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Bicopter Virbro-Acoustic Response and Stealth Flight Path

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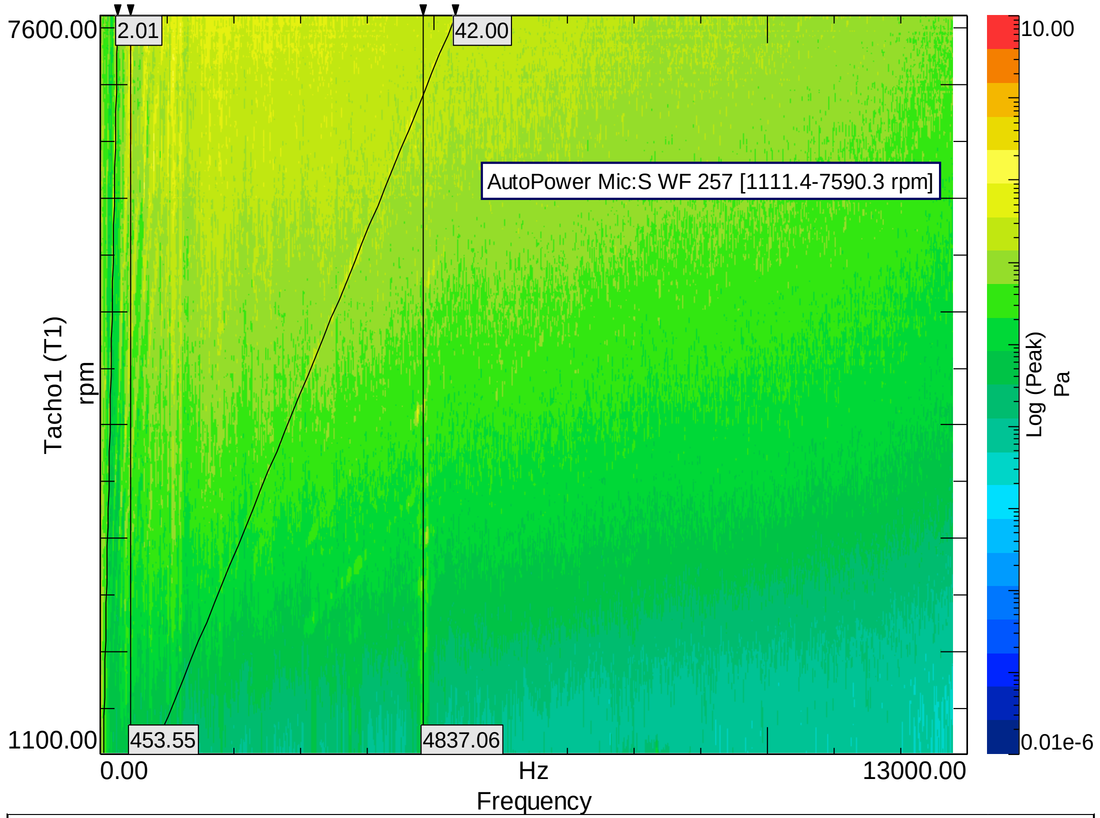
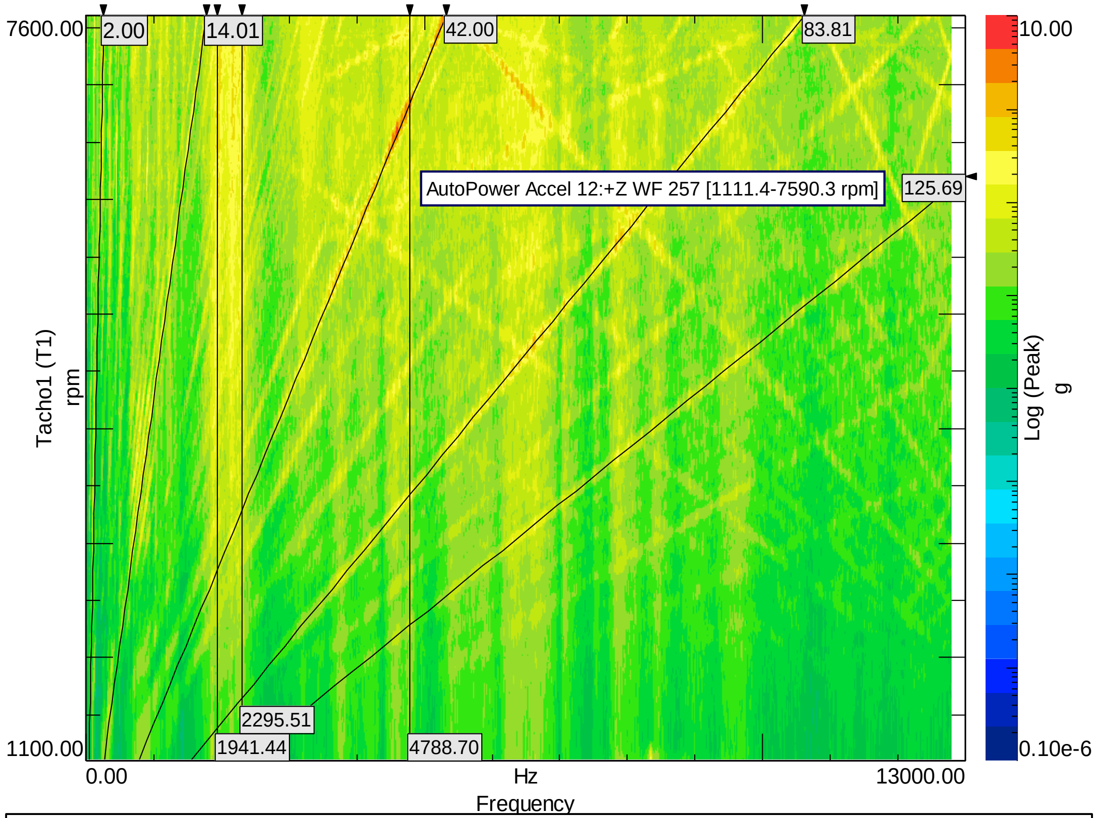
1. Test Plan

