**WAVE DRIVEN ELECTRONIC PROPULSION TECHNOLOGY: A NOVEL APPROACH TO INCREASING THRUST EFFICIENCY USING SOUND**

**PART 1, OF A CONTINUING SERIES**

*Qualities of increased Kinetic Energy in SF6*

**Undergraduate Research 294**

Winter 2018 Quarter Research Proposal (ENGINEERING REVISION 1)

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**Abstract**

Present and future spaceflight missions depend on the ability to produce high exhaust velocities while reducing the dependence on chemical fuel and its mass onboard a spaceflight vehicle. Oscillation of gaseous molecules during pre-ejection stages via embedded wave driver allows for ejection at higher velocities, increasing chemical fuel efficiency. Oscillation of granulate and liquid reagents using simple harmonic motion has been shown to excite particles, forming geometric patterns when using calibrated frequencies. Methods shown to induce geometric patterns were used to attain similar formations in the reagents *Lycopodium*, CO2(g) and SF6(g). Oscillation of *Lycopodium* was used as a proven method to target, observe, and calibrate specific sound formations for experimentation with gases. Sulfur hexafluoride (SF6) was used to simulate xenon, a dense gas used in modern electronic propulsion devices. Ten-millimeter polypropylene, air-filled mass objects were used to observe acceleration, force, and velocity for a dense gas during oscillation and resulting formations. Observation of non-zero forces within gas formations during oscillation shows that additional thrust velocity can be achieved through the oscillation of propellant gas via wave drivers embedded within experimental electronic propulsion systems. Force and velocity calculations taken during oscillation of SF6 demonstrate proof of concept for future experimentation using xenon as an oscillation and ionization medium for ejection at velocities which can be used for spaceflight. Results of this experiment introduce a novel method for achieving increased velocity during space flight using sound as a performance enhancer.

1. **Introduction:**

Increasing thruster performance while reducing dependency on chemical fuel is essential to future spaceflight applications. (1) Research being done at North Seattle College consists of using the oscillation of wave drivers to create kinetic energy in propellant gas. Sound will be used as a method to transfer energy into chemical propellant, increasing exhaust velocity beyond what standing propellant gas could achieve.

**NEW RESEARCH**

Currently, increasing propellant chamber pressure in electric propulsion devices before expelling exhaust through a nozzle is done with thermal and electromagnetic energy. Current methods for increasing thruster performance include manipulation of cathode shape(2), wall materials(3), anode geometry(4), channel length(5) and magnetic field strength(6) and configuration(7).

The purpose of this research and experimentation is to use sound waves as a method for increasing kinetic energy and pressure in electric propulsion devices, before the stage requiring application of heat or electromagnetic field.

**II. Research Question:**

**“Can an embedded wave driver be used to increase kinetic energy in electronic propulsion devices?”**

**ADRESSING BIG PICTURE**

This research is being done to address the issue of both space transportation efficiency and thruster performance during future spaceflight missions. Research in using sound as a method to transfer stored electrical power into usable exhaust velocity provides a means of reducing overall dependence on chemical fuel and its associated mass during space flight. Higher Velocities can be attained while maintaining a greater inertia during long voyages by increasing kinetic energy of propellant gases during pre-ejection stages.

Harmonic oscillation of propellant gases using an embedded wave driver is a novel method for increasing thrust efficiency during spaceflight. This experiment looks for qualitative and quantitative results during oscillation of SF6, an inert gas with a density to gases in the 5th period near xenon, a known thruster propellant. Experiments done by Hans Jenny with lycopodium(8); a gas like particle used in physics have been done which produce a spherical vortex formation when under specific ranges of frequencies. Size and shape of vortex formations can be increased and decreased through tuning of amplitude and frequency during calibration. In this experiment, we will attempt to modify Hans Jenny’s previous experimentations by using SF6 as a test medium for observing and recording the effects of pressure waves on thruster propellants.

**III. Methods:**

**Part 1: Construct Lab Environment for oscillation of reagents using SHM.**

For this experiment, a modular testing environment will be designed and constructed which will test various mediums in a simulated thruster channel (during pre-ejection stages). The lab environment for this experiment will consist of a pressurized chamber with an imbedded wave driver and an air column for oscillation of reagents in varied concentrations. This modular experimental environment allows for resonation of reagents both in a resonance chamber and on diaphragms of various materials for observation and recording data. Observations in reagents at this stage of experimentation will be used during spring 2018 to predict force patterns for xenon gas, during plasma ionization. This first stage of experimentation is part of a 3-quarter series in which we will use the Undergraduate Research program at NSC to build a fully functional thruster which operates on principals of using a wave driver to create additional thrust velocity.

