Simulating Steam Jets due to Rapid Plate Tectonics: A Computational Fluid Dynamics Analysis

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Acceptance of Senior Honors Thesis

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Abstract

According to the Bible's account of earth's physical history, the majority of geological change from creation to the Ice Age is a consequence of the global Flood cataclysm described in Genesis 6-8. The changes included large-scale tectonic activity, recycling all pre-Flood ocean floor into the mantle, and generating all present-day igneous ocean floor by seafloor spreading at mid-ocean rift zones. Along the middle of these zones, strips of newly formed seafloor were present near the melting temperature of basaltic magma. Above these strips of extremely hot rock, intense jets of steam would almost certainly form. This research seeks to investigate the physical complexities of steam jets that formed above these strips of hot sea bottom and utilize ANSYS Fluent to create a tentative model of jet behavior. The main objectives of this project are to view how high the jets rise into the atmosphere, capture how the jet disrupts the surrounding ocean water, and determine what other parameters need to be considered to improve the model's accuracy in the future.

Simulating Steam Jets due to Rapid Plate Tectonics: A Computational Fluid Dynamics Analysis

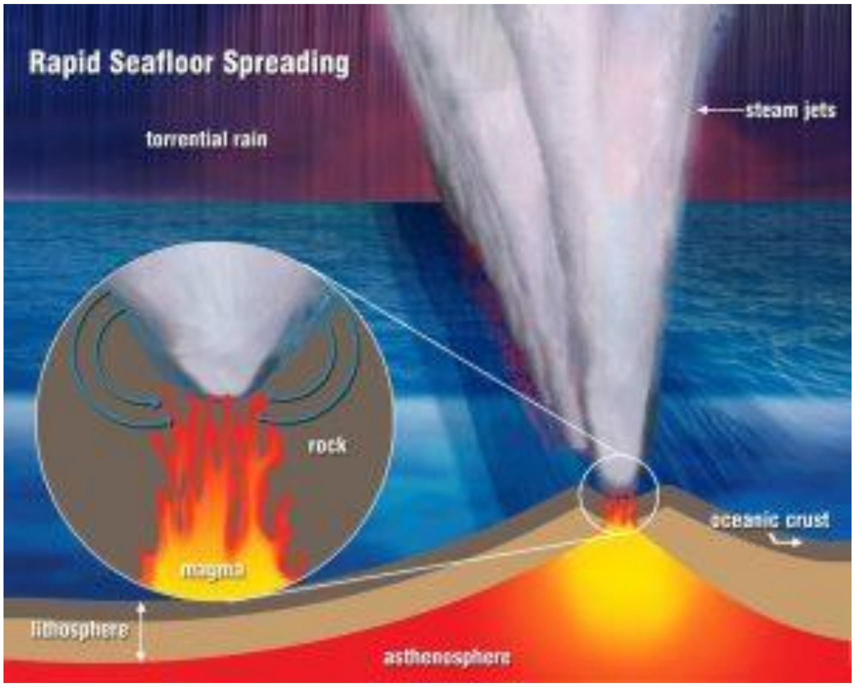
The biblical flood account recorded in Genesis 6-9 is the narrative of a global catastrophe that occurred four to five thousand years ago. For decades, scientists have studied the evidence for a global flood and the extreme geological activity that would have taken place during this event [1], [2], [3]. A noteworthy insight from about 40 years ago for creation scientists is that this cataclysm involved large scale tectonic change and included rapid flow rock inside the earth. From these insights, the concept of catastrophic plate tectonics (CPT) was developed and has since been applied to further understand the details of this devastating, global catastrophe [4], [5], [6].

The purpose of this research is to apply computation fluid dynamics (CFD) to model the steam jets that logically arise above hot spots as tectonic plates pull apart on the ocean floor during the flood. These jets seem to correspond to the breaking up or pulling apart of the "fountains of the great deep" from Genesis 7 to create intense, thermal anomalies on the ocean floor. Such, rapid sea floor spreading would produce strips of ocean floor with temperatures of approximately 1400 K (Fig. 1). Sea bottom rock with these temperatures would vaporize the adjacent ocean water, creating violent, multiphase jets with extremely high velocities. As they penetrate the upper ocean-air interface, the jets entrain liquid water and carry this water into the atmosphere, which then falls back down to the surface as rain. Ultimately, these are the phenomena that should be represented in a more advanced CFD model.

Many people have questioned the reality of a global flood due to wondering how it could actually rain violently for 40 days and 40 nights like the Bible says. Scientists also wonder where that rain came from and how there could be enough of it [7], [8]. The steam jets simulated in this study may serve as a potential answer to these questions. Since the jets would entrain ocean water to fall back down to the earth as rain, they could be a significant source of precipitation, causing deep ocean water to become rain or even become crystalized in the atmosphere to be deposited elsewhere if the jets rose high enough into the stratosphere. Although these jets would not be the only source of water, they could certainly be a source. By demonstrating the behavior of cataclysmic steam jets, this research could show that there are options that make the large amount of rain fall during the flood possible.

Figure 1

Steam Jet Problem Definition



Note: This schematic was produced by an artist at the Institute for Creation Research between 2005 and 2007. Figure was sourced through Dr. John Baumgardner

There are five main objectives of this study. First, a basic, working CFD model of a large steam jet and the surrounding ocean and atmosphere should be developed. Once the model is running, the impact of steam injection velocity on the max height of the jet will be determined.

Next, the jet's impact on the surrounding ocean water will be studied. This can be accomplished by viewing the movement and tracking the velocity within the oceanic zone. Additionally, it is important to investigate the amount of water and air that the jets entrain. The level of entrainment will affect how much precipitation the jets can sustain. Lastly, it might be noteworthy to examine the behavior and formation of droplets within the jet stream and around its outermost boundary. The formation of droplets, along with the process of entrainment, may not be captured with this preliminary model. However, the model presented here should later be improved until these phenomena can be studied appropriately. Overall, this research is to serve as a basic, introductory level study of the large steam jets that form due to rapid sea floor spreading. This model can then be adapted and used to complement the CPT theory.

Background

The purpose of this research is to examine the geological events that likely took place during the Genesis flood. People throughout generations have raised questions about what happened during the flood and how many of its features were scientifically possible. Although this study will be conducted with the knowledge that the Bible is true, the goal of the simulation is to understand what one consequence of rapid plate tectonics during the flood was like. The steam jets that are simulated through the culmination of this research are expected show how rain could have continued for 40 days and 40 nights just as the Genesis flood narrative states. The main point of this study is not to prove the validity of the biblical flood account, but we offer a brief explanation as means of useful background information.

Biblical Origin

Genesis 6-9 gives an account of the historical, biblical flood cataclysm in which nearly all land-dwelling, air-breathing creatures are killed and the entire earth surface is greatly modified by means of a global, diluvial catastrophe. Many critics question the reality of this flood event, but there are over 200 flood stories from ancient civilizations all around the world [9], [10]. This suggests one of two possibilities. Either the commonality between ancient civilizations is indeed evidence for a global flood, or the Genesis flood narrative is merely one ancient civilization myth among many. If the Bible if true, then the multitude of similar flood accounts would make sense. In Genesis 11, God scatters the people as separate groups across the earth, with each speaking a different language. In that case, the account of the flood would have been passed down through the different people groups, explaining the numerous versions we observe today [11].

There are notable similarities between the biblical flood account and the flood stories of other cultures such as *The Epic of Gilgamesh* [12], [13], [14]. However, the biblical narrative possesses unique attributes that present the story as a valid, historical piece of writing. First, the Genesis account is written in the genre of a historical narrative [15]. The Bible provides specific information, such as the details of the structure of the ark used to survive the flood, the people who were on it, how long the flood lasted, what types of animals were brought onto the ark, and even an insight into the geological events that initiated the flood.

