

Atmospheric Plasma Jet Propulsion - Research Paper

Jilani Abedin

Abstract

Atmospheric Plasma Jet Propulsion presents a revolutionary zero-emission electric alternative to conventional fossil-fuel-based jet engines. By utilizing high-voltage electrical energy and ambient atmospheric air, plasma jet engines heat air to ionized plasma states via high-power microwave radiation and radiofrequency fields, generating immense thermal expansion and high-velocity thrust without chemical combustion. This paper provides a comprehensive investigation into the fundamental physics, multi-stage operational dynamics, global experimental prototypes, aerospace integration milestones, critical engineering bottlenecks—including massive power density demands, extreme thermal degradation, and power system mass scaling—and long-term strategic feasibility for sustainable aviation.

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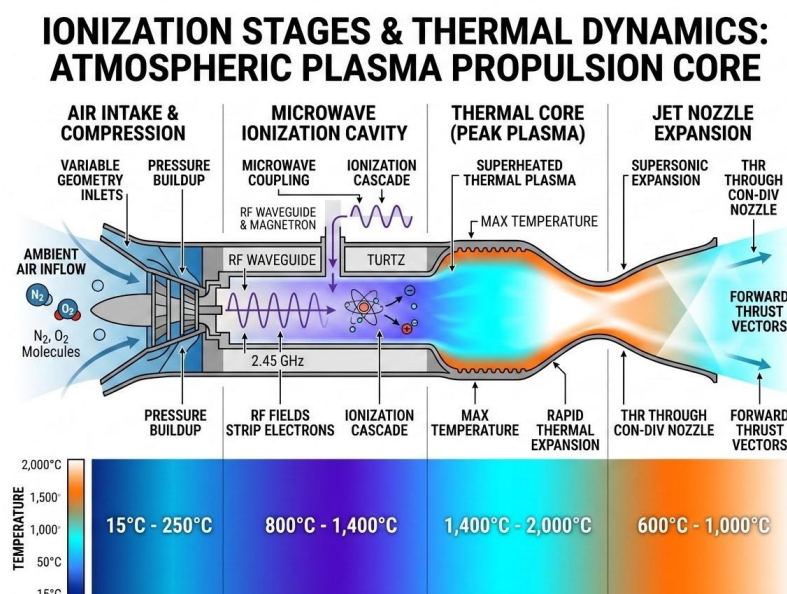
I. Introduction & Fundamental Physics

Conventional aviation relies heavily on Aviation Turbine Fuel (ATF) combustion, generating substantial carbon dioxide emissions, nitrogen oxides (NO_x), water vapor contrails, and soot particles at high altitudes. In contrast, atmospheric plasma jet engines utilize electrical power to ionize compressed ambient air into a superheated plasma state exceeding 1,000°C to 2,000°C. Rapid thermal expansion through an aerodynamic jet nozzle converts electrical energy into kinetic thrust according to Newton's Third Law of Motion.

The physical mechanism of atmospheric plasma generation relies on breaking down neutral gas molecules into free electrons, positive ions, and excited species. When a strong electromagnetic field is applied to compressed air, free electrons accelerate, colliding with neutral nitrogen (N₂) and oxygen (O₂) molecules. This cascade ionization produces a high-density, non-equilibrium plasma discharge. The absorbed electrical energy rapidly thermalizes through elastic electron-heavy particle collisions, elevating gas kinetic temperatures within milliseconds and driving sonic expansion.

Ionization Stages & Thermal Dynamics

Below is a dynamic schematic illustrating the thermal progression and ionization states of ambient air as it transitions through the propulsion core:



Process Stage	Physical State	Temp Range (°C)	Key Thermodynamic Behavior
1. Intake & Compression	Neutral Gas (N ₂ , O ₂)	15°C - 250°C	Mechanical pressure buildup & velocity stabilization
2. Microwave Cavity	Ionized Plasma Breakdown	800°C - 1,400°C	Electromagnetic coupling & high electron excitation
3. Thermal Core	Superheated Thermal Plasma	1,400°C - 2,200°C	Rapid kinetic expansion & peak pressure generation
4. Jet Nozzle Expansion	Recombining Gas Jet	600°C - 1,000°C	Supersonic nozzle conversion to forward thrust

