TunesFlow: Studying Aerosol Flow Spread for Wind Instruments and Singing

Team Members

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Brief Description

For musicians in a symphony orchestra or singers of opera, the act of safe physical distancing is antithetical. Close interpersonal interactions are intrinsic to these musical art forms. However, with growing awareness of how the novel coronavirus spreads, traditional orchestra and opera performances have ground to a halt. Tens of thousands of professional musicians are being furloughed, and the hopes of returning to concert halls packed with patrons are rapidly dimming. The question that arises in this circumstance is whether it's possible to modify how orchestras and singers perform, observing safe distancing protocols, until such time that we return to some semblance of normalcy. In this project, we will study the air-flow created by both the wind instruments and singing using high-speed contrast imaging called Background Oriented Schlieren (BOS).

Motivation

The formula for distributing audiences safely within a given space is currently well understood. Guidelines for arranging a woodwind or brass section of a symphony orchestra or juxtaposing two singers at healthy distances, however, is currently beyond our reach. Wind players and singers expel air (and vapors) in multiple directions and at variable distances, but measurements and/or empirical data regarding these phenomena are currently incomplete.

Obtaining this information and disseminating it to professional orchestras, opera companies, and educational institutions would be transformative. It would potentially save a significant portion of the performing arts from financial ruin while enabling music training to proceed. Developing the research protocols to address these questions is accordingly an urgent matter.

Study and Design

The study can be categorized into two main sections: visualizing aerosol propagation from orchestra musicians and opera singers while they are performing. While both of these categories are encompassed within the Classical Music Industry, the significant difference between these categories is orchestra musicians make use of an inanimate object to produce musical notes. A standard orchestra is composed of four main categories of instruments: strings, woodwinds, brass, and percussion. This study focused on visualizing aerosol flows from woodwind and brass instruments because these instruments require the musician to blow air into a mouthpiece or across an edge. Visualization of aerosol flow of a string player with and without a mask was also included.

Typically, woodwind instruments are constructed from a wooden or metal tube with an inlet and outlet hole. Along the tube there are several smaller openings that are covered with keys. To play the instrument the musician blows across a mouthpiece or into one-two reeds at the tube inlet while pressing down different keys to produce different notes. This leads to the hypothesis that most aerosols will be ejected from the keyholes and inlet area of the instrument relative to the outlet bell. Experiments were designed to capture all of these positions of interest while each musician performed various excerpts. Table 1 lists all of the excerpts performed and the reasoning why each excerpt is of interest in relation to aerosol propagation. For each excerpt the musician performed perpendicular and parallel to the imaging system, allowing for a side and front view of the flow fields to be captured. The woodwind instruments used in the study are flute, piccolo, clarinet, oboe, and bassoon.

Table 1. Woodwind and brass instrument experimental excerpts

Instrument Category	Musical Excerpt	Aerosol Propagation Interest
Woodwinds	Sustained playing in extreme registers at extreme dynamics: (loud/high, soft/high, loud/low, soft/low)	Majority of aerosols will expel from tone holes and inlet area relative to outlet bell
Brass		Majority of aerosols will exit the bell or escape from the sides of a musician's mouth
Woodwinds	Sustained note: (one finger down, three fingers down, all fingers down)	Focus on tone holes and how flow changes based on the number of holes closed
Woodwinds	Sforzando	Introduces a series of loud bursts with pulling back on each note
Brass		
Woodwinds	Lyrical passage	Consists of a prolonged air stream with a long string of notes
Brass		

Woodwinds	Blowing out/Swabbing	Musicians clean excess saliva that has built up in the instrument due to extended playing
Brass		

Table 2. List of woodwind and brass instruments used in the study

Woodwind Instruments		Brass Instruments
Flute		Trumpet
Piccolo		Trombone
Clarinet		French horn
Oboe		Tuba
Bassoon		