Additionally, a group of researchers with Answers in Genesis conducted simulations testing the boat structures that several ancient flood narratives provides [9]. Fig. 2 and Fig. 3 display the models of the container described in two ancient flood accounts: *The Epic of Gilgamesh* and *The Coracle*, respectively. By contrast, Fig. 4 shows a rendering created from biblical dimensions tested during the length of the biblical account. Simulations show that the structures in the first two figures would not be suitable to keep humans and animals safe during a global flood. Results from their study can be seen at the Ark Encounter in Williamstown, KY and clearly show that only a boat made with the exact dimensions given by God in the Genesis flood record would survive the conditions of the global flood catastrophe. Even if the other vessels had managed to remain afloat, they are not shaped in such a way that would allow for the survival of either people or animals due to the extreme wave activity that would be present in the stormy flood waters.

Figures 1 and 3

Epic of Gilgamesh and Coracle Ship Models [9]

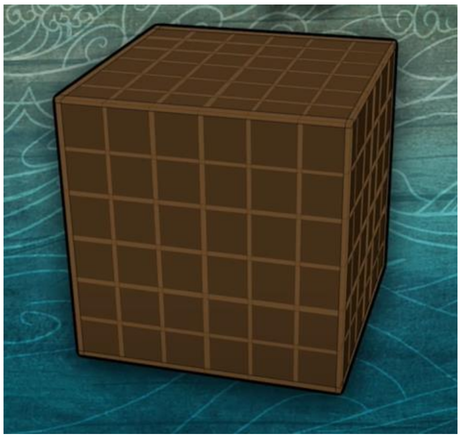


Figure 4

Biblical Ark Model [9]

Furthermore, an interesting difference between the biblical flood account and these ancient myths is that the biblical record states that the flood was caused not just by raining falling from the sky. The beginning of this cataclysmic event is recorded in Genesis 7:11-12 which states "In the six hundredth year of Noah's life, in the second month, on the seventeenth day of the month, on that day all the fountains of the great deep burst open, and the floodgates of the sky were opened. The rain fell upon the earth for forty days and forty nights" [16]. Very few of the civilizations with flood narratives, such as Hawaii and The Lakota tribe, have flood stories that mention water coming out from beneath the ocean's surface [9], [17]. Although overlooked by many, the fountains of the great deep in the Genesis flood record are a great topic of interest for many scientists and add to the evidence of the catastrophic nature of the flood event.

History within Creation Science

Within the study of flood geology and plate tectonics, many have often wondered what the "fountains of the great deep" were in Genesis 7:11. Based on the types of present-day features on the ocean bottoms, these fountains were probably similar to the black smokers that occur today along midocean ridges [18]. Black smokers are hydrothermal vents in the ocean from which plumes of hot water rich in iron oxide are expelled from these chimney-like structures. Hydrothermal vents are found along spreading centers, where tectonic plates are moving apart from each other [19]. Thousands of miles of seafloor spreading occurred in the world's ocean basins during the flood [1], so these black smokers would certainly be present during that time.

Looking more specifically into the biblical description of the events that occurred at the beginning of the flood, Scripture states that the fountains "burst open" (NASB) or were "broken up" (NKJV). If these fountains were located in regions where tectonic plates split and began to move apart, an episode of rapid plate tectonics would have initiated a large break-up of existing hydrothermal vent features similar to the black smokers explained above. As these sea-bottom features began to split apart, the geological separation would cause magma from below to rise to the surface of the sea bottom. The hots strips of sea bottom would then heat up ocean water to produce the steam jets that this project is modeling.

It is predicted that these turbulent jets would entrain large quantities of ocean water as they rise above the ocean surface and then penetrate into the overlying atmosphere. The jets would greatly disturb the surrounding liquid ocean water and whatever water that left the ocean surface with the jet would be carried into the atmosphere. This water then falls back down to the earth's surface in the form of rain. Capturing this mechanism is a complex task beyond the scope of this undergraduate project, but it is highlighted here to indicate the richness and complexity of the topic. Therefore, upon its completion, this research is expected to crucial new insight on the dynamics of the flood cataclysm. Based on the biblical text, the steam jets simulated in this study would chronologically immediately arise with the breaking apart of the fountains of the great deep (Genesis 7:11) and would continue for 150 days (Genesis 7:24-8:3).

Creation scientists agree that the flood cataclysm was due to some type of major tectonic activity, but there are various views on how the flood was initiated. Throughout the last few decades, creationists have been studying the geological record of the earth to obtain a better understanding of the Genesis flood and its effects. In the early 1980s, geophysicist and creationist, John Baumgardner, developed a computer model of the earth's mantle to investigate the physical processes associated with CPT [4], [5], [6]. Baumgardner's research covers several different areas of geophysics and demonstrates how the earth today shows powerful evidence of both a global flood and a young age for our planet [1]. As the ability to simulate large-scale problems that more accurately represent the earth's history has advanced, Baumgardner's research has expanded to include processes responsible for the formation of the earth's fossil-bearing sediment record during the flood.

The CPT model strives to explain how the earth's natural design points to a global catastrophe, like the Genesis Flood, that formed the majority of the natural features of the earth like mountain chains, igneous ocean rocks, fossil-bearing sedimentary rocks, and the current layout of the continents [4]. It also covers the causes and effects of the flood and what impact that has on the earth's structure, climate, and tectonic activity today. This research aims to add to the findings of CPT by studying an event that would have occurred during the flood, while ocean water was being vaporized by heat from the earth's mantle. The steam jets modeled here would occur while processes like rapid sea floor spreading and subduction were taking place [5].

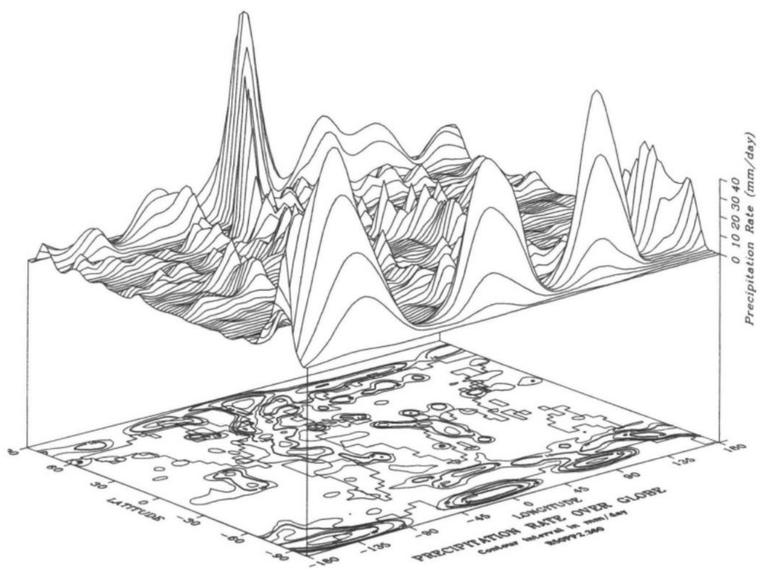
To explain the fountains of the great deep and what initiated the flood, some creation scientists have speculated that there were large bodies of water stored beneath the earth's crust. Tectonic activity then shifted both oceanic and continental crust, which caused that water to emerge from beneath the crust and flood the earth [20], [21]. This view is based on the assumption that the internal structure of the antediluvian earth much different from our earth today. A major difficulty for the idea of large antediluvial subterranean water chambers is their lack of hydrodynamic stability. The water would have a strong tendency to exploit even tiny cracks in the overlying rock to break out and quickly empty onto the surface. Although this is one possibility, it is worthwhile to investigate whether or not the source of the majority of the flood water was not merely the pre-flood ocean.