Structural & Performance Comparison

Technology Feature	Conventional Jet Engine	Atmospheric Plasma Jet Engine
Primary Energy Source	Chemical Fossil Fuel (ATF)	Electricity (Battery / Solar / Nuclear)
Working Medium	Fuel + Compressed Air	Ambient Air converted to Plasma
Exhaust Output	CO ₂ , Water Vapor, Soot, NO _x	Superheated Air & Nitrogen/Oxygen Ions
Moving Parts	High-friction turbines & fuel injectors	Minimal / No rotating turbines in core
Carbon Footprint	High direct emissions	100% zero direct carbon emissions

II. Operational Mechanism

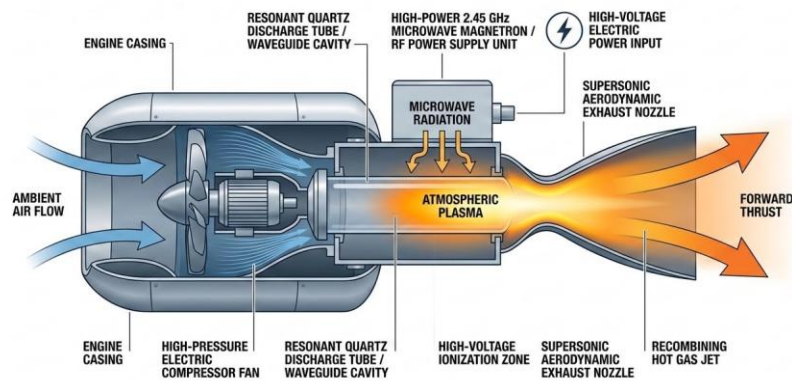
The operational mechanism of an atmospheric plasma jet engine relies on the precise synchronization of fluid mechanics, high-voltage electrodynamics, and thermodynamic nozzle design across three primary structural stages:

1. **Air Compression & Intake Stage:** An electric motor-driven axial or centrifugal compressor draws ambient air through variable geometry inlets, elevating static pressure and velocity profiles to optimize intake air density before entry into the ionization chamber.
2. **Microwave Plasma Ionization Stage:** Compressed air enters a high-Q resonant quartz or ceramic waveguide chamber. High-power microwave radiation (typically 2.45 GHz or higher) is directed into the chamber via magnetrons or solid-state RF generators. The intense field strips electrons from N₂ and O₂ molecules, initiating an avalanche ionization process that heats the gas into a dense plasma state above 1,200°C without requiring chemical reactants.
3. **Thermal Expansion & Nozzle Acceleration Stage:** The superheated, highly pressurized plasma stream undergoes extreme volumetric thermal expansion. As the gas flows through a convergent-divergent convergent aerodynamic nozzle, thermal energy is efficiently converted into supersonic kinetic energy, generating massive linear thrust vectors.

Engine Architecture & Structural Schematic

The physical architecture of a microwave atmospheric plasma jet thruster can be envisioned as a integrated concentric system:

- a. **Stage 1 (Air Intake & Compression):** Ambient air is drawn into the engine through variable inlets and compressed by a high-pressure electric compressor fan to establish optimal static pressure.
- b. **Stage 2 (Microwave Energy Coupling & Ionization):** High-voltage electrical power drives a magnetron or RF generator, delivering 2.45 GHz microwave radiation into a resonant quartz discharge tube to rapidly ionize the air into superheated plasma (>1,200°C).



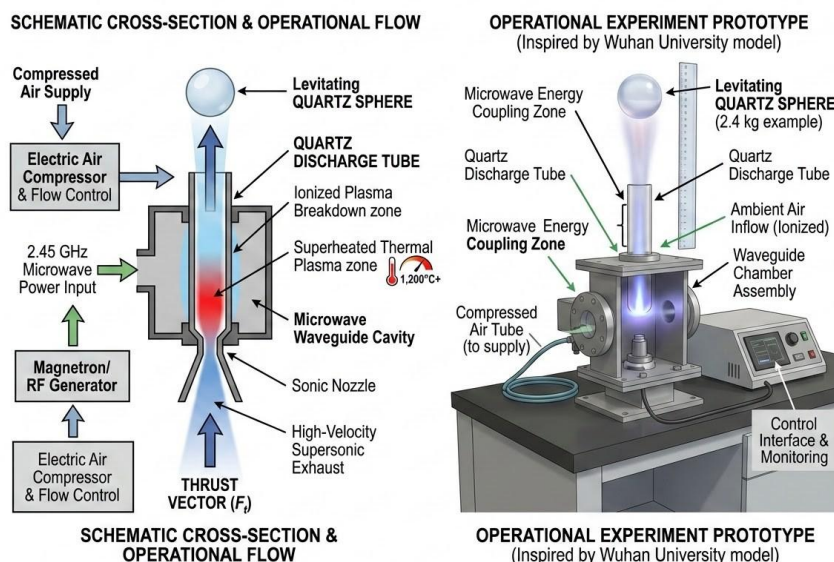
c. **Stage 3 (Supersonic Acceleration & Exhaust Output):** The superheated plasma rapidly expands through a supersonic aerodynamic exhaust nozzle, converting thermal expansion directly into high-velocity forward thrust.

