Contents

Motivation

- Chronic respiratory problem: a persistent condition impacting the lungs and airways.
- 7.4% of the world's population, live with chronic-respiratory failure conditions. (Burney et al 2021)
- Mechanical Ventilation –the most common and effective method

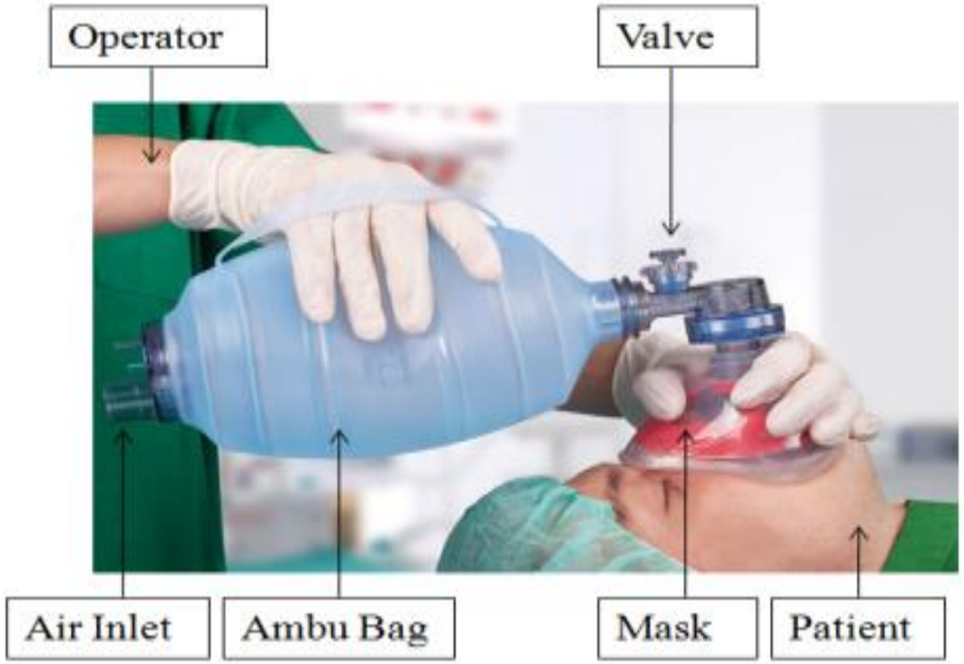


Fig. 1. Respiratory Failure solution using Mechanical Ventilator

Related work

- Evolution of from open loop to closed loop control methods Aim: Alleviating clinician burden and improving patient care (T.P. Laubschar 1994)
- Three lung models developed for Respiratory Parameter Control (T.P. Laubschar 1996)
- Monitoring Respiration Rate and Tidal Volume with PSIMV Utilization of Pressure Synchronized Intermittent Mandatory Ventilation (PSIMV) (R. L. Chatburn et al 2003)
- Innovative Oxygen and Air Blending lung-ventilator prototype for blending and delivery Enhancing oxygen delivery precision (H. Luepschen et al 2009)

Related work (Cont.)

- A. Darwood et al designed a portable and low-cost mechanical ventilator which was published as “The design and evaluation of a novel low-cost portable ventilator” in Anaesthesia, 2019.

- Leonardo Acho et al designed a Low-Cost, Open-Source Mechanical Ventilator with Pulmonary Monitoring for COVID-19 Patients in 2020, published in Actuators vol 9.

- Omor Flor et al designed a low-cost emergency mechanical ventilator which is designed with affordable materials and a design procedure called SURKAN mechanical ventilator in 2020

- Abdellah El-Hadj et al designed and simulated a stepper motor based on one-directional pusher rod mechanical ventilator which is published in Chaos, Solitons & Fractals in 2021.

Objectives

- Optimizing mechanical and fluid-flow parameters,
- Developing, simulating, and executing a high-performance, affordable portable mechanical ventilator
- Support patients suffering from chronic respiratory failure.