Many assume that God only acted at the exact starting point of the flood, but Dr. Mark Horstemeyer and Dr. John Baumgardner propose that God may have designed His pre-flood world with conditions that slowly led up to the rapid tectonic activity that occurred during the flood. By studying the material properties and behaviors of olivine and investigating the various means for instability in material, Horstemeyer and Baumgardner were able to show that the earth could have plausibly been designed in a way that led to geological instabilities causing rapid, runaway subduction to initiate the flood cataclysm [3]. Researcher Wayne R. Spencer also agrees with Baumgardner's and Horstemeyer's view and shows how the geophysical effects of the flood are numerous and diverse. Through his research on impacts from stratified material, Spencer suggests that the effects of the flood could possibly include tsunami waves, low light levels, acid rain, and large jets of vaporized water, like that which will be studied here [22].

Numerical simulations have also recently been used to demonstrate how an increase in temperature of ocean surface affects the behavior of ocean water, precipitation, and natural disasters. Through his simulations of mid-ocean ridges, Larry Vardiman showed that ocean surface temperatures have a significant effect on the amount of precipitation occurs directly above a specified surface location. Fig. 5 demonstrates the precipitation distribution when the ocean surface temperature is 50 degrees Celsius along mid-ocean ridges. As the temperature is raised from 30 to 50 degrees C, the number of locations with precipitation rates of 5 mm/day or greater doubled, displaying the significant impact that ocean floor temperature can have on the amount of rainfall [23]. This is an important argument for flood geology, as hot spots occurring along mid-ocean ridges could help explain a prolonged period of rain fall after the flood.

Figure 5

Effect of Ocean Temperature on Precipitation Rates [23]



Note: This picture has been used with the written consent of Dr. John Whitmore at Cedarville university, who oversaw the publishing of this paper.

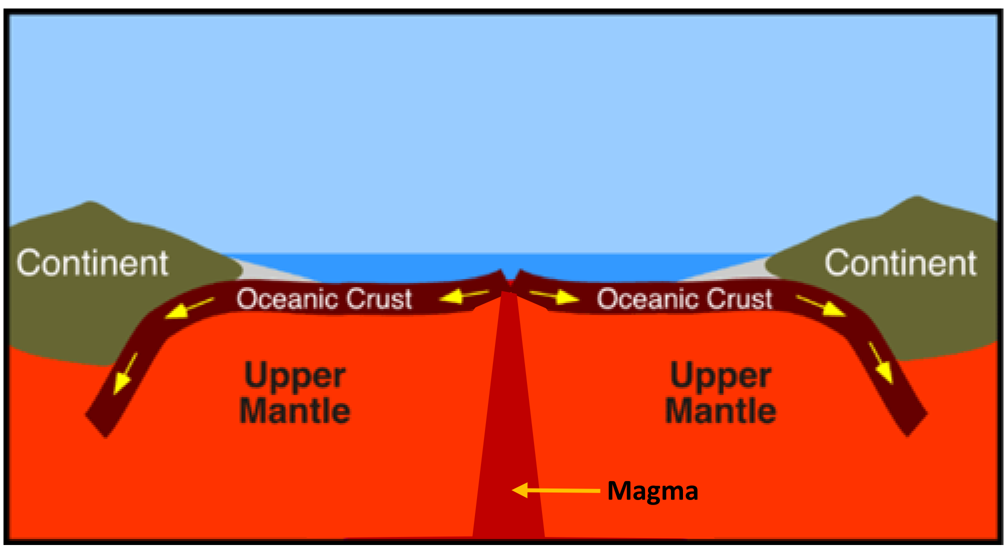
Geological Background

The steam jets being studied can be compared to both a geyser and a hydrothermal vent but have distinct differences that impact how the jets will be modeled and analyzed. Geysers arise when the heat from the earth converts water stored in a tubelike reservoir into steam, while hydrothermal vents occur in a similar fashion but on the ocean floor [19]. The expansion of volume that occurs during the phase change from water to steam results in an eruption of large steam jets traveling at very high velocities [20]. As jets in the ocean rise toward the surface, they have the ability to entrain water that combines with the steam in the jet. Typical jets can rise from 10 to 100 feet above the surface, and once the geyser has reached the atmosphere, some of the steam and entrained water can come back down to earth as rain [19], [26]. Whether or not jets break the ocean surface is dependent on the depth at which they form at along with both mass eruption rate and vent width [24].

The steam jets being modeled in this study are thought to behave the same as the jets created from geysers and hydrothermal vents. However, they initiate from within the open ocean from the heat of a hotspot instead within a contained column or channel. Fig. 6 illustrates the conditions under which ocean steam jets in this study form [25]. The large yellow arrow points to a hot spot on the ocean floor that has formed from sea floor spreading. It is important to note that presently, this process occurs at a very slow rate, but the simulations being conducted will be based on rapid plate tectonic movement that occurs during a global flood cataclysm.

Figure 6

Tectonic Activity along Midocean Ridges [25]



Once the hot spot forms from sea floor spreading, that thermal anomaly quickly heats up ocean water to become supercritical water and then steam. This violent conversion from water to steam causes instabilities which may then produce turbulence. As the jet breaks through the surface, it entrains water from the ocean and mixes ocean water and steam within the jet. How high these jets rise also depends on mass eruption rate, hot spot size, and ocean depth. Once the jet breaks the ocean surface and enters the atmosphere, it would behave similarly to a massive geyser, where steam-lofted water falls back to the earth's surface in the form of rain. Depending on how high the cataclysmic jets rise, water droplets also have the potential to freeze and become ice crystals in the stratosphere.

Computational Fluid Dynamics

In order to properly model the steam jets that occur during an episode of rapid plate tectonics, a CFD analysis is conducted. CFD is a process that uses numerical modeling to "produce quantitative predictions of fluid-flow phenomena based on the conservation laws (conservation of mass, momentum, and energy) governing fluid motion" [26]. CFD is a useful tool for studying of fluid mechanics that allows researchers to approximate the behavior of different fluids and systems before testing them in real life. CFD is especially helpful in prototyping and design because it provides a way to test different materials and configurations before any physical materials are purchased.

There are several tools that can be utilized to conduct CFD modeling, but Ansys Fluent will be used in this study. According to their website, "Ansys Fluent is the industry-leading fluid simulation software known for its advanced physics modeling capabilities and industry leading accuracy" [27]. Fluent can be used to model 3D fluid phenomena and has the capability to approximate the effects of multiple types of fluids and phases all in one simulation. It is also compatible with other common modeling software such as Solidworks that can be used to design initial geometries before the meshing and set up parts of the simulation process. Lastly, Fluent has the ability to capture different features of a fluid's behavior such as turbulence and the formation of droplets [28]. This is specifically beneficial to areas such as atomization or the study of jets that is being investigated here.

Previous CFD analysis has been conducted to study the condensation of steam jets and the behavior of geysers [29], [30]. Additionally, the overall behavior of hydrothermal vents has been modeled and a tool has been developed to predict how a hydrothermal vent will entrain certain materials such as air, ocean water, and miscellaneous ocean debris while rising through the water. Although not specifically in the geological scope of this project, one study investigated how steam condensed and mixed with its surrounding atmosphere when a jet of steam was injected into an enclosed tank [30].

Even though the study was originally performed for industrial application, its results provide a starting point for how larger scale steam jets might behave. The CFD simulation showed that steam condensation could reach steady state under atmospheric conditions when the steam injection rate was equal to the steam condensation rate. This is interesting for the current project because at a catastrophic level, those conditions would not be met, and an unstable system would be expected. The study also was compared to experimental results, showing that CFD simulations provide an accurate way to predict the behavior of steam jets without physical testing [31].