Brass instruments are characterized with long curved pipes, up to 16 feet long for tubas. The pipes usually widen in diameter as they approach the outlet of the instrument forming a bell-like shape. Along the pipes there are several values and sections of tubing that the musician can press down and slide in order to change the effective length of the instrument. At the inlet a musician will vibrate their lips while blowing air into the mouthpiece. Some musicians will also add mutes into the bell of the instrument in order to change the tone of the sound. Based on the design of brass instruments, having valves instead of tone holes, it is hypothesized that most of the aerosols will be coming out of the bell of the instrument when playing loud in a low register, and most will escape out of the sides of the mouth in the high register with loud playing. A similar set of experiments were designed for brass instruments which are listed in Table 1. For each excerpt the musician performed perpendicular and parallel to the imaging system, allowing for a side and front view of the flow fields to be captured. The brass instruments used in this study include: trumpet, trombone, French horn, and tuba.

Opera singers differ from other professional singers of various genres because they use more resonance to amplify their voices. Opera singers do not use microphones, but instead use their body as a chamber to resonate their voice. Experiments were designed to visualize the aerosols projected from the opera singers mouth upward, downward, and sideways. In order to capture flow fields in these directions the opera singer performed each excerpt perpendicular and parallel to the imaging system. Table 3 contains all of the designed excerpts performed by the opera singers with justifications for including each excerpt.

Table 3. List of excerpts performed by opera singers with justifications

Opera Singing Excerpt	Aerosol Propagation Interest
Sustained lyrical singing in extreme registers at extreme dynamics: (loud/high, soft/high, loud/low, soft/low)	Measure propagation distance of aerosols from singer mouth in the upward, downward, and sideways directions
Accented syllables in Italian, English, and German (loud and soft dynamic levels)	Focus on the effects accented syllables have on aerosol patterns
Short passage of recitative (moderate and loud dynamic levels)	Provides comparison between lyrical and recitative excerpts
Recite text (loud and soft levels/with and without accented syllables)	Relative difference of aerosol patterns when singing opera versus talking

Methods

Experimental Setup:

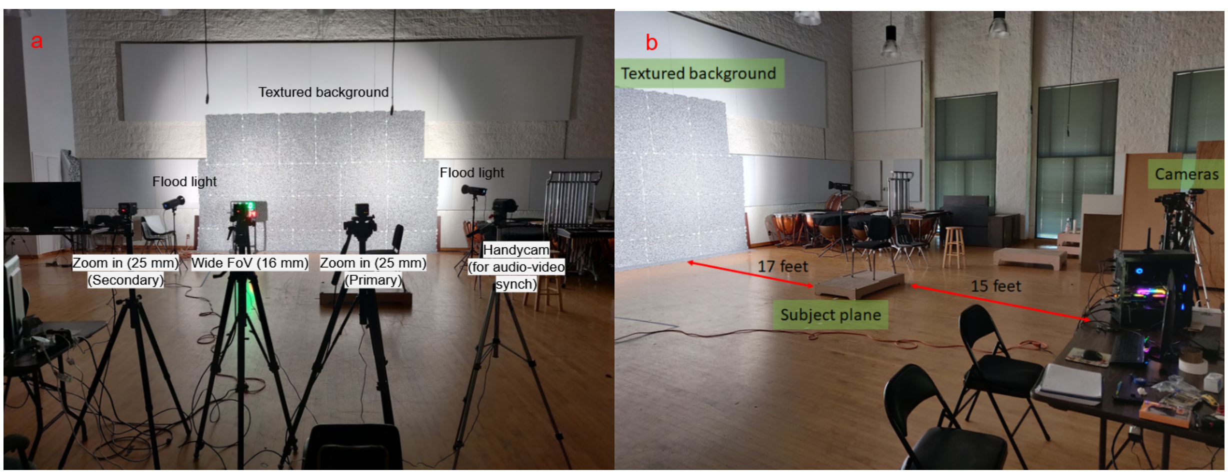

Figure 1: Images of experimental setup. (a) shows different cameras (and lenses) used for recording video. (b) shows the distance between background, subject and cameras.

