Viability of Heat Expansion Driven Water Propulsion System Through Computational Analysis

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Air travel has undergone a great deal of progress since its inception; the invention of ramjet and scramjet engines have revolutionized the industry. Water travel has maintained the same basic technologies relying primarily on propeller type thrusters. This project aims to assess the validity of an underwater Scramstyle propulsion system that uses heat energy as its source of energy. The simulation involved utilized the Navier-Stokes equations to compute fluid flow within the system. It was assumed that the flow was laminar at all times, thus there were no turbulent or chaotic points within the water flow. The simulation resulted in two graphs which showed the effect of a heated region on water both with and without the physical component of the simplified Scramstyle structure, which appear similarly noisy suggesting partially random motion. The average velocity induced by the heated region were, for just the heated region -0.024$\mathrm{m\,s^{-1}}$ and with the structure -0.049$\mathrm{m\,s^{-1}}$. The standard deviations for these results was 0.491$\mathrm{m\,s^{-1}}$ and 0.378$\mathrm{m\,s^{-1}}$ respectively. The size of these deviations suggest that our results may be due to statistical variances and not indicative of the validity of a heat-based underwater propulsion system, thus the results are inconclusive.

1 Introduction and Background

I attempted to simulate the operation of an underwater propulsion system which was based upon the operation of Scramjet engines. That is the simulated structure will operate in the same way as any jet engine, the medium is taken in, accelerated, then exhausted at higher speed than entry. What defines a Scramjet system is that the medium does not need to be slowed down before it is accelerated [3]. There are many factors that make Scramjets in particular attractive for analogous development for aquatic travel. Firstly, there is the fact that the medium does not need to be slowed to be accelerated in the intake system, this will reduce the significant amount of drag produced by the slowing of water, which is much denser than air. Additionally, these systems are highly efficient in their use of energy, which is a critical factor for ensuring that any new technology will be a viable replacement for an old one. With these in mind, a preliminary sketch of how an underwater Scram style propulsion system might operate was developed (see Fig. 2). This is the basic physical interpretation of the system I simulated, or at least attempted to determine the validity of such a system through simulation.

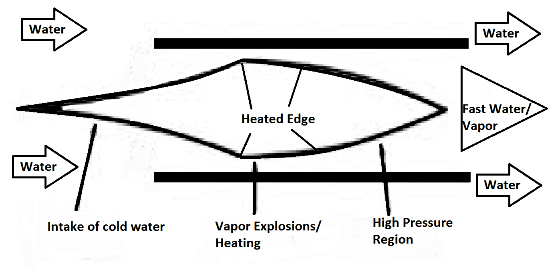

Figure 1: How an aquatic ScramJet engine style propulsion system is proposed to operate

I propose to develop an efficient Scram style system which simply heats the water to increase its velocity and cause high pressures, thus generating thrust. There are a lot of notable fluid phenomena that are good candidates for such a system, the most promising I researched was vapor explosions. When water is heated extremely quickly it can evaporate so quickly that it resembles an explosive reaction. This phenomena has been so powerful as to even cause damage to nuclear reactors, where such occurrences are a prevalent concern [7]. If this phenomena was properly exploited then a new, more efficient form of aquatic travel would be at hand.

A significantly simplified simulation was all that was reasonable in the given time. With that in mind a simplistic two dimensional structure was needed as that was all that the available systems could simulate in a reasonable time frame. The simplest proposed structure, was a triangle with the tip removed as an intake and an open opposite side as an outflow, inside these there would be a simulated source of heat. Though this simplification already moves us out of the realm of full simulation, the results even after this significant a change should still be a good indicator of the viability of the more complex structure. With this in mind, a structure was strictly defined within the program, as can be seen in Figure 3. This structure within the simulation should provide a decent indicator as to whether or not an underwater Scram style propulsion system is reasonably viable.

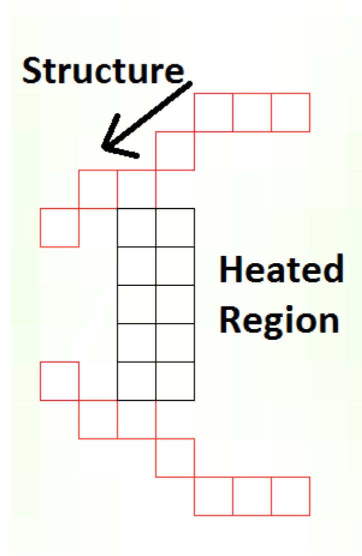

Figure 2: A structure wherein a centralized source of heat is simulated, and the exterior structure is more supportive rather than instrumental, the black boxes are the regions of simulated heat being added, and the red region is the surface of the structure itself

2 Theory

In order to properly simulate this it is necessary to understand the basics of mathematical modeling for aerodynamic and hydrodynamic flows. The most important set of equations in this field are known as the Navier-Stokes equations. Many variations on these equations have been developed to account for various circumstance however the most basic form is two simple equations. [14]. These equations represent a series of coupled partial differential equations that describe the motion of incompressible, non-chaotic fluids. More complex forms account for turbulence, non-laminar flows, chaotic perturbations, shock-waves, and a variety of other potential fluid phenomena. However for this simulation I assumed that chaotic flows were not possible, allowing for the use of a simplified version.