Methodology

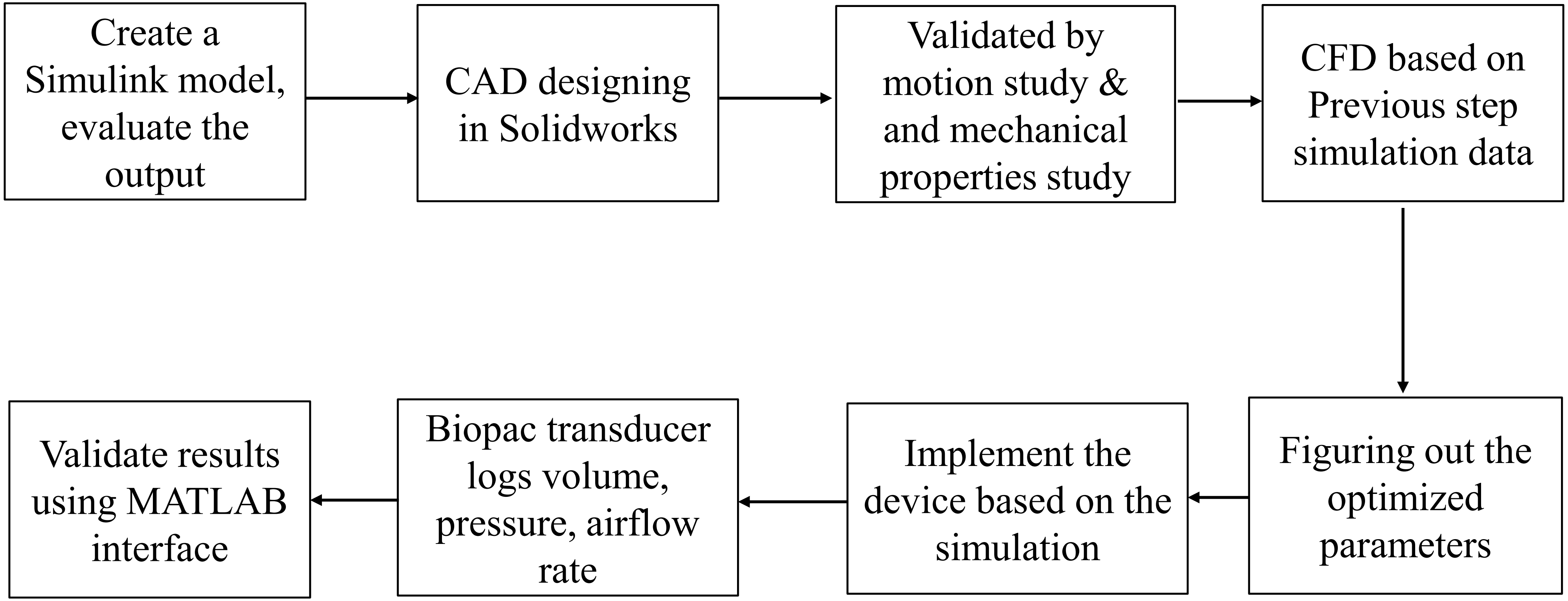


Fig: Flow chart of the

Methodology (Cont.)

