Improving the Breathability of a Tracheostomized Patient

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Abstract

The purpose of this investigation is to contribute to an effort to improve the breathability of a particular tracheostomy speaking valve for an active tracheostomized patient. It has been theorized that the patient may be struggling to breathe through the tracheostomy speaking valve due to too large of a pressure gradient across the valve. However, no significant work is being done to improve these valves for use in an active patient due to the fact that most of the patients who use these valves are usually limited in their ability to be physically active. In this study, various engineering computational, experimental, and analytical methods and tools are employed in an integrated and iterative approach to decrease the pressure drop across the valve while also maintaining its structural integrity. Computational Fluid Dynamics (CFD), flow experimental testing, Structural Finite-Element Analysis (FEA), compression experimental testing, and analytical methods are all employed in the characterization of the flow and structural characteristics of the original valve design and each subsequent design iteration. The impact of various geometrical modifications to the original design on the valve's flow and structural performance are presented. Recommendations for future work are also discussed and presented. The results of this study will continue to be utilized in the continuing effort to improve the speaking valve and to inform the development of future design iterations. Overall, the results from this study have the potential to contribute to the future improvement of quality of life for the particular tracheostomized patient and to be extended to serve other patients as well.

Introduction and Rationale

Across the different disciplines of engineering, the primary goal in many engineering projects is to serve others through helping to improve their quality of life. Often, the engineering solutions that are developed and implemented to so are designed to meet the greatest demand or need in the most efficient and effective way possible. However, while this may usually be an effective framework to employ from a business standpoint, there are a variety of needs that only affect a very narrow audience. These individual needs may often go unnoticed and unmet because the demand for them is comparatively low. The application of research and development using engineering tools and methods may be extremely valuable in helping to meet the needs of individuals and to communicate that each person is valuable as ones created in the image of God.

In this project, the needs of one active tracheostomized patient are the primary concern and motivation for this research effort. Instead of trying to serve society and meet a need for which there is a great need and large potential demand for, the goal of this project is simply to help improve the quality of life for one patient. While the project holds potential to also serve other patients, it will be considered worthwhile if it just helps improve the quality of life for this one person. The main issue that this research effort is focused on is to improve the breathability for this active tracheostomized patient by decreasing the pressure drop across the tracheostomy speaking valve currently being used by this patient. Thus, the overarching purpose of this research effort is to implement the use of a variety of engineering tools and methods to optimize the tracheostomy speaking valve by minimizing the pressure drop while maintaining the valve's structural stability.

Methods

In order to perform this investigation to improve the breathability of the Tracheostomy Speaking valve currently being used by the patient, an iterative optimization methodological framework was developed and employed. The developed methodological framework integrates the use of a variety of engineering computational, analytical, and experimental tools and methods to develop a series of design iterations. The geometrical modifications for each design iteration are modeled using Computer-Aided Drafting (CAD) tools in SolidWorks and then imported into a Computational Fluid Dynamics (CFD) model in ANSYS Fluent and a Static Structural FEA model in ANSYS Static Structural. Analytical and experimental methods are utilized to inform the definition of the model boundary and loading conditions. Simulations of both models are performed and the results are then analyzed to determine the effects of the geometrical modifications on the flow and structural behavior and performance of the speaking valve itself. The results from the computational simulations are then validated using flow and compression experimental testing methods. The comprehensive results from each design iteration are then used to inform the development of future iterations until a final optimized design iteration is developed.

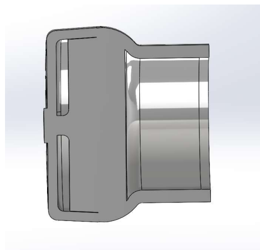

Figure 1: Section-view of original speaking valve design modeled in CAD using SolidWorks

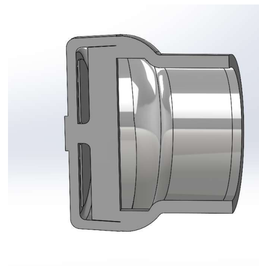

Figure 2: Section-view of speaking valve design iteration SV-1 (support bar is half of the length of the original valve design) modeled in CAD using SolidWorks

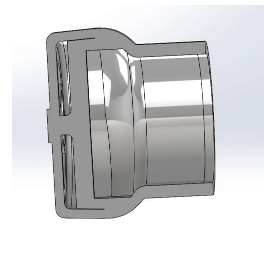

Figure 3: Section-view of speaking valve design iteration SV-2 (support bar is a quarter of the length of the original valve design) modeled in CAD using SolidWorks

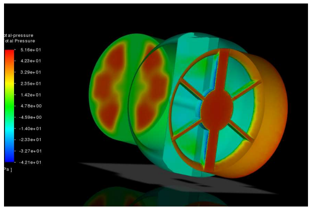

Figure 4: Total Pressure Contours for original speaking valve from ANSYS Fluent CFD model simulation results