Motor 1		Motor 2		LMS Test.Lab Information	
Pulse Width (ms)	Motor Speed (rpm)	Pulse Width (ms)	Motor Speed (rpm)	Section Name	Run Name
				Install and Calibrate sensors	
		1-2ms		Speed Sweep	Sweep 1
1.6				Coherence	Coherence 1 motor 1.6
		1.3		Coherence	Coherence 1 motor 1.3
1.6		1.3		Coherence	Coherence 2 motors 1.3 _ 1.6
1.6		1.6		Coherence	Coherence 2 motors 1.6 _ 1.6
1.22	3000	1.22	3000	Steady State	SS_3000rpm
1.36	4000	1.36	4000	Steady State	SS_4000rpm
1.48	5000	1.48	5000	Steady State	SS_5000rpm
1.64	6000	1.64	6000	Steady State	SS_6000rpm
1.81	7000	1.81	7000	Steady State	SS_7000rpm

2. Speed Sweep Colormaps

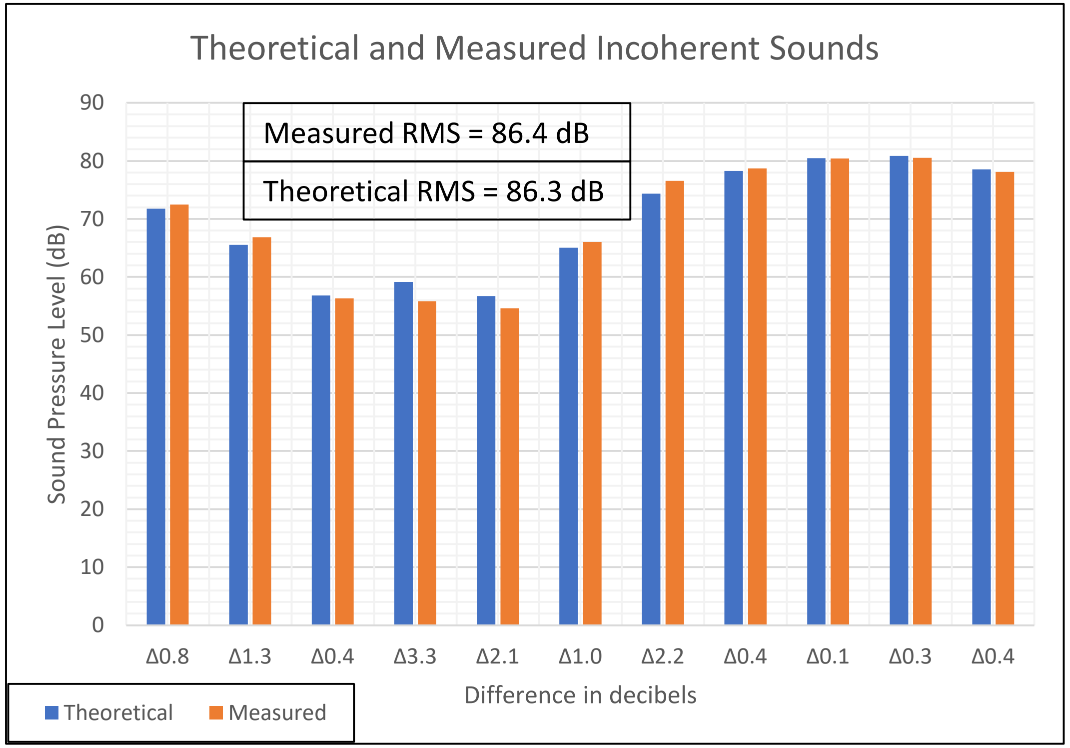


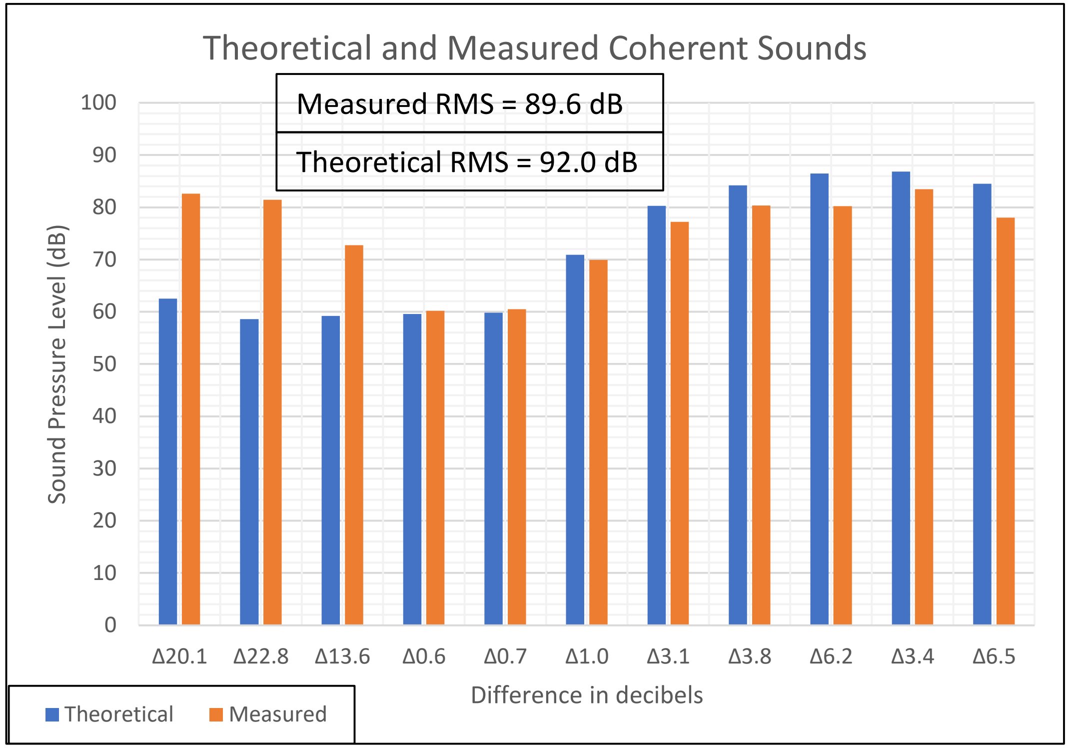


The most prominent orders on the colormaps are the 42nd and the 84th order. These are most likely due to the motor itself spinning and the two propellers on the motor causing the orders.

The natural frequencies of the bicopter are present in the data as resonances. Though the data is not granular enough to show the fundamental frequencies themselves, the resonances identified are likely harmonics of them as they are close to integer multiples with 64 and 110 Hz.