It has also been shown that turbulence kinetic energy has a significant effect on the dispersion of particles. In Fluent, the k-omega SST turbulence model has default values that can be used for simulation. Gorle´, however, has demonstrated that in order to properly capture particle dispersion of steam jets at atmospheric boundary conditions, correction factors need to be applied to shift the default values from the turbulence modeling [32]. This is an important parameter to consider for the simulation of cataclysmic steam jets but will not be applied in the first pass of the problem as presented in this study.

As mentioned above, several CFD models have been designed to study the behavior and entrainment of both geysers and hydrothermal vents. Wang was able to demonstrate the initial boiling that occurs in a geyser before eruption [33]. This was a significant discovery due to the complexities that arise when simulating multiple phase changes and modeling both heat transfer and fluid dynamic aspects. The simulations were able to demonstrate how fast geyser water boiled and cooled based on a specified input temperature. The steam jets modeled here will not include this phase change because of the complexity of the modeling, but the results from this study are utilized to determine whether or not the input velocity of the steam injection is reasonable given the hotspot temperature [33].

The subsequent CFD models on geysers and hydrothermal vents mainly dealt with the process of entrainment. When steam jets occur above the ocean surface, such as when geysers erupt into the atmosphere. They can entrain large amounts of air. It has been shown that this air entrainment causes large coalescence of air bubbles and breakup of the jet stream [34]. In contrast, when the jets are moving through ocean water, such as in hydrothermal vents, large amounts of sediments and mineral particles can be entrained and then deposited in widespread locations due to the unstable movements of the jets [35]. Furthermore, the k-omega turbulence model in Fluent was used to estimate how the amount of matter a hydrothermal vent entrains is dependent on the position of the jet relative to the total plume height [36]. The k-epsilon model does not have the ability to resolve turbulence, but it can only approximate the effects of turbulence. Therefore, it is important to note that any specific length and time scale information about turbulence is not available in these studies. Lastly, in a study that modeled hydrothermal jets 100 m in diameter, similar in size to the cataclysmic steam jets modeled in this study, the jets were able to entrain ambient ocean water, organic matter, and microbes into the main traveling stream [37].

Methodology

Problem Definition

The goal of this research is to design and build a base-level CFD model of steam jets that would occur over an ocean hotspot during an episode of rapid plate tectonics using Ansys Fluent. The main objectives of the model are to demonstrate how high a cataclysmic steam jet could rise above the surface of the ocean along with the tracking how the jet impacts the surrounding ocean water. Due to the complexities that arise when attempting to model phase changes in fluent, specifically due to thermal conditions, the model will not include the original process of sea water boiling as caused by the extreme temperature of the hotspot. The model also will not utilize conditions that would allow for inclusion of water in its supercritical state. Additionally, all parameters tracked through this research will largely be unsteady processes and will be a function of space and time.

Although created in Ansys Fluent, which has numerous advanced CFD features available to increase the accuracy of a model, the simulation here will utilize basic geometry and CFD setup that is suitable for one with an undergraduate level of computational modeling experience to replicate. This initial model can then be handed off to more advanced researchers to be developed and refined. Since the geological conditions necessary to create steam jets of this magnitude are not present today, this model will serve as a potential way to investigate the effects of a historical, natural phenomenon that could never be studied in the field by present-day geologists.

Initial Predictions

In order to properly replicate how large steam jets would behave in nature, the model should produce a fast moving jet that breaks the ocean surface and significantly impacts the surrounding ocean water. Due to the extreme conditions through which this phenomenon would occur, the injected steam velocity will be extremely high. It is predicted that the steam jets will be able to break through the ocean surface and continue rising into the atmosphere. Through this path, it is believed that the jets should entrain ambient ocean water and then large volumes of air as the jet breaks the ocean surface. After the jet enters the atmosphere, it is expected that the jet slows down and the steam should then recondense into water droplets. These droplets, and any entrained ocean water, would then fall back down to the ocean's surface in the form of rain. The majority of the rain created will be previously entrained ocean water. It will also be worthy to note how the jets break apart and it is expected that many droplets form and will be shed from the mainstream of the jet.

Model Specifications

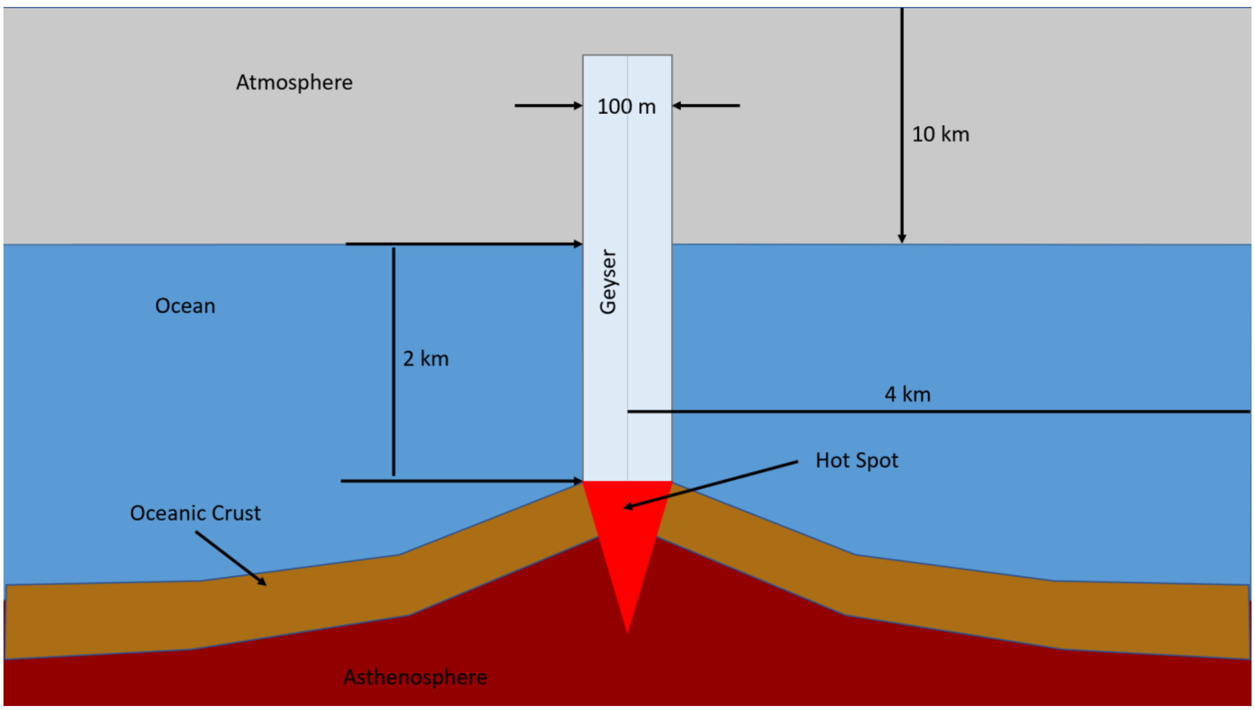
Overview

The problem to be modeled is separated into several key components. The jet will be defined as if the ocean and atmosphere expanse form a cylindrical volume, and there is one hotspot and steam jet along the central axis. In reality, these jets would most likely happen in a chain of cylindrical jets or multiple slotted jets along the line of the location of rapid seafloor spreading. However, only one jet is being studied now as the base model. If multiple jets were added, the results would be even more extreme than what is demonstrated here. Fig. 7 displays the basic components of the system and the steam jet is labeled as a "geyser" since its behavior is thought to be similar to the jet portion of a geyser that occurs under water.

As seen below, the hotspot is formed in the middle of seafloor spreading as oceanic crust separates and penetrates the asthenosphere. During an episode of rapid plate tectonics like that during the flood, it is thought that the hotspot would have a temperature of approximately 1400 K. Instead of complicating the model with phase changes, the simulation will begin as if the water already had been completely vaporized by the hotspot. This will be completed by injecting steam into the specified inlet of the steam jet. This also means that the hotspot, oceanic crust, and asthenosphere will not be modeled in Fluent.