**Lab Environment Physical Specifications:**

|  |  |
| --- | --- |
| **QUALITY** | **MEASUREMENT** |
| CHAMBER DIAMETER | ~200mm |
| CHAMBER DEPTH | ~150mm |
| HORIZONTAL AREA | ~3.1416e4 mm2 |
| CHAMBER VOLUME | 4.71239e6 mm3 |
| SPEAKER VOLUME |  |
| TOTAL ENVIRONMENT VOLUME |  |

**This lab environment will support the following experimentation:**

* Oscillation of Lycopodium with a diaphragm of stretched paper
* Partial/Total Pressure Experimentation of Gases under SHM
* Experimentation of Plasma Ionization under SHM
* Investigation of wave path using rubber diaphragm, mirror and laser.

**Part 2: Calibration of Frequencies using Lycopodium**

In this portion of this experiment, methods published by Hans Jenny (9) will be used to find specific frequencies which create geometric patterns in test mediums. Testing frequencies using Hans Jenny’s methods are required to find which specific ranges of frequency work to create vortex like geometric patterns (Calibration of Frequencies), which can be used on a dense gas during spaceflight. For the calibration, Lycopodium powder on an oscillating diaphragm will be used to simulate a layer of gas within the SHM experimentation chamber.

While observing Lycopodium during oscillation, frequencies which produce vortex formations will be recorded. Recorded frequencies will then be observed under varying amplitudes to calibrate which frequency offers the most structural stability under high amplitude vibration. Higher amplitudes of oscillation within our vortex pattern will give us a higher transfer of energy into our propellant gas from our wave driver which will allow for higher exhaust velocities.

**Step 1:** Add Thin layer of Lycopodium powder to paper diaphragm of experimentation environment.

**Step 2:** Begin testing full range of frequencies, adding additional lycopodium powder to increase visualization area and replaced initial volume lost during fallout during oscillation.

**Step 3:** Find vortex patterns and experiment on stability with adjustment of frequency and amplitude.

**Step 4:** Measure vortex diameter, height and angular velocity of vortex

**Step 5:** Use amplitude and frequency adjustment to scale vortex size to fit inside gas oscillation chamber

**Step 6:** Record calibration results, plot data and look for trends in calibration results.

**Part 3: Testing Calibrated Vortex Frequencies using SF6**

After vortex pattern forming frequencies have been recorded and tested, various amplitudes will be used on Sulfur Hexafluoride, to record both qualitative and quantitative data. In this experiment, SF6 is used to simulate the physical characteristics of xenon, a propellant gas used in spaceflight. Experimentation for this portion of this investigation will consist of loading the SHM chamber with incrementally increasing partial pressures of SF6 and observing vortex formations created by sound. Observations will be conducted using miniature ping pong balls which will float above the layer of SF6 and allow for tracking of changes in velocity, acceleration and force.

**Sulfur Hexafluoride vs Xenon Comparison**

|  |  |  |
| --- | --- | --- |
| **QUALITY** | **XE** | **SF6** |
| DENSITY (STP) | 5.761 kg/m3 | 6.164 kg/m3 |
| MOLECULAR MASS | 131.29 g/mol | 146.055 g/mol |
| INERT | YES | YES |

**Sulfur Hexafluoride & floating orbital Experiment**

10mm Ping Pong Balls will be used to visualize patterns of movement in gas by floating on SF6 layer and moving with vortex formation. By recording the mass of a single ping pong ball and finding it’s acceleration, the force of the gas vortex can be calculated.

The system pressure of the SHM testing chamber before application of sound will not exceeded 1 Atm, which is the common range of an electronic thruster. Depending on the physical limitations of the containment vessel, a vacuum environment will be attempted in range of 0.3 Atm and 1.0 Atm. Lower pressure will allow for a closer replication of pressures used in modern electric propulsion devices and will also allow for visualization of low pressure Noble gases when ionized.

**Step 1:** Measure Ping Pong Ball Mass with Uncertainty

**Step 2:** Add Ping Pong Balls to SHM Experimentation Chamber

**Step 3:** Fill SHM Experimentation environment with desired of concentration of SF6. Use visualization of gas level (ping pong balls) or gas flow rate to calculate concentration levels.