The figure above shows the experimental setup used for data collection in this study. Four cameras were used to collect data: three FLIR Oryx 10GigE cameras for high resolution video of airflow from the musician and a fourth Sony Handycam for audio and video synchronization (Figure 1a). The Oryx camera with the 16 mm lens captured the entire FOV while the two Oryx cameras with 25 mm lenses allowed for high resolution zoom-ins of the FOV (specifically zoom-in on the musician). The cameras were focused to the plane of the textured background which was illuminated by two Godox SL-200W light sources. The subject was placed 17 feet away from the textured background and the cameras were placed 15 feet away from the subject as shown in Figure 1b. These distances were chosen to maximize signal from subject while maintaining a large FOV at the subject plane. Videos from the Oryx cameras were streamed to a computer using two 10GigE Network Interface cards provided by FLIR. Audio and video from the Handycam were stored on an SD card and were transferred to the computer offline.

<u>Data Collection</u>:

Subjects recruited for the study were musicians from the Houston Symphony and Shepherd School of Music at Rice University. Subjects were asked to perform 10-second excerpts in two different directions: (1) parallel to the textured background and (2) toward the cameras. The cameras captured the 10 second excerpts at 50 fps. Figure 2a shows an example raw capture of a simple breathing excerpt. In some cases, subjects repeated excerpts using masks, shields, cloths, and other accessories to reduce aerosol from the subject. Before and after each subject performed, a background image was collected (without the musician present) to be used for BOS processing.

<u>Image Processing</u>:

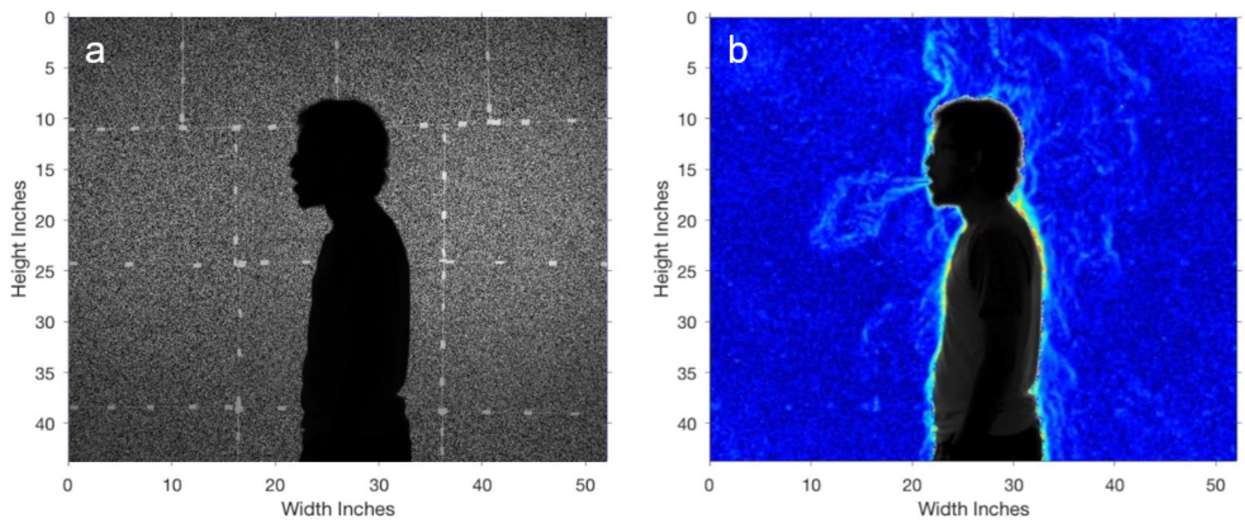

Figure 2: BOS processing visualized aerosol ejection. (a) shows a raw captured image of a subject breathing. (b) shows the same frame after performing BOS processing.

Since all recordings were captured in-doors, videos were first temporally filtered using a bandstop filter (between 17-23 Hz) and blurring kernel to remove any unwanted temporal flickering. Next, the BOS algorithm computed the sub-pixel displacements caused by airflow coming from the subject as seen in Figure 2b. Very briefly, the BOS algorithm works by computing the shift of a local window from the background image to the image with the subject. Aerosol causes distortions of the textured background, resulting in small displacements of this local window.

