

# Phase-Controlled Nonlinear RF Plume Control for Momentum-Flux Modification in Magnetized Electric Propulsion Plumes

A Foundational Research Paper for Metadynamic Aerospace Research

Metadynamic Aerospace Research, LLC — Parent Company: thesecretlab

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**Abstract.** Electric propulsion systems convert electrical power into directed exhaust momentum, enabling high specific impulse operation for spacecraft station-keeping, orbit transfer, and deep-space missions. Practical plasma thrusters, however, experience performance losses associated with imperfect power coupling, plume divergence, thermal spread, instability, wall interaction, and incomplete conversion of plasma pressure or electromagnetic stress into useful axial momentum. This paper proposes a bench-scale research program investigating whether phase-controlled radio-frequency (RF) excitation can measurably modify the momentum distribution of a magnetized low-density plasma plume.

The proposed method, termed *Nonlinear RF Plume Control* (NRPC), uses multiple RF channels with independently controlled phase, amplitude, frequency, and modulation profile to drive repeatable wave-plasma interactions inside or near an exhaust plume. In the intended operating regime, RF excitation is not treated merely as a plasma-generation mechanism. Instead, it is used as a downstream plume-control layer intended to alter axial ion current density, ion energy distribution, plume divergence, and off-axis momentum components. Candidate mechanisms include ponderomotive density modulation, nonlinear coupling between high-frequency electrostatic fields and lower-frequency ion response, RF-induced plasma pressure gradients, and magnetized-plume momentum conversion mediated by magnetic-field geometry.

The paper explicitly rejects reactionless or propellantless interpretations. Any measured thrust must be consistent with momentum carried by exhaust plasma, electromagnetic fields, or environmental interaction. The research objective is narrower and experimentally falsifiable: determine whether phase-controlled RF excitation produces repeatable plume or momentum-flux changes that cannot be explained by total RF power alone and that disappear or diminish under randomized-phase and RF-only null tests.

**Keywords:** electric propulsion; RF plasma thruster; magnetic nozzle; plasma plume diagnostics; nonlinear wave-plasma interaction; ion-acoustic response; Langmuir wave coupling; thrust vectoring; plume collimation; RF phase control; plasma control software; momentum flux.

## 1. Introduction

Electric propulsion (EP) is a mature spacecraft technology family that trades high electrical power demand and relatively low thrust for high propellant efficiency. Ion thrusters, Hall thrusters, RF plasma thrusters, magnetoplasmadynamic devices, pulsed plasma thrusters, electro-sprays, and related architectures differ in implementation, but each must ultimately convert stored electrical energy into directed exhaust momentum [1, 2].

The performance question is therefore not whether momentum conservation can be bypassed. It cannot. The useful question is whether the conversion of electrical power into directed momentum can be improved, stabilized, diagnosed, or vector-controlled. Real plasma plumes are not ideal one-dimensional exhaust jets. They exhibit divergence, nonuniform ion energy distributions, unaccelerated neutral flow, wall losses, imperfect RF coupling, thermal spread, facility effects, and measurement uncertainty. Consequently, plume shaping and downstream momentum management are legitimate engineering targets.

Metadynamic Aerospace Research is founded on the technical position that closed-loop RF plasma control may become a useful layer in electric propulsion development. The first program, NRPC-1, is a bench-scale test article designed to determine whether multi-channel, phase-controlled RF excitation can create repeatable, measurable changes in a magnetized plasma plume at fixed mass flow, magnetic-field configuration, plasma-source settings, and total RF input power.

This paper defines the founding academic rationale for the company and the NRPC-1 program. It establishes a conservation-law boundary, reviews relevant technical context, states the hypothesis, describes proposed mechanisms, specifies the test article and software architecture, and defines validation criteria. The emphasis is deliberately conservative: strong baselines, null tests, artifact rejection, repeatability, and diagnostic traceability are treated as first-order design requirements rather than afterthoughts.

