Air Masks for Aerobic Fitness Tests

Jess Anstee, Pramit Chalise, Sarah Roberts, Libbie Sudweeks, Cameron Williams

Advisor: Dr. Marc Calaf

Department of Mechanical Engineering
THE UNIVERSITY OF UTAH

Introduction

Aerobic fitness testing is a way to quantify fitness levels and is used by a plethora of people, ranging from Olympic athletes to regular people that want to get healthier. In these tests, the users put on a mask that directs air flow. Current masks are cumbersome and uncomfortable for users because they have poor fluid flow and as such, pressure builds up within them. Our goal was to design a mask that would allow air to flow more freely and be comfortable for the users, allowing them to perform at the top of their ability. Our design directs air flow through a central hub, comprised of a straight shaft and a 45-degree bend, and two duckbill valves. We performed both CFD and experimental analyses on our design. The results are promising, with significant improvements in most design metrics.

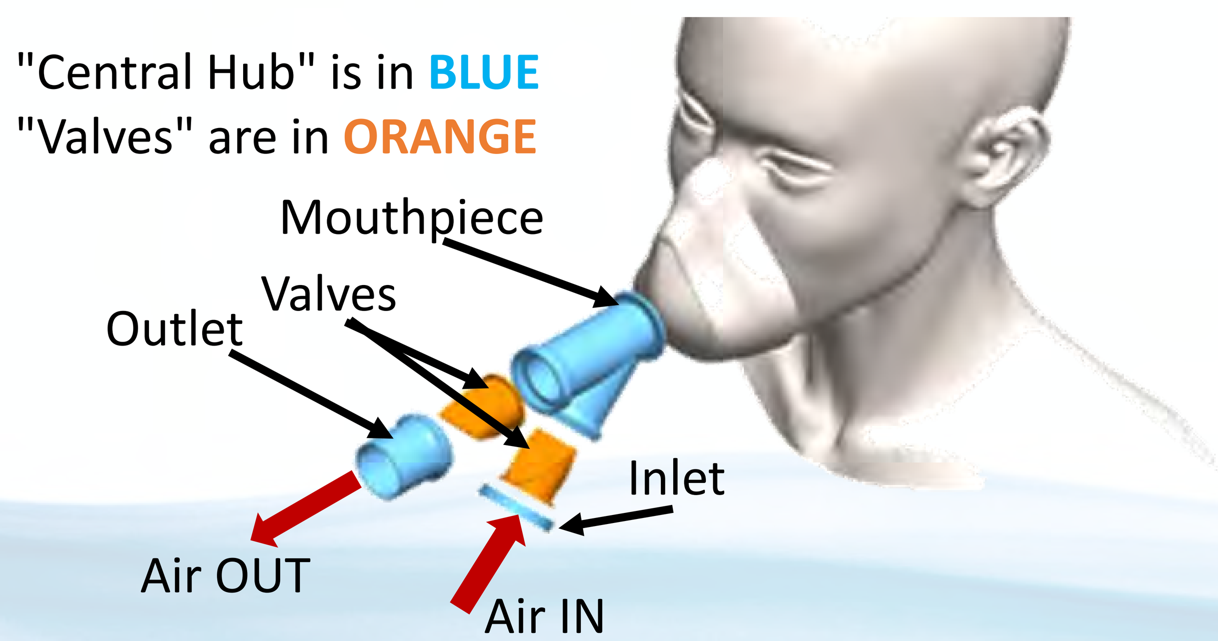

Figure 1. CAD model diagram of the air mask for aerobic fitness tests design. The design is comprised of the Central Hub and the Valves, which are labeled. The air flows in through the 45-degree angle inlet and out through the straight shaft.

Problem

Current central hub and valve shapes used in VO2 masks cause large pressure drops in the system that led to substantial flow resistance, making breathing difficult for the user. The purpose of this project was to develop a new air mask system that decreases energy losses as air flows through the setup while the user is breathing.

Metrics

Table 1. Metrics that guided design of the central hub and valves, note that metrics 3 and 6 are constraints.

#	Metric Description	Units	Target	Result
1	Pressure difference across outlet and inlet valve	psi	<0.06	0.079 (in) 0.018 (out)
2	Mass of central hub and valves	g	<134	58
3	Hub connection point fits with existing mask	Binary	Y	Y
4	Valve base diameter	mm	37	37
5	Cost	$	<413	123.40
6	Hub and valve material adhere to medical & sanitation standards	Binary	Y	Y
7	Number of hub and valve parts	Quantity	<9	5

Figure 2. Image of the final manufactured design.

Methods

Researching and experimenting with currently available mask designs.

