Investigation Into Ion Powered Aircraft Within Earth's Atmosphere, At Low Altitudes and Airspeeds.

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Nomenclature

B_S	Secondary field strength,	T
B_p	Primary field strength,	T
B_t	Transformer field strength	T
F_M	MAIE Module Thrust,	N
F_e	MAIE Thrust,	N
F_p	Point Thrust,	N
I_p	Point current,	A
I_C	Capacitor Current,	A
I_R	Resistor Current,	A
I_e	Engine current,	A
I_s	Source current,	A
N_S	Secondary Turns	
N_p	Primary Tuns	
P_d	Dry Pressure,	Pa
P_v	Vapor Pressure,	Pa
P_s	Source Power,	W
P_e	Engine Power,	W
R_{VL}	Voltage Logger Resistance,	Ω
R_d	Specific gas constant dry,	$J \cdot kg^{-1}K^{-1}$
R_e	Electrode Resistance,	Ω
R_v	Specific gas constant vapor,	$J \cdot kg^{-1}K^{-1}$
T_a	Temperature of air,	$°K$
V_C	Capacitor Voltage,	V
B_e	Engine field strength,	Vm^{-1}
V_{tP}	Voltage Primary,	V
V_e	Electrode Voltage,	V
V_{ts}	Voltage Secondary,	V
V_s	Voltage Source,	V
d_e	Electrode Distance,	m
ρ_a	Density of Air,	kg/m^3
e	Electron Charge, $1.602 \times 10^{-19} J$	
g	Force of Gravity,	$9.807 ms^{-2}$
T	Time,	s
ρ	Density,	kg/m^3
β_p	Point Loss Coefficient.	
μ	Ion Mobility of air,	$2.2 \times 10^3\ cm^2 v^{-1} sec^{-1}$
N_M	Number of Modules	

Abstract

A large amount of the current research into methods of propulsion using Ion thrusters is focused on space travel with noble gas propellants, for instance Xenon gas, which can be used in low earth orbit operations. However, another method of ion propulsion is atmospheric fed Ion propulsion. This method is currently undeveloped, which may be due to little current research into atmospheric ion engines using the atmosphere as a fuel and the fact that the ion engines have a low direct thrust. Thus, the aim of this research is to investigate Ion powered aircrafts at low altitudes and airspeeds, and how the engine and aircraft will perform. To do this, an Ion Thruster (Electrohydrodynamic (EHD) Thruster) using the atmosphere as a propellant by having two electrodes, the negatively charged electrode being the emitter and positively charged electrode being the receiver. If a high voltage is applied across these terminals' electrons will "jump" the gap creating a corona which ionises particles causing them to become negatively charged and attracted to the positive plate. These

particles will gain kinetic energy causing the effect called "Ionic wind". The results from this investigation were inconclusive due to a significant range of error in the measured data and safety concerns. Thus, further research is needed but it was determined based on theoretical information and qualitative results that ion propulsion within Earth's atmosphere is infeasible, and further research is recommended.

1. Introduction

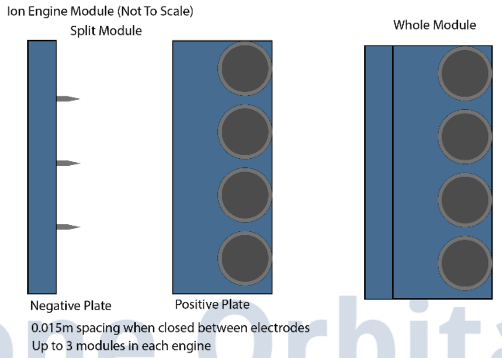
Electrohydrodynamic (EHD) thrusters are currently in the focus of research for interplanetary and high atmosphere methods of propulsion. This is due to EHD thrusters' high specific impulse which means that EHD thrusters can increase the speed of a particles to large velocity. This means that EHD thrusters are highly efficient. However, EHD thrusters have low thrust, and this means that there is a lack of research into atmospheric EHD thrusters for Aircraft. In this investigation it the design of a modular atmospheric EHD thruster called the Modular Atmospheric Ion Thruster (MAIE) and how it is intended to operate from the theoretical principles and results during development. The systems that are designed to evaluate MAIE in an operating environment will be discussed and how they are designed to test MAIE to find if EHD thrusters can be used if capacitors are powering them within Earth's atmosphere. The results will be gathered from wind tunnel testing due to time and operating limitations for aircraft testing. Then the data will be analysed to determine whether Atmospheric EHD thrusters are feasible for aircraft propulsion.