**Step 4 (Vacuum Experiment Only):** For Vacuum Experimentation at .66 Atm, fill the chamber with 33% SF6 and 66% air, then pump out 1/2 of the volume of air from the top gas port to achieve a 50/50 mixture.

**Step 4 (Vacuum Experiment Only):** For Vacuum Experimentation at .5 Atm, fill the chamber with 25% SF6 and 75% air, then pump out 2/3 of the volume of air from the top gas port to achieve a 50/50 mixture.

|  |  |  |
| --- | --- | --- |
| **RUN** | **SF6 %** | **Air %** |
| #1 | 20% | 80% |
| #2 | 35% | 65% |
| #3 | 50% | 50% |
| #4 | 75% | 25% |
| #5 w/ Vacuum (.66 Atm) | 50% | 50% |
| #6 w/ Vacuum (.50 Atm) | 50% | 50% |

**Step 5:** Oscillate SF6 air mixture with calibrated frequencies and observe patterns. Record Angular Velocity, Linear Velocity, Angular Acceleration, Linear Acceleration and use this data to calculate the force of the vortex using the mass of the Ping Pong Balls.

*Fvortex (torque) = (mping ping ball)(alinear)*

*alinear = (rvortex)(aangular)*

*(aangular) = (Δvangular)( Δt)*

*(vangular) = (Δθ)( Δt)*

The ping pong ball experiment can be used to gain a rough estimate and record qualitative data regarding force exerted by gas during oscillation. Any non-zero forces observed during oscillation of SF6 using a wave driver means that a novel means of generating gas velocity for spaceflight has been discovered. Additional equations from mechanical statistics can be used to calculate exact force, and velocity data from this experiment.

***Total Force exerted by all particles:***

***Force exerted perpendicular to container wall per unit (Pressure)***

***Sum of total Force exerted per volume***

**IV. Equipment, Reagents, Supplies and Other Needs:**

**GREEN** = AVAILABLE ON CAMPUS

**PURPLE** & **GOLD** = POSSIBLE ACADEMIC LOAN

**RED** = LOOKING FOR AT LIBRARY

**GREY** = SOURCE AFFORDABLY

**A. Materials Needed for SHM Oscillation of Reagents**

|  |  |  |  |
| --- | --- | --- | --- |
| Function Generator | [Available NEW from Pasco](https://www.pasco.com/prodCatalog/PI/PI-8127_function-generator/index.cfm). Available USED, everywhere else. | Outputs sine, square, triangle, positive and negative ramps with a frequency range of 0.001 Hz to 150 kHz in addition to DC | $775  Available ON CAMPUS! For FREE |
| Reagent Grade Lycopodium Powder, 500g | [Widely available](https://www.flinnsci.com/lycopodium-powder-reagent-500-g/l0034/) | Small, gas like particles Used in physics to visualize sound waves and electrostatic charge. | $21 |
| Sulfur Hexafluoride SF6 |  |  |  |
| CO2 Gas / Dry Ice | Widely Available | Gas which is safe and visible |  |
| 8” JMH Audio Driver | JMH Audio | Can be used to create pressurized sound chamber for gas/plasma and lycopodium testing at midrange frequencies. | $179 |
| Acrylic Cylinder | [ePlastics](http://www.eplastics.com/Plastic/ACRCAT8-000ODX-375) | Plexiglass - Clear Cast Acrylic Tube 8.000" OD x .375" Wall Cast Acrylic Tube  Item ID: ACRCAT8.000ODX.375 | $93 |
| Acrylic Cylinder Sheath | [ePlastics](http://www.eplastics.com/Plastic/ACRCAT8-500ODX-250) | Plexiglass - Clear Cast Acrylic Tube 8.500" OD x .250" Wall Cast Acrylic Tube | $122 |
| Acrylic Sheet (x2) | [Delvie’s Plastics](http://www.delviesplastics.com/p/clear_acrylic_sheet.html) | Cast Plexiglass Sheet, will be used for cap to testing environment | $30 |
| Paper Diaphragms of Varying Sizes (x2)  *Possibly Drumheads* |  | Will be used for replication of Hans Henny experimentation & Calibration. | $30 |
| Mounting Hardware |  |  | $25 |
| Shop and Machining Resources @ NSC |  | Will need to use certain cutting equipment, sanders and drill press for engineering of gas/plasma chamber and lycopodium testing chamber. |  |