Figure 7

Steam Jet Problem Definition with Dimensions



The ocean depth at the point of the jet inlet is 2 kilometers. Because the steam would become supercritical at a depth of 2.2 kilometers, a depth shallower than that was chosen to avoid another phase change within the jet. There is also 10 kilometers worth of atmosphere above the surface of the ocean to mimic the correct amount of pressure above the steam jet inlet.

This also gives the jet room to rise into the atmosphere and condense. Additionally, a large radius of water and air surrounds the boundaries of the steam jet area. This serves two purposes: the jet will be able to break down and disperse into the surrounding volume, and the hydrostatic pressure on the sides of the jet will better resemble the actual conditions during the catastrophe. The geyser has an initial radius of 100 meters corresponding to the size of the hotspot. This radius will be variable as the jet rises through the atmosphere, but it is displayed as a constant block in Fig. 7 for simplicity of the problem definition.

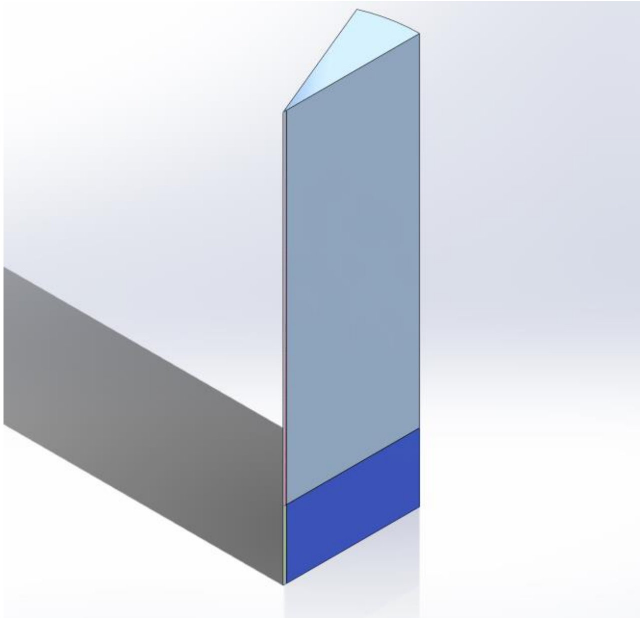
Geometry

To create a geometry for Ansys Fluent, one must model the space which the fluid will be filling. For the steam jet problem, there needs to be a very small section of area for the jet inlet compared to the larger sections of ocean water and air around it. This is done to properly replicate the conditions that the steam jet would experience in the ocean, with several kilometers of static pressure on either side and above it. This also allows the outer water and air boundary conditions to be treated as a wall initially. That parameter can be modified if the effect of the jet is seen that far away, but that is not the initial expectation.

The geometry created is a 1/16th wedge of the problem defined above. Additionally, due to the vast length scales that the problem entails, the geometry is scaled down to be in meters instead of kilometers. This scale change makes the jet diameter 1 millimeter instead of 1 meter, which is quite small for analysis, but it also scales the ocean and atmosphere domain to only be 4 meters in diameter instead of 4000 meters. Fig. 8 displays the problem geometry which was made in Solidworks. The four colors represent the four main portions of the project. Dark Blue represents the ocean, light blue the atmosphere, green the main jet stream under the ocean, and pink the main jet stream above the ocean. It is important to note that the jet portion specified is only the radius into which the steam will be injected into, and Fluent allows the fluids to mix into different portions of the model as expected.

Figure 8

Steam Jet Model Geometry

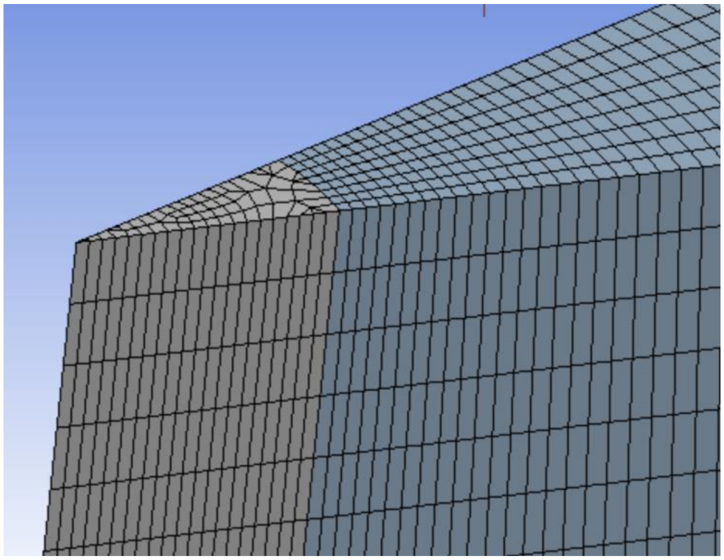


Meshing

The mesh used in this study has approximately 450,000 nodes. The model consists of quad elements, and the largest element size is on the outer boundaries of the ocean and atmosphere. The element size is then scaled by a bias factor of 0.1 until the mesh reaches the central geyser region. The larger portions of the geometry were swept from the bottom edge of the geometry to the top. With exception of the triangular elements, all elements in the small geyser portion were set to be equal in width to the width of the smallest ocean and atmospheric elements Fig. 9. This was accomplished through an edge sizing of 2.5 millimeters and there was no bias factor used. The jet section has uniform resolution throughout and was also swept from the bottom edge to the top.

Figure 9

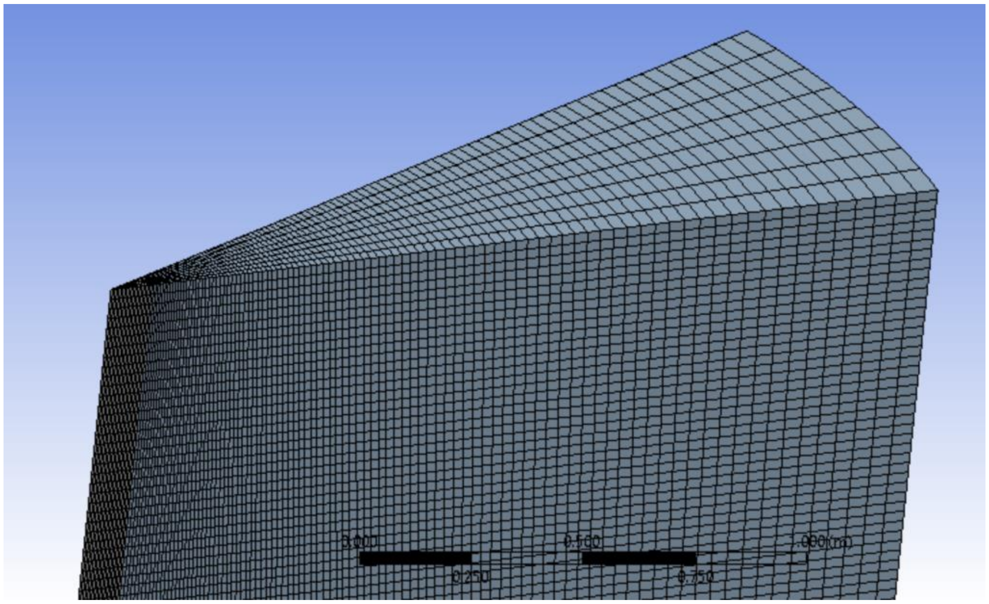
Meshing of Geometry Tip



After edge sizing had been applied, sweeps were then added to the mesh to create a more uniform sizing throughout the mesh. The sizing of the elements was adapted several times over a few weeks process to create a mesh that was small enough to capture the behavior expected to be seen by this model while still keeping the quad elements uniform and smoothly decreasing in size from the outer most boundary to the geyser tip Fig. 10. Lastly, each different surface of the mesh was given a proper name to correspond to its role in Ansys Fluent. By specifying the model inlet, outlet, and walls, one can then seamlessly import the model into Fluent and it will select the right type of boundary condition for each portion of the model. These boundary conditions are then refined later in the setup portion of the modeling process.