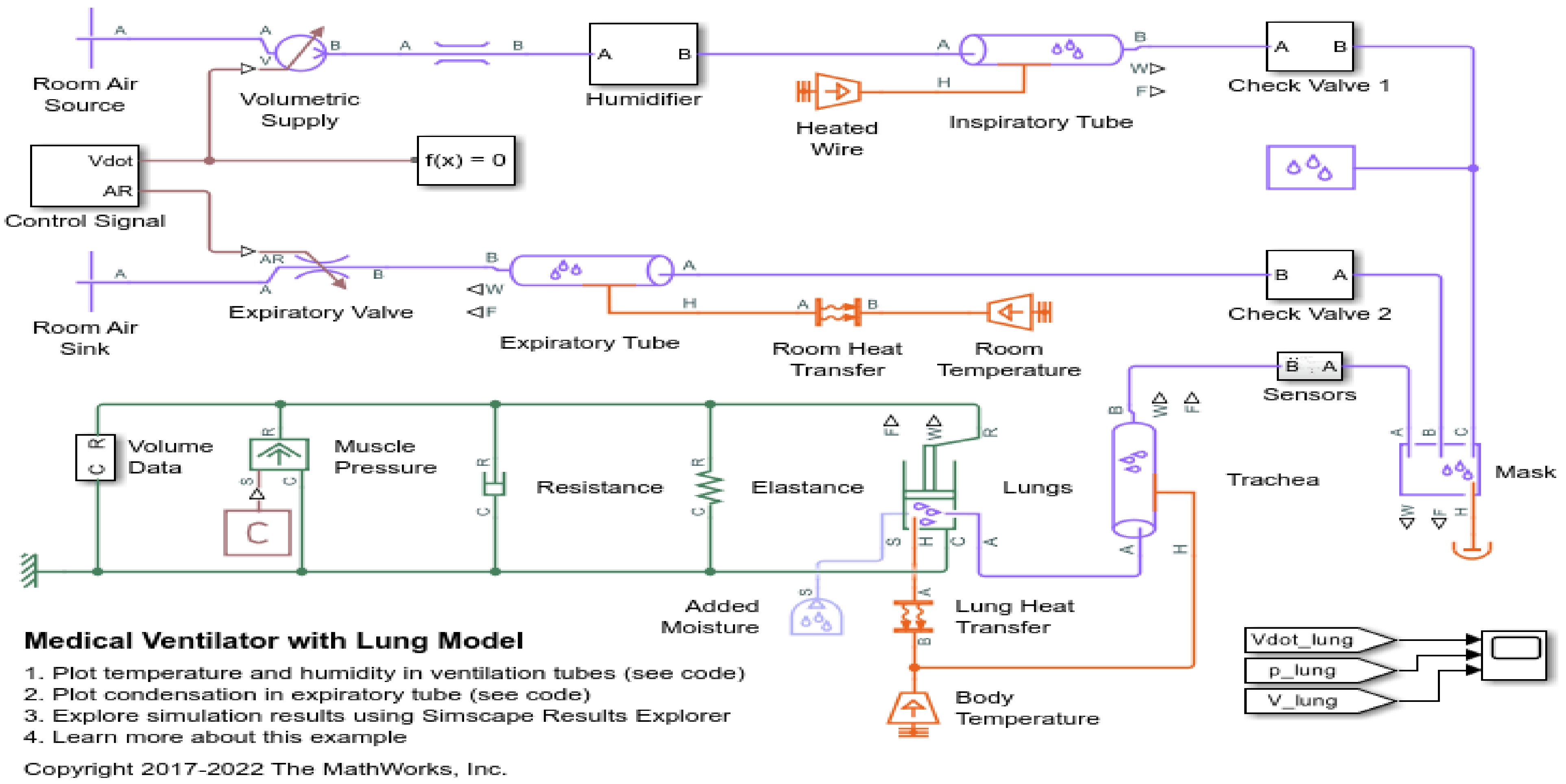


Fig. 2. Simulink Model of Mechanical ventilator with lung

Methodology (Cont.)

Table 1: Simulink model development blocks

Package used : Simscape		
SL	Name of the Block	Specification
1	Volumetric supply	2L
2	Humidifier	98%
3	Inspiratory tube	0.01m,laminar fraction 64
4	Check valve (1/2)	1e-4 m^2 internal passage area
6	Lung model	same as human lung

Table 2: Selected Values For Mechanical Ventilator

Parameter	Value
Tidal Volume	6-8 ml/kg PBV
Rate	2-16 BPM, for ARDS UP TO 35 BPM
PEEP	5-10 cmH2O
FiO2 Inspiration Flow	Adjusted to obtain SpO2>90% 40-60 L/min
Trigger Flow	2 L/min

Methodology (Cont.)

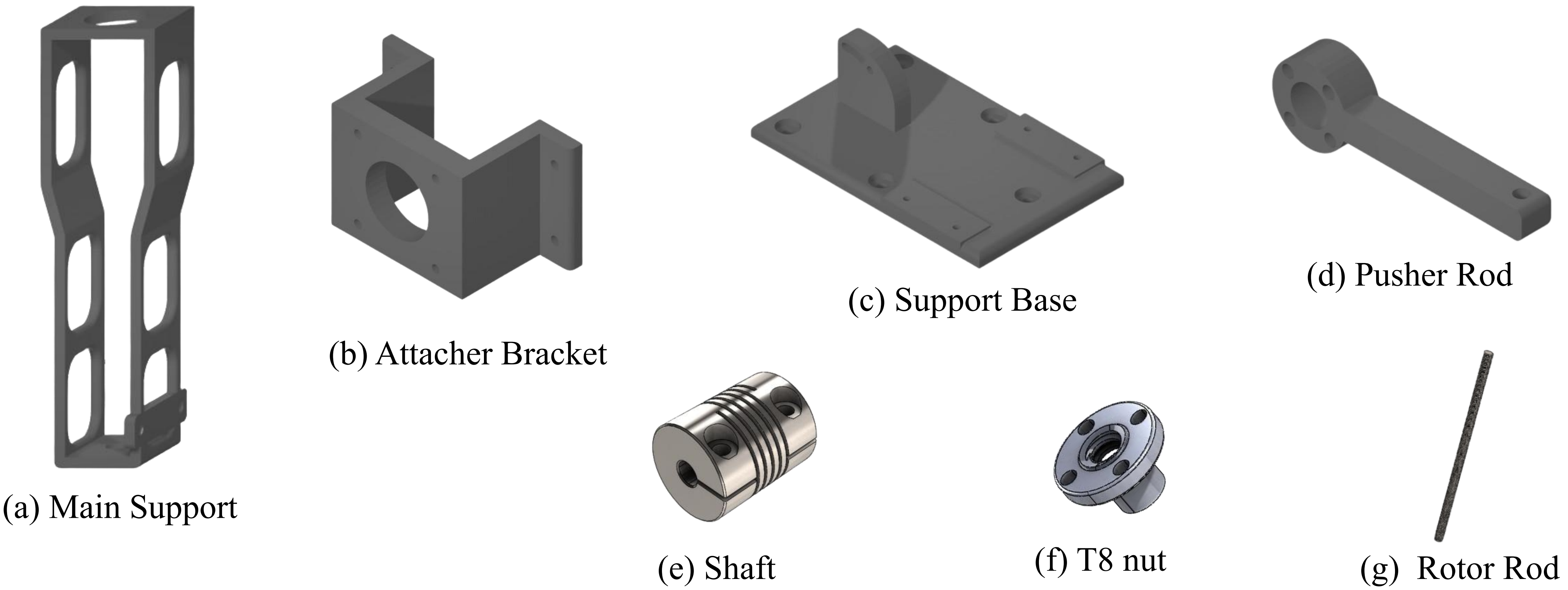


Fig. 3. Different Parts of CAD design in ~~what~~

Methodology (Cont.)

