Using Simscale to Model R.C. Airplane Propeller Noise Reduction

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Abstract

This research paper will explore the sound pressure level of a propeller. The geometric features of the propeller manipulate the main factor of noise: vortices. There are different advantages and disadvantages regarding having quieter propellers such as less lift, which decreases velocity. This paper demonstrates the effect of the differing velocity inlets that change the gauge pressure and magnitude of the velocity. Using the velocity inlet magnitudes, I drew a relationship between the velocity inlet magnitude and the sound pressure level, showing how future propeller designs should increase the rotational speed to minimize noise levels. Making the radio-controlled airplanes less loud would allow them to play a significant role in transportation.

Personal Motivation

When I look at modern technology, I always wonder how humans were able to learn to create such complex devices. One of the first times this happened was when I was around 10 years old, sitting on a bench while watching my dad fly his radio-controlled airplane. I looked with awe as the plane looped around in the sky, making a loud *whoosh* sound as it zoomed past. I was fascinated by how a styrofoam plane with the circuits and servos hiding inside can spin and loop around in the wind. As I got older, my dad taught me how to fly RC airplanes and explained some technical aspects of its assembly. The journey of learning how to control the plane's flight was full of obstacles and setbacks. The feeling of finally successfully flying the plane felt fulfilling and rewarding. This shared hobby built my curiosity in unraveling the aspects of engineering behind this childhood memory.

Introduction

The creation of RC airplanes are credited to Walter Good and Bill Good back to 1937 [1]. The first RC plane they flew was a 8-foot free flight model. Later on, Leo Weiss advanced RC planes by adding in an eight-channel radio system. As this technology became more popular, they played a bigger influence in society. During World War II, Radioplanes, which were RC planes, played the role of military target drones in the US army. The development of model planes became more advanced after transmitters were able to be programmed in order to manipulate specific components of the plane like the servo angle, extrema of the servo speed, and travel curves.

RC airplanes, which are usually seen as miniature planes flying around as a hobby, have the potential to play a significant role in society through its fast transportation. These planes are typically lightweight and less costly which are benefits to fields that need quick and small shipments. However, like all technology, the RC airplane has some downsides: one of which is the loud noise generated from the propellers. Noise is mainly caused by vortices forming where the noise generated is called vortex noise [2]. There are many factors of RC planes that would affect the noise level. There are designs that manipulate the vortices by varying the twist angle, the surface area of the blades, or the material of the propeller. In this paper, we will specifically observe the effect of rotational speed on noise.

The higher the sound pressure level, the louder the noise. By modifying the geometrical features of propellers, it is possible to change the rotational velocity to manipulate the sound level. Using a computer-aided engineering simulation program called Simscale, we can find the relationship of the rotational velocity and the noise level. Using simulations, we can observe the velocity and gauge pressure from the two-blade propeller to observe how the forces affect the noise.

Methodology

Using the CAD library found on SimScale, I found a model of a two-blade propeller. Inputting the CAD into a simulation allows the analysis of the pressure produced by the propeller with specific conditions of the surroundings (Fig. 1). The simulation shows the velocity magnitude and gauge pressure produced by the propeller, comparing it with different initial velocities inlets. We can see whether the noise increases or decreases through the change in pressure when the RPM progressively increases.
According to Oscar Liang in ref. [3], the formula for the normalized sound power is:

$$\text{PWL - 10log}\frac{A_a n}{B}\left(\frac{D_H}{D_T}\right)^2$$

where PWL is the energy flux per unit area in decibels, A_a is the rotor annulus area that's the area from the center to the tip, n is the rotor speed in revolutions per minute, B is the number of blades of the propeller, D_H is the diameter of the propeller's hub, and D_T is the diameter from the propeller's tip.
According to in Zaheer Akhtar in ref. [10], we can calculate the PWL by using the formula:

$$\text{PWL = 10log(Pressure} \times 10^{12})$$

Using the gauge pressure at Point A and comparing the simulation values for the sound pressure to the theoretical values, we can observe how changing the initial speed of air changes the noise level.

