Performance Analysis of Argon and Xenon Gas Flow Through a 2D Nozzle Using CFD

CU-Prime Boulder

Department of Physics
UNIVERSITY OF COLORADO BOULDER

Authors: Krishna Khare, Kushrajsinh Zala, Parin Ravula
Advisor: Abhistha Singh, Zainalabidin Parkar

Introduction

- Electric and magnetic fields play a central role in modern plasma thrusters, where ions are accelerated electrostatically and electromagnetically to generate high exhaust velocities.
- Understanding how energy input, pressure, and magnetic confinement shape the flow is critical for optimizing thrust and minimizing plume divergence.
- Before introducing full plasma physics, analyzing the neutral gas flow behavior provides key insight into how future charged-particle exhaust will evolve under E and B fields.
- This study models argon and xenon gas flow through a thruster-like 2D nozzle to examine energy transfer, acceleration trends, and velocity shaping that occur prior to ionization and electromagnetic acceleration.

Hypothesis

- H1 — Increased Energy Input → Higher Exhaust Velocity
  - Raising chamber pressure (our stand-in for stronger E-field acceleration) will increase exhaust velocity and thrust.
- H2 — Gas Species Matter
  - Because argon is lighter than xenon, it will accelerate more for the same energy input and should display higher velocities and more plume expansion.
- H3 — Flow Shape Will Mirror Magnetic Confinement Effects
  - Velocity contours will show: Strongest acceleration near the throat, plume widening at higher pressures, analogous to how weak magnetic confinement allows ion plumes to diverge.

Theory

Ion thrusters work by ionizing a neutral gas and accelerating the charged particles with electric and magnetic fields. Their motion is governed by the Lorentz force:

$$\vec{F} = q(\vec{E} + \vec{v} \times \vec{B})$$

Electric fields provide axial acceleration:

$$a = \frac{qE}{m}$$

Thrust scales with mass flow rate and exhaust velocity:

$$T \approx \dot{m} v_{\text{exit}}$$

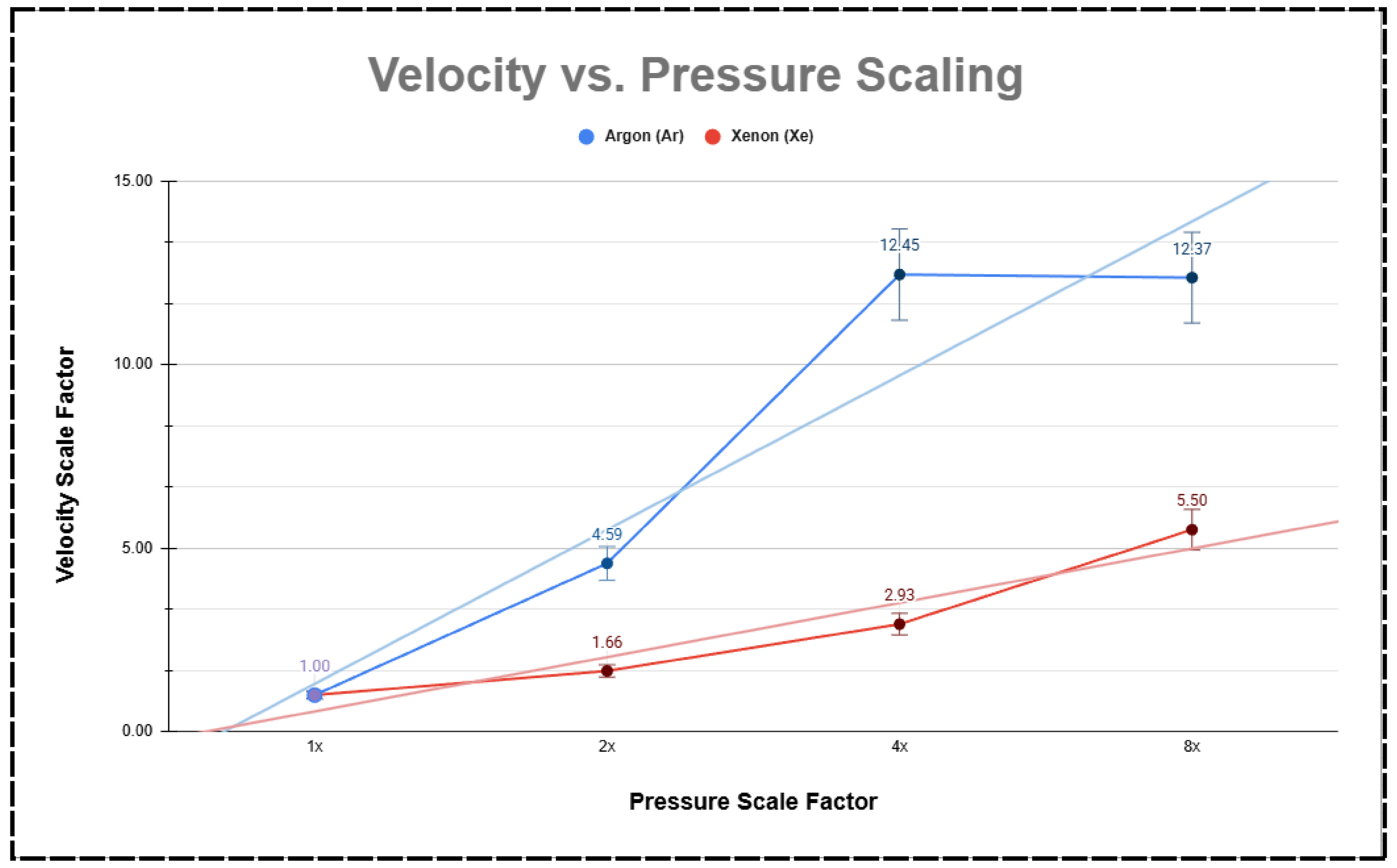
Magnetic fields improve performance by confining electrons, increasing ionization efficiency, reducing wall losses, and shaping the plume.