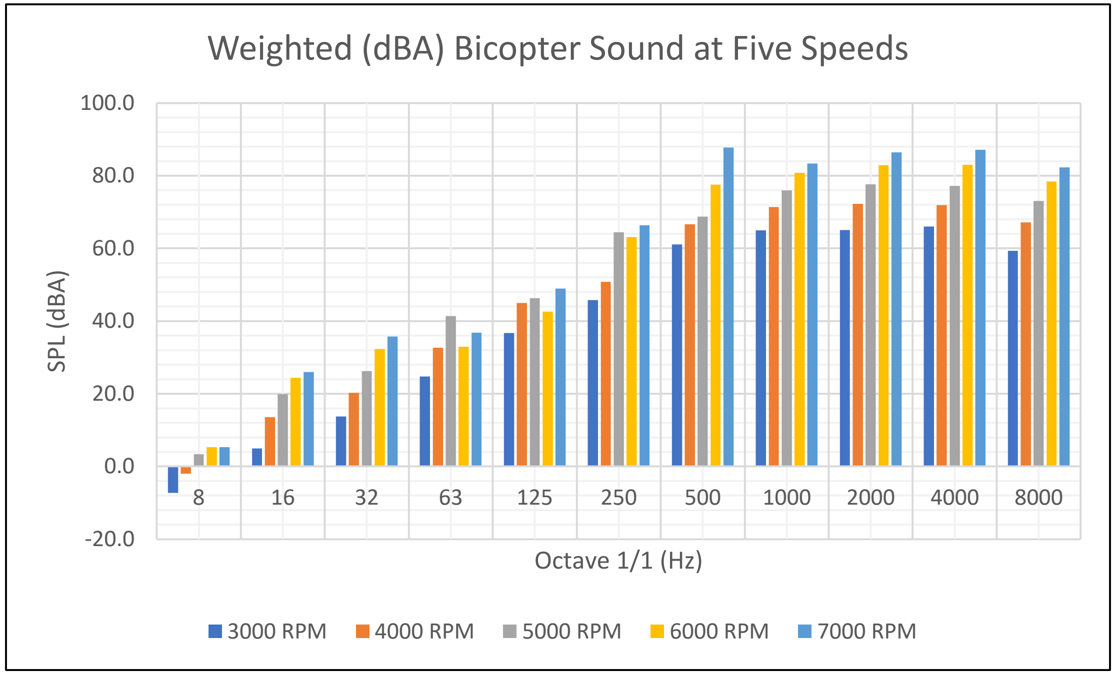
3. Combining Sound Pressure Levels





On the charts above, the theoretical and measured sound pressure levels of coherent and incoherent sounds are shown. The theoretical was calculated by taking standard sound pressure level equations for coherent or incoherent sounds and combining data with either data from a previous run or with itself. The difference between the measured and theoretical is shown on the x-axis below the bars. The incoherent data matches well, but the coherent does not. This may indicate that the motors are not identical, and they the sounds are not actually coherent. Because of this there is not a 6 dB difference in the "coherent" data. The standard graphs for combinging SPL work well for the incoherent data, but not the coherent. To validate this SPL model better, using a reference sound instead of noisy mechanical motors would work better.

4. Bicopter SPL at Five Speeds



Speed (RPM)	3000	4000	5000	6000	7000
RMS SPL (dBA)	71	77.5	82.5	88.1	92.9
RMS SPL (dB)	73.8	80.0	85.4	89.9	94.5

Some of the weighted sound levels are extremely low at the lower frequencies, negative for the first two speeds. These are valid still as the unweighted SPL were above the noise floor of the microphone.

The overall RMS SPL at each speed, as expected increases as the speed increases. The weighted and unweighted RMS SPL are surprisingly right inline with each other. But as the human ear is roughly logarithmic, the perceptual sound of the 7000 RPM would only be about 30% louder than the 3000 RPM steady-state.

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6. Outside Quadcopter Extrapolation

Speed (RPM)	SPL (dBA)	SPL (dB)
3000	74.3	77.1
4000	80.8	83.3
5000	85.8	88.7
6000	91.4	93.1
7000	96.1	97.8

The bicopter SPL data analyzed in part 5 was then extrapolated for a quadcopter outside. This was done by assuming the waves are spherical waves and applying the following equation:

