With unbridled fury, the Niagara River leaps from its confining banks, for one moment in time, creating a horseshoe shaped, freefalling wall of water that man has yet to fully tame, thus inciting awe and tantalizing the senses for young and old who venture to experience this masterpiece of Mother Nature known as The Horseshoe Falls. The aforementioned falls, located on the Canadian side of Niagara Falls, flow at a rate of 600,000 gallons per second from a height of 176 feet and distribute the outflow of $1/5^{th}$ of the Earth's supply of freshwater from the Great Lakes region. ("Niagara Facts")

Everyone holds some level of wonderment for the entity of water. The previous paragraph may render differing reactions depending on the reader. Those who lean towards a more right brained approach to thinking would react immediately to the opening sentence and quickly become unenthused once numbers were introduced in the second sentence. Left brained people, who seek numerical explanation to all facets of life, would draw a diminutive reaction from the opening statement, but the seeds of curiosity would be planted after reading the second sentence and formulating the mathematical relationships in their mind.

This leaves one last group of people which encompasses those who would react with an equal degree of excitement from both sentences, those who realize the same level gratification from sketching a toy sailboat as it floats down a babbling brook and deriving Bernoulli's equation in the case of insipient cavitation. One could call them "whole brained", but in the context of this essay they will be named "Da Vincian" thinkers. During his life, Leonardo Da Vinci was referred to as a Master of Water through his extensive research and intrinsic fascination in hydrodynamics and fluid mechanics. At first glance, one would think that the extent of this research was only used for his engineering endeavors,

but his allure into the flow of air and water also invaded his artistic achievements. In this essay, the notion of how fluid mechanics affected Leonardo Da Vinci's artistic and scientific careers will be explored.

During the height of Da Vinci's artistic career, he resided in Florence, Italy at the onset of the Florentine Renaissance. It was a period where art was resurrecting from the awkward, rigid style of the Middle Ages into the Humanist era which, for the first time in the history of art, glorified the human body and attempted to inject life and movement into art. Da Vinci shed optimism on this new movement of art, but was still critical of the artists of the period because he felt they weren't doing justice to the works they put forth.

He saw masterpieces of the day displaying modest humanistic depictions of biblical figures in the foreground and the backgrounds showing idealized landscapes that were devoid of any semblance of life, movement, or geographic accuracy. In order for an artist to truly bring life to art, Da Vinci believed they must be able to bring life to the space around their focal figure, accurately representing nature and how it coalesces with man. The only way to accurately depict nature is to understand its scientific processes. This was a school of thought which Leonardo lived by and desperately publicized, but was met with much condemnation from his peers. Not only being able to paint something from sight was enough but utilizing research of the physics and dynamics of the subject truly brings it to life in an artistic medium. In his *Treatise on Painting*, Leonardo remarked on other artists through the following quote. "You, o painter, who long for the greatest perfection, must understand that if you do not achieve it on the solid basis of the study of nature, you will produce many works with little honour and less gain." (Heydenreich, 107)

In researching natural processes and how to accurately depict them through art, Da Vinci spent a significant portion of his life researching the movement of water and air. One aspect of this research that greatly influenced his artistic technique was the study of fluid turbulence and the vortex. Turbulence in fluid refers to a disruption of smooth or laminar flow resulting in a random unpredictable flow pattern. Although practically impossible to model mathematically, Da Vinci strove to accurately depict this condition through detailed drawings in order to explain to the people how this occurs. Up to this point no one had attempted to tackle the dynamics of fluid, only static theory, making Leonardo a pioneer in subject. By observing different forms of turbulent water including river bends, waterfalls, and ocean waves, he generated various theories explaining this phenomenon, some of which were precursors of proven laws taught in academia today.

One such theory states, "A river in each part of its length in equal time gives passage to an equal quantity of water, whatever the width, the depth, the slope or the tortuosity." (O'Malley, 180) This passage represents the theory of continuity in a premature form, which simply states that the flow rate into a system equals the flow rate out of a system assuming no gains or losses in energy. He explained that the velocity of river entering a point of decreased channel width will increase. When this channel reverts back to its former width the river must then also revert to its former velocity which creates an obstacle for the water rushing in at greater speed.

Complementing this law, he culminated his explanation of turbulence by describing how a flow of water will react at an obstacle. He states:

> "Hence, the current of water desires to maintain its course according to the force that caused it, and when it finds an opposing obstacle, it completes the length of the

initiated course by circular and whirling movements which will traverse the same length during the same time as if the path had been straight."