- Exhalation is more challenging than inhalation since more pressure builds up.
- Metrics set with the goal of being better than the current design

Analytical calculations

- Used Bernoulli's equation and head loss equations to determine pressure drops for various designs.
- The 45-degree angle inlet and straight shaft outlet was the best design with the lowest predicted pressure drops.

Computational Fluid Dynamics (CFD) analysis

- Validated analytical calculations

Simulated VO2 max test

- Used a mechatronic system to measure pressure at the inlet, outlet, and mouthpiece.
- Analyzed data to check our design against the metrics

Design Iterations

- Internal geometry and valve dimensions

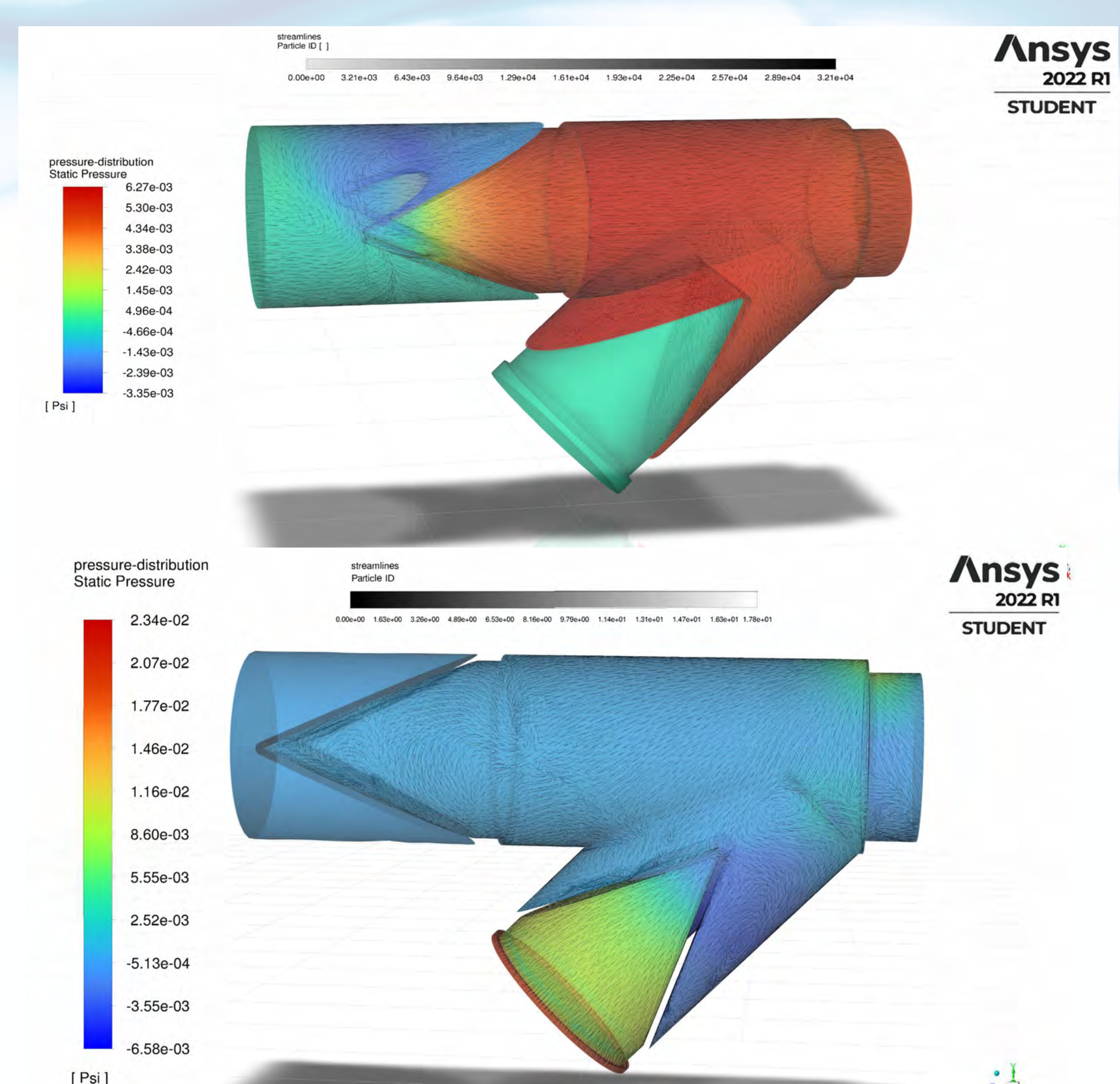

Figure 3. A computational fluid dynamics model shows the airflow within the mask during exhalation (top) and during inhalation (bottom). The pressure distribution is shaded and the streamlines show the path followed by the air.