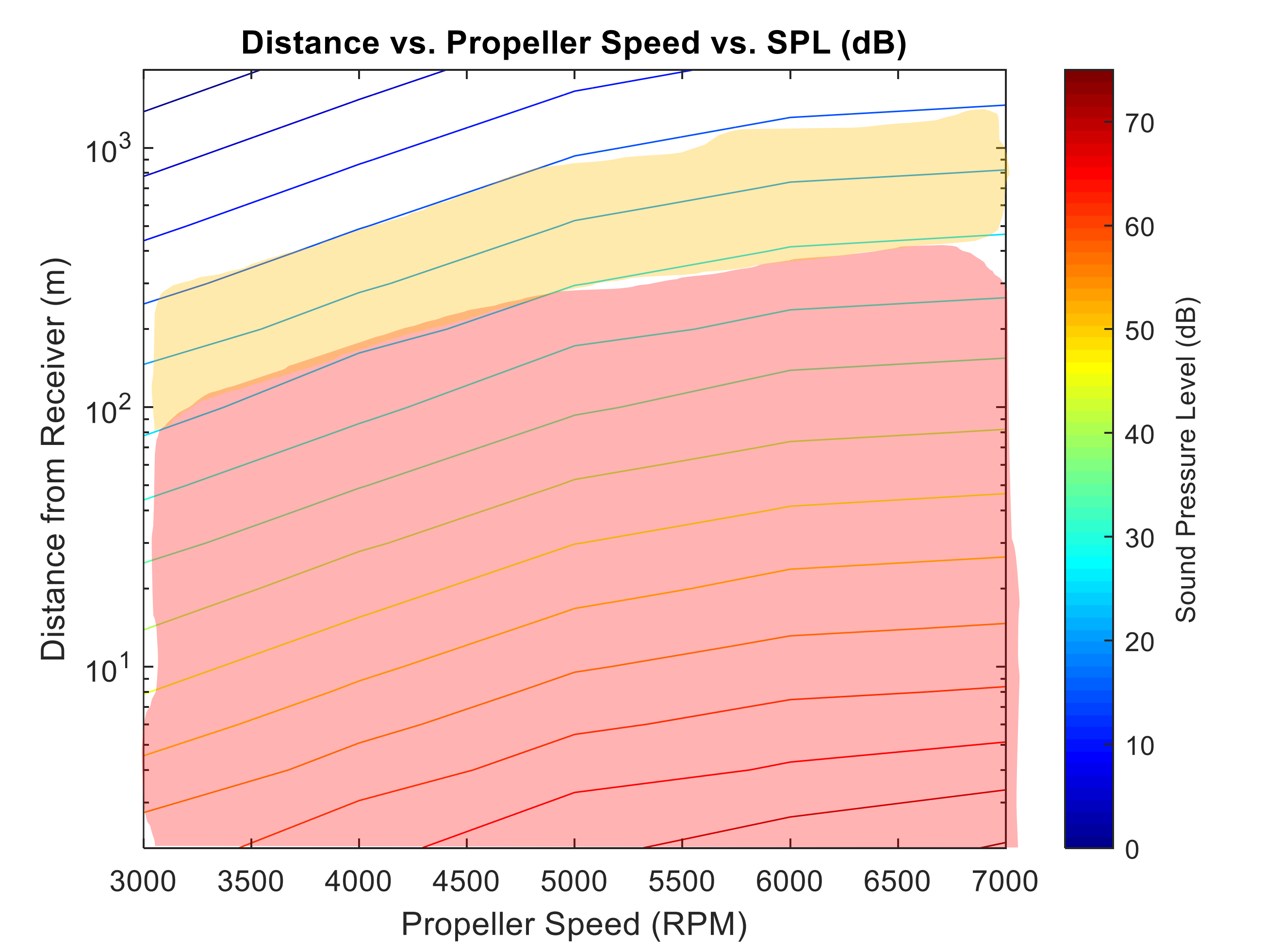
$$L_p = L_W + 10\log_{10}\left(\frac{Q_\theta}{4\pi r^2} - \frac{4}{\bar{\alpha}S}\right)$$

With L_p representing the measured SPL, and L_W representing the bicopter sound power. This sound power was then doubled (combined with itself) to approximate having four blades, then plugged into the following equation:

$$L_p = L_W + DI - 20\log_{10}(r) - \alpha r + \Delta L - 10.8$$

Where L_p represents the outside SPL of the approximated quadcopter. This process was done for the weighted and unweighted SPL and can be seen to the left.

