Physics 426: Term Project Proposal

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1 Introduction

Current models of Jupiter's atmosphere suggest the possibility of convection occurring deep within the planet's atmosphere. As early as 1977 Prinn & Barshay suggest in their paper that the presence of convection within the atmosphere at 1100K would explain the appearance of carbon monoxide within the upper atmosphere, as observed in 1977 (Beer & Taylor, 1977). More recently with observations from the Galileo mission to Jupiter, convection was inferred from the direct observation of long lived storms on the planet, appearing as "zonal jets" or "long-lived ovals" (Ingersoll et al. 630). The appearance and longevity of the storms suggests an energy source within the planet and the transfer of energy from said source to the atmosphere via a form of convection (Ingersoll et al, 2000). With convection being a probable process occurring within the atmosphere, an attempt to study and become more familiar with the mechanisms associated with convection in an Earth-based laboratory could yield important results. An experiment will be performed in order to observe and characterize convection cells on laboratory scales, after which the effects of rotation and the possible induction of turbulance may also be explored. The results of this "table top" convection experiment will then be discussed in an attempt to relate any findings to the larger scale of the Jovian atmosphere.

2 Experimental Set-Up

The first component of the experiment consists of investigating convection in a fluid with density gradients. To match the boundary conditions of a solid lower surface and free upper surface a vessel with an open top will be used. The vessel will be cylindrical to minimize interactions at the vertical boundaries when vessel is rotated for the second component of the experiment. The vessel will be filled with water at room temperature, dissolved salts added to the fluid will modify the density of the fluid in order to produce a vertical density gradient in the fluid. Depending on time constraints and the relative difficulty of either situation the target density profile used in the experiment will be either two discontinuous layers of differing density, a single fluid with continuous density gradient or both. In either case the fluid will be setup in the stable configuration with the denser fluids lower in the vessel. The temperature gradient necessary for convection will be driven by an ice bath in a thermally conductive container placed in contact with the free surface of the fluid.

The second component of the experiment consists of investigating convection in a rotating reference frame. The vessel, the density gradients and the apparatus for inducing temperature gradients will remain unchanged from the first component of the experiment. The cylindrical vessel will be placed on a rotating platform which rotates at a constant angular velocity for the duration of the experiment.

The same tools and methods for data collection and analysis will be used in both components of the experiment. A digital camera and/or video camera will be used to record the dynamics of the fluid made visible by introducing additives and coloring agents to the fluid. Dyes will be added to the fluid in proportion to the salt concentration to act as a measurable marker of salinity, and additives to produce rheoscopic behavior in the fluid will be used as a visible maker of fluid flow. With appropriate calibration the salinity of the fluid will be determined by the apparent color of the fluid in images and videos of the experimental runs, and with some modeling the size and rate of flow in the convection cells may be determined from images and video of the fluid when it is exhibiting rehoscopic behavior.

3 Goals

This experiment will aim to observe, study and characterize convection within a laboratory setting. As mentioned in the above section, convective cells will be generated within a cylindrical vessel and observed through the aid of high speed cameras, rheoscopic fliuds and various dyes. In order to determine the required temperature difference between the bottom of the vessel and the top to induce convection, a mathematical study will be made investigating the Rayleigh-Benard Instability. This will be done using the definition of the dimensionless Rayleigh Number, noting that the density profile of the vessel will be treated as a free variable. Working from the definition of the Rayleigh number.

$$R_a = \frac{g\beta}{\nu\alpha}(T_b - T_u)L^3$$

$$R_a = \frac{g\beta}{\mu k}c_p\rho^2(T_b - T_u)L^3$$

Noting above that all the variables excluding $T_b - T_u$ and ρ are fixed constants related to the thermal and viscous characteristics of the fluid to be used, while L is the height of the vessel and g is the acceleration due to gravity. The critical Rayleigh number, R_c, represents the value of the Rayleigh number, representing the ratio of gravitational to viscous forces, at which convection occurs in the system. For the solved case, in which the bottom boundary is rigid, while the top is free, the case of this experiment, the critical Rayleigh number is known. Thus, the temperature difference required to induce convection may then become only dependent on the density profile of the vessel. If the density if discrete, the temperate difference may be deduced for each layer of different density fluids, if the density profile is continuous the temperature difference required may be expressed in equation (2) where density becomes a function of height in the vessel. $\rho = \rho(L)$ (Bahrami, 2016).

$$(T_b - T_u) = \left(\frac{\mu k}{g\beta}\right) \frac{R_c}{\rho^2 L^3} \tag{1}$$

$$(T_b - T_u) = \left(\frac{\mu k}{g\beta}\right) \frac{R_c}{\rho^2(L) L^3} \tag{2}$$

The density profile of the vessel will be approximated as being both linear and discrete as both continuous and discrete density profiles will be investigated. In reality the easier of the two to generate and model will be used in the final experiment to determine the required temperature difference as given in equations (1) or (2).

A computational simulation will be created in order to investigate the feasibility and compatibility of both modeling convection in three dimensions and modeling convection in three dimensions via investigating convection in two dimensions. This will be done using COMSOL, Python and possible Fortran for any numerical analysis that may be necessary. The goal associated with the computational aspect of the project will be to successfully model convection in two dimensions with the possibility of extending to three.

Experimentally, the goal of the project will be to generate and observe convection cells. Once convection cells have been observed in a stationary reference frame, rotation will be introduced in an attempt to observe and record any perturbations to convection that might occur due to rotation. Any resultant turbulence that could could occur upon the introduction of rotation into a convective system will also be investigated. The effects of rotation will only be investigated upon the successful creation of convection within a stationary reference frame.

Utilizing the results from the mathematical, computational and experimental components of the project an overall result and inference as to the possibility of convection within Jupiter's atmosphere will be made. This will be done in part theoretically, through noting the temperature difference required in order to generate convection for fluids of a specific density, or density profile, and comparing this against the known density profile of the planets atmosphere. Experimentally, observing convection in the system could lead to inferring the existence of convection within Jupiter's atmosphere after considering comparable scale lengths and temperature differences between the two systems. If the appearance of convection is further supported through the appearance of convection computationally, via modeling, this will lead to further confidence in the final result.

4 References

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