## 2. Conservation-Law Boundary

The vehicle, plume, electromagnetic field, and surrounding test environment form a coupled system. Internal forces between a spacecraft and its own plasma cannot produce sustained net acceleration unless momentum leaves the spacecraft-control volume as exhaust mass, field momentum, or interaction with an external medium. For a plasma propulsion system, a simplified axial force balance can be expressed in terms of momentum flux and stress across a control surface:

$$F_x \approx \int_A \rho v_x^2 dA + \int_A p n_x dA + \int_A T_{EM,x} dA, \quad (1)$$

where  $\rho$  is mass density,  $v_x$  is axial plasma velocity,  $p$  is plasma pressure,  $n_x$  is the axial component of the surface normal, and  $T_{EM,x}$  is the electromagnetic stress contribution. For an idealized rocket-like exhaust stream, thrust is commonly related to mass flow and effective exhaust velocity:

$$F = \dot{m} v_e, \quad (2)$$

and ideal jet power is

$$P_j = \frac{1}{2} \dot{m} v_e^2 = \frac{F^2}{2\dot{m}}. \quad (3)$$

A useful momentum-conversion proxy is therefore

$$\eta_m = \frac{F^2}{2\dot{m} P_{in}}, \quad (4)$$

where  $P_{in}$  includes the relevant electrical and RF input power. NRPC does not attempt to bypass these relationships. Its proposed benefit is narrower: for a fixed operating condition, phase-controlled RF excitation may change how much of the outgoing plasma momentum is directed axially, how narrow the plume divergence becomes, or how controllably the exhaust vector can be biased.

The boundary statement for Metadynamic technical communication is:

NRPC is an electric propulsion plume-control architecture. It does not claim reactionless or propellantless thrust. Measured thrust must correspond to exhaust plasma momentum, electromagnetic field momentum, or interaction with the test environment.

## 3. Technical Background

### 3.1 Electric propulsion and plume losses

EP performance depends on ionization, acceleration, power processing, thermal management, and plume behavior. Even when propellant is accelerated effectively, plume divergence and non-axial velocity components can reduce useful thrust. Diagnostics and test facility effects also complicate interpretation, especially for low-thrust devices.

### 3.2 RF and helicon plasma thrusters

RF plasma thrusters and helicon sources can generate plasma without electrodes immersed in the main discharge. A typical helicon-like configuration includes an RF antenna, dielectric tube, and magnetic field. In magnetic-nozzle RF thrusters, plasma expands along a diverging magnetic field, and part of the plasma pressure can be converted into directed axial momentum. Recent work has shown continuing improvements in radiofrequency plasma thruster and magnetic nozzle performance, including reports of kW-class magnetic nozzle RF plasma thrusters approaching or exceeding notable efficiency milestones [3, 4].

NRPC does not replace that research line. It extends the design space by treating downstream or plume-region RF phase relationships as active control variables. The question is whether RF phase schedules can create measurable differences that are not captured by total RF power alone.

### 3.3 Magnetic nozzles

A magnetic nozzle can guide and expand plasma in a manner loosely analogous to a gas-dynamic nozzle. Electrons can remain magnetized, pressure gradients and ambipolar electric fields can accelerate ions, and Lorentz forces can contribute to axial momentum conversion. Detachment remains a key challenge: plasma must leave the spacecraft and not remain indefinitely tied to magnetic field lines.

For NRPC-1, the magnetic assembly has two experimental roles. First, it creates a repeatable plume region for measurement. Second, it provides a background field in which RF-driven perturbations may produce spatially structured plume response.

### 3.4 Nonlinear wave-plasma interaction

Plasmas support many wave modes, including Langmuir oscillations, ion-acoustic waves, lower-hybrid waves, helicon/whistler waves, and magnetosonic modes. High-frequency electric fields can couple to slower density response through ponderomotive or related nonlinear effects. A simplified one-dimensional Zakharov-type model captures the conceptual coupling between a high-frequency field envelope and low-frequency density perturbation [8, 7]:

$$i \frac{\partial E}{\partial t} + \alpha \frac{\partial^2 E}{\partial x^2} = nE, \quad (5)$$

$$\frac{\partial^2 n}{\partial t^2} - c_s^2 \frac{\partial^2 n}{\partial x^2} = \beta \frac{\partial^2 |E|^2}{\partial x^2}, \quad (6)$$

where  $E$  is a high-frequency field envelope,  $n$  is a density perturbation,  $c_s$  is an ion-acoustic speed, and  $\alpha$  and  $\beta$  are coefficients determined by model assumptions and plasma parameters. NRPC-1 does not assume this reduced model directly describes the test article. It uses this class of nonlinear coupling as a rationale for testing phase-controlled RF excitation in a plume-relevant geometry.