Analysis

The simulation does have some limitations that would produce results that are different if the experiment was conducted in real-life conditions. Below in Figure 1, there are input parameters for the simulation where the conditions are set to ideal for the propeller. The simulation does not account for real life conditions like wind. Wind would increase the noise due to the increase of the velocity of the surrounding air and would cause the propeller to generate more noise.

Material of surroundings	Air (Kinematic viscosity (v): 1.529e^{-5} m^2/s; Density (ρ): 1.196 kg/m^3)
Initial Gauge Pressure (P)	0 Pa
Initial Velocity (U)	U_x= 0 m/s; U_y= 0 m/s; U_z= 0 m/s
Type of flow	Laminar flow
Initial Specific Dissipation Rate (ω)	3.375/s
Boundary Conditions	Slip wall
Propeller Surfaces	Full resolution no-slip wall
Velocity Inlet	Fixed value; Velocity (U): U_x= 0 m/s; U_y= -4 m/s; U_z= 0 m/s; Automatic turbulence
Pressure outlet	Fixed value; Gauge pressure (P): 0 Pa
Forces and Moments	x = 0 m, y = 0 m, z = 0 m,
Mesh	Hex-dominant algorithm; 6,427,466 volumes

Figure 1: Conditions of the Simulation, Setting the Parameters for Propeller Flow

In Figure 2a, we can observe that as the propeller runs with the velocity inlet of 2 m/s, there is a pattern of the resulting air velocity being around 9 to 10 m/s. The color represents the velocity magnitude, shown from the color legend located at the bottom. The path of the increased velocity slowly condenses as the displacement from the propeller increases. Shown through the data of velocity and pressure in Figure 3, when velocity inlet is 2 m/s, it has not reached the maximum of the propeller efficiency. This is why there is a decreasing behavior in velocity at Point A and the gauge pressure at Point B. This is seen through Figure 2b for pressure where the pressure was condensed at the tips. According to ref. [8], when propeller efficiency is represented on an advanced ratio versus blade angle graph, it results in concave down graphs. The concavity shows why there is a changing pattern in the pressure.

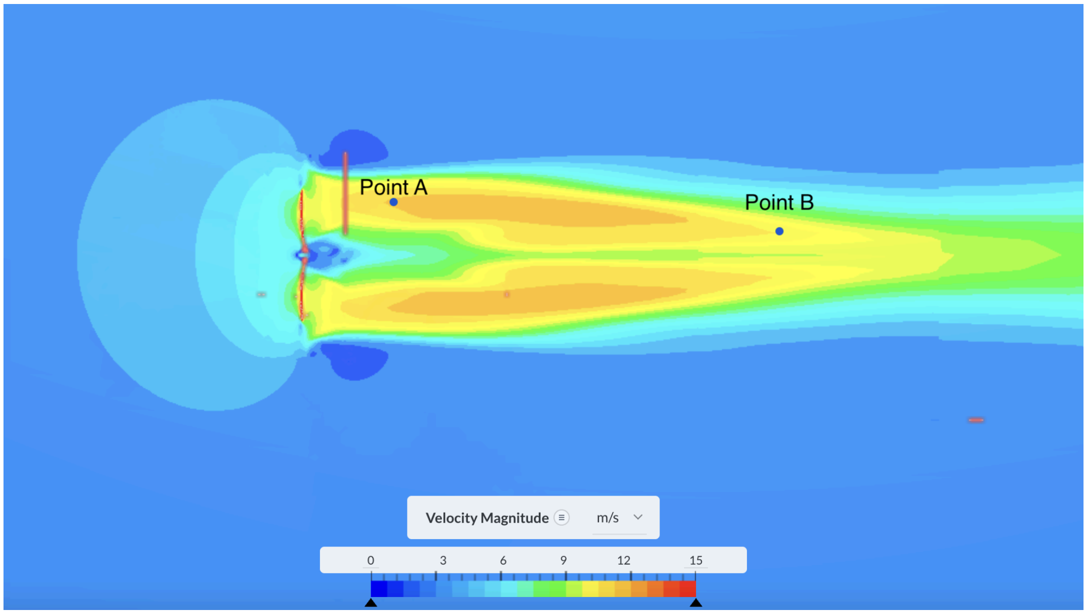

Figure 2a: Velocity Magnitude from Velocity Inlet of 2 m/s.