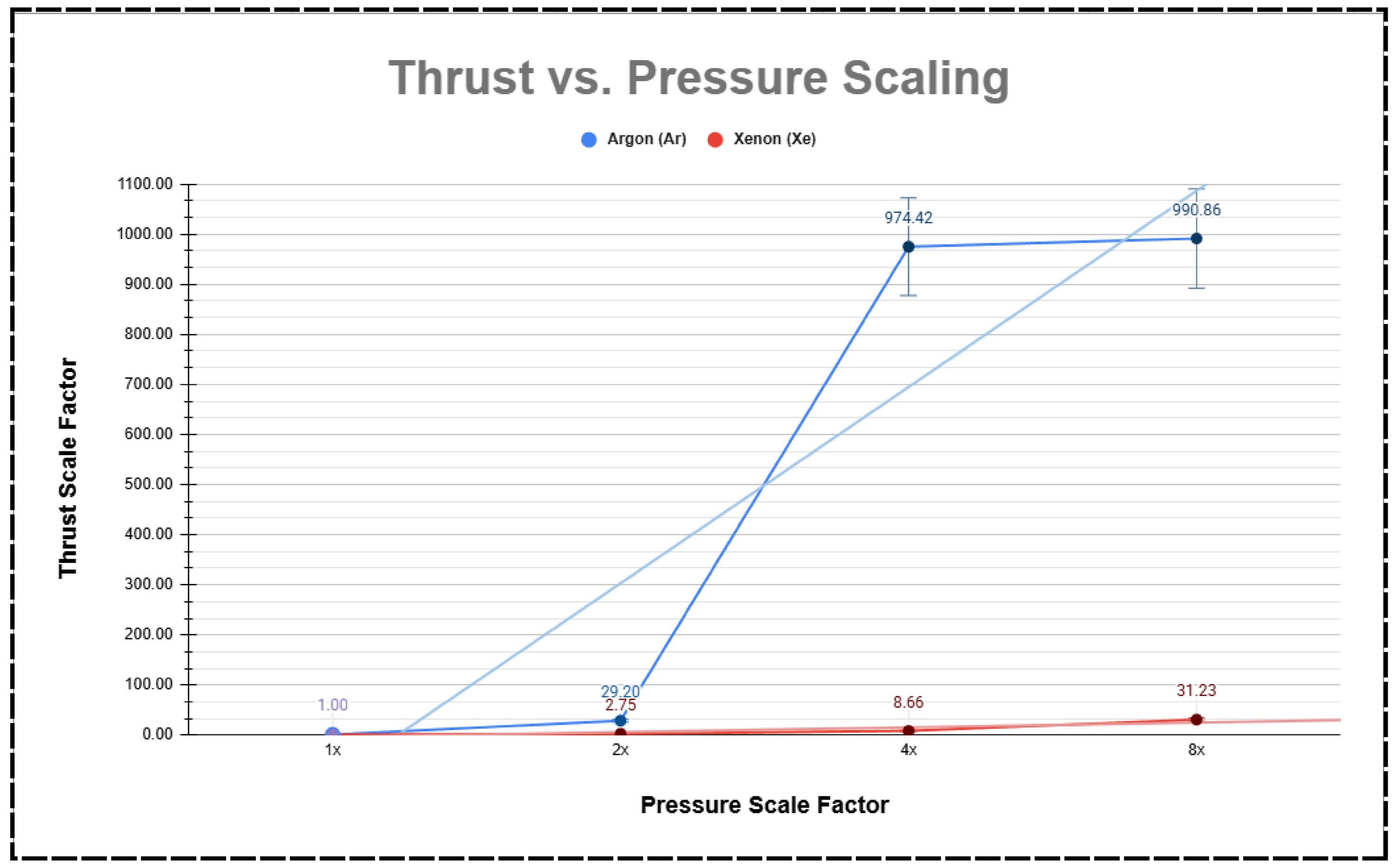
Although our CFD model uses neutral gas rather than plasma, the pressure-driven acceleration and plume spreading still mimic early flow behavior prior to full ionization, offering qualitative insight into how increased energy loading affects exhaust velocity and collimation. We will still utilize the equation for Thrust.