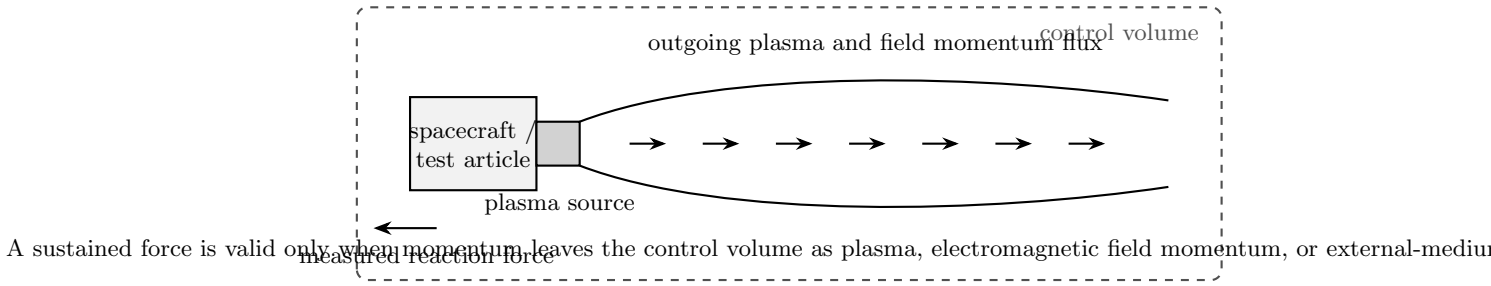


Figure 1: Control-volume framing for NRPC. The concept is conservation-law compliant by construction: the research target is modification of outgoing momentum distribution, not force without exhaust momentum.

### 3.5 Measurement discipline

Small-thrust measurements are vulnerable to false positives: thermal drift, cable forces, RF pickup, magnetic coupling, gas-feed impulse, outgassing, and facility interaction. Recommended practices in electric propulsion thrust measurement emphasize calibration, thermal control, stand dynamics, and artifact rejection [5]. Non-invasive diagnostics such as laser-induced fluorescence (LIF) are valuable for velocity distribution measurements, but require careful implementation and analysis [6]. NRPC-1 is therefore designed around baselines and null tests from the beginning.

## 4. Core Hypothesis

The core NRPC hypothesis is:

A magnetized low-density plasma plume subjected to phase-controlled multi-channel RF excitation can exhibit repeatable changes in momentum distribution, plume divergence, ion current density profile, ion energy distribution, or thrust-vector proxy measurements when compared with non-phased and randomized-phase RF excitation at equal mass flow, magnetic field, plasma-source power, and total RF input power.

This hypothesis decomposes into four testable sub-hypotheses:

1. **H1: Phase-dependent plume response.** Changing the relative phase among RF excitation channels produces a repeatable change in plume properties such as axial ion current density, radial current profile, plasma potential, optical emission structure, or plume divergence.
2. **H2: Coherence dependence.** A randomized-phase RF condition at equal total RF power produces a reduced, absent, or statistically different plume response compared with a controlled-phase condition.
3. **H3: Momentum-flux relevance.** At least one phase-controlled condition produces a measurable increase in axial momentum-flux proxy, thrust, or impulse-bit measurement relative to baseline operation.

4. **H4: Vectoring potential.** Asymmetric RF phase or amplitude schedules produce repeatable off-axis plume asymmetry that could support electronic thrust-vector modulation in later prototypes.