Table 3: CAD Design Specification

Software used : Soliworks		
SL	**Name of the Part**	**Material**
1	Main Support	Steel
2	Attacher Bracket	Steel
3	Base	Steel
4	Pusher rod	Steel
5	Spring rod	Steel
6	Shaft	Steel

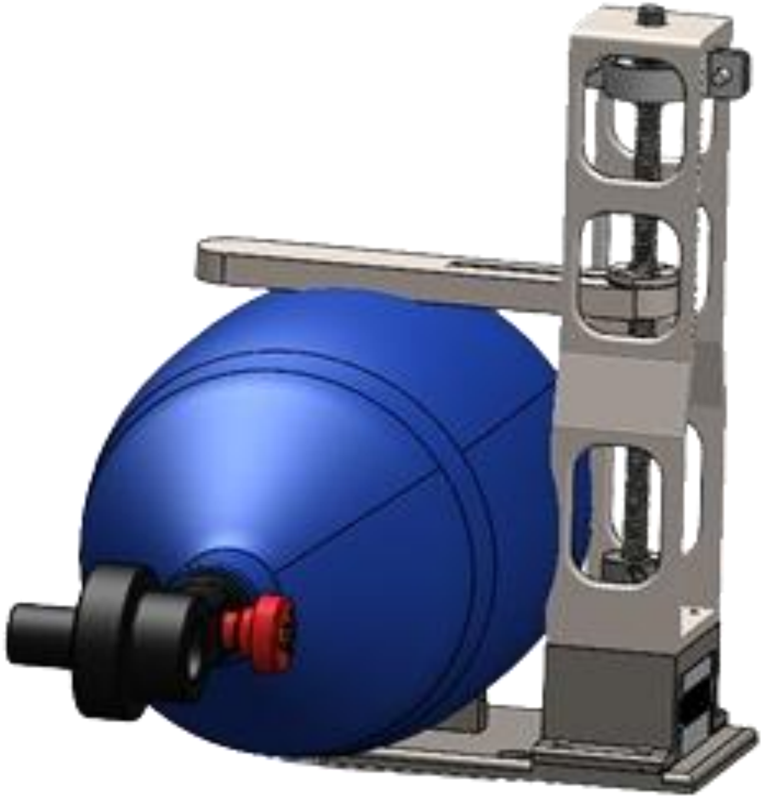


Fig. 4. CAD Assemble Model.

Methodology (Cont.)

Table 4: Mechanical properties simulation study

Software :Solidworks Simulation			
SL	**Topic**	**Specification**	**Function**
1	Simulation type	Static	Static mechanical analysis
2	Simulation Subject	Ambu bag under load	Exclude whole assembly
3	Simulation Topic	Von Mises Stress, URES deformation, Equivalent Strain	Identical for proper fluid flow profile
4	Fixtures advisor	Fixed geometry	Mechanical reference
5	Load	Pressure on the surface	2000 N/m^2
6	Connection	Component interactions	--
7	Material	Sillicon rubber	Better mechanical properties and availability

Methodology (Cont.)

Mathematical modeling

FEM: Finite Element Method

$$\{v\}^T[[M]^T[M']]\Big|_0^1\{u\} - \{v\}^T\left[\int [M']^T [M']\right]\{u\} = \{v\}^T\left[\int [M]^T [M]\{f\}\right]$$

$$\underbrace{\left[([M]^T[M'])\Big|_0^1 - \int [M']^T[M']\right]}_{\{\mathrm{K}\}}\{u\} = \underbrace{\left[\int [M]^T[M]\{f\}\right]}_{\{\mathrm{M}\}}$$

[M] and [K] represent the mass and stiffness matrices of the system, respectively. The vector {f} represents the external forces acting on the system.

Methodology (Cont.)

Von Mises Stress:

$$\sigma_v = \frac{\sqrt{\left(\sigma_{xx} - \sigma_{yy}\right)^2 + \left(\sigma_{yy} - \sigma_{zz}\right)^2 + (\sigma_{zz} - \sigma_{xx})^2 + 6\left(\sigma_{xy}^2 + \sigma_{yz}^2 + \sigma_{xz}^2\right)}}{2}$$

Equivalent strain:

$$\varepsilon_{eq} = \ln\left(\sqrt{1 + 2\varepsilon_{xx} + 2\varepsilon_{yy} + 2\varepsilon_{zz}}\right) + \ln\left(\sqrt{1 + 2\varepsilon_{xy} + 2\varepsilon_{yz} + 2\varepsilon_{xz}}\right)$$

URES Deformation:

$$\sigma = D.\varepsilon$$

Where
- ✓ σ is the stress tensor,
- ✓ D is the elasticity matrix,
- ✓ ε is the strain tensor.