2. Ion System Development

Modular Atmospheric Ion Thruster (MAIE)

Ion Engine (MAIE) Design

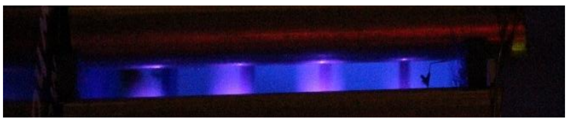
Through this paper the Ion thruster will be referred to as Modular Atmospheric Ion Engine (MAIE). Over the course of development of MAIE there were many revisions and design changes. The most common change in design change was electrode spacing. This is because electrode spacing governs the "flow" of electrons across the gap. The electrode set up of MAIE is the inverse of Vacuum operated engines notably NASA's AEPS - HERMeS [1]. This is because MAIE has a negative electrode charged with 10 – 20kV (10-12kV during flight, and ~20kV charging). 15mm away from the tip of the negatively charged electrode is the positively charged electrode which is a round steel pipe. A round pipe was chosen for the positive electrode because a round positive electrode will minimize any direct paths to be formed. This allows for an even corona discharge to be formed in the direction from the negative electrode to the positive electrode. The corona discharge causes collisions between charged and neutral particles which results in a net directional momentum transfer creating the effect of "Ion wind". The thrust produced by this corona discharge is called Electrohydrodynamic (EHD) thrust [2]. MAIE consists of up to three modules each having 12 negative electrodes and 4 positive electrodes.



(Fig 2.1) Diagram of MAIE module.

Figure 2.1 shows the positioning the negative electrodes in the centre of the positive electrodes. This was done to produce the most thrust. Because EHD thrust is the thrust that is produced by corona discharge which is the collision of charge and neutral particles and placing the negative electrode allows for a corona discharge to two different positive electrodes. The placing of the negative electrode reduces the number of collisions to the positive electrode by the neutral particles. Which were transferred momentum by the charged particles jumping the gap.

(Fig 2.2) Image of the corona discharge creating EHD thrust on a MAIE prototype in late July 2023.



(Fig 2.3) Side on view of the MAIE protype during operation showing the corona discharge from the negative electrode to the positive electrode.

Figure 2.2 and *Figure 2.3* shows the corona discharge between the positive and negative electrodes. *Figures 2.2 and 2.3* also show the importance of having equal spacing between all the positive and negative electrodes. This is due to electricity taking the path of less resistance. This means that if one of the electrodes are fractions of a mm closer an uneven power distribution will occur. This was shown with the furthermost right electrode in *figure 2.2* being "dimmer" which shows that the corona effect was not properly occurring because the other breakdown points had less resistance. Thus, the electrons took this path rather than the right electrodes causing a decrease in efficiency in the engine. To avoid this from happening in later models of MAIE all electrodes will be evenly spaced with as small of an error margin as possible with the available tools. This configuration and type of electrode is uncommon within Atmospheric ionic thrusters. Most of the research utilises Blade and Wire electrodes instead of point electrodes featured within this design. However, point electrodes were chosen to be the negative electrodes in MAIE. Because the pins that are used have a small curvature radius at their edges, which facilitates corona inception at a lower breakdown voltage compared to wired and blade electrodes, [3]. Using point electrodes allows MAIE to have a lower mass because each module only requires 12 pins totalling 36 across MAIE. If point electrodes were not used. Blades would be used because blades share the property of having a lower breakdown voltage than wire electrodes [3]. nine blades will need to be used each spanning the hight of MAIE and this will make MAIE heavier. Therefore, it was chosen to use the lighter point electrodes to keep the weight of MAIE as low as reasonably achievable.

The spacing of the electrodes was originally found using qualitative testing. Thus, there could have been room for improvement in finding the most effective electrode spacing. The method that was used to find the most effective electrode spacing was first finding the most effective positive electrode and orientation. The first test was tested with the positive electrode being a pipe in parallel with the point electrode. This electrode orientation created insufficient thrust and formed an uneven corona due to inconsistencies in cutting of the positive electrode.

(Fig 2.4) Picture of the qualitative testing set up to find electrode type of MAIE engine. Note – this testing method could have been improved to gain more reliable results. Therefore, if this would have to be repeated it would be a controlled quantitative test.

The next test used a positive pipe electrode which was perpendicular to the point electrode and was at a 45-degree angle to the positive electrode at 0.02m as shown in *Figure 2.4*. When tested this electrode produced significantly more thrust which was sufficient to blow out a candle when tested and the ammeter detected that the "Ionic wind" was $2ms^{-1}$. This test verified using qualitative results that the positive electrode being peridural at 45 degrees was better than the positive electrode being parallel. The next step was to find the most effective spacing and this was done off the quantity of "Ionic wind" produce and was tested in 1mm increments from 25mm down to 5mm. The findings of the distance test were that an electrical corona that proceed EHD thrust was within the range of 10 – 15mm. This was because if the spacing was less than 10mm an ark began to form and above 15mm minimal force was created. Therefore, from these tests it was decided that MAIE will have a positive electrode which is a pipe that is perpendicular to the point electrodes which are at an angle of 45-dergress to the positive electrode. At 11.6mm due to limitations in production.