## 5. Candidate Physical Mechanisms

The NRPC program is intentionally mechanism-tolerant at the start. The dominant physics may vary with density, magnetic field, neutral pressure, RF frequency, antenna geometry, and source design.

### 5.1 Ponderomotive density modulation

A spatially nonuniform oscillatory field can exert a time-averaged ponderomotive force. In simplified form,

$$\mathbf{F}_p \propto -\nabla|E|^2. \quad (7)$$

A phase-controlled multi-channel RF system may create moving or biased intensity gradients. The resulting density redistribution could affect local pressure gradients, plasma potential, or coupling to a magnetic nozzle region.

### 5.2 Ion-acoustic-scale response

If RF modulation couples to ion-acoustic time scales, the plume may respond through low-frequency density or pressure waves. A simplified ion-acoustic speed estimate is

$$c_s \approx \sqrt{\frac{k_B T_e}{m_i}}, \quad (8)$$

where  $T_e$  is electron temperature and  $m_i$  is ion mass. For argon test plasmas, this estimate helps select modulation frequencies and diagnostic sampling rates.

### 5.3 Ion energy distribution modification

RF fields can modify plasma potential, sheath behavior, and local acceleration regions. A retarding potential analyzer or equivalent diagnostic can test whether phase-controlled operation changes the ion energy distribution, but a useful result requires not simply more energy, but improved directed momentum or reduced transverse spread.

## 5.4 Magnetic-nozzle interaction

RF-induced density or pressure perturbations may interact with a magnetic nozzle. If phase-controlled excitation changes where pressure gradients form or how plasma couples to the field, the effective plume expansion profile may change. The term *RF virtual nozzle* is used as engineering shorthand for such controllable plume-shaping behavior.

## 5.5 Electronic vectoring

A segmented RF excitation pattern may produce controlled plume asymmetry. At the NRPC-1 stage, the goal is not flight vectoring but repeatable off-axis plume-current or thrust-stand response under asymmetric phase schedules.

# 6. NRPC-1 Test Article

NRPC-1 is a bench-scale experimental system, not a flight thruster. It is designed to produce data sufficient to accept, refine, or reject the NRPC hypothesis.

## 6.1 Major subsystems

The test article includes:

- low-flow plasma source assembly;
- fused silica or quartz optical discharge section;
- magnetic field assembly;
- multi-channel RF excitation subsystem;
- mechanical mounting base and alignment fixtures;
- vacuum chamber interface;
- diagnostics and sensors;
- data acquisition system;
- Metadynamic Control Stack (MDCS) software.

## 6.2 Plasma source

The initial plasma source should prioritize repeatability over maximum performance. Argon is preferred for early testing due to cost and handling simplicity. Krypton or xenon may be considered later for higher electric-propulsion relevance. The source must produce a stable baseline plume before phase-controlled RF experiments begin.

## 6.3 Fused silica or quartz optical section

A fused silica or quartz component provides optical access, electrical insulation, and a controlled plasma boundary. It is not a structural pressure member beyond fixture requirements. Edge finish, point-load avoidance, thermal shock control, and metal-glass expansion mismatch must be treated as design risks.

## 6.4 Magnetic field assembly

The first magnetic assembly may use an axial solenoid, permanent magnet ring, hybrid configuration, or simple diverging nozzle. Magnetic-field mapping with a Hall probe or equivalent instrument is required before plume-control claims are made.

## 6.5 RF excitation subsystem

The RF subsystem requires at least two independently controlled channels, with four or more channels preferred. Each channel should support control of frequency, amplitude, relative phase, modulation, and timing. Forward and reflected RF power measurement is required.

Operating modes must include RF off, non-phased RF, fixed phase offset, phase sweep, randomized phase, asymmetric phase, RF-only/no-plasma artifact mode, and dummy-load checks.

## 6.6 Diagnostics

Minimum diagnostics include a thrust stand or torsion balance, Faraday cup or Faraday cup array, RF forward/reflected power measurement, chamber pressure measurement, thermal sensors, magnetic-field measurement, and optical imaging. Preferred diagnostics include a retarding potential analyzer, Langmuir probe, RF pickup or B-dot probe, optical emission spectroscopy, and LIF if resources permit.