Methodology (Cont.)

Table 5: CFD simulation study specification

Software: Solidworks Flow Simulation			
SL	**Topic**	**Specification**	**Function**
1	Simulation type	Fluid Flow :external	External Fluid Flow
2	Simulation Subject	Ambu bag under load with existing and proposed condition	Comparing the fluid flow profile
3	Simulation Topic	Flow velocity, Fluid Temperature, Density, Vorticity, Pressure	Evaluation of Physiological Compatibility
4	Condition	Including cavities.temp:293 K ,wall: adiabatic	subjecting all holes
5	Flow direction	Z axis	0 m/s^2 initial
6	Gravity	Y axis	-9.81 m/s^2
7	External load	Static, on the ambu bag	2000 pa

Methodology (Cont.)

Mathematical modeling: CFD (Or CAD)

Continuity Equation:

$$\nabla \cdot v = 0$$

Momentum Equation (Navier-Stokes Equation):

$$\rho\left(\frac{\partial t}{\partial \mathrm{v}} + (\mathrm{v} \cdot \nabla)\mathrm{v}\right) = -\nabla p + \mu\nabla 2\mathrm{v} + \rho g$$

3.Energy Equation (if solving for temperature distribution):

$$\rho cp\left(\frac{\partial t}{\partial T} + (\mathrm{v} \cdot \nabla)T\right) = \nabla \cdot (k\nabla T) + \rho H$$

Methodology (Cont.)

Mathematical modeling: CFD

Vorticity Equation:

$$\omega = \nabla \times \mathrm{v}$$

Mach Number (Ma) Equation :

$$Ma = |\ \mathrm{v}\ |\ /c$$

where
|v| is the magnitude of the velocity vector,
and *c* is the speed of sound in the fluid.

****All the symbol means the traditional meaning**

Methodology (Cont.)

Table 6: Electrical hardware specification

SL	Component Name	Function	Specification
1	Arduino Nano	Microcontroller	5-volt ,14 pin, 50mA
2	Motor Driver	L298N	Double H Bridge , 46V(Max),2A(Max)
3	Steeper Motor	NEMA 17	1.8° full step 0.9° half-step, 12V at 400 mA, 30 ohms
4	Adapter	Variable	0-24 volt ,2A
5	Data cable	Code uploader	For Arduino nano
6	Cable	Jumper wire	Locally brought

Programming interface : Arduino editor

Methodology (Cont.)