**Timeline:**

**ORANGE** = BEHIND SCHEDULE

|  |  |  |  |
| --- | --- | --- | --- |
| **Period** | **In Class** | **At Home** | **Goals** |
| ***Week 1*** |  |  |  |
| ***Week 2*** |  |  |  |
| ***Week 3*** | * Shopping for hardware required for assembly of experimentation equipment. * Overviewing Designs and methods * Work with Physics Instructors for relevant Equations * Work with Chemistry Instructors for relevant chemistry Equations * Work with Math instructors for measurement and calculation methods | * Shopping for hardware required for assembly of experimentation equipment. * Networking with campus faculty for assembly assistance. * Preparing home environment for at home assembly work. * Researching known frequency ranges and combinations of tuning methods. * Reading Hans Jenny Material and Videos * Working on Design Features * Consulting with audio professionals, Chemistry and physics faculty. * Start working on abstract * Write Abstract | 1. Acquire Equipment 2. Complete Measurements for chamber construction 3. Publish Proposal as new Plasma Vortex Theory 4. Home Lab Setup |
| ***Week 4*** | * building acrylic pressure chamber * Frequency Calibration * Recording Data and Video of Frequency Calibration.   **Abstract Writing Workshop**   * Edit Abstract | * Engineering Test Environment - Changes & Problems * Calculations related to Frequency Calibration * Organizing Video Sequences for Documentation. * Discussing Results with peers * Reading and Watching Similar Research Projects | * Start Testing with Wave Driver |
| ***Week 5*** | * Testing Noble Gas Ampoules / Micro Vortex Possible? * Finishing Chamber * Pressure Test Chamber * Lycopodium testing * Work on Abstract   **Optional Draft Abstract Due to instructors (in Canvas)** | * Work on Abstract * Promote Vortex Theory * Watch and Edit Recorded Video for Report * Work on Report Journal | * Attain Vortex Formation with Lycopodium |
| ***Week 6*** | * ~~Test Noble Gas and Sound in Completed Chamber~~ | * Make Hardware Adjustments * Work on Abstract | * Finish Abstract |
| ***Week 7*** | * ~~Work on Plasma creating Plasma in the lab~~ * ~~Conduct Laser Experiment~~   **~~Progress Report Session 1~~**  **~~UW Abstract Due 2/13~~** | * Research Electromagnetic Propulsion and Plasma Theories * Make Hardware Adjustments * Work on Abstract | * Edit and Compile Experimental Video Footage |
| ***Week 8*** | * Writing Results * Recording Video Documentation * Recording Promotional Video   **Progress Report Session 2** | * Start Micro Documentary * Create Scientific Pages & Groups |  |
| ***Week 9*** | * Recording Interviews of Scientists involved in Project * Introduce Scientific Journal for Publishing | * Work on PPT Presentation of experimental data * Work on Scientific Journal for Publishing   **Research Presentation PPT draft due to instructors (in Canvas)** | * Draft Results in Scientific Journal * Demonstrate Plasma Vortex for Scientific Review |
| ***Week 10*** | * Work on Scientific Journal | * Edit Video Footage For Micro Documentary For Presentation and Social Sharing for scientific review.   **Rehearsal of Presentation, Peer Review** | * Complete Scientific Journal for Publishing * Complete Micro Documentary |
| ***Week 11*** | **Final Presentations** |  |  |

**Conclusion:**

The most significant challenge to face during this experiment is sourcing hardware which falls within the budget for this project, and a lack of aerospace engineering support within an undergraduate research program with a heavy biological research influence. The first problem is directly related to the latter, the small group size for this project severely limits how much can be spent on this project because of “per student funding” limitations.

Many problems related to lack of engineering support are solved with heavy independent research and consulting with other faculty members on-campus. Instructors in physics, chemistry, mathematics and electrical engineering departments have been consulted with as to methods, hardware availability and overall project feasibility. So far, positive support has come from every department on campus and through consultations with outside university instructors.

This project relies heavily on the development of new methods and applications which rely on known scientific principals which might not be understood outside of a physics classroom. Problems finding recent, relevant sources for experimentation using harmonic motion to manipulate gaseous clouds for the purpose of spaceflight have also led to problems when dealing with a scientific audience with a heavy biology and organic chemistry background. Much of the resources used for this experimentation of come from physics and mathematics principals which are found in textbook literature, and scientific research done at the beginning of the last century. References which are included in this presentation are not used to provide the reader with examples of other experiments which are similar to this research. References cited in this proposal are instead to inform the reader of basic principles of physics and electric propulsion sciences which allow for connections to be made which lead to a better understanding of the overall experiment and its contributions to our existing knowledge.

**References**:

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