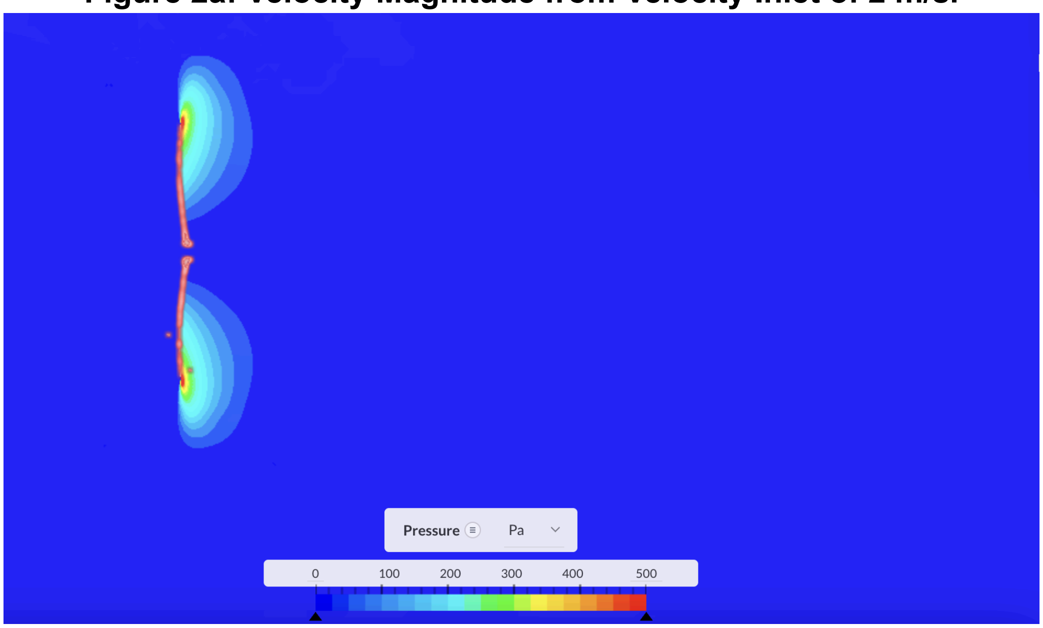

Figure 2b: Gauge Pressure from Velocity Inlet of 2 m/s.

In Figure 2c where the velocity inlet was increased to 5 m/s, there is a similar shape of the path like Figure 2a where the velocity inlet was 2 m/s. However, shown through the color gradient on the results, there is a higher velocity magnitude than the previous figure. This indicates that as the velocity inlet increases, the velocity magnitude of the surrounding medium, which is air, from the propeller also increases. When the velocity inlet is 2 m/s, the revolutions per minute, or otherwise known as rotational speed, is 3000 RPM. As the velocity inlet increases to 5 m/s, the rotational speed increases to 7500 RPM. This shows how as the rotational speed increases, so does the velocity magnitude of the surrounding air. Another difference between the two velocity magnitude figures is that the path from Figure 2c starts condensing at a farther displacement. In Figure 2d which shows the gauge pressure of the propeller from the velocity inlet of 5 m/s, the pressure is still condensed to the edges but it slowly migrates closer to the ends. Due to the small increase in velocity inlet, it is difficult to observe the change.