(O'Malley, 184)

This introduces the inception of the vortex and spiral getties, made famous by many artworks including Da Vinci's set of *Deluge* drawings displaying this dynamic motion, and the idea that water will turn back on itself in a spiral fashion when reaching an obstacle. Depending on the impulse force of the water, the magnitude of spiraling movements will be different. Thus, the vortexes seen at the bottom of the waterfall will be much greater than those witnessed at the bend of a babbling brook. Although these theories were left as such and not scientifically proven, they greatly reflect the formal studies performed by Osborne Reynolds. Four centuries later, Reynolds was made famous for the derivation of the Reynolds Number, which provides criterion for dynamic similarity and correct modeling in many fluid flow experiments especially turbulence. ("Osborne Reynolds")

Not only did Da Vinci use these models of spiral getties and vortices for use in depicting flowing water in art, but he also used these same theories in bringing life to other objects in an artistic medium. In a remark made in his *Treatise of Water*, Da Vinci compares the movement of fluid to that of hair. He believed the movement of both subjects can be characterized with two components. In the context of hair, one component of movement would be caused by the weight of the hair which would be equivalent to the normal movement of water by the principal current. The second component describes the movement of hair caused by curling which can be seen if one would try to straighten a strand of curly hair and then quickly release. The spiral, recoiling motion that occurs is equivalent to the motion of a vortex of fluid. This idea can be seen in Leonardo's painting,

Leda and the Swan. In this piece Leonardo depicts the Greek mistress of Zeus with a wig of spiraling braided hair comparable to the "corn row" style of the present time. Taking a closer look at the orientation of the curl of each braid, there is a direct comparison with Da Vinci's depiction of the vortex and spiral geddie. (Kemp 81)

Because Da Vinci was a pioneer into the realm of fluid dynamics, he was often sought after by political dignitaries to apply his vast knowledge of fluids and exercise his ingenuity in real life engineering applications. Leonardo actually received the title "Master of Water" from Florentine authorities after brainstorming ideas and providing counsel concerning ways to change the flow of the Arno River between Florence and the Ligurian Sea in order to divert the river away from impassible terrains. (Kemp, 141) Fascinated in the areas of canalization and river flow, Da Vinci developed an elaborate and fascinating, yet far fetched, plan to remedy the situation which involved diverting the river northwest through a manmade canal. Not only did this plan create a navigable waterway leading to the sea, but it also would have brought improved commerce to arid regions of Prato and Pistoria where a key center of the wool industry of Italy was located.

There were two significant obstacles involved in this plan that Da Vinci addressed with unconventional tactics. One obstacle was a mountainous region near Serravalle that restricted navigable flow. Instead of attempting to avoid the region by altering the course of the diversion, Da Vinci designed a tunnel system which would navigate the canal underneath the mountain pass. A detailed sketch of this plan is offered in his notebooks, providing methodology for accurate excavation of the mountainside. (Reti, 194)

The second obstacle was the issue of being able to maintain a navigable water level through the length of the canal. Another brilliant and insane proposition was made by Da

Vinci concerning this issue, which involved linking the Arno River to both the Tiber River and Lake Trasimeno. (Reti, 195) In order to do so, another underground canal system would have to be developed connecting the Tiber River and Lake Trasimeno. To make the final link and connect the Arno River to the other bodies of water, Da Vinci suggested creating an artificial lake by flooding the marshlands near Arezzo and connecting them with Lake Trasimeno creating an immense water network. Due to obvious economic, technological, and labor restraints, this plan could not be implemented, but it instead provided an insight into the brilliance that is Leonardo.

This is just one example of Da Vinci's engineering offerings in the realm of fluid mechanics. Numerous engineering projects concerning river flow are found throughout his notebooks, but most of them suffered a similar demise as the previous example. Leonardo's ingenuity surpassed technological development by many centuries. Many wonder what it would have been like if Leonardo would have lived in the present generation with all of the technological advancements the 21st century has to offer. In my opinion, one would be quite naïve to believe that even modern technology would be able to facilitate Leonardo Da Vinci's expansive intelligence.

The effects of his research in fluid dynamics can be seen as a two fold benefit. By pioneering the study of fluid flow, Da Vinci established a framework of thought in the subject that was utilized and expanded upon by engineers following him. He also used his studies to wage his personal war to fuse science and art; a pursuit although unfruitful on a grand scale, planted the seed for future generations. His existence was a pure gift to mankind that will be relished until the end of time; Leonardo Da Vinci a Master of Water, the Ambassador of Thought.

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