III. Global & Indian Research Landscape

Global State of Research

Wuhan University Microwave Thruster Prototype: Led by Prof. Jau Tang, researchers successfully developed a prototype microwave atmospheric plasma thruster. Utilizing 400 W of microwave power at 2.45 GHz, the device ionized compressed air to lift a 2.4-kg quartz sphere over a discharge tube. The resulting thrust pressure was calculated to be comparable on a scaled energy-density basis to commercial jet engines, proving the physical feasibility of microwave-driven atmospheric plasma propulsion.

CONCEPTUAL LABORATORY MICROWAVE ATMOSPHERIC PLASMA THRUSTER PROTOTYPE: Technical Diagram and Operational Prototype



MIT Electrohydrodynamic (EHD) Flight Demonstration: In 2018, MIT researchers achieved solid-state flight using an electrohydrodynamic propulsion system. By applying 40,000 volts across high-voltage emitters, the aircraft ionized air molecules to generate an "ionic wind" that sustained a

55-meter powered flight without moving mechanical parts or direct emissions. **European Union & Industrial Research Programs:** Academic and defense consortiums across Europe are exploring high-frequency plasma actuators and microwave-heated jet concepts for noise reduction, active flow control, and zero-emission regional aviation transport.

Indian Aerospace Landscape

Atmospheric Propulsion: Unexplored commercially and academically in India, offering early-stage research opportunities.

Space Vacuum Applications: ISRO completed a 1,000-hour continuous endurance test on space-qualified electric plasma thrusters in March 2025. The Institute for Plasma Research (IPR), Gandhinagar, provides underlying plasma physics research.

IV. Key Engineering Challenges & Bottlenecks

Transitioning atmospheric plasma jet propulsion from small-scale laboratory experiments to full-scale commercial aviation requires resolving major fundamental engineering and physical bottlenecks:

1. **Immense Power Density Requirements:** Standard commercial aircraft require massive thrust outputs (e.g., ~150 kN per engine for an Airbus A320). Generating equivalent plasma-based thermal expansion requires continuous electrical power in the range of 10 MW to 50 MW per thruster, far exceeding current aircraft power generation capabilities.
2. **Energy Storage Specific Energy Limits:** Modern lithium-ion batteries (~250-300 Wh/kg) fall short of jet fuel specific energy (~12,000 Wh/kg). Carrying the battery mass required for transcontinental flights would make the aircraft too heavy to take off, necessitating breakthroughs in solid-state batteries, hydrogen fuel cells, or compact nuclear reactors.
3. **Extreme Thermal & Material Degradation:** Continuous exposure to plasma temperatures above 1,500°C causes rapid erosion of electrodes, discharge tubes, and nozzle linings. Developing advanced ceramic matrix composites (CMCs), active cooling channels, and magnetic confinement fields is crucial for continuous operational reliability.
4. **Electromagnetic Interference & High-Voltage Safety:** Operating megawatt-class microwave and high-voltage power networks creates severe electromagnetic interference (EMI) that can disrupt avionics, navigation, and communications. Robust shielding and arc suppression architectures are mandatory for airworthiness certification.

V. Feasibility Assessment & Strategic Benefits

Implementation Horizons

Short-Term Applications (High Feasibility): Uncrewed Aerial Vehicles (UAVs), high-altitude pseudo-satellites (HAPS), tactical reconnaissance drones, and small regional cargo platforms requiring lower overall thrust profiles.

Long-Term Applications (Conditional Feasibility): Regional commercial passenger aircraft and hypersonic atmospheric transports, highly dependent on next-generation energy storage advances (such as ultra-dense solid-state batteries, liquid hydrogen fuel cells, or compact fusion reactors).

Strategic Impact

Zero Emissions & Climate Mitigation: Total elimination of aviation greenhouse gas emissions and soot.

Energy Security & Fuel Independence: Transitioning from imported crude oil dependency to domestic renewable or nuclear electrical generation.

Operational Simplicity: Removal of fuel lines, turbomachinery stress, and combustion mechanics, reducing maintenance overhead and acoustic noise signatures.