Example Processed Aerosol Visualizations

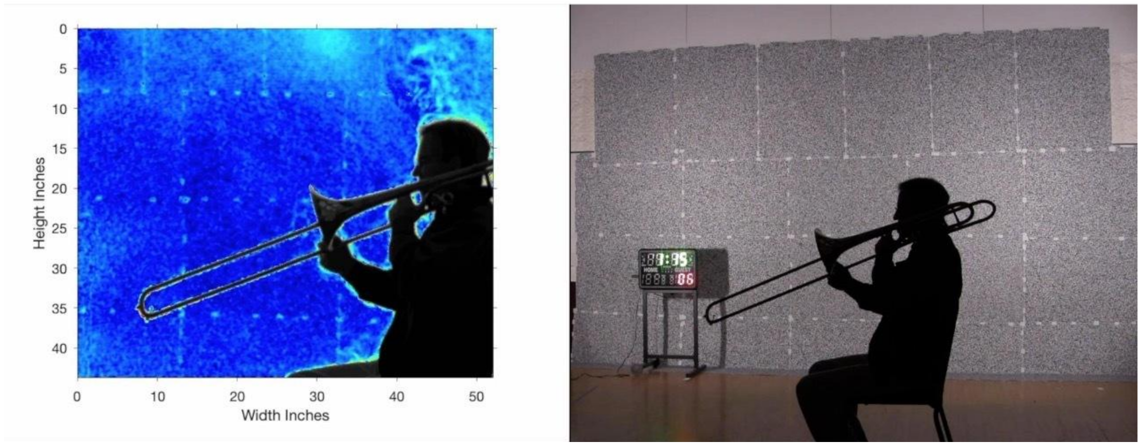

Figure 3: BOS processing result of trombone player. Image on the left shows the processed image of a musician performing with a trombone. Image on the right shows the full field of view captured using the Handycam.

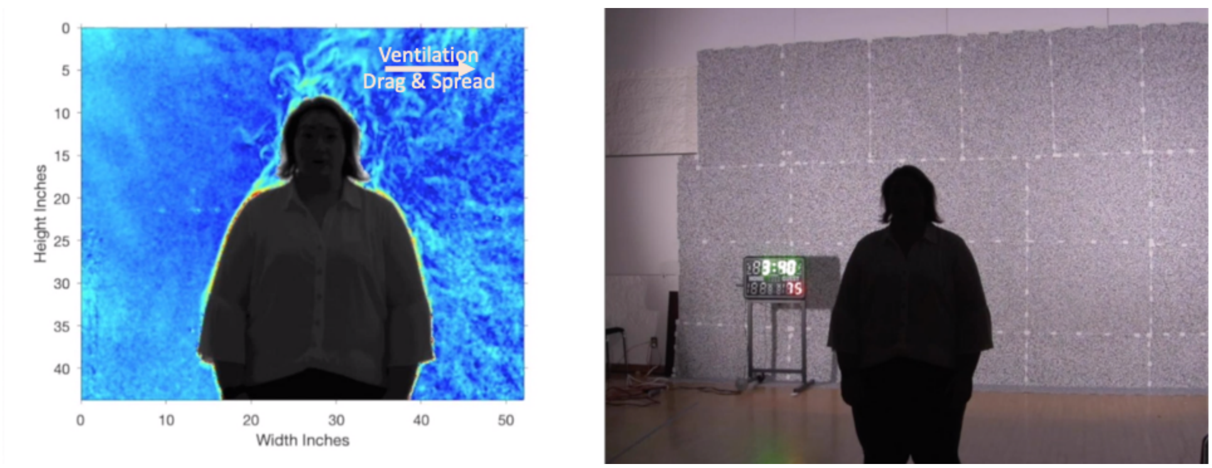

Figure 4: BOS processing result of opera singer. Image on the left shows the processed image of an opera singer.The drag on exuded air due to the ventilation is indicated. Image on the right shows the full field of view captured using the Handycam.