Results

The data collected during testing was plotted to show the pressure difference across the valves while breathing. The average maximum inhalation and exhalation pressures were 0.092 and 0.027 psi, respectively. The maximum exhalation pressure exceeded the design metric by 70%, while the maximum inhalation pressure fell short of the metric by 24%.

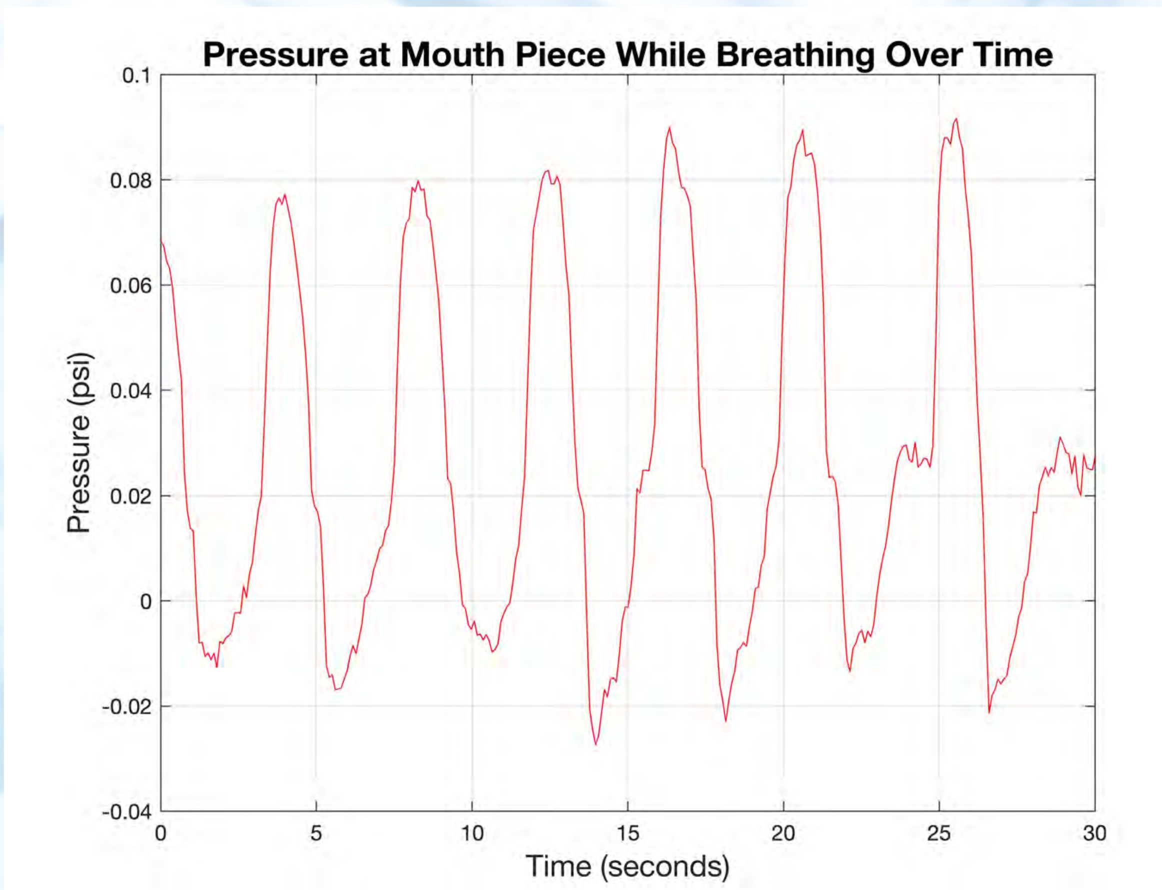

Figure 4. Pressure difference in the system during a simulated VO2 max test. The positive data shows inhalation pressure measurements (across the inlet valve) and the negative data shows exhalation pressure (across the outlet valve).

Table 2. Average maximum inhalation pressure across the inlet and exhalation pressure across the outlet. The data has a low variance, demonstrating that the peak pressure values are relatively consistent.

Average Maximum Inhalation Pressure (psi)	Average Maximum Exhalation Pressure (psi)	Variance (psi^2)
0.079	0.018	1.15E-3

Qualitatively, we noticed during testing that the new design felt significantly easier to breathe through than the currently available design. Specifically, it was not as difficult to exhale through the redesigned valves, which is a good indication that the pressure drops are lower than the original design

Conclusion

All the metrics for the design were met or exceeded, except for the pressure difference across the inlet valve. During preliminary interviews and testing of the existing design, it was determined that the exhalation pressure was of greater concern, since it had a greater pressure difference and users agreed it was harder to exhale than inhale. During experimental testing it was apparent to the user that the redesigned central hub and valves were easier to breathe through than the original design. Overall, the redesigned hub and valves are an improvement from the existing design.