# 7. Metadynamic Control Stack

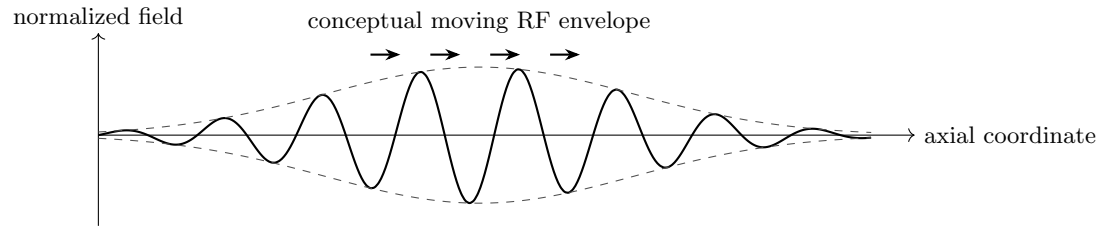
The Metadynamic Control Stack (MDCS) is a closed-source software platform for simulation, command, diagnostics, optimization, and data management. It is part of the research apparatus and a potential long-term commercial moat.

## 7.1 MDCS-SIM

MDCS-SIM estimates plasma parameters, performs parameter sweeps, and proposes candidate RF operating points. Early outputs include plasma frequency estimates, ion-acoustic speed estimates, Debye length estimates, cyclotron frequency estimates, candidate RF bands, and phase-offset sweep plans. It does not present simulated values as validated performance.

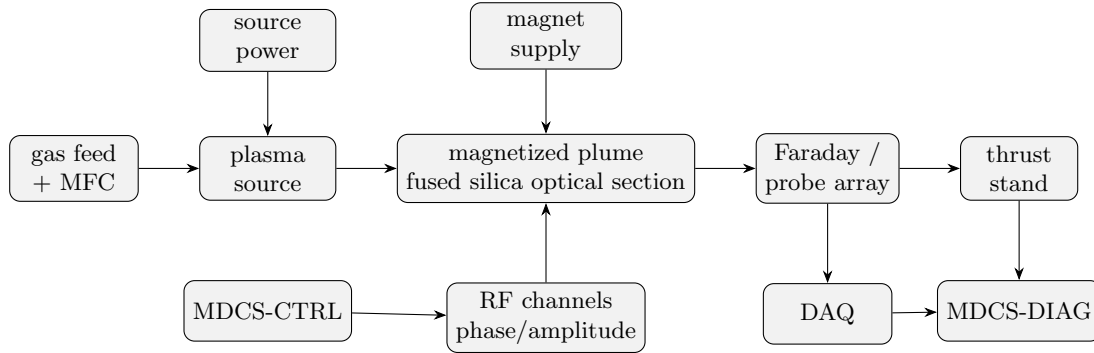
## 7.2 MDCS-CTRL

MDCS-CTRL commands RF channels, logs magnetic-field and source settings, enforces test limits, manages interlocks, and records timestamped operating states. It must support baseline, null, phased, and vectoring modes.



NRPC tests whether phase-controlled envelopes produce repeatable plume response beyond equal-power randomized RF excitation.

Figure 2: Conceptual RF envelope. The figure is not a validated field solution; it illustrates the control variable: phase-programmed RF intensity structure that may couple to slower plasma response.



Fixed mass flow + controlled magnetic field + multi-channel RF excitation + synchronized diagnostics.

Figure 3: NRPC-1 bench article architecture. The RF system is treated as a controlled plume-interaction subsystem rather than only a plasma-source heater.

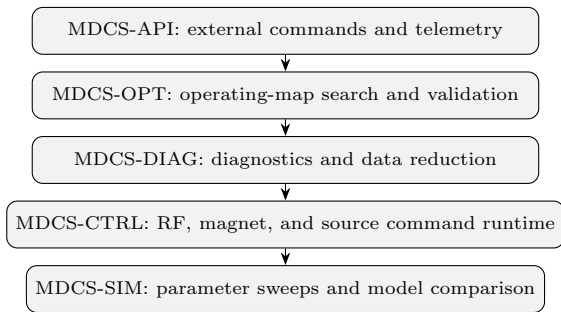


Figure 4: MDCS software stack. Low-level waveform logic, calibration maps, operating envelopes, and diagnostic reconstruction models remain internal trade secrets.