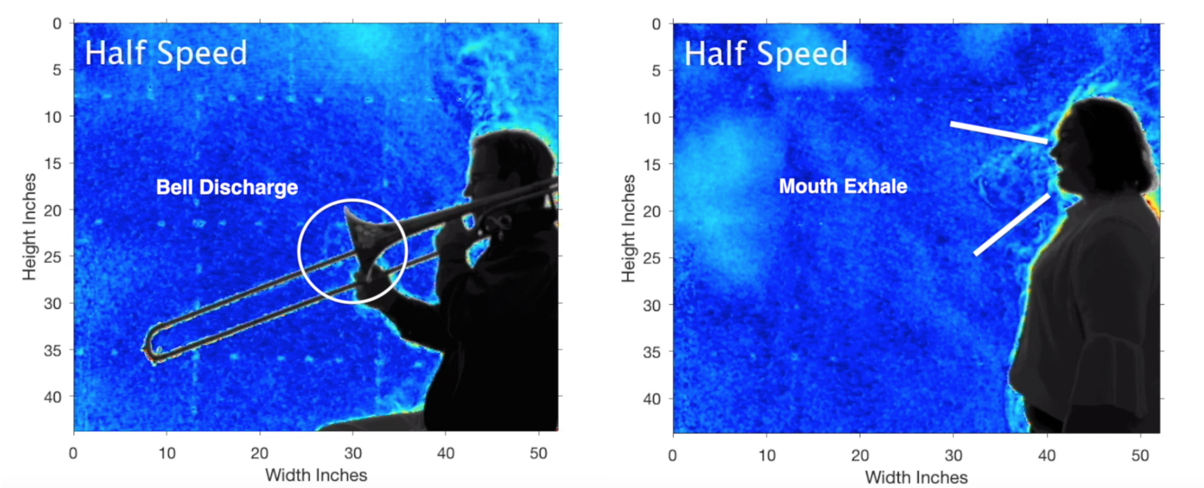

Figure 5: Annotated BOS processing result of trombone player and opera singer. Image on the left shows the processed image of a trombone player, indicating the bell discharge. Image on the right shows the processed image of an opera player, indicating the

mouth exhale during a Loud-High excerpt.

Effect of Room Ventilation

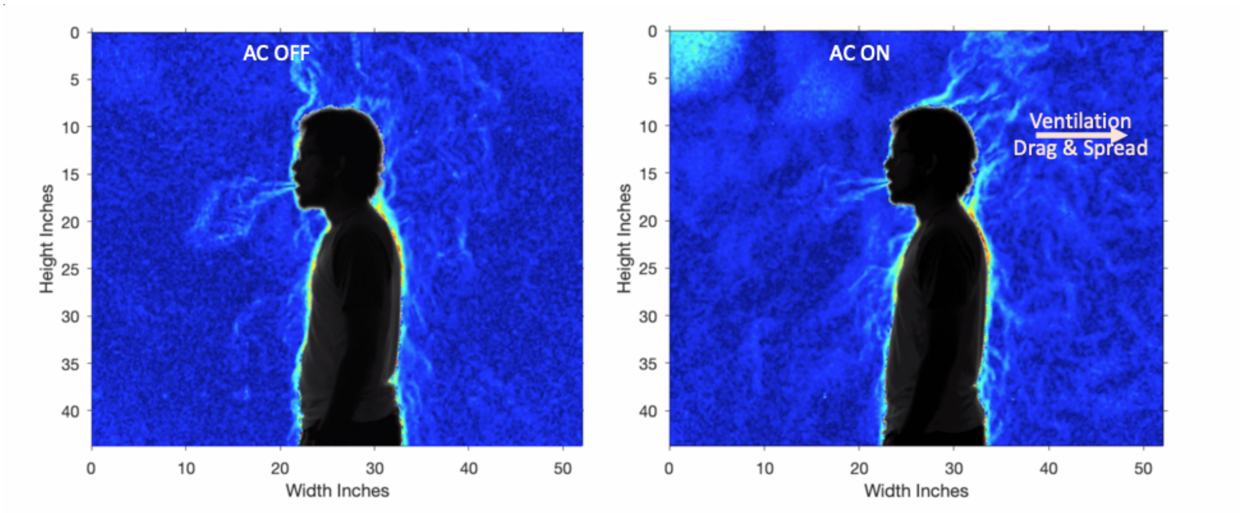

Figure 6: BOS processing with and without room air conditioning . Image on the left shows the processed image of subject breathing when the room ventilation is turned OFF. Image on the left shows the processed image when the room ventilation is turned ON. The drag on exuded air due to the ventilation is indicated.