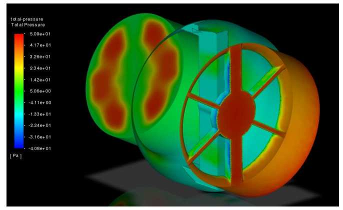

Figure 5: Total Pressure Contours for speaking valve design iteration SV-1 from ANSYS Fluent CFD model simulation results

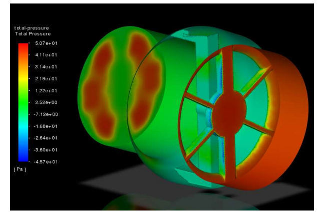

Figure 6: Total Pressure Contours for speaking valve design iteration SV-2 from ANSYS Fluent CFD model simulation results

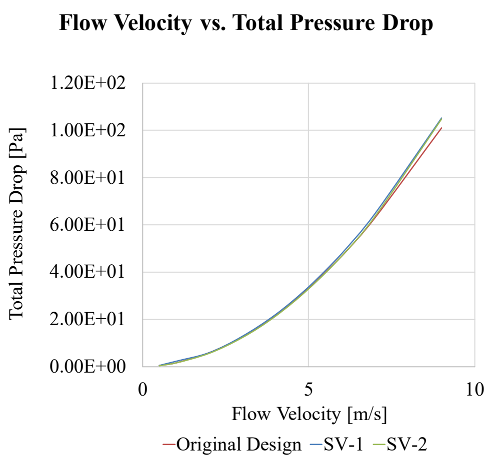

Figure 7: Flow Velocity vs. Total Pressure Drop plot comparing the flow characteristics of the three speaking valve design iterations.

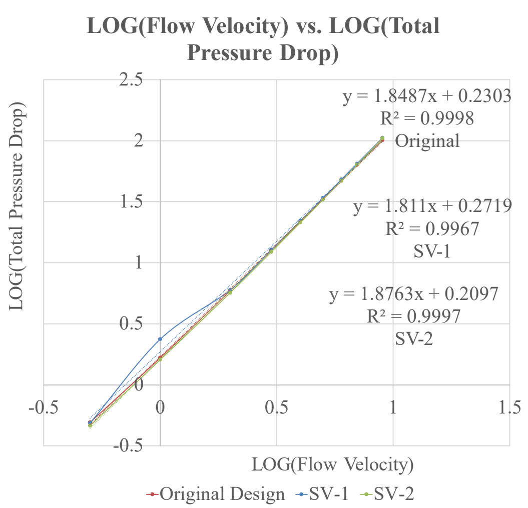

Figure 8: Flow Velocity vs. Total Pressure Drop log-log plot comparing the flow characteristics of the three speaking valve design iterations.

Results and Conclusions

So far, the developed iterative optimization methodological framework has begun to be implemented. Several design iterations of the original tracheostomy speaking valve model have been developed and modeled in SolidWorks. (See Figures 1 through 3). The design iteration labeled "SV-1" (pictured in Figure 2) has a middle support bar that is half the length of the original and the design iteration labeled "SV-2" (pictured in Figure 3) has a middle support bar that is one-quarter the length of the original. These 3 developed iterations have been simulated and analyzed in ANSYS Fluent in the developed CFD model to characterize their flow performance and determine the pressure drop across each valve design iteration. The pressure drop contours for these iterations are pictured in Figures 4 through 6. Essentially, the largest pressure drop appears to be occurring across the transition region between the larger and smaller diameters of the valve. The pressure drop has been slightly altered in the iterations analyzed, but work remains to be done to further analyze the specific effects of the geometrical parameters on the flow performance of the speaking valve. In Figures 7 and 8, the pressure drop across each valve design iteration was plotted against the flow velocity to compare and analyze the flow behavior of each valve design iteration. While slightly altering the pressure drop across the valves, the middle support bar does not appear to significantly affect the flow performance of the valve. Thus, in future design iterations, the middle support bar may not be the focus of the proposed geometrical modifications. Currently, work is being done to model more design iterations as well as to complete the Static Structural FEA model and implement the flow and compression experimental methods and tools. Future efforts will continue with this project to further the implementation of this methodology and to continue the optimization of this particular tracheostomy speaking valve.

Overall, the results from this research effort represent an example of the implementation of engineering methods and tools to help serve the needs and improve the quality of life of one particular person. The data and information gained through this research study will contribute to the development of an improved tracheostomy speaking valve for a particular active tracheostomized patient. The tools employed and the approaches utilized in this study also have the potential to encourage the development and initiation of other research efforts to implement engineering methods in the meeting of particular needs of others around the world.

Future Work

1. Continue to develop and analyze the CFD models characterizing the flow performance of the speaking valve design iterations.
2. Development and implementation of the Static Structural FEA models to characterize the structural performance of the valve design iterations.
3. Design and run experimental tests to verify and validate the flow and structural performance results from the computational models.
4. Continued work to arrive at a finalized and improved final design iteration.

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