(Fig 2.5) 3D model of the MAIE engine showing the air inlets between each of the modules.

Figure 2.5 shows MAIE being fully assembled and shows the 3 modules. MAIE was decided to have 3 engine modules because of the fundamental calculation for an EHD thruster that uses the corner effect. Which is,

$$F_p = \beta_p \frac{I_p d_e}{\mu} \quad (1), [2]$$

Where F_p is the force that each negative point electrode produces. β_p are loss coefficients that are the functions of the point electrode. μ is the ion mobility of air. I_p means point current, and d_e means electrode distance. Equation (1) is the fundamental equation for an EHD thruster which states that if β_p, d_e, μ are all constant then,

$$F_p \propto I_p \quad (2)$$

This means the current of the electrode is responsible for the EHD thrust. Therefore, the more electrodes that are included in the circuit the lower the current will be per point electrode. Which means that if resistance of air within MAIE is too great the thruster will produce less force. This is why MAIE has a modular design allowing for modules to be removed during testing if required allowing for increased current per point electrode therefore a greater force per point electrode which may increase the total thrust of the thruster.

(Fig 2.6). Image of the constructed 3 module MAIE

Figure 2.6 shows what tolerances were used during the production of MAIE and gives an idea of how close it was to the model version of the engine. The main body is 3D printed and there is a grid of point electrodes being the metal pipes. This is the back end of the engine.

Calculations

Nomenclature for MAIE Calculations

d_e	Electrode distance,	0.116m
V_e	Electrode Voltage,	12000V
N_e	Electrode Number,	12
T_a	Temperature of air,	$293.15°K$
R_d	Specific gas constant dry air, $287.05 J \cdot kg^{-1} K^{-1}$	
R_v	Specific gas constant water vapor, $461.52 J \cdot kg^{-1} K^{-1}$	
P_d	Dry Pressure,	101325Pa
e'	Vapor Pressure,	2338.8Pa

μ Ion Mobility of air, $2.2 \times 10^3\ cm^2 v^{-1} sec^{-1}$

R Molar Gas Constant. $8.31441 \pm 0.0026\, J \cdot mol^{-1} K^{-1}$ [4]

Density of Air during MAIE calculations

The density of the air is important in some equations that are required to calculate the efficiency of MAIE by theoretical principles. Then the theoretical efficiency will be compared with measured results. Below is the formular to calculate the density of air.

$$\rho = \frac{PM_a}{RTZ}\left[1 + (\epsilon - 1)\frac{e'}{P}\right] \quad (3),\ [4]$$

Another equation can be used to also find air density and this equation is.

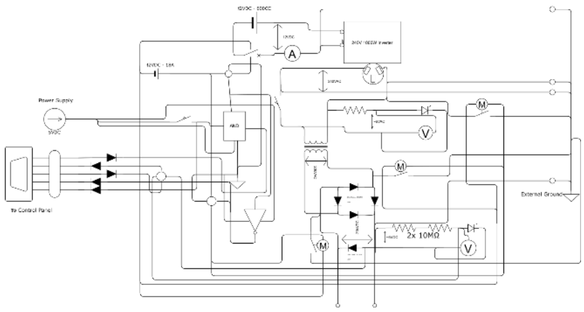
$$\rho = \frac{P_d}{R_d T_a} + \frac{P_v}{R_u T_a} \quad (4)$$

$$\rho = \frac{101325\text{Pa}}{287.05 J \cdot kg^{-1} K^{-1} \cdot 293.15°K} + \frac{2338.8\text{Pa}}{461.52 J \cdot kg^{-1} K^{-1} \cdot 293.15°K} = 1.22 kg\ m^3$$

Circuit Design & Development

The circuit powering the Ion engine.

To charge the MAIE aircraft for flight while also allowing for ground operation in a wind tunnel a high voltage circuit was required. Therefore, the circuit had to be capable of delivering high power high voltage from a DC battery. Thus, the primary circuit is powered by a 12V Lead Acid battery with a cold crank amp rating of 300A. The circuit is rated for 1,000W which means that the battery is required to discharge at 83.3A at maximum power of the circuit. [redacted].



(Fig 2.8) This is a schematic of the voltage multiplier and shows what components are being used.

Within figure 2.8 there will inefficiencies created by the LED indicators which indicate whether the circuit is still charged while also allowing for a voltage bleed for it the grounding switches fail to make contact leaving the circuit isolated from ground, the LED indicators will allow for the circuit to dissipate charge. Thus, making the circuit safe to touch again.