Figure 10

Geometry Meshing Pattern



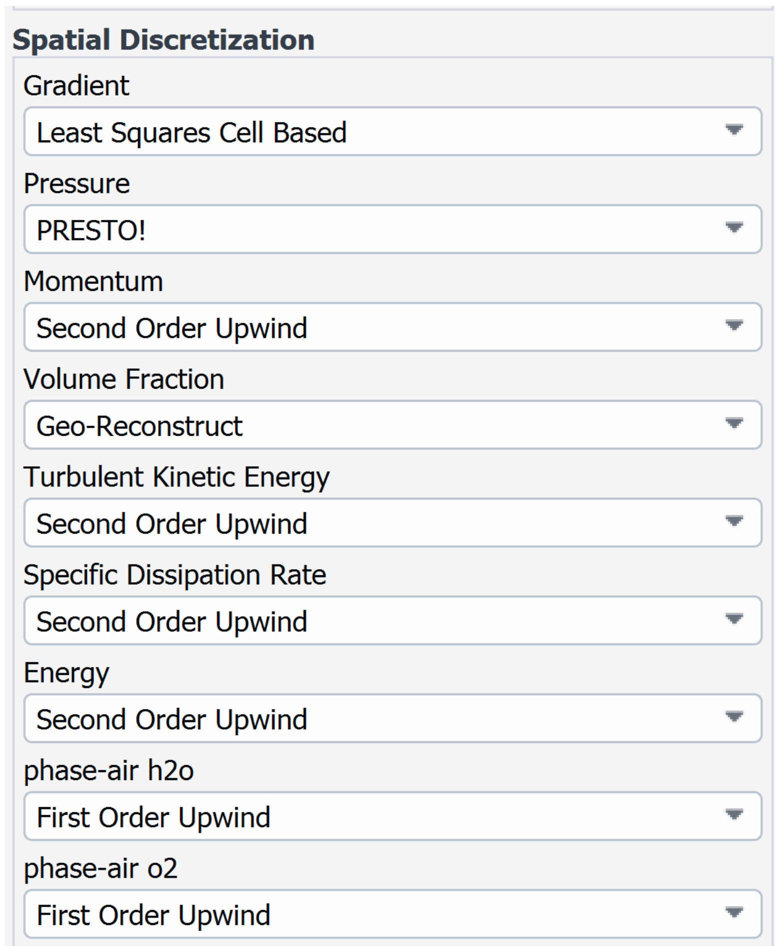
Fluent Setup

After the mesh had been successfully created with proper surface titles, the mesh was imported into Ansys fluent using the double precision solver. To begin setting up the mode, first the cell zones that Fluent had split upon reading the mesh were then merged together. Next, the material type of each section of the geometry was specified. To properly represent the two phases seen in this model (liquid and gas) while also ensuring that the ocean water, atmospheric air, and water vapor fluids were all present, a multiphase model with two species for the gaseous phase was used.

The explicit Volume of Fluid (VOF) multiphase model was selected with the primary phase being gas, which included both air and water vapor, and the secondary phase set as liquid water. To define the two species of gas, a mixture was created containing both air and water vapor. Later on in the setup process, volume fractions of these gases were defined to create the proper boundary and initial conditions for the model. The defining properties of these fluids were found from the Fluent database. This model also utilized the k-omega SST turbulence viscous model with all default settings for the first run. For solution methods, SIMPLE Pressure-velocity coupling was selected. Additionally, Fig. 11 displays the spatial discretion settings chosen.

Figure 11

Spatial Discretization Settings



Next, the boundary conditions for the model were defined. The inlet of the model is contained in the small geyser portion of the geometry’s bottom face. This was defined as a mass flow inlet that equals the mass of fluid per second needed to match the initial geyser eruption velocity assumed to be 1700 meters per second. This mass flow inlet value was also scaled down to match the scale of the model and then divided by 16 since the model is a $1/16^{th}$ wedge of the full geometry. It was crucial that the inlet material be defined as water vapor entering the liquid water domain. Therefore, the inlet phase was specified as the gas phase with a volume fraction of 1 for the water vapor species and 0 for the air. This ensured that all the fluid coming into the model was water vapor instead of air. In the end, the ocean zone was filled with water with a density of 998 kg/m^3 and the initial steam density was 0.762 kg/m^3.

Additionally, the model outlet was the top face of the model and set as a mass flow outlet. The outer boundaries of the geometry were considered to be walls, and the side walls of the model were defined as periodic boundaries to signify that the geometry being modeled is just a 1/16th wedge that would be repeated to compile the total, cylindrical problem geometry. When the simulation was first initialized, the geometry completely filled with a mixture of air and water vapor, which made up the primary phase. To fix this setup and make sure that the ocean domain was filled with water, while the atmosphere domain was filled with air, a patching process was used to define the initial fluid present in each zone of the geometry. Finally, the simulation was started with a selection of a global courant number of 1, and an initial time step of 1e-05. Adaptive time advancement with a maximum of 10 iterations per time step was also chosen to allow the simulation to adapt its time step size based on what was needed to maintain a stable solution.

Changes Made

After the model was first run, there were several errors that needed to be addressed. First, the whole geometry was filled air, and there was no liquid water present in the model. This occurred because initially the model was defined using three phases, which Fluent's operating system did not understand. This led to the development of a mixture containing two species and the utilization of only two phases in the multiphase model, as explained above. Secondly, the simulation was diverging due to an exceedingly high global courant number. To resolve this issue, the initial time step size was lowered to 1e-06 and the global courant number limit to 0.9. After the simulation stabilized with these conditions, the time step and courant parameters were switched back to the initial settings for the remainder of the run time.