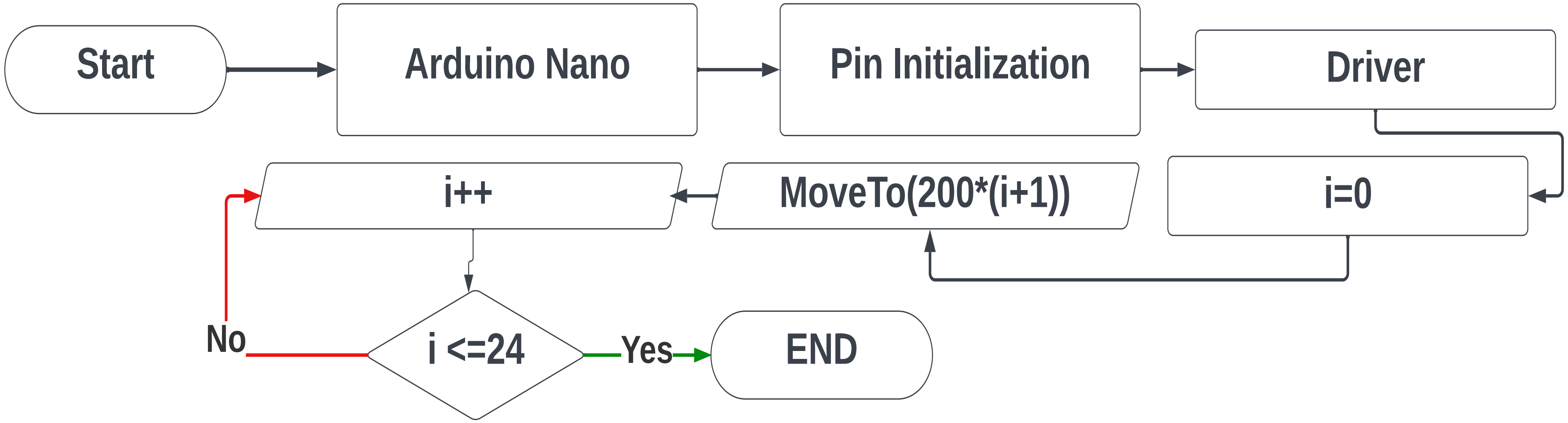


Fig. 5. Flowchart Machine Control

Table 8: Rotational Specification

Topic	Rating
Motor Torque	35 Nm
BPM	12
RPM	24

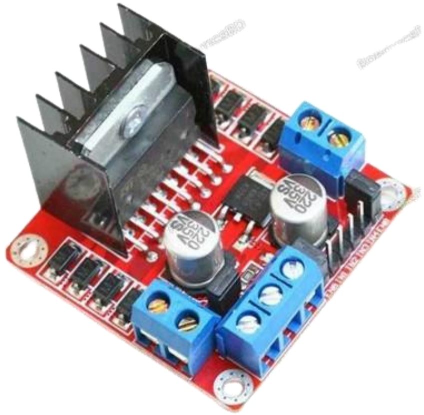
Methodology (Cont.)

Electric Component Part by Part

(a) Arduino Nano & Data cable

(b) NEMA 17 Stepper motor

(c) Jumper wire



(c) L298N motor driver

(d)Variable Adapter

Fig. 6. CAD Assemble Model.

Methodology (Cont.)

Implementation

Ambu bag compressed

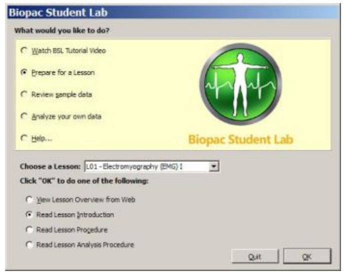
Ambu bag uncompressed

Fig. 7. Implemented and integrated hardware

Methodology (Cont.)

Data Extraction from Implemented Device

Ventilator ambu bag → Respiratory ventilator filter → SSL1A Airflow Transducer → MP36



$$\frac{\partial t}{\partial T} = \alpha(\partial x^2 / \partial T^2) - \beta\left(\frac{\partial x}{\partial V}\right)$$

$$I = \rho c\left(\frac{\partial t}{\partial T}\right) + k(\partial x^2 / \partial T^2) + Q$$

Here V is the velocity of the airflow, I is the current

Methodology (Cont.)