Figure 2.8 shows that the primary power supply to charge the capacitors for MAIE. The capacitors that will operate onboard the aircraft for MAIE operations are 2×12 kV 330pF. This totals to a total capacitance of 660pF. Prior to testing the resistance of the aircraft during operation and rate that the capacitors discharge will be uncertain.

Aircraft Design & Development

The aircraft that will be used as the vessel for the MAIE flight is 3900mm in width and 1800mm in length. The total weight of the aircraft is needed to be below 3kg because the wings from simulation and testing as will be explained later the aircraft will produce at an airspeed of $5ms^{-1}$. The wings will follow a straight format with supports every 300mm that are designed to form the correct wing profile when the plastic wrap is heat shrunk. The MAIE will be placed in the centre of the aircraft and the capacitors which have the responsibility of storing the charge during flight will be located at the aft of the aircraft. This was done to allow switching to take place between the centre of the 2 vertical stabilisers and the switches are going to be used to allocate power to the voltage logger. The switches govern whether the capacitors are disconnected. Which means during the short loop is disconnected during charging and connected during flight. Allowing for decreased charging times because the rate at which the capacitors are discharging is insignificant in comparison to the rate that the capacitors is charging.

(Fig 2.9) Image of the airframe designed for the MAIE flight test. This image is a render of what the aircraft frame may look like and was limited, which meant that the wrap around the wings was unable to be included.

Figure 2.9 shows the overall design of the airframe showing the two vertical stabilizers at the aft of the craft, and the MAIE being located at the centre of the craft. The voltage logger will be located at the tip of the left wing, and this was done to minimise the amount of EMF radiation that the MAIE engine will produce because it is a EHD thruster. This means that the corona creates large fields that will be able to affect nearby wires and components. Thus, it was decided to place any voluble components that are affected by EMF radiation as far away as reasonably achievable. Which meant placing the Voltage Logger at the tip of the wing which is ~1900mm away from MAIE.

(Fig 2.10) Laser Cutting map of wing. Length is 700mm.

Figure 2.10 Above shows the wing profile which is designed to operate at an airspeed of $5ms^{-1}$. Then Figure 2.10 Shows what the laser cut showing that areas of the profile are empty to reduce weight. The reduction in weight allows for the aircraft to carry more circuity and decreases the required airspeed.

Wing testing & Calculations

During the design phase of the airframe testing was needed to find how to produce the wings for the airframe. The other purpose of these tests was to find the airspeed coefficient above and below the wing.

(Fig 2.11) This is the wing within the wind tunnel during testing.

The results from this experiment found that the current wing design is sufficient for flight having difference in airspeed above and below the wing have a delta of 1.25. This means that the wing should be capable of producing enough thrust during flight onboard the aircraft.

The wings onboard the aircraft will be each 1800mm long and 700mm wide and at the end of each of the wing segments are shielded areas. Which are wrapped in Aluminium foil which the purpose of hopefully minimising the effect that the large electromagnetic fields have on circuitry. However, this shielding is not grounded, this may reduce the effectiveness of the shielding.

Everything onboard the aircraft will operate independently of each other, but some will use the aid of an Arduino for control of the servo systems on the aircraft. Any Electronics corelating to safety and operation will preside within the shielded areas of the aircraft with the purpose of minimizing the effect of the electromatic fields.

Overall Test set up developments.

Wind Tunnel

The first half of this investigation will be conducted within a wind tunnel that has a nominal wind speed of 4.3 ms^{-1}. This means that MAIE will be tested within conditions of that aboard an aircraft prior to flight testing. This will allow for more measurements to be taken without major risk to MAIE which are significantly more likely for failure during flight due to the nature of the aircraft moving and 1 with an object during flight.

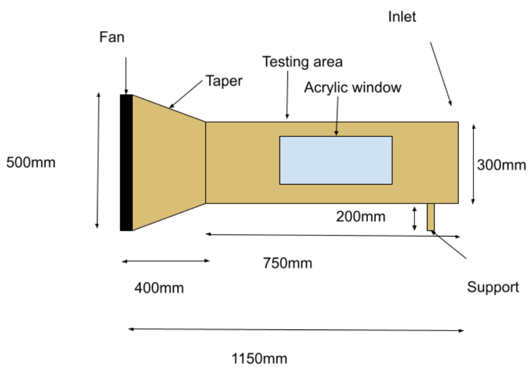


Fig (2.12) A diagram of the wind tunnel. This was designed for a previous investigation and will need to be altered for testing of MAIE.