Results and Analysis

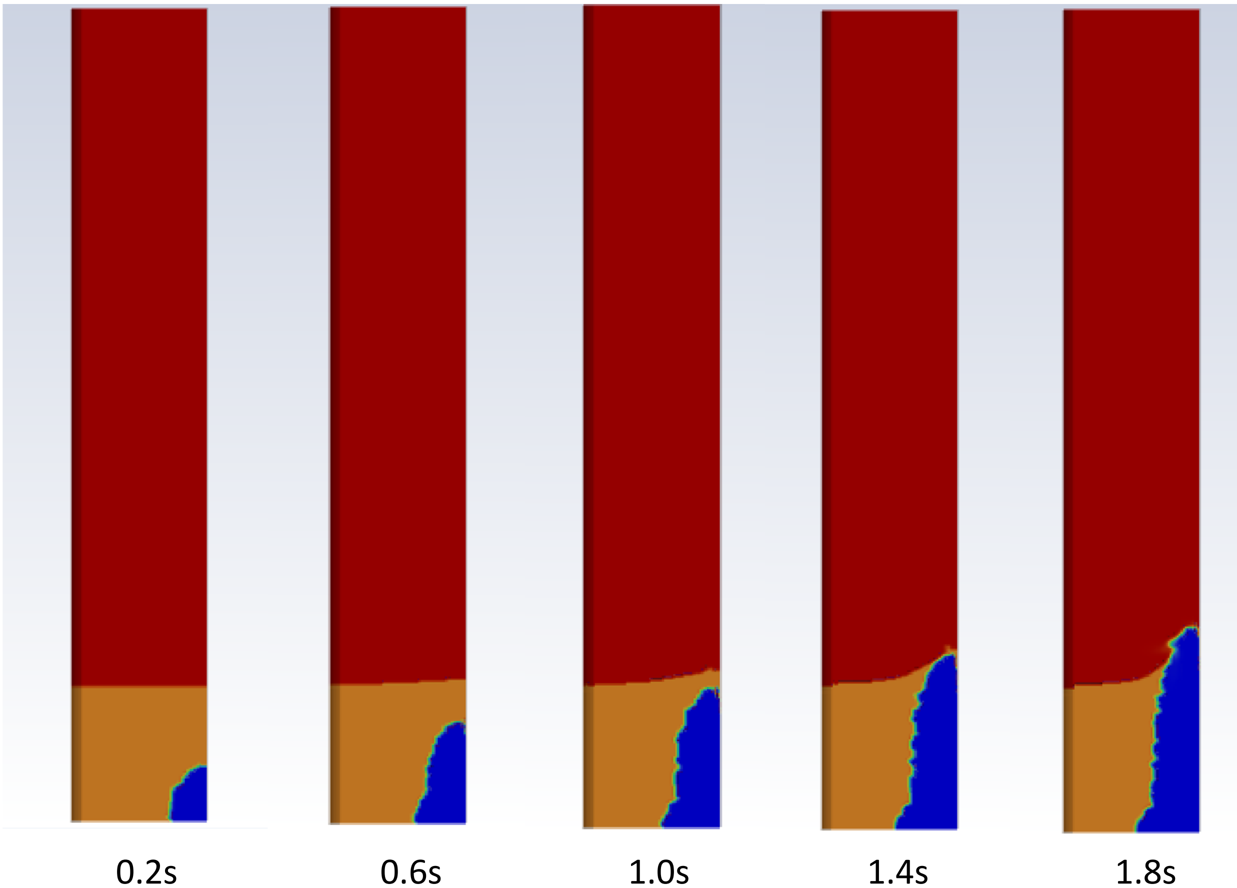
Initial Findings

Throughout the duration of this simulation, several different parameters were tracked by means of contour plots recorded every 0.01 seconds of flow time. Density or both the gas phase and the mixture, along with velocity magnitude, and total temperature were saved and analyzed. Fig. 12 displays the motion of the jet as it rose through the ocean region up until it was just beginning to break through the surface of the ocean. It is important to note that the plume of steam is much wider than expected, expanding approximately 8 times the width of the steam inlet specified in the model geometry. Furthermore, it can be seen that the jet is moving extremely fast, reaching the top of the ocean in about 1.4 seconds. This is consistent with the expectation of a violent eruption coming from the hot spot on the ocean floor.

Secondly, Fig. 13 shows the behavior of the jet once it has broken through the surface of the ocean. In approximately 1.2 more seconds, the plume of steam begins to narrow out and have a mushroom-like top. This is the shape expected from a high velocity jet and is a more accurate representation than the plume that was initially rising underneath the ocean’s surface. One can also see the large curl of fluid highlighted in green in Fig. 13. This represents a higher density gas than the steam itself, indicating that the water vapor is mixing with the air around the jet. At this point, the jet is still rising very quickly, and the simulation needs to be run for a longer period of time to continue tracking the jet behavior.

Figure 12

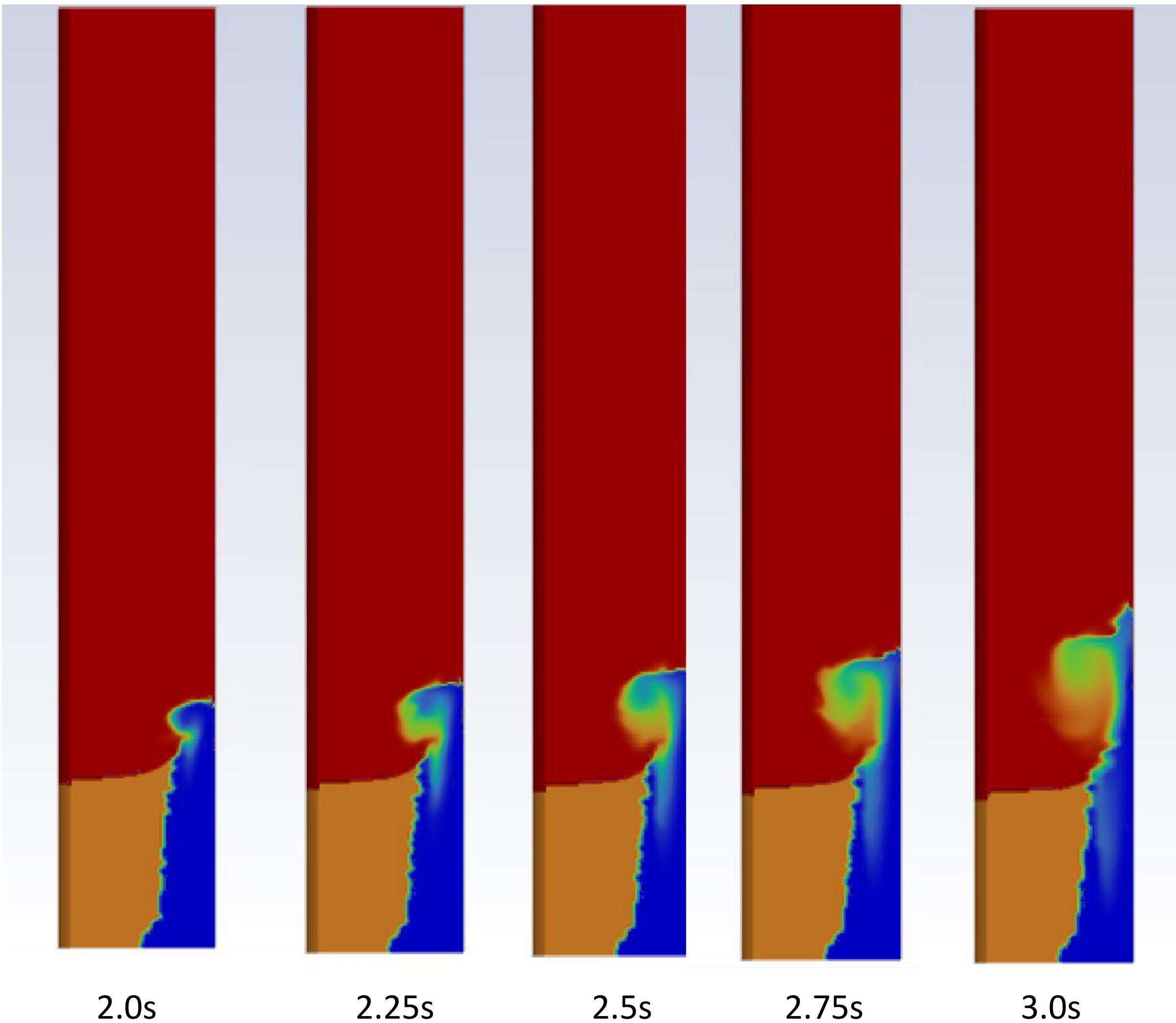
Steam Jet Movement Underneath the Ocean Surface



Note: This figure demonstrates the progress of the steam jet (blue) through the ocean water (orange) before it breaks the surface of the ocean. The labels given represented the flow time passes, in seconds.

Figure 13

Steam Jet Movement Above the Ocean Surface



Note: This figure demonstrates the rising of the steam jet (blue) into the atmosphere (red). The labels given represented the flow time passes, in seconds.

Furthermore, Fig. 14 and 15 display the overall mixture density and the mixture's velocity magnitude, respectively. Since the density of the steam and air are so close to one another and 3 orders of magnitude smaller than the density of the ocean water, they are considered one color (blue) in Fig. 14. The biggest take away from this contour plot is that portion of ocean water are being carried up above the ocean surface by the steam jet. Although this model is not refined enough to capture entrainment, this is a promising sign that ocean water is being carried by the steam jet. In Fig. 15 it can be seen that the velocity of the jet below the ocean's surface is much higher than that of the jet once it has broken the ocean's surface. The velocity underneath the surface has a maximum of over 1600 m/s, where as above the surface it is between approximately 500 and 800 m/s. Although this is a significant drop in velocity, it is what is expected from this model. The jet would lose a lot of energy breaking through the surface of the ocean because it would have to overcome the force needed to break the surface tension of the water.