Additionally I assumed incompressibility of the fluid and water is nearly incompressible making this a reasonable approximation. The evaluation of these equations allows for a reasonable simulation of water flowing through and around an arbitrary structure.

$$\frac{d\vec{v}}{dt} = -(\vec{v} \cdot \vec{\nabla})\vec{v} - \frac{1}{\rho}\vec{\nabla}p + \nu\nabla^2\vec{v} \tag{1}$$

$$\vec{\nabla} \cdot \vec{v} = 0 \tag{2}$$

This variation of the Navier-Stokes equations is quite interesting in terms of physical analysis. If we examine the first equation, (eq. 1) we can see that it describes the velocity dependence. The first term is the relationship of the fluid's velocity to that of the fluid around it, and how it is changing. That is to say, this term describes the relationship between the velocity of a cell and the velocities of surrounding cells. The next term relates the propagation on pressure, and involves the density of the fluid. The last term involves the viscosity of the fluid and the effect it has upon the velocity propagation in the medium. The second equation (eq. 2) is far simpler and is simply a mathematical statement of incompressibility, as it is stating that any fluid that flows into a closed region must also flow out with the sum of inflow and outflow being zero.

The base code that I used and modified to evaluate these Navier-Stokes equations used finite differencing on a staggered grid to determine the updated velocity and pressure values of a thin channel [14, 15]. The Navier-Stokes equations were evaluated with the density and viscosity set to simulate the behavior of water at $280°K$. The program was set up so that there was water being pumped in and out at the edges with a velocity of 5 $\mathrm{m\,s^{-1}}$. This works because it is only a forced boundary condition, like water being pumped in and pumped out at the same rate to ensure a constant volume within the system. In this way if the propulsion system operates we would see a simulation of slightly more pressure behind it, but not a violation of laminar flow. That is the $5\mathrm{m\,s^{-1}}$ outflow speed is fixed to allow only ever $5\mathrm{m\,s^{-1}}$ outflow, thus the water contained by the simulation is of constant volume, despite the variations in velocity. The outflow speed of the simulated structure was recorded by averaging the velocities on the outflow side and subtracting the average velocities on the intake side. This is a good way to determine how much speed is gained by the water as it passes through the manifold. Figure 4 explains well what is going on within the simulated channel. It is worth noting that temperature was not inherently calculated, and merely the effects of temperature and vapor explosions were simulated. This was accomplished by giving the fluid in this region a velocity "kick" where it simply attains high speed in a random direction.

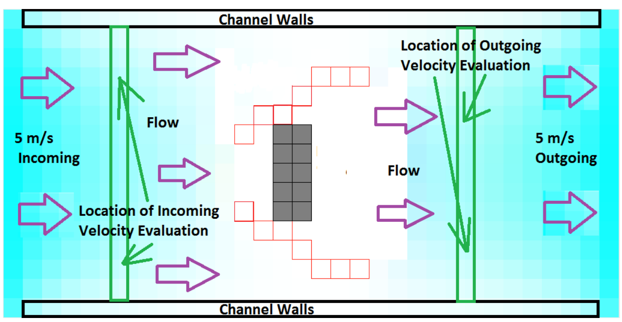

Figure 3: The nominal operation of the simulation, the green bars show the regions where the velocity is average

At this point many simplifications and approximations have been implemented into this simulation. The computational result that is achieved is not a good measure of the actual performance of such a system underwater. This remains however a valid proof of concept simulation to determine whether such a system could reasonably operate at all. Thus the methodology is to compare two long run simulations. First I evaluated the velocity of the high temperature region with no structure present. This value should stay close to zero, but may vary slightly due to the random nature of the high temperature approximation method. This can then be compared to a run of the simulation with the open triangle structure in place. Comparing these two runs should give us a reasonable idea of whether or not this is a viable means of underwater propulsion.

3 Computation and Analysis

The first run wherein the heated region was simulated without the presence of the structure operated efficiently, the velocities of the simulation seemed to fluctuate erratically and wildly, but ultimately fell into an unstable pattern. A picture of this simulation operating is Figure 5

This simulation was run for several hours and produced the following graph, Figure 6.