Figure 2.12 shows that the wind tunnel includes an observation window allowing for observations within the tunnel while avoiding turbulence in the airflow of the wind tunnel. The entrance to the wind tunnel has a grid arrangement which has the purpose of reducing turbulence in incoming air. Then the fan is extracting air from the tunnel to prevent turbulence from the blades spinning on the fan.

It was calculated that at an average airspeed of 5.6 ms^{-1} the lift produced by the aircraft through the equation

$$P_2 - P_1 = \rho(v_2^2 - v_1^2) \qquad (5)$$

Which gave an lift of 2998 grams which is a lift to weight ratio of 1.25 with the predicted weight of the aircraft.

Aircraft Launcher

There will be a launcher which has the responsibility of launching the aircraft at the required airspeed of $5ms^{-1}$. The launcher has a wooden frame due to budgetary constraints, and will use a linear actuator, tightening ratchet, and spring to launch the aircraft. When a launch command is sent the linear actuator will retract causing the tightening rachet to replace allowing the spring to propel the aircraft forward.

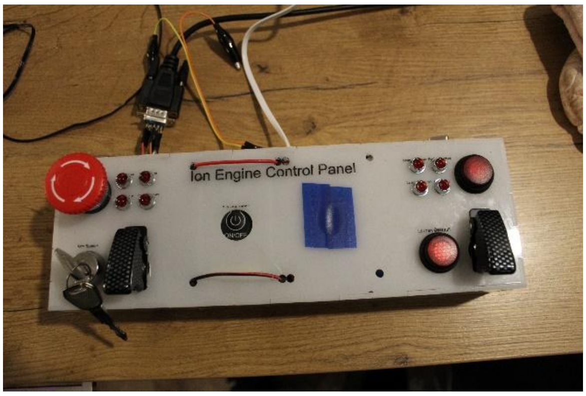
(Fig 2.13) Shows the launcher during testing, with the aircraft on top of the launcher.

There will be a two-cable system for redundancy with one primary pully and a secondary safety pully that will only be used if there is a failure on the primary pully. The cable system is only intended for safety in case the aircraft alters from the intended flight plant it will be stopped by the pully. This system will also allow for breaking at the end of the testing area to minimise the wear and tear on the aircraft after each test, this is due to the aircraft being designed to be as light as reasonably achievable, this will mean that if a large force impacts the aircraft in a non-intended area, it will damage the aircraft. This pully braking system will mean that the breaking force will only be applied on areas designed to tolerate the forces. These areas are attachment points above MAIE between the 2 wings.

3. Method

Wind Tunnel Testing

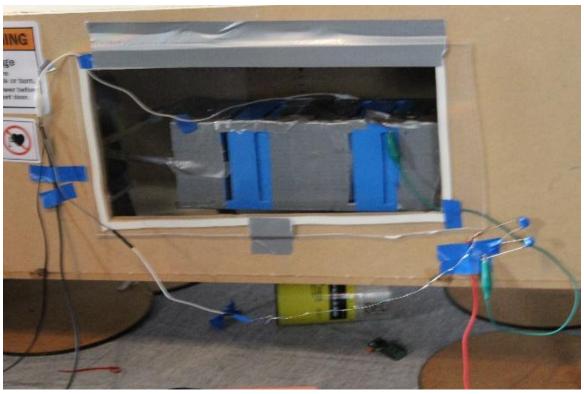
The general method for wind tunnel followed strict steps for safe operation. This followed many steps which are as follows. Check over the entire circuit for foreign debris and or any short potentials. After this attach all the safety wires together. Test wind tunnel servos by app to confirm contact. Repeat this step 5 times. Then with the control panel it was required to run a test 2 times.



(Fig 3.1) Control panel for MAIE

Release emergency stop. Then switch key into on position to set circuit to arm then flip toggle switch to activate circuit. After this it will take 200 seconds for the circuit to carry out the required steps then the circuit will need to be reset. Verify that the Wind Tunnel servos are connected to the reast of the circuit (Off position). Then connect negative terminal on battery and then positive and look over the circuit once more. Afterwards announce that the circuit will be online and then initiate the test. Wait for the Primary Relay to switch and after 5 seconds press the inverter switch to activate the high voltage circuit. Begin a time for 50 seconds from the point that the inverter switch is online and then turn off inverter while setting servos to on position. Wait until the circuit disconnects batteries and grounds, then wait for capacitor to discharge ~30 minutes and or once circuit is below 50V. Repeat tests until satisfactory number of results are measured.

Then calculate the power and force from each electrode. Have a camera with a 1-minute exposure to capture any corona discharge. And turn on scales inside of wind tunnel.



(Fig 3.2) MAIE inside of wind tunnel.

4. Results

Wind Tunnel

Due to safety and time constraints, there are limited results from wind tunnel testing.