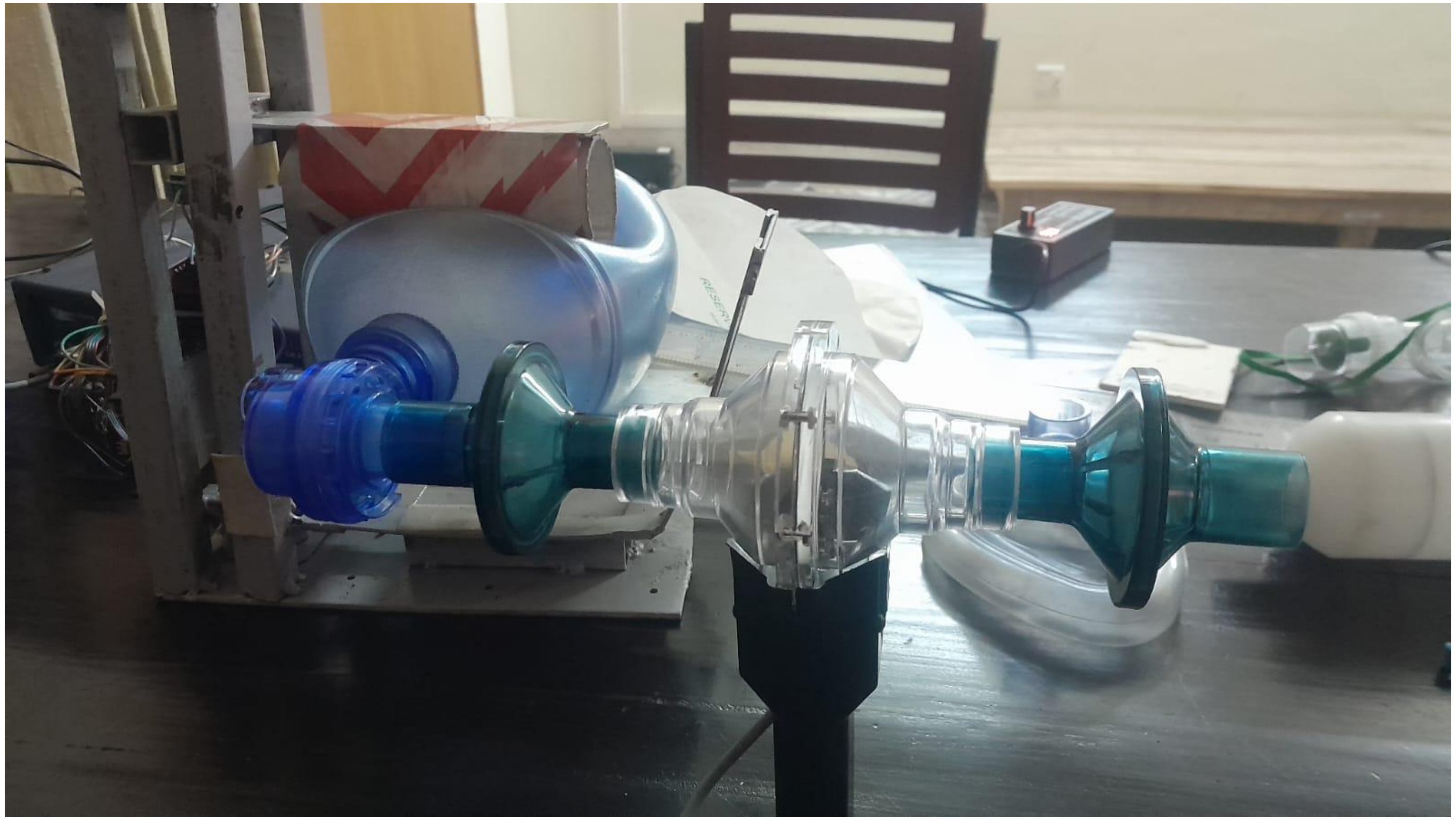
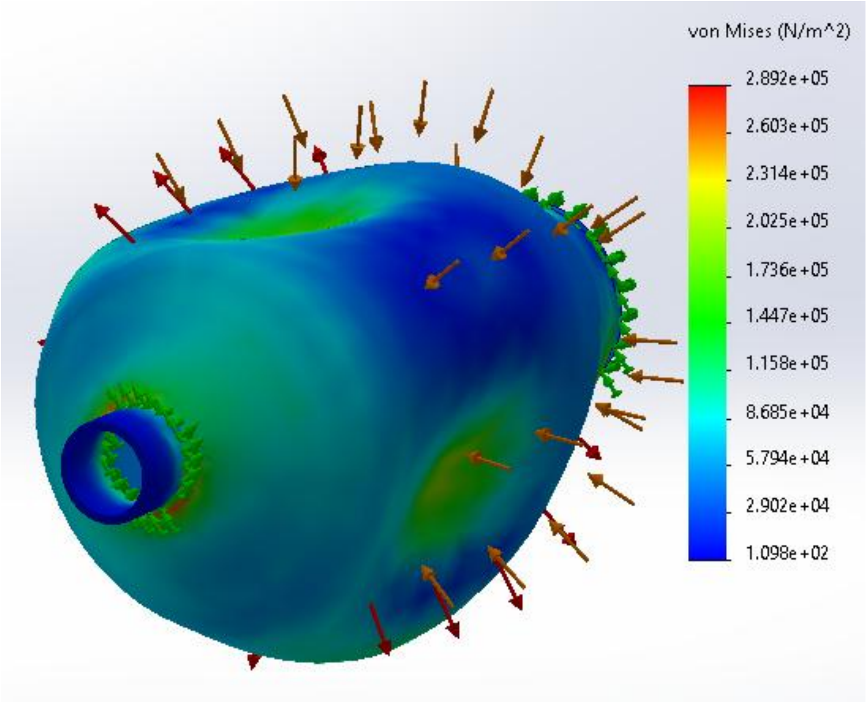
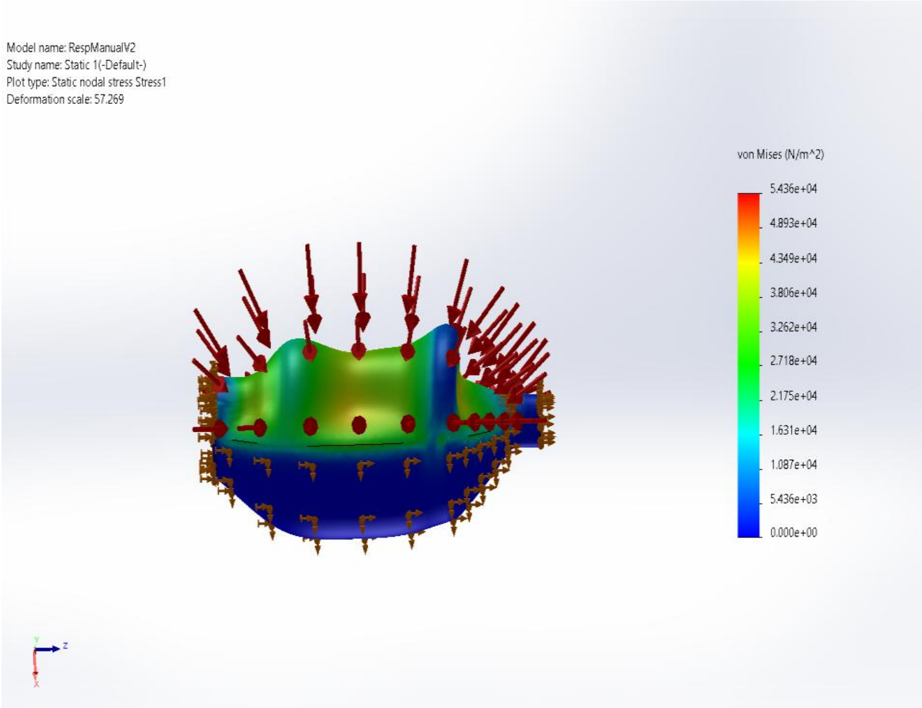