Figure 14

Contour Plot of Mixture Density

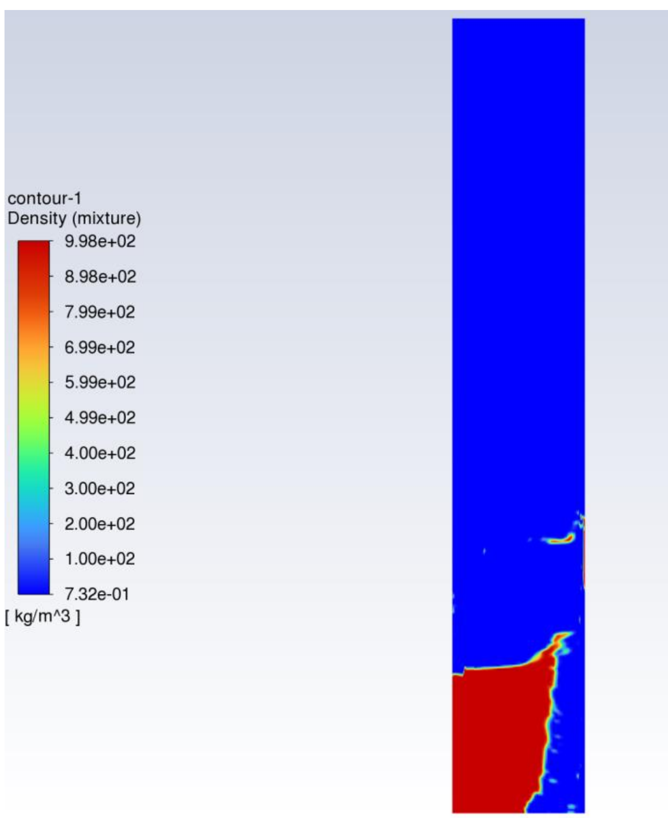
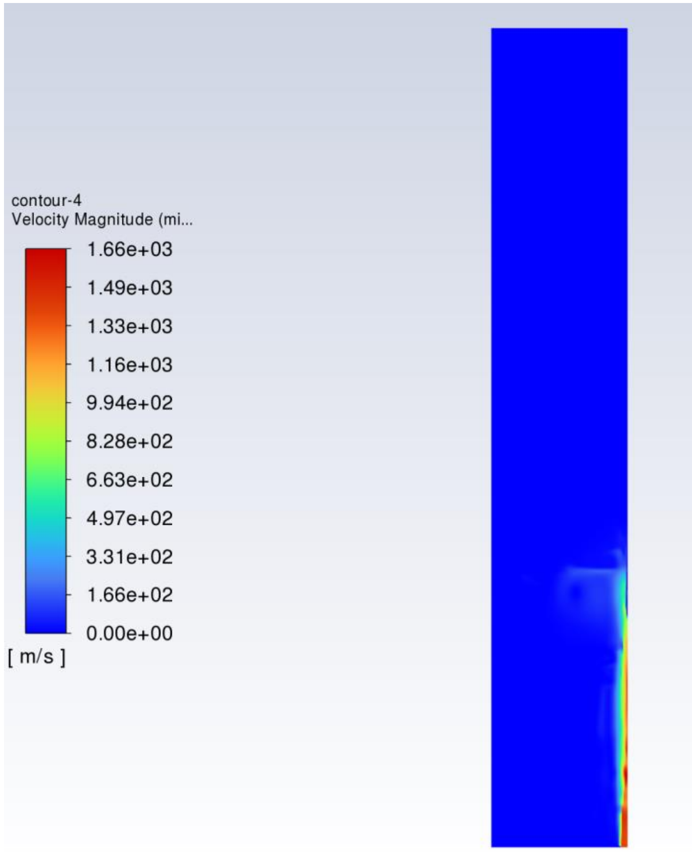


Figure 15

Contour Plot of Mixture Velocity Magnitude



Discussions

Model Limitations

Since the model presented in this study is created with the CFD knowledge suited for an undergraduate student, there are numerous limitations that prohibit the simulation from fully representing a catastrophic steam jet. As noted above, the width of the steam plume is much wider than expected. This could be due to multiple factors, but is overall caused by the jet not being able to rise fast enough. The assumption that the geometry needed to be scaled in order to run the model effectively was incorrect, and actually likely caused several accuracy issues during the simulation, such as the large plume width. Additionally, a VOF explicit multiphase model was chosen for this model. Although this comes with several benefits, VOF does not leave room for controlling the size of droplets, making it difficult to solve the plume width problem while keeping this multiphase model selection. One solution to this problem is just to let the model run for longer, but that is not ideal when wanting to study how the jet initially rises through the ocean.

Another large limitation of this model is its inability to quantify turbulence and capture the entrainment of fluid with the jet column. To comprehensively study the behavior of cataclysmic jets that would have occurred during the biblical flood account, turbulence and entrainment are two major components. Being able to capture entrainment is especially important because the jet behavior could provide an additional method for continuous rain fall during the 40 days and 40 nights of the flood duration. The model needs to be greatly improved using techniques beyond an undergraduate scope of knowledge to accomplish these tasks.

Future Work

In order to improve the validity of this simulation, there are several changes that need to be made and areas of research that need to be explored. First, the model geometry needs to be adapted to where it is no longer scaled down. Unlike some other 3D modeling software, such as Solidworks, Fluent is not impacted by the overall scale of the system but rather the scale disparity within the system. The scaling present is due to an improper assumption by the author and serves no benefit for the model. Secondly, it is recommended that the solution technique is changed from VOF explicit to Eulerian-Eulerian with a slip velocity model. The errors encountered and the large velocity magnitude are great indicators that the modeling approach needs to be drastically changed. In this case, the gas phase should be set to the secondary phase instead of the primary phase. This change will provide a potential solution for the large width of the steam plume. However, this solution will not be able to capture droplets in the gaseous phase.

The steam jet problem presented is extremely complex and will take several more improved versions to model it accurately and represent the physics adequately.

In future studies, a solution should be developed on how to both capture the entrainment process and quantify the turbulence within and around the steam jet. As noted previously, these are two of the most important aspects of this problem and will provide the most impact insights for creation scientists. Lastly, the model presented needs to be run longer to fully capture how the jet is behaving with the set up and solution techniques chosen. As the model progresses, it is recommended that a cluster of computers is utilized to expedite the time it takes run the simulation. Currently, while running on 4 cores of a single PC, it takes about 5 days for the solution to progress 0.1 seconds of flow time. This is largely due to the small time step needed to keep the solution to the violent eruption stable.

Conclusion

The purpose of this research was to develop a basic CFD model of steam jets that would form above hot sea bottom that result from rapid sea floor spreading during the Genesis Flood. The Genesis Flood account records the largest catastrophic event in history, and there are numerous geological components that greatly transformed the makeup and structure of the earth. The steam jets studied here could help account for portions of the continual rainfall over the duration of the flood and would greatly disrupt the surrounding ocean water. The model created was able to show that the jets rise rapidly and definitely disrupt the surrounding ocean region. Once the violent jet breaks the surface of the ocean, its velocity decreases, it carries ocean water up into the atmosphere, and it begins mixing with the surrounding air. Although large improvements need to be made in order for the model to appropriately represent the problem at hand, the developed research and created simulation serve as a catalyst for future students to continue investigating the events of the Genesis Flood.

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