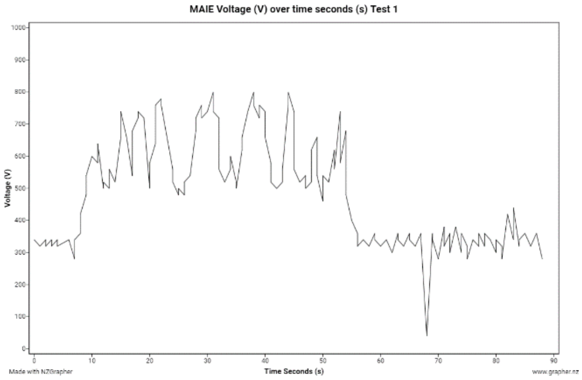
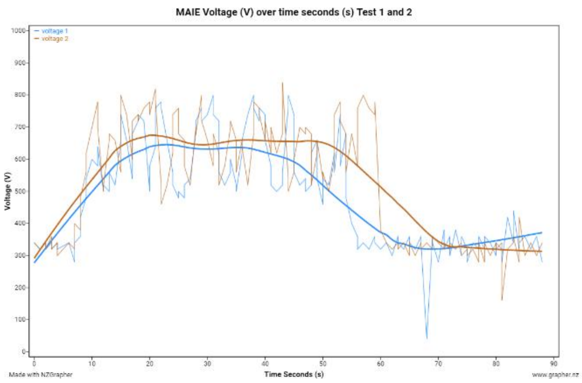


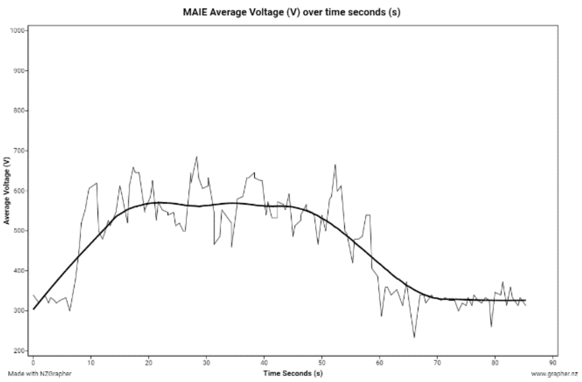
Figure 4.1. MAIE voltage for test 1

(Fig 4.1) is a graph of the voltage over the first test, maximum voltage that was reached during this test was 798.6 VDC at 31 seconds, and again at 38 and 44 seconds into the test. Figure 4.1 also shows how there is a repeating increase in voltage then decrease with a difference in peak to trough of ~ 300 VDC. At 68 seconds the servos were enabled. This means that the circuit across the voltage logging was shorted, and this was shown with a decrease in the voltage across MAIE from 359.4 VDC to 39.9 VDC.



(Fig 4.2). MAIE voltage for tests 1 and 2.

Figure 4.2 shows the difference between tests 1 and 2 where test 2 had a longer operational duration of 50 seconds compared to tests 1 operation period of 46 seconds. Therefore test 2 operated for 4 seconds longer. The voltage dip from servos activating was delayed when compared to test 1. With an activation time of 76 seconds into test 2. This is compared to the operational time of test 1 at 68 seconds. Therefore, during test 2 the servos disconnected from the power supply 8 seconds after test 1. 4 seconds after circuit termination for test 2. When the servos shorted the circuit the voltage drop was from 319.5 VDC to 159.7 VDC



(Fig 4.3). Average across all MAIE high voltage tests.

3 tests were conducted due to time limitations this was the maximum number of measured tests. Figure 4.3 shows that across all 3 tests the average maximum voltage point was 685.5 VDC at 28.3 seconds into each test. The average lowest voltage point across the 3 tests was 242.9 VDC at 66 seconds into each test. The average test duration lasted 49 seconds at voltages above 400 VDC. Test 3 had significantly lower voltage with a maximum voltage of only 559.0 VDC at 28 seconds into testing.

Across all tests the current draw on the 12V supply from batteries was 0.7 A for logged tests. When the 1000W power supply was tested the clamp meter detected a maximum current of 17.8 A. During logged tests there was a small fluctuation in the current with a decrease in current draw of 0.1 A occurring periodically following each of the peaks. On the 230 VAC supply lines during test tests the starting voltage reached 230 VAC but decreased to 15.3 VAC as logged with the use of a multimeter.

