Journal of Physics Special Topics

An undergraduate physics journal

P5 7 Sailing around at the speed of sound

H. Charman, T. Boyce, E. Cross and T. Chu

Department of Physics and Astronomy, University of Leicester, Leicester, LE1 7RH

December 11, 2025

Abstract

In this paper we determine whether a simplified fluid dynamics model can accurately determine how fast Sonic the Hedgehog would have to run to run on water. The velocity required to run on water came out as 7.9 ms^{-1} - unrealistically slow. This lead us to conclude that our models were too simple for something as complex as running on water.

Introduction

In this paper, we will define a simple fluid dynamics model inspired by Hsieh's more complex work on basilisk lizards running on water [1], and determine whether the model is appropriate or not. We will do this by using the model to calculate the velocity required for the video game character 'Sonic' to run on water like he does in the film *Sonic the Hedgehog 2* [2]. We will then discuss what the results say about the accuracy of our model.

Sonic is a famous video game character who first appeared in the 1991 game *Sonic the Hedgehog*. The character is known for being a remarkably fast runner, with multiple claims that he can easily break the speed of sound on foot. One of the most impressive displays of speed he has achieved was in *Sonic the Hedgehog 2* [2], a film based on the early video games. In this film, Sonic runs across the ocean without sinking or swimming.

Theory and Method

In the film *Sonic the Hedgehog 2* [2], Sonic starts sprinting on the coast and is already at great speed when he reaches the water. He appears to accelerate to max sprinting speed near-instantaneously. We will therefore assume that, while on the water, Sonic is doing no lateral acceleration, as he is already at max speed. Therefore, the calculation for the minimum velocity required for Sonic to run on water does not include any extra force required to accelerate Sonic to his maximum speed on the water.

The forces involved in running are complex - we must create a simple model that allows us to represent the different stages of the foot's interaction with the ground, or water in this case. In Hsieh's work [1], running on water is split into three interactions:

First, the foot 'slaps' the water - this is a vertical interaction with the water, where the foot first makes contact. We will assume that this phase has only forces that are completely vertically directed.

The second stage is the 'stroke'. In this stage, the foot is already in the water and applies a force diagonally down and behind the runner pushing them forward. We will assume that this force occurs at a 45 degree angle to the vertical.

The final stage is the 'recovery' stage, where the foot is brought out of the water and back to the starting position. In this paper, we will ignore this stage as Sonic's running technique means he almost always has a foot on the floor, rendering the effect of the recovery stage negligible.

For the two stages of the foot-water interaction, we will use two different equations to resolve the forces. For the slap stage, we will develop an expression for the force on the water driven by Sonic's foot. This force is given by:

$$F = \Delta p / \Delta t \quad (1)$$

where Δp is the change in the momentum of the water and is opposite to the change in the momentum of Sonic, and Δt is the amount of time the slap stage lasts. We can expand this expression by recognising that the change in the momentum is equal to the total momentum of the water after the interaction, giving us:

$$F = v_w \rho_w V_w f \quad (2)$$

where f is the frequency of the slaps or steps per second, equal to $1/\Delta t$. The force is represented by the velocity, density and volume of the water displaced by Sonic's foot. For the stroke stage, we will model the interaction as a dynamic pressure on the section of the water beneath Sonic's foot. Starting with the dynamic pressure formula, Equation 3:

$$p = \frac{1}{2} \rho_w v_f^2 \quad (3)$$

where v_f is the velocity of Sonic's foot. You can find the force from the stroke stage by multiplying both sides of Equation 3 by the area A of Sonic's foot. To resolve the vertical forces, we set Sonic's weight equal to the sum of the slap force and the vertical component of the stroke force:

$$\frac{A \rho_w sin(45)}{2} v_f^2 + \rho_w V_w f v_f - mg = 0 \quad (4)$$

which allows us to solve quadratically for the speed of Sonic's foot in the vertical direction, and since the foot is moving at a 45 degree angle to the vertical as stated earlier, this is also the horizontal speed of the foot and therefore the speed Sonic is running at.

Measurements and Results

Sonic's mass is listed as 35 kg on the Sonic Wiki Zone [3]. For his feet, we estimated an area of 0.015 m^2 each. We used this to calculate the volume of water displaced V_w by multiplying the area by the depth Sonic's foot sank into the water. We estimated this to be 0.01 m, an estimate made from a close up shot on Sonic running on water in the movie [2]. From the same scene, you can hear that Sonic runs at a frequency of 12 steps per second. We took the density of water as 1000 kgm^{-3}. Subbing all of these values into Equation 4 and solving for v_f, we get a running speed of 7.9 ms^{-1}.

Conclusion

Our value of 7.9 ms^{-1} is clearly unrealistic, as that is only about three times the average human's running speed [4]. An article in Runner's World [5] estimates that the average human would have to run 98 fts^{-1} or 29.9 ms^{-1}. Although Sonic is lighter with human-sized feet so would not require as much speed, 7.9 ms^{-1} is still clearly far too low - even if we assume Sonic needs to run half the speed of a human, our calculated velocity is still small. Our model of the forces required to counteract the weight of Sonic treats water as a solid, static surface where momentum is exchanged parallel to the leg when Sonic pushes off - in reality, water moves and shifts when pushed downward, distributing momentum throughout the water in more complex ways that our models do not account for. One example of this is the generation of vortices - the transfer of momentum creates swirling water vortices that produce dramatically different reactionary forces to a static surface. As a result, the velocity required to create a force large enough is significantly higher than we have calculated.

References

[1] *Running on water: Three-dimensional force generation by basilisk lizards* ST Hsieh et al, November 2004

[2] *Sonic the Hedgehog 2*, J. Fowler, Paramount Pictures

[3] `https://sonic.fandom.com/wiki/Sonic_the_Hedgehog#:~:text=Classic%20Sonic%20is%2075%20centimeters,to%20blue%20in%20Sonic%20Heroes`. Accessed 9 November 2025

[4] `https://pmc.ncbi.nlm.nih.gov/articles/PMC9169516/#:~:text=We%20found%20that%20on%20these,transport%20curves%20about%20the%20minima`. Accessed 9 November 2025

[5] `https://www.runnersworld.com/news/a64892628/science-behind-shacarri-richardson-running-on-water/` Accessed 1 December 2025