Methods of Low-Density Gas Simulation in the Context of Beamed Propulsion Techniques

Eric A. Comstock, Christopher M. Limbach

Introduction

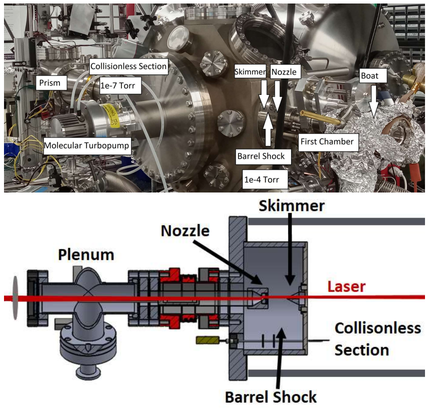
Beamed propulsion circumvents the need to carry fuel and reaction mass on spacecraft, potentially making it a viable option for quick interstellar flight.

To prevent the diffraction that renders lasers and particle beams ineffective at long distances, we use a self-coupling interaction in a combined beam:

- Dipole forces from the laser keep particles inside laser
- Refraction from the particles keeps light inside particle beam

Our Apparatus

At LDPDL, a combined beam is created using a collisionless atomic jet, generated from expansion of a flow of evaporating rubidium in a carrier gas to extremely low pressure.



Our apparatus – sections labelled

Simulation

To measure the effect of the self-coupling, absorption and refraction spectroscopy are used on the laser component once separated using a heated prism.

A simulation of these spectra was created to determine the optimal carrying gases, and to generate control results for the spectra if no coupling occurs.

ABSORPTION SPECTRUM

The simulation of the flow was done using a quasi-1D model, with the first chamber, nozzle, barrel shock, and collisionless sections modelled separately, and spliced together.

- Subsonic to Supersonic flow
- Continuum to Collisonless flow

Three quantities have to be found for the absorption and refraction spectra to be calculated:

- Volumetric concentration

$$Tr = e^{-N\varepsilon l}$$

- Longitudinal velocity

$$\Delta\omega = \frac{\omega V}{c}$$

- Longitudinal temperature

$$g(V) = \sqrt[2]{\frac{m}{2\pi kT}}\, e^{-\frac{mV^2}{2kT}}$$

$Tr = Transmittance$
$\mathrm{N} = Concentration$
$\varepsilon = Absorbance$
$l = Path\ length$
$\Delta\omega = Frequency\ difference$
$\omega = Frequency$
$c = Speed\ of\ light$
$V = Longitudinal\ velocity$
$g = Velocity\ distribution$
$m = Particle\ mass$
$k = Boltzmann\ constant$
$T = Temperature$

Voigt Profile

The absorption spectra were calculated based on the methodology in [1], using the classical harmonic oscillator model.

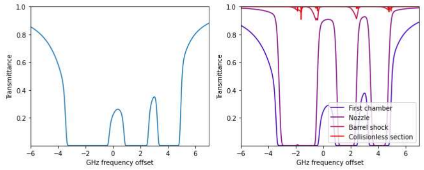
This created a Voigt profile for the spectrum, a convolution of the gaussian velocity distribution, and lorentzian classical broadening.

- Lorentzian broadening always dominates far from the peaks
- "Fat tail" – 2^{nd} order power law

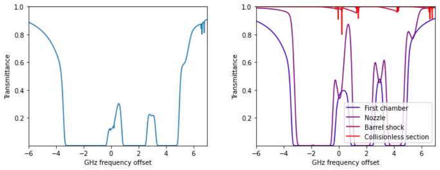
Results and Gas Choice

The initial simulations used Argon as the carrier gas. However, as can be seen below, it is not ideal.

- Absorption peaks from collisionless section completely overshadowed by absorption from the first chamber
- Higher gas velocities needed to remove collisionless peaks from first chamber peaks



Simulated absorption spectra at 343 K with argon – right shows entire spectrum, left shows spectrum divided by apparatus section



Simulated absorption spectra at 393 K with helium – right shows entire spectrum, left shows spectrum divided by apparatus section

Reaching these higher velocities could be done by using helium as a carrier gas instead of argon.

- Higher speed of sound
- More acceleration upon expansion
- Higher Doppler shift

Conclusion and Future Work

The knowledge that helium is the most conducive carrier gas to be used in this experiment will be extremely helpful when using the apparatus, as will a control spectrum to compare the results to.

Future work will include an in-depth look at refraction spectroscopy, analysis of failure modes of the apparatus, and additional validation of the current methods.

References

1. Anuj Rekhy, Alexandros Gerakis, David Feng, Mikhail N. Shneider, Arthur Dogariu and Richard B. Miles. "Temperature Profiling of the Atmosphere from an Airborne Lidar by Dispersed Filtered Rayleigh Scattering in Atomic and Molecular Vapors," AIAA 2019-3286. *AIAA Aviation 2019 Forum*. June 2019.

TEXAS A&M UNIVERSITY
Department of
Aerospace Engineering

Laser Diagnostics and Plasma Devices Laboratory Texas A&M University, College Station, TX 77843
http://ldpdl.engr.tamu.edu