Using the equation

$$P_s = V_s I_s \qquad (6)$$

Which when calculated

$$P_s = 12V \pm 0.012 \times 0.7A \pm 0.1 = 8.4 \pm 1.3W$$

This means that the power of the circuit is 8.4 watts with an error of 15.3% which equates to 1.3 watts. The power consumption of the rectifier will be contrite to most of this power consumption. With the datasheet stating that base load power consumption was 0.6 watts. This means that the power consumption of the circuit is $0.1 \pm 0.09A$ which re-calculating.

$$P_e = 12V \pm 0.012 \times 0.1A \pm 0.09 = 1.2 \pm 1.1W$$

Therefore, the high voltage circuit was consuming 1.2 W with an error with power consumption of 1.1W. Which means that if the maximum average voltage across MAIE was 685.5 VDC with an error of 16.1 V. This error is due to the voltage logging system being an Arduino Uno Wi-Fi r4 which has 1024 analogue values which if maximum reading is 20,000V across voltage multiplier error value equals 16.1V per unit. Using a rearrangement of the power equation gives.

$$I_e = \frac{P_e}{V_e} \qquad (7)$$

Which when calculated gives. 93.3

$$I_e = \frac{1.2 \pm 1.1W}{685.5 \pm 16.1V} = 1.8 \times 10^{-3} \pm 1.6 \times 10^{-3}A$$

Thus, the current draw from the high voltage MAIE set up was $1.8 \times 10^{-3}A$ with an error percentage of 93% which gives an absolute error of $1.6 \times 10^{-3}A$. The voltage divider used for logging data had a resistance of 40,880,000±1% Ω for R1 and R2 had a resistance of 10000±1% Ω. This totals 40,890,000 Ω with an error of 408,900 Ω. Using the equation

$$I_R = \frac{V_e}{R_{VL}} \qquad (8)$$

Which gives

$$I_R = \frac{685.5 \pm 16.1V}{40{,}890{,}000 \pm 408{,}900\Omega} = 1.676 \times 10^{-5} \pm 5.6 \times 10^{-7}A$$

This means that the power used by MAIE during this operation was $1.78 \times 10^{-3} \pm 1.6 \times 10^{-3}A$. This means that the current across all 36-point electrodes in parle will be approximately $4.45 \times 10^{-5}A$.

Due to measured AC voltage being 15.3 V with an error of 0.02 V. This reading means that after the voltage multiplier the voltage was expected to be

$$V_e = 15.3 \pm 0.02V \times 48 = 734 \pm 7V$$

This calculated voltage is within range of measured results at points during circuit operation.

No measurable corona nor thrust was observed from all 3 tests.

5. Conclusion

The measured voltages were significantly lower than was expected with the maximum average voltage measured across all 3 tests being 685.5 VDC. Which is lower than the expected 1105V for the high voltage supply that was used. This was further shown by no thrust nor corona being shown by MAIE which means that the voltage was not sufficient, to cause a corona formation between the electrodes, in which 685.5 V is not due to MAIE having a rough operating range of 6,000 VDC – 15,000 VDC. This means that the measure voltage was outside of the operating range. The point electrode current was measured to be $4.45 \times 10^{-5}A$. With an error of $4.4 \times 10^{-5}A$. This error may mean that at points during the tests the current at each point electrode was close to 0 A. the distance between the positive and negative electrode is 11.6 mm which equals 1.16cm. Estimating that during testing μ which is the Ion mobility of air is $2.2 \times 10^{3}\ cm^{2}v^{-1}sec^{-1}$. Using the theoretical equation (1) with the loss coefficients removed due to limitations in data analysis

$$F_p = \frac{I_p d_e}{\mu} \qquad (9)$$

Which gives when calculated a force of

$$F_p = \frac{4.45 \times 10^{-5} \pm 4.4 \times 10^{-5}A \times 1.16\text{cm}}{2.2 \times 10^{3}\ cm^{2}v^{-1}sec^{-1}} = 2.35 \times 10^{-8} \pm 2.3 \times 10^{-8}N$$

Therefore, the force generated would be $2.35 \times 10^{-8} \pm 2.3 \times 10^{-8}N$. This means that the total thrust generated by MAIE generated on average across all 3 tests was $8.45 \times 10^{-8}N$ with an error of $8.4 \times 10^{-7}N$ This means that periodically the energy was offline. This means that during the test the total thrust produced my MAIE was undetectable due to only generating $8.45 \times 10^{-8}N$ of thrust.

During the operation of MAIE there are power fluctuations this may be due to charge building until it is able to discharge across the data logger and or MAIE engine giving voltage spikes and dips during operation. Due to the spikes having a drop off it is assumed that this is due to the MAIE engine operating for a few miller seconds at a time.