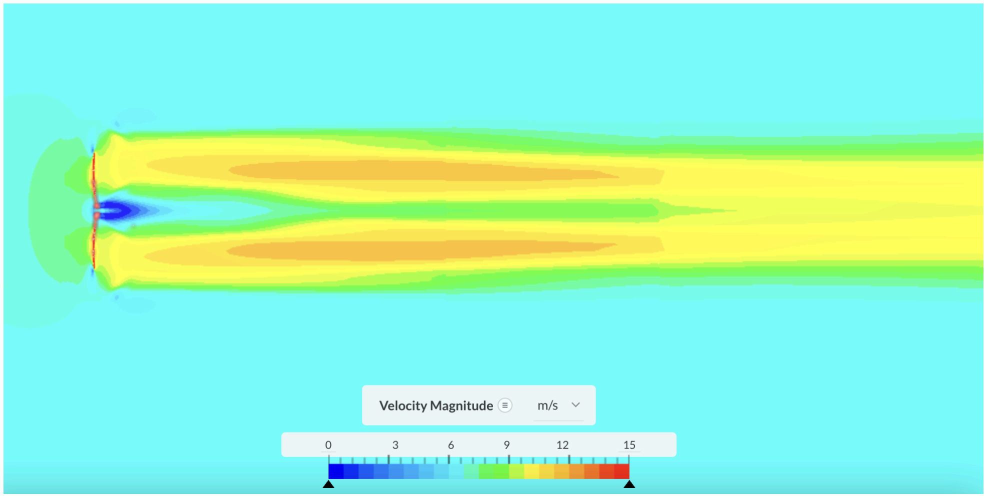

Figure 2c: Velocity Magnitude from Velocity Inlet of 5 m/s.

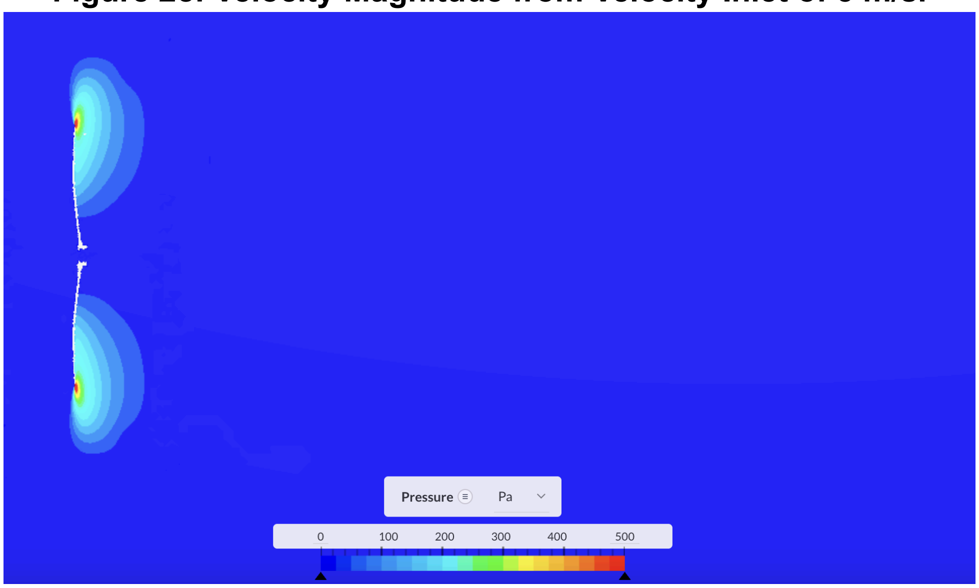

Figure 2d: Gauge Pressure from Velocity Inlet of 5 m/s.

In Figure 2e, there is the same change we noticed in the previous figures where the velocity magnitude of the surrounding medium increases shown through the increase in the yellow and orange coloring. Similarly, the path of the velocity is stretched even more, showing how a higher velocity inlet and rotational velocity results in a longer path. In Figure 2f, it is more clear that the pressure is moving towards the tips of the propeller due to propeller efficiency. There is also a decrease in the range of the pressure shown through the shrink in size. The results show the gauge pressure of the air becoming more and more condensed, increasing the magnitude of the pressure. This further shows as the velocity inlet increases, the gauge pressure increases as well.

