site, and a flight-termination system designed to contain explosions. Our airship has none of these. It ascends as slowly as a cloud; there is no moment of “launch.” Yet because it will eventually exceed Mach 1 and reach orbital velocity, it falls under spaceflight jurisdiction. The result is paradoxical: it cannot legally fly as an aircraft, yet must be licensed as a rocket it does not resemble.

A Hybrid Atmospheric–Orbital Vehicle Class

The remedy is to recognize a new category - a **Hybrid Atmospheric–Orbital Vehicle** (*HAOV*). Its defining traits would be:

- **Continuous domain crossing:** ascent from surface to near-space without discrete staging.
- **Low kinetic energy flux:** total momentum exchange with the atmosphere many orders of magnitude below that of rockets.
- **Passive fail-safe behavior:** on loss of power, the craft drifts and descends; it does not fall ballistically.
- **Cooperative tracking:** always visible to radar and satellite sensors, broadcasting its state vector much as ADS-B transponders do for aircraft.

The HAOV framework would allow certification of such craft under **performance-based** rather than **hardware-based** criteria - defining safety in terms of energy release, ground footprint, and autonomous descent capability instead of the presence of engines or fuel.

Oceanic or desert **corridors** could be designated where HAOVs may operate continuously, monitored by existing space-traffic networks. Their ascent would pose less hazard to aviation than a single weather balloon, yet current rules offer them no path.

The Politics of Patience

Regulation follows culture, and culture is addicted to speed. Aerospace milestones are measured in thrust-to-weight ratios and minutes to orbit. The idea that a vehicle might take **three weeks** to reach orbit sounds, at first hearing, like regression. But patience is the price of sustainability. The airship proposes a different metric: not "how fast can we burn energy" but "how continuously can we accumulate it."

To space agencies accustomed to launch windows and countdowns, such a craft demands a shift in operations: mission planning by seasons rather than seconds; orbital insertions that depend on sunlight geometry, not pad availability. Yet this change aligns with the broader turn toward **steady-state infrastructure** - solar-electric spacecraft, reusable stations, persistent climate platforms.

Strategic Value

A reusable solar-EAD vehicle offers capabilities no rocket or airplane can match:

- **Persistent high-altitude observation and communications:** before full orbit, the airship can hover for months in the upper stratosphere, relaying data or imaging Earth.
- **Incremental cargo delivery:** small payloads can be raised gently without the acoustic and thermal shocks of launch.
- **Planetary analogs:** on Mars, where orbital speed is only 3.6 km/s and atmospheric pressure favors long-path ion acceleration, the same architecture could function even better.
- **Environmental stewardship:** no exhaust, no propellant spills, negligible acoustic impact.

Economically, the first operational HAOVs would not replace rockets but complement them, serving niches where payload patience outweighs urgency. Strategically, they would decouple access to near-space from propellant supply chains - an appealing feature for space agencies seeking sustainable infrastructure.

Engineering the Rulebook

Creating a HAOV category is less about lobbying than about **measurement**. Regulators trust data. The path forward is experimental transparency:

1. **Helium-based demonstrators** in remote corridors, instrumented to record trajectory, energy use, and fault behavior.

2. **Continuous telemetry** shared with civil-aviation and space-tracking networks to prove predictable flight dynamics.
3. **Simulation and risk models** showing that worst-case kinetic-energy flux over inhabited regions is negligible.

Once agencies see quantified evidence that a HAOV cannot harm aircraft or ground populations, the legal architecture will follow - as it did for high-altitude balloons and drones before them.

Ethical Dimension

Slow flight has moral weight. Chemical launchers pollute not because engineers are careless but because physics offers no time to recycle their heat. A solar airship, by contrast, consumes nothing irretrievable. It replaces noise with silence, flash with glow. Its ascent would be visible from the ground as a bright, unhurried point, a human artifact climbing without violence.

In an age of urgency, such deliberate motion is a statement: that technological ambition need not be explosive to be profound.

The Patience of Light

When a rocket reaches orbit, it does so by brute acceleration: seconds of combustion that leave the sky trembling. The electroaerodynamic airship arrives differently. Each photon that strikes its skin contributes a whisper of momentum, mediated by electrons, ions, and the quiet mathematics of Maxwell's equations. Over three weeks these whispers accumulate into orbit.

The same expression - $\mathbf{f} = \rho_e \mathbf{E}$ - that describes a microampere of ion drift in a laboratory also governs a thousand-ton lifting body sliding through the upper atmosphere. The scale changes; the principle does not. Maxwell's tensor, Coulomb's law, and the patience of sunlight are universal.

If humanity learns to exploit that patience, we gain a new way to leave the Earth - one that can be repeated indefinitely, powered by the same star that sustains us.

Toward an Age of Reversible Flight

Chemical rocketry is a one-way gesture: immense effort to reach orbit, and abrupt end upon re-entry. The electroaerodynamic airship suggests a **reversible path**. It can climb and descend at will, dwelling anywhere from troposphere to orbit. It is both spacecraft and habitat, vehicle and station.

In that continuity lies a philosophical reversal: spaceflight not as departure but as extension of atmosphere. The gradient from air to vacuum becomes navigable terrain. Such craft would blur the line between meteorology and astronautics, turning the "edge of space" into a living workspace rather than a barrier.

Closing Reflections

No new physics are needed - only endurance, precision, and re-imagined regulation. The orbital energy budget can be paid in sunlight; the thrust can arise from electric fields acting on ions; the time can be borrowed from the patience of engineers.

The obstacles are cultural and bureaucratic: convincing agencies that something which looks like a balloon can, through mathematics and persistence, become a satellite. Yet every transformative technology began as an anomaly in the paperwork.

When the first of these solar electroaerodynamic vessels ascends, its progress will be almost imperceptible hour to hour. But day by day it will gather speed, until at last it glides beyond the reach of weather. There will be no roar - only the faint, continuous hum of fields and the steady accumulation of sunlight into motion.

That will mark the beginning of **reusable, sustainable, and gentle access to orbit**: a way to rise, to fly, and - without ever striking a match - to orbit.

References & Further Reading

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