**7.3 MDCS-DIAG**

MDCS-DIAG ingests time-synchronized diagnostic streams and computes derived metrics such as plume divergence proxy, ion current profile, RF reflection ratio, thrust response, thermal margin, and repeatability measures.

**7.4 MDCS-OPT**

MDCS-OPT searches operating space within safe limits, identifies stable regions, rejects unsafe parameter sets, and builds proprietary operating maps tied to hardware

configuration and calibration state.

**7.5 MDCS-API**

MDCS-API exposes high-level commands and telemetry while hiding waveform generation, calibration maps, state-estimation logic, and optimization heuristics.

**8. Experimental Design**

The research design depends on comparing phase-controlled operation against strict controls. Table 1 summarizes required test cases.

**8.1 Controlled variables**

All comparisons must control or log propellant species, mass flow rate, chamber pressure, plasma-source power, total RF input power, RF frequency and phase relationship, magnetic-field setting, pulse duration, duty cycle, test duration, diagnostic position, and hardware thermal state.

**8.2 Measured outputs**

Primary outputs include thrust or impulse bit, axial ion current density, radial ion current distribution, ion energy distribution, plume divergence angle, reflected RF

Table 1: Required NRPC-1 baseline, null, primary, and repeatability tests.

Test ID	Mode	Purpose
T0	System checkout	Verify sensors, RF chain, logging, and interlocks
T1	Plasma source only	Establish unmagnetized baseline plume
T2	Plasma + magnetic field	Establish magnetized plume baseline
T3	Plasma + non-phased RF	Measure generic RF power effects
T4	Plasma + randomized-phase RF	Test coherence dependence
T5	Plasma + controlled-phase RF	Test primary NRPC hypothesis
T6	Plasma + asymmetric RF phase	Test vectoring response
T7	RF only, no plasma	Identify RF measurement artifacts
T8	Plasma on, RF into dummy load	Isolate RF coupling and instrumentation artifacts
T9	Repeatability campaign	Confirm persistence over multiple runs

power, plasma density proxy, plasma potential proxy, optical plume structure, thermal margin, and repeatability across runs.

### 8.3 Success criteria

NRPC-1 is technically successful if it demonstrates at least one repeatable phase-dependent plume-control effect that survives baseline and null-test comparison. A minimum acceptable result is

$$R_{phased} \neq R_{randomized} \quad (9)$$

for at least one diagnostic response  $R$ , at equal total RF power and equivalent plasma-source conditions. Preferred results include

$$F_{phased} > F_{baseline} \quad (10)$$

or

$$\theta_{div,phased} < \theta_{div,baseline}, \quad (11)$$

where  $F$  is measured thrust or impulse proxy and  $\theta_{div}$  is plume divergence angle.

### 8.4 Falsification criteria

The hypothesis is weakened or rejected if controlled-phase and randomized-phase modes are indistinguishable, RF-only tests produce comparable thrust-stand signals, apparent effects correlate with thermal drift rather than RF phase, repeated runs do not reproduce phase-dependent behavior, diagnostics contradict each other without explanation, or effects vanish after shielding and cable-force corrections.

## 9. Data Reduction and Diagnostic Metrics

### 9.1 Time synchronization

All RF commands, source settings, pressure data, thrust data, probe data, optical frames, and temperature data must be time-aligned. Phase-dependent claims require

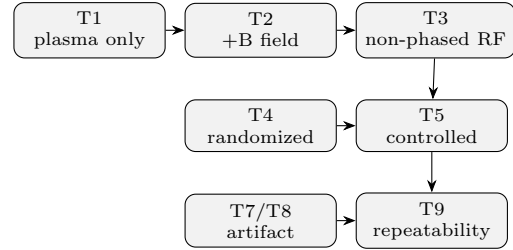


Figure 5: Validation logic. A positive result must separate controlled phase from equal-power randomized phase and RF-only or dummy-load artifacts.

knowing when waveform changes occurred relative to measured plume response.