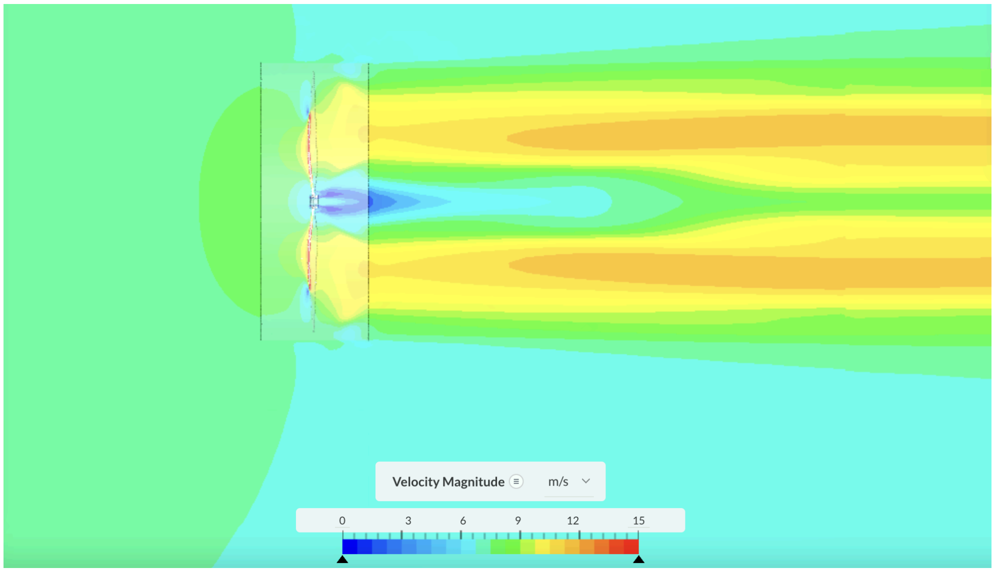

Figure 2e: Velocity Magnitude from Velocity Inlet of 6 m/s.

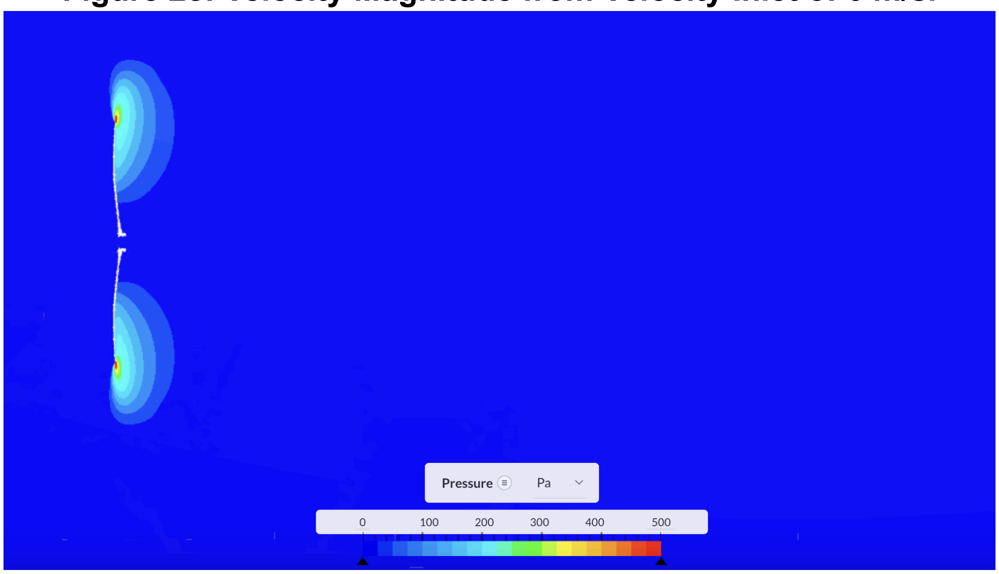

Figure 2f: Gauge Pressure from Velocity Inlet of 6 m/s.

In Figure 2g where the velocity inlet is 10 m/s, we see the same pattern of an increase in velocity and a stretched path. In Figure 2h, the gauge pressure continues to shift towards the tips of the propeller and the range continues to condense. Similar to the discrepancies of gauge pressure when the velocity inlet is 2m/s, the gauge pressure at Point A when the velocity inlet is 10 m/s may also be confounded by the propeller efficiency's effect.