Current recommendations

<u>Note: We are still in the process of collecting more data, furthering the analysis and will continue to update these recommendations as more data/analysis becomes available.</u>

1. Our study outcomes so far are quite surprising and point to other factors that we need to pay attention to other than just social distancing. The main points the study data raise are:
    a. The airflow disturbance is concentrated around the mouth of the subject and the holes in the various instruments --- but even for instrumentalists there is significant airflow disturbance near the mouth.
    b. Because human exudate air is hotter than room air much of this air rises within a foot or two from the exit point (mouth or instrument holes) ---- this is very different from large macro droplets which we know drop down quickly!
    c. It is clear from our data that room air currents (driven by ventilation) have a major effect on the flow of this exudate air after it leaves the subject. In particular the air flow direction in some cases could be opposite of the exudate direction because of room air currents driven primarily by ventilation.

2. Given these outcomes, it's clear that one of the critical aspects to consider when designing performance spaces for safe performance has to do with aerosol transmission modality. With that in mind, these are important aspects that any performance venue should seriously consider.

a. Quantity of Room Ventilation: Since exudate air very quickly rises and mixes with room air it's important to have good ventilation --- many recommendations from federal sources today indicate to increase air circulation as much as possible and increase the rate of air exchanges per hour to as high a rate as possible. The general infection avoidance guidance from CDC is available at https://www.cdc.gov/infectioncontrol/guidelines/environmental/appendix/air.html#. Our data for ventilation was acquired with ventilation units set to perform 6 air exchanges per hour.
b. Directionality of air currents especially above the performance stage: It might be important to pay attention to directionality of air current above the performance stage. Ideally, if there is a way to encourage rising air from performers to be caught or sucked out through above head vents by clever airflow designs that might help. Large outflow vents above performance stages will help greatly.
c. Ventilation filtration: There are currently existing recommendations for ventilation filtration systems -- from MERV13 filters on the low end to HEPA filters and UV irradiation on the high end --- being aggressive about this filtration at least on the vents immediately above performers stages could be a useful strategy to further minimize risk. Study the detailed ventilation guidelines provided at ASHRAE [1].
d. Masks: Encouraging performers to wear masks with holes or flaps in them to insert musical instruments through, will serve to further reduce the quantity of spray from performers. [2]
e. Social distancing: While our data doesn't look at macro droplets, the data from other studies indicate that these large droplets fall down to the ground rapidly and so following standard social distancing guidelines of 2 meters is always important [3,4]. As the distancing that can be achieved in a performing arts stage increases, that does subsequently reduce the risk, especially from macro-droplets and directly expelled spray.

3. In addition to above, an aggressive testing strategy, if at all possible, will provide an added layer of risk reduction. Testing or pool-testing all performers periodically may actually be another practical strategy that helps minimize risk.

Future steps

1. We will be compiling and analyzing the data of the rest of the musicians that were collected.
2. We will be extending our study of musicians with different ventilation settings.
3. We will be consulting with aerosols experts with extensive knowledge of HVAC systems.

References

[1] Schoen, Lawrence J. "Guidance for building operations during the COVID-19 pandemic." ASHRAE Journal, Columbia (2020).

[2] “Preliminary Recommendations from International Performing Arts Aerosol Study Based on Initial Testing Result.” *NHFS,* https://www.nfhs.org/media/4029971/preliminary-recommendations-from-international-performing-arts-aerosol-study.pdf

[3] Kähler, Christian J., and Hain, Rainer. "Singing in choirs and making music with wind instruments–Is that safe during the SARS-CoV-2 pandemic." *University of the Bundeswehr Munich, Germany* (2020).

[4] Ontario Agency for Health Protection and Promotion (Public health Ontario). COVID-19 Transmission Risks from Singing and Playing Wind Instruments – What We Know So Far. Toronto, ON: Queen’s Printer for Ontario; 2020