7. Instrument Observed SPL with Distance

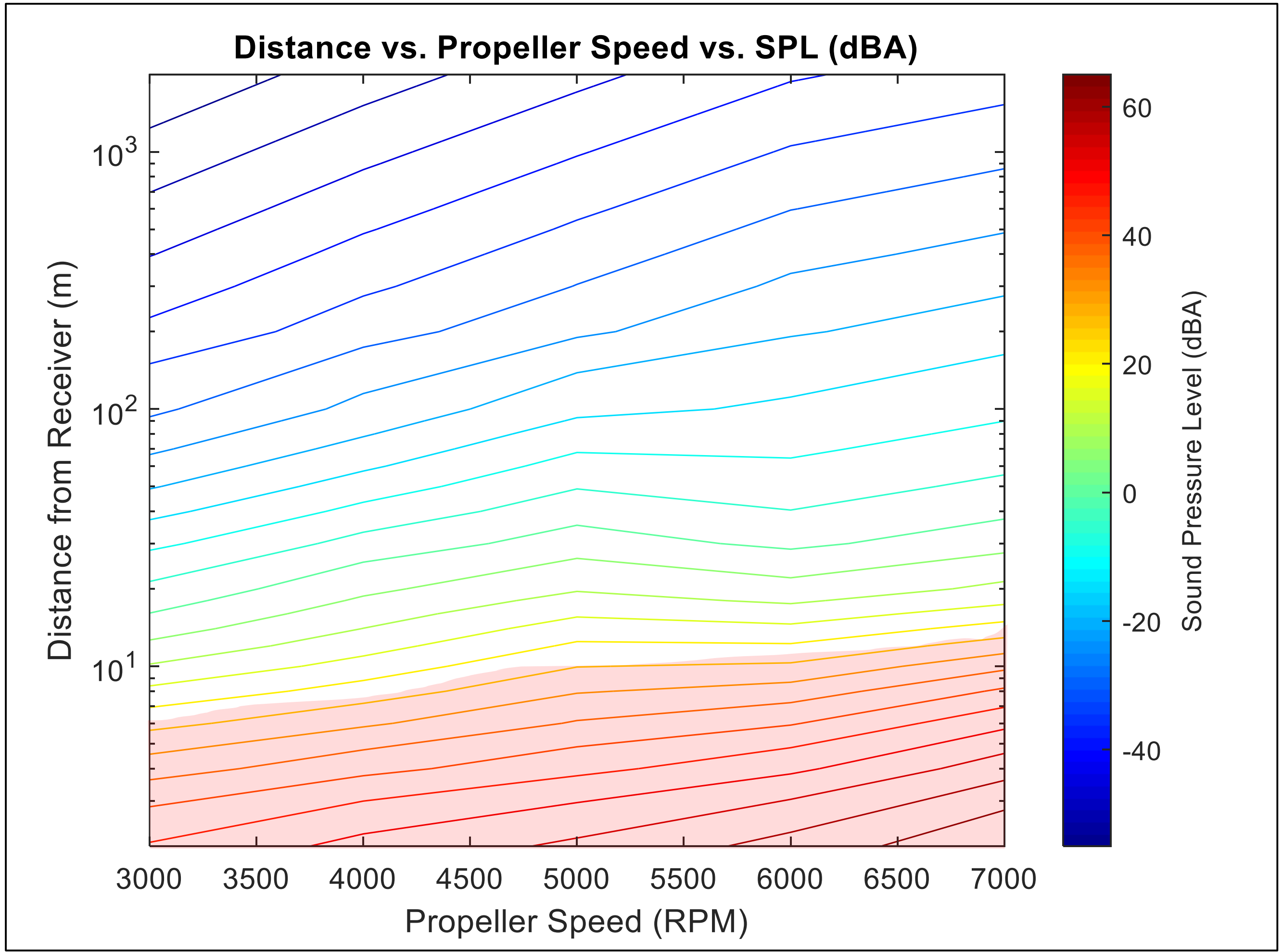


The possible paths and motor speeds for the quadcopter are shown on the left contour plot. This plot is the unweighted sound pressure level on the contour, which is what an instrument such as a microphone would pick up.

The assumed noise floor of a microphone in this situation is 17 dB, but the ambient environment has a SPL of 25 dB, therefore the region between the two is marked in yellow. Above 25 dB is marked in red as the instrument would be able to pick up the quadcopter at that range and speed without having to sort through noise.

The copter can get as close as 1175 meters at 7000 RPM before crossing the threshold of entering the noise floor, and 7000 RPM goes above the ambient SPL at 450 meters. At the slowest speed, 3000 RPM, the copter hits the yellow region at 275 meters away. The closest the quadcopter can get to the instrument at 3000 RPM is 75 meters before crossing the ambient threshold of 25 dB.

8. Human Observed SPL with Distance



The path of the quadcopter with the A-weighted sound pressure level is shown on the left. As the ambient environment is assumed to have a SPL of 25 dBA it is also assumed that the human receiver has a sharp cutoff as 25 dBA, and that is highlighted in red. The copter can get as close as 13 meters with the propellers at 7000 RPM, and it's closest is at 6 meters at 3000 RPM. The microphone is much more sensitive compared to the human, as most of the time the human's observed SPL is below zero.