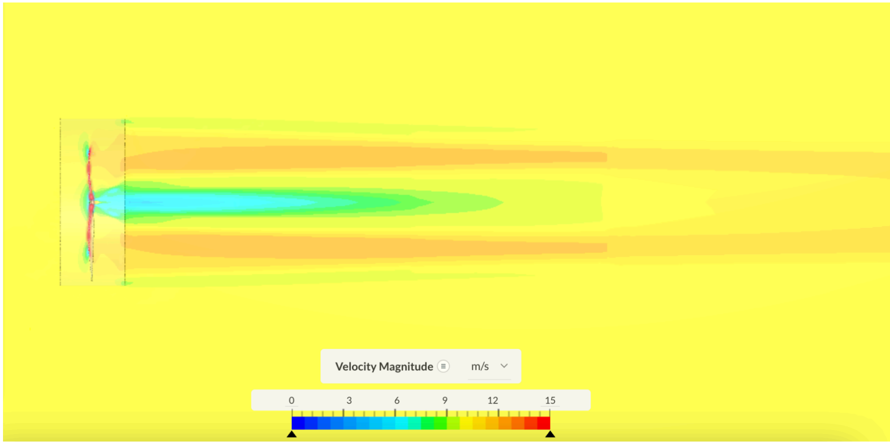

Figure 2g: Velocity Magnitude from Velocity Inlet of 10 m/s.

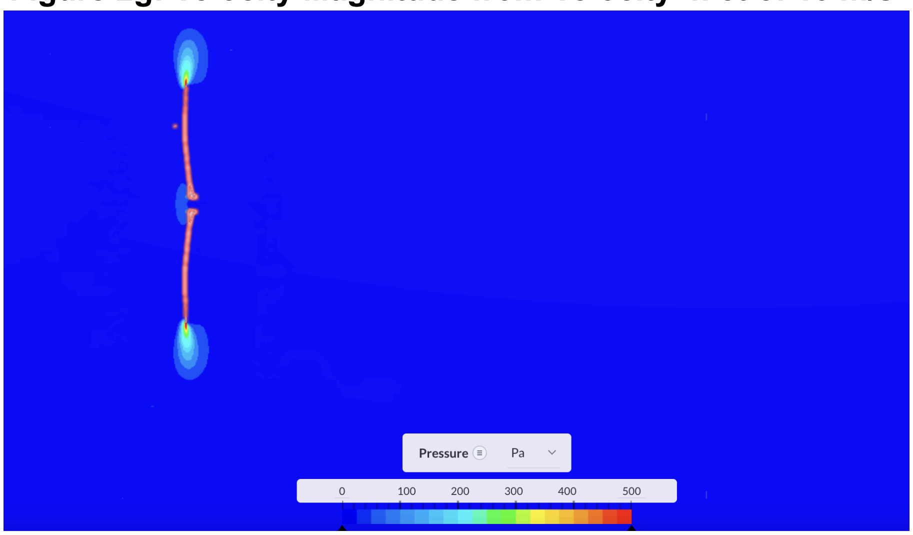

Figure 2h: Gauge Pressure from Velocity Inlet of 10 m/s.

In Figure 4, it takes the data from the simulation to illustrate the different relationships more clearly. The graph demonstrates the relationships between RPM and velocity, RPM and gauge pressure, and RPM and sound pressure. Shown through the visuals in Figure 2 and 4 from the data in Figure 3, most of the trials demonstrate how as the velocity inlet increases, there is a decreasing behavior in velocity and an increasing behavior in gauge pressure for Point A and B, and a decreasing behavior in sound pressure level.

Velocity Inlet Magnitude (m/s)	RPM (revolutions per minute)	Gauge Pressure (Point A) (Pa)	Change in Gauge Pressure (Point A) (Pa)	Velocity (Point A) (Pa)	Gauge Pressure (Point B) (Pa)	Change in Gauge Pressure (Point B) (Pa)	Velocity (Point B) (Pa)	PWL (dB)	Sound Pressure (Pa)
2	3000	2.45326	N/A	12.0243	-5.19214	N/A	11.2304	123.90	41.14
5	7500	3.74783	1.29457	11.4637	-5.58193	-0.38979	11.0790	125.74	39.01
6	9000	5.15992	1.41209	11.4474	-4.08539	1.49654	10.8721	127.13	39.60
10	15000	1.52707	-3.63285	12.2226	-0.88720	3.198189	9.39326	121.84	32.10