Fig. 8. Implemented Ventilator

Result: Von mises Stress



(a)



(b)

Fig. 9. Comparison between (a) traditional two-side pressed MV and (b) proposed MV model Von Mises Stress

Result: Von mises Stress

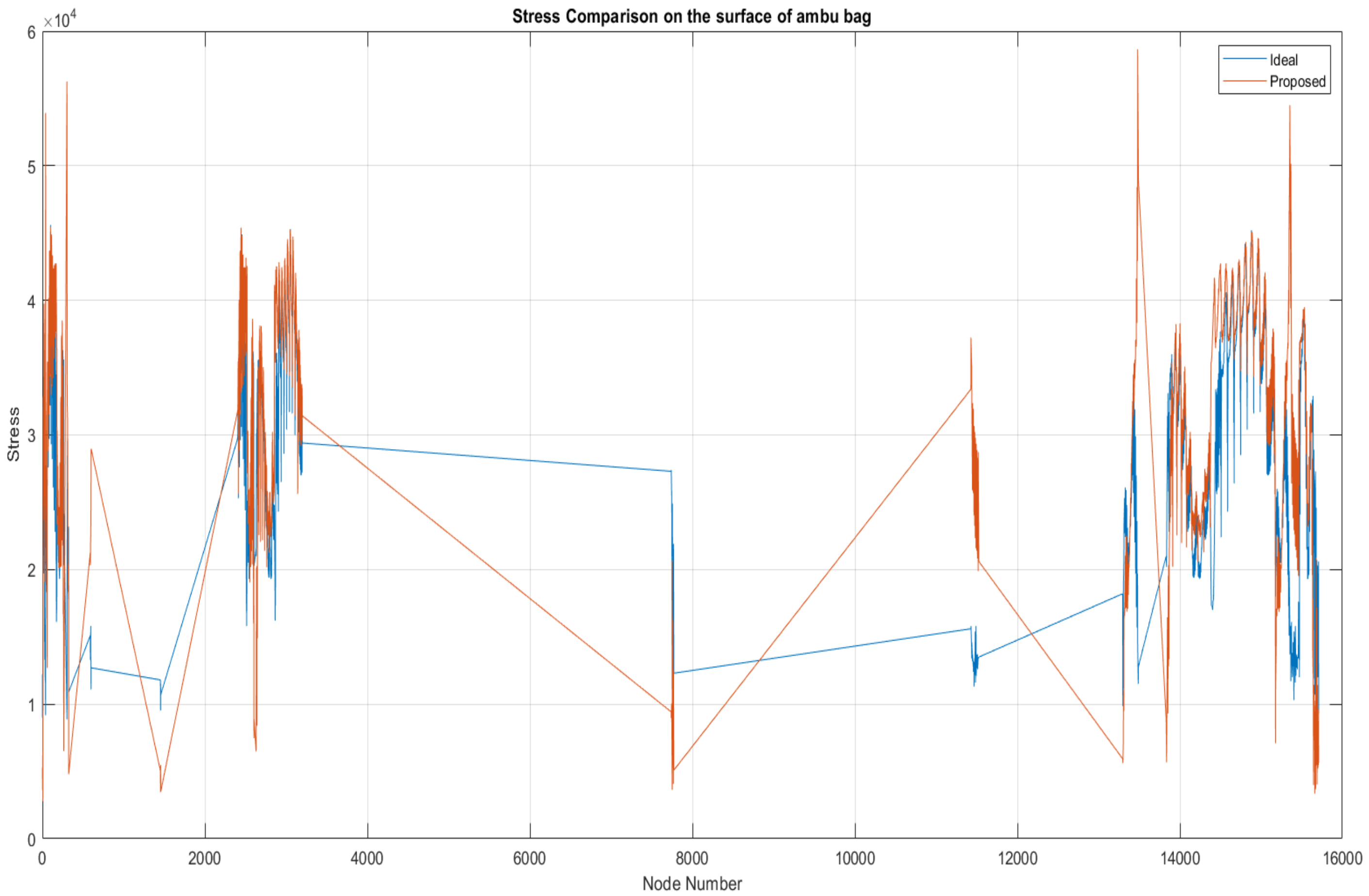