6. Discussion

The overall result from this investigation is inconclusive. This is because of the limited testing that occurred. Which was because of the difficulty of measuring information within a high voltage environment and the limitations of the equipment that was available. Near the end of testing just after the tests 1 – 3 were conducted there was an investigation into how to solve the issue that the voltage logging system had a base load detection of ~ 350 VDC across R2. However, this occurred when R2 was not charged, and the actual difference was 0 VDC. This may have been due to uncertainty with impedance in the loglog sensing circuit which means that the logger was detecting a value of 18/1023 without any charge being applied. While attempting to rectify this issue a high voltage technician advised "To walk away with a pulse" and this was the point where it was decided to stop any further testing. The reason behind this suggestion was because the circuit that was going to be used for high power operations was unsafe to operate and the usage of capacitors and no way to rapidly discharged. This means that it was unsafe to interact with the circuit until 30 minutes after operation. This is because it took 30 minutes for the voltage in the voltage multiplier and MAIE capacitors to decrease below 50V.

No aircraft testing was able to be conducted due to time limitations. This is because the space intended for testing was only available for 5 hours. However, since setting up the aircraft took 4 and a half hours it was decided to cancel the test. This means that the data provided above is some of the only data obtained during this investigation. The MAIE aircraft also had an issue that needs to be rectified before testing which is the structural integrity of the wing attachment. If it was to be repeated it would be recommended to use Aluminium. The largest issue from this investigation was lack of time, funds and knowledge of systems. Thus, the high voltage systems were unable to be designed properly and to a safe satisfactory standard.

From prototype testing MAIE was found to be functional, but improvements could have been made by conducting further testing with quantitative analysis during the protype development of MAIE to improve efficiency and thrust. Another problem that was found during the test of MAIE was that there is a large inefficiency in earth's atmosphere, which is that the major byproduct of MAIE was ozone which can pose a danger to humans and the nearby environment due to ozone's strong oxidising ability. This means that if larger versions of atmospheric EHD thrusters were produced there will be a large hazard to the environment due to ozone and this problem needs to be further investigated to find how to decrease the production of ozone if possible. Another issue is EHD thrusters have a large specific impulse but relatively small thrust. This means that at full efficiency it would be estimated that MAIE could only produce $4.4 \times 10^{-5}N$ theoretically and this would be insufficient for flight of an aircraft that. The measured results shows that there is a problem with the circuit only measuring 15 VAC which agave the average maximum voltage across 3 tests being 685.5 VDC. This meant that the thrust produced by the MAIE was $8.45 \times 10^{-8}N$ with an error of 99.9%. Which means that this reading cannot be truly considered due to the error being the same as the measured result, thus meaning that the force produced could have been 0V. This means that the results from this investigation are invalid due to the error being too significant.

To improve on this further testing and investigation is needed to gain valid quantitative results and measurable thrust. This can be done by having a greater knowledge of high voltage systems and designing a circuit that is capable of significant power. The results that were given by this investigation stated that Electrohydrodynamic thrusters within earth's atmosphere as a form of aircraft propulsion is insufficient due to low thrust and high-power consumption which requires heavy equipment. This means that ion engines are currently unable to be used for aircraft propulsion for long duration flight because the fast rate that the capacitor discharged, safety.

Disclaimer

This is the first research paper that this writer has produced, and this has not yet been peer reviewed. This means that the information discussed may be incorrect. Thus, further research must be done before disclosing any information discussed within this paper to other individuals. This paper may also be bias due to a lack of qualifications within the field of study of atmospheric EHD thrusters.

This research paper should not be replicated without the proper precautions, and knowledge behind high voltage circuits. This is because of the dangerous nature of high-power circuits operating at high voltage having the ability to kill a user if used incorrectly or touched without any protection or precautions. This is why safety was of the upmost priority when designing and using the high-power circuits shown within this article.

Some of the materials and byproducts from this research pose a health risk to any nearby users in the area. This is because the main byproduct of the Ion engine is Ozone which can cause inflammation to airways, aggravate lung diseases such as asthma, emphysema, and chronic bronchitis [5]. This means the engine had to be tested in a well-ventilated area. Ozone produced by the engine can also pose harm to the local environment because ozone can enter the stomata within the leaves of plants and oxidize the tissue during respiration therefore damaging the tissue of the plant [5]. Which means that prolonged engine use should not be done near any plants.

During testing any induvial whom had a medical implant that would be affected by electromagnetic radiation was removed from the areas of testing. This is due to the nature of the high voltage environment producing large electromagnetic fields which area able to cause bit changes and or cause power surges within electrical equipment. This is due to the intense electric field near the emitter ionizes the gas, which causes a corona discharge between the two electrodes. [3], [6]

The production of parts like the transformer (Welding and laser cutting the plates), soldering the safety systems, and laser cutting may all produce dangerous gasses therefore these had to be done in well-ventilated areas, and were only used when necessary.

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Contact

Some information within this document is incorrect This includes anything mentioning transformers and or circuitry. Therefore, it is recommended to conduct further research into the circuits powering Electrohydrodynamic thrusters before mentioning anything disclosed in this document.

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