Figure 3: Table of data from the simulation runs

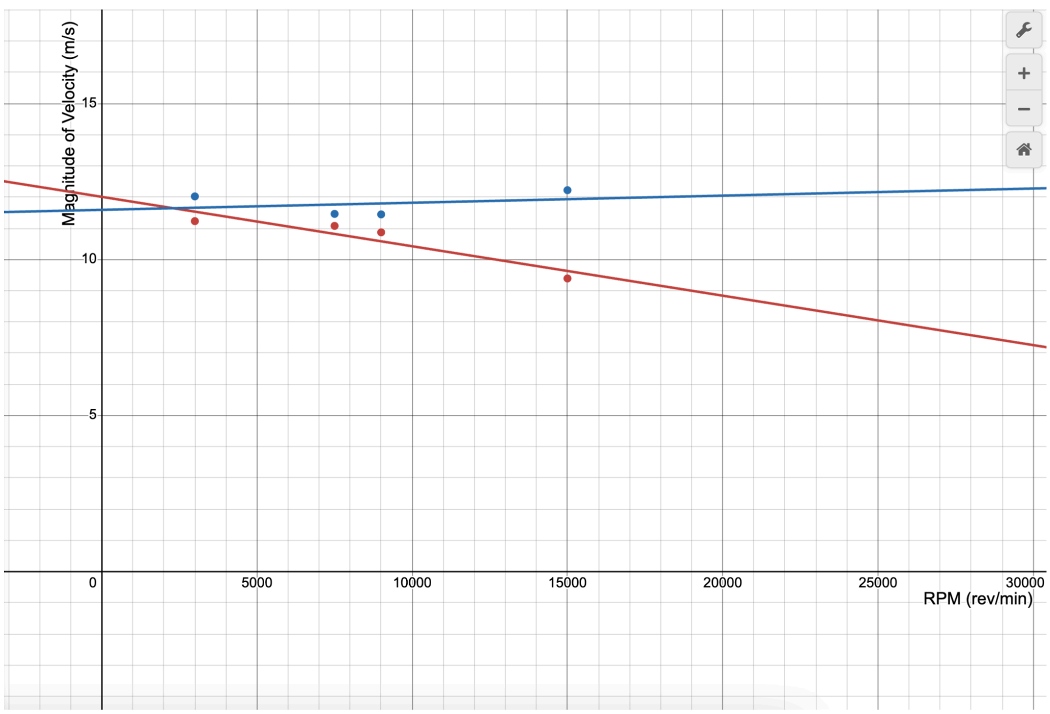

Figure 4a: RPM vs Magnitude of Velocity (Blue: Point A, Red: Point B)