Method

- A 2D axisymmetric thruster-nozzle model was created in SolidWorks to study how inert gases accelerate under varying energy inputs.
- Independent variable: chamber pressure (200 kPa → 1600 kPa) used to mimic increased accelerating field strength.
- Argon and xenon were selected due to their widespread use in electric propulsion and because their differing masses provide clear, visual differences in plume development.
- A realizable k–ε turbulence model was used to capture acceleration, shear layers, and expansion patterns consistent with nozzle-driven exhaust behavior.
- Velocity magnitude and thrust metrics were extracted from Fluent for all test conditions.
- Geometry Scaling Adjustment:
  - Because ANSYS Fluent cannot reliably mesh extremely small thruster geometries, the nozzle had to be uniformly scaled up.
  - This preserved proportional geometry while enabling stable meshing and computation, allowing us to study qualitative flow trends despite not resolving true ion-engine dimensions.

Results





Data Analysis

General Trends Observed:

- Velocity increased with pressure, confirming that higher energy loading produces stronger acceleration, but there was a level-off
- Argon consistently reached higher velocities than xenon at all pressure levels, consistent with its lower molecular mass and easier acceleration.
- Thrust increased sharply with pressure, but xenon showed lower velocities and lower thrust due to its higher mass and slower acceleration.
- At high pressure levels, plume spreading increased (especially for Argon but less for Xenon), mirroring how insufficient magnetic confinement allows ion plumes to diverge.
- The unexpectedly large numerical differences between argon and xenon highlight the limitations of modeling plasma physics using neutral-gas CFD, which does not include:
  - True E-field acceleration
  - magnetic confinement
  - space-charge effects

Despite these limitations, the qualitative trends match expectations for real ion thrusters.

Conclusions & Future Work

- Increasing chamber pressure (our analogue for increased electric/magnetic acceleration energy) produced higher exhaust velocities and thrust for both gases.
- Argon showed greater acceleration than xenon due to its lower molecular mass, while xenon produced slower but denser flow.
- Plume expansion increased at higher pressures, reflecting the lack of magnetic confinement and highlighting how geometry influences flow spreading.
- Because the simulation used neutral gas, scaled geometry, and no real E–B field physics, the results represent qualitative trends rather than realistic ion-thruster performance.

Future Work:

- To more accurately model plasma propulsion, future simulations should incorporate ionization physics, electrostatic acceleration, and magnetic confinement. Coupling ANSYS Fluent with Maxwell or a dedicated plasma solver would enable Lorentz-force modeling, improved plume predictions, and more realistic exhaust velocity and thrust measurements.

Scan to see more data!

References

Ansys Fluent 2022 and Anysy Workbench 2022

Acknowledgements

We would like to thank our instructors Margert Huber and Jack Farrell and our advisors Abhistha Singh and Zainalabidin Parkar for their support and guidance.