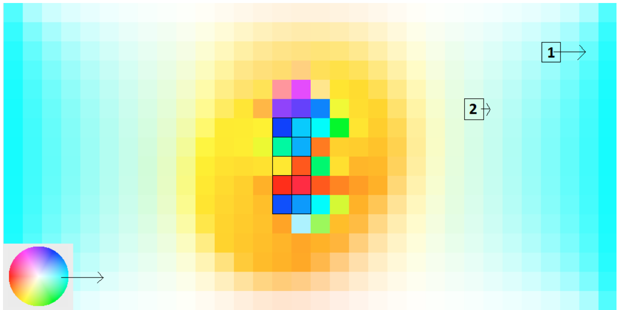

Figure 4: The operation of the simulation where the structure is not present, the colors shown are displaying velocity where the colors indicate direction and color darkness indicates magnitude, as per the legend in the bottom left corner. for example if you consider the boxes labeled 1 and 2 in the picture we will see they are both light blue, and therefore both contain fluid pointing to the right, as per the black arrow on the legend. However the box labeled 2 is much lighter than box 1, indicating that it is not showing fast movement relative to box 1. This difference in magnitude is shown by the black arrows emanating from the boxes.

Figure 6 resembles static or noise indicating that the left right motion of the heated region on its own is more or less random. This result is actually quite promising for the simulation as it suggests that we have accurately simulated the heated region, this is the exact behavior one would expect from the simulation as it should have no preferred direction. The average value for the velocity of this simulation with just the heated region was -0.024m s^{-1} with a standard deviation of

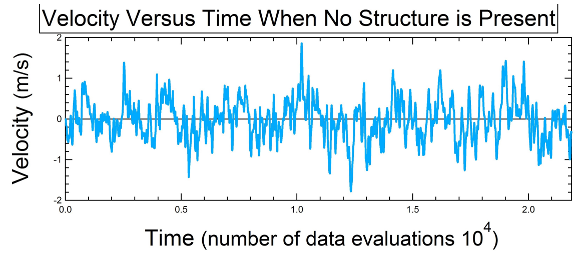

Figure 5: The average velocity increase caused by the heat region without the structure present

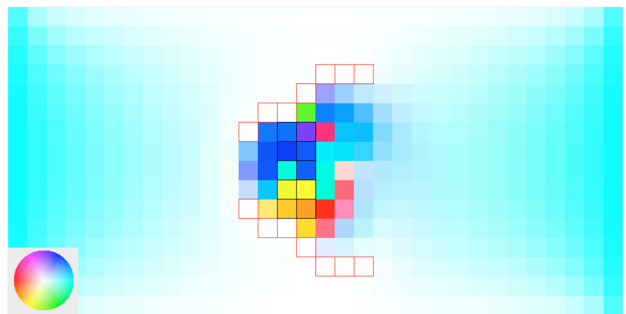

Figure 6: The operation of the simulation where the structure is in place, the colors shown are displaying velocity where the colors indicate direction and color intensity indicates magnitude, as per the legend in the bottom left corner. Velocity on this is shown in the exact same manner as the previous image (see Fig. 5 wherein just the simulation of the heat region is shown.

0.491m s^{-1}. The operation of the simulation with the structure present can be seen in Figure 7.

This simulation with the structure in place produced the following graph after simulation, Figure 8. This simulation of the heated region with the surrounding structure in place produced an average value of 0.049m s^{-1}

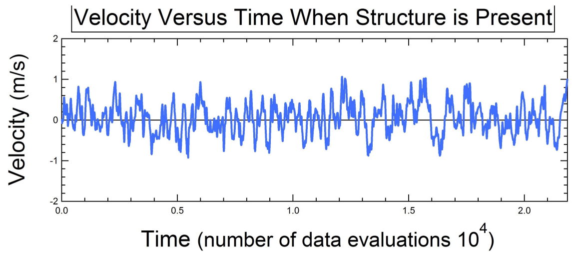

Figure 7: The average velocity increase caused by the full Scram style structure system

and a standard deviation of $0.378\,\mathrm{m\,s^{-1}}$.

4 Conclusions

The development of this simulation led to a great deal of approximation and compromise, however the end result is a reasonable simulation of validity for the underwater propulsion system. This is shown by the velocities generated by the graph of the heated region alone. This regions jittering back and forth velocity results are exactly what one would expect from such a circumstance physically. The output of the simulation is two graphs that, on basic inspection seem quite similar. This suggests that even with the structure in place, the high temperature region still produced a large effect on the negative direction despite the physical shielding of the structure. So much so that the velocity went negative at many points. On a more hopeful note, the average velocity with the structure is twice as large as the velocity produced by random motion, which suggests a positive result. Unfortunately, both of these results are completely overshadowed by the standard deviations of their respective results. Each result has a standard deviation that is a full order of magnitude larger than the numerical average. This suggests that our results are unreliable and may be due to a statistical hiccup. However, the fact that the graph with the structure in place is much smoother and its standard deviation is $0.2\,\mathrm{m\,s^{-1}}$ smaller is suggestive of the effect of the structure on the simulation. The structure seems to have a stabilizing effect on the velocities produced by the heated region. This is promising as it suggests that further tweaking may yield a positive result within this simulation scheme. That being said the statistical analysis shows that the results of this simulation are not conclusive, and the viability of a heat based Scramstyle water propulsion system remains unknown.

5 Acknowledgements

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