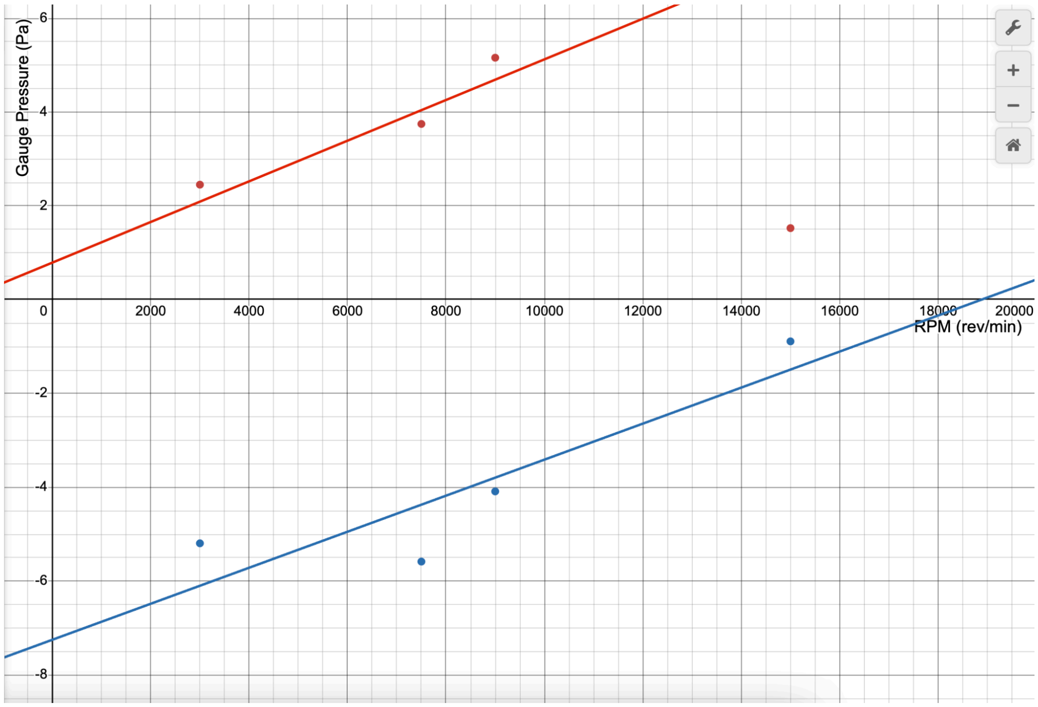

Figure 4b: RPM vs Gauge Pressure (Red: Point A, Blue: Point B)

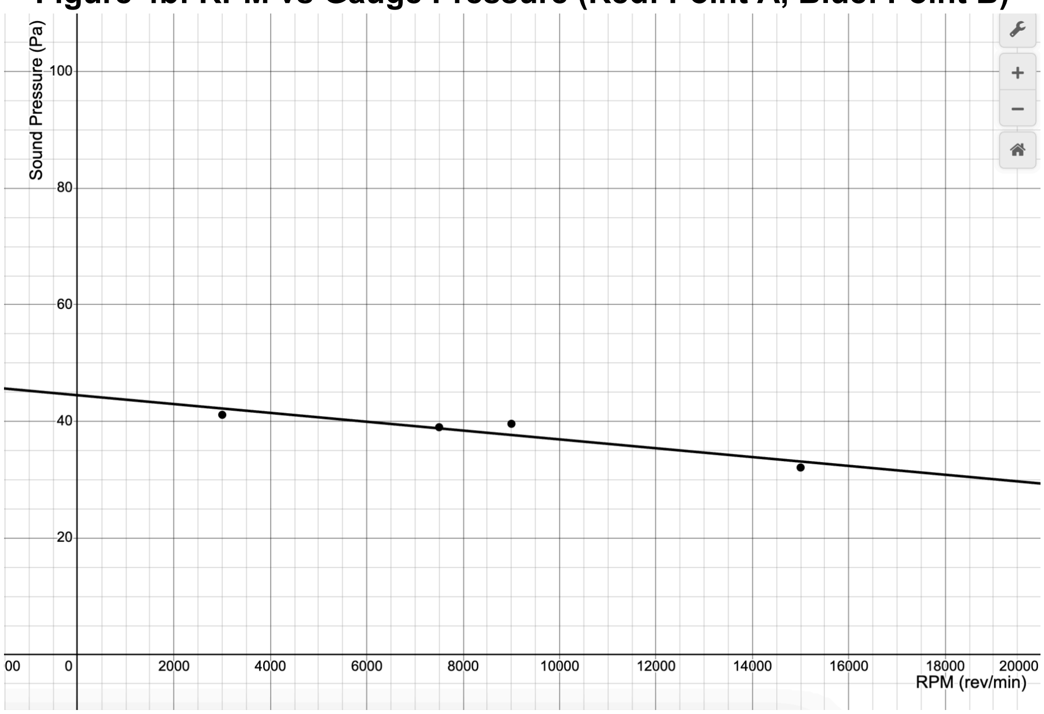

Figure 4c: RPM vs Sound Pressure

Conclusion

In this simulation, testing the different velocity inlets was to represent varying rotor speeds to reveal the relationship with rotational speed and sound pressure. Through observing the decreasing relationship between the velocity inlet and the sound pressure level, we can see that with higher rotational velocity, there would be a lower noise level. This shows how future designs of propellers should utilize a geometric design that results in an increase in rotational speed in order to minimize the noise that the propellers make. Making this change allows RC airplanes to have more use in society for its efficient yet unobstructive function.

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