### 9.2 Artifact rejection

The system must explicitly test for cable forces, RF pickup in thrust sensors, magnetic coupling to the stand, thermal expansion drift, gas-feed impulse, chamber-wall interactions, outgassing effects, and sensor saturation. RF-only and dummy-load tests are mandatory.

### 9.3 Momentum-flux closure

The strongest validation would show consistency among thrust stand data, Faraday cup profiles, ion energy measurements, plume divergence estimates, and RF power accounting. Exact closure may not be possible during early bench testing, but the program should converge toward it.

Example diagnostic metrics include ion current density proxy

$$J_i(r, z) = \frac{I_i(r, z)}{A_{probe}}, \quad (12)$$

plume divergence proxy

$$\theta_{div} \sim \tan^{-1} \left( \frac{r_{1/2}}{z} \right), \quad (13)$$

RF reflection ratio

$$\Gamma_P = \frac{P_{reflected}}{P_{forward}}, \quad (14)$$

and phase-dependent response function

$$R(\phi) = M(\phi) - M_{baseline}. \quad (15)$$

## 10. Expected Result Classes

### 10.1 Positive result

A positive result would show that controlled-phase RF operation produces a repeatable plume response not reproduced by non-phased or randomized-phase RF at the same power. If the response increases axial ion current density, reduces divergence, or changes thrust measurement consistently, it justifies continued development.

### 10.2 Partial result

A partial result may show phase-dependent optical or probe response without a clear thrust change. This remains useful if repeatable and physically interpretable, because plume-control observability is a prerequisite for later optimization.

### 10.3 Null result

A null result may show no meaningful difference between controlled-phase and randomized-phase modes. That would not invalidate RF plasma propulsion generally, but it would weaken the NRPC hypothesis for the tested geometry and parameter range.

### 10.4 Artifact result

An artifact result occurs if apparent thrust or plume change is traced to RF pickup, thermal drift, chamber interaction, or sensor coupling. Such results should be preserved because they improve the test methodology and prevent false claims.

## 11. Relevance to Future Propulsion Systems

If validated, NRPC could support plume collimation, electronic thrust vectoring, low-mass-flow operation, and software-defined propulsion control. Reduced plume divergence can improve useful axial momentum for a given plasma source. RF-controlled plume asymmetry could reduce reliance on mechanical gimbaling for small vector adjustments. Proprietary control maps, waveform libraries, calibration files, and diagnostic models may become as important as the physical thruster head.

The practical product thesis is therefore not a single miracle engine. It is a hardware-software propulsion-control stack: RF excitation hardware, diagnostic instrumentation, validated operating envelopes, and closed-source control software.

## 12. Intellectual Property Position

### 12.1 Patentable system concepts

Potential patent coverage may include plasma source plus magnetic-field assembly plus phased RF excitation system; phase-controlled modification of plasma plume momentum distribution; nonlinear wave-envelope formation in an exhaust plume; RF virtual-nozzle behavior; feedback-controlled plume collimation; electronic thrust-vector modulation using RF phase relationships; pulsed plasma packet synchronization with RF waveform timing; and diagnostic-driven RF plume control.

### 12.2 Trade secret assets

Trade-secret candidates include waveform synthesis algorithms, RF phase recipes, frequency-selection methods, calibration maps, state-estimation models, optimization heuristics, stability boundaries, data-reduction methods, and hardware-specific operating maps.

### 12.3 Public communication rules

Public materials should avoid reactionless propulsion, propellantless thrust, impossible drive language, performance claims before testing, flight-readiness claims, and suggestions of violated conservation laws. Approved framing is:

Metadynamic Aerospace Research develops closed-loop RF plasma-control software and bench-scale test hardware to study plume collimation, momentum-flux modification, and thrust-vector control in electric propulsion systems.

## 13. Research Roadmap

### 14. Limitations

This document is a research proposal and foundational technical draft, not a demonstration of validated performance. Several limitations are acknowledged:

1. The dominant RF-plasma mechanism is not yet established.
2. Bench-scale results may not scale directly to flight-relevant systems.
3. Diagnostics may initially provide proxies rather than full momentum-flux closure.
4. RF interference may complicate thrust measurement.
5. Plasma instabilities may dominate controlled envelope behavior.
6. Thermal and material constraints may limit duty cycle.
7. Magnetic nozzle detachment remains a difficult problem.
8. Phase-controlled plume modification may be measurable but inefficient.

Table 2: Research roadmap for the NRPC-1 program.

Phase	Deliverables
Phase 0: Documentation and IP	Invention disclosure, system requirements document, prior-art map, provisional patent draft, initial simulation assumptions, test matrix.
Phase 1: Simulation and control bench	MDCS-SIM first model, RF timing simulator, parameter sweep tool, control interface mockup, data schema, candidate operating-point list.
Phase 2: Vacuum bench prototype	Low-flow plasma source, magnetic-field assembly, multi-channel RF excitation hardware, MDCS-CTRL runtime, basic diagnostics, baseline and null test data.
Phase 3: Diagnostics and optimization	Faraday cup array, RPA or probe integration, MDCS-DIAG pipeline, MDCS-OPT first optimization loop, phase-dependent response maps, internal technical report.
Phase 4: Integrated engineering model	Integrated thruster head, embedded controller prototype, thermal management design, hardware-in-the-loop simulator, repeatability map, preliminary spacecraft interface document.

9. Software optimization may overfit noisy laboratory conditions unless validation is disciplined.

These limitations define the work that must be done rather than invalidate the program.

## 15. Conclusion

The founding technical idea behind Metadynamic Aerospace Research is that electric propulsion plumes may be actively studied and controlled using phase-coherent RF excitation and closed-loop diagnostics. The proposed NRPC approach does not attempt to bypass conservation laws or claim reactionless propulsion. Instead, it investigates whether nonlinear RF wave-plasma interactions can measurably modify plume momentum distribution, divergence, or vector direction under controlled bench-scale conditions.

NRPC-1 is intentionally conservative. It prioritizes baselines, null tests, artifact rejection, repeatability, and diagnostic traceability. If successful, the program would justify deeper research into RF virtual-nozzle behavior, plume collimation, electronic thrust vectoring, and software-defined plasma-control systems. If unsuccessful, it would still produce valuable negative data, test infrastructure, and clearer boundaries around RF plume-control claims.

The company thesis is therefore not that propulsion has already been solved. The thesis is that closed-loop RF plasma control is an underdeveloped engineering layer in electric propulsion, and that a disciplined research program can determine whether this layer offers measurable performance, control, or integration advantages.

## Acknowledgment

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## A. Example Test Run Record

Each test run should include a unique test ID; date and operator; hardware configuration; chamber pressure; propellant species; mass-flow setting; plasma-source power; RF frequency per channel; RF phase per channel; RF forward/reflected power; magnetic-field setting; probe positions; thermal state; raw diagnostic data path; derived metrics; fault flags; operator notes; and post-run inspection notes.

## B. Internal Claim Discipline

Allowed after technical review: NRPC investigates phase-controlled RF modification of magnetized plasma plumes; the system is conservation-law compliant; the objective is plume collimation, momentum-flux modification, and thrust-vector control; the current stage is bench-scale validation.

Avoid: reactionless drive; propellantless thrust; breaks physics; free acceleration; flight-ready propulsion system; guaranteed breakthrough efficiency.

## C. Company Implication

Metadynamic Aerospace Research is justified as a company if NRPC-1 can produce one or more of the following assets: patentable RF-plume-control architecture; proprietary waveform and calibration data; repeatable phase-dependent plasma response maps; closed-source control software; bench-scale prototype evidence; advisor-validated research plan; grant-ready experimental program; and a credible path toward plume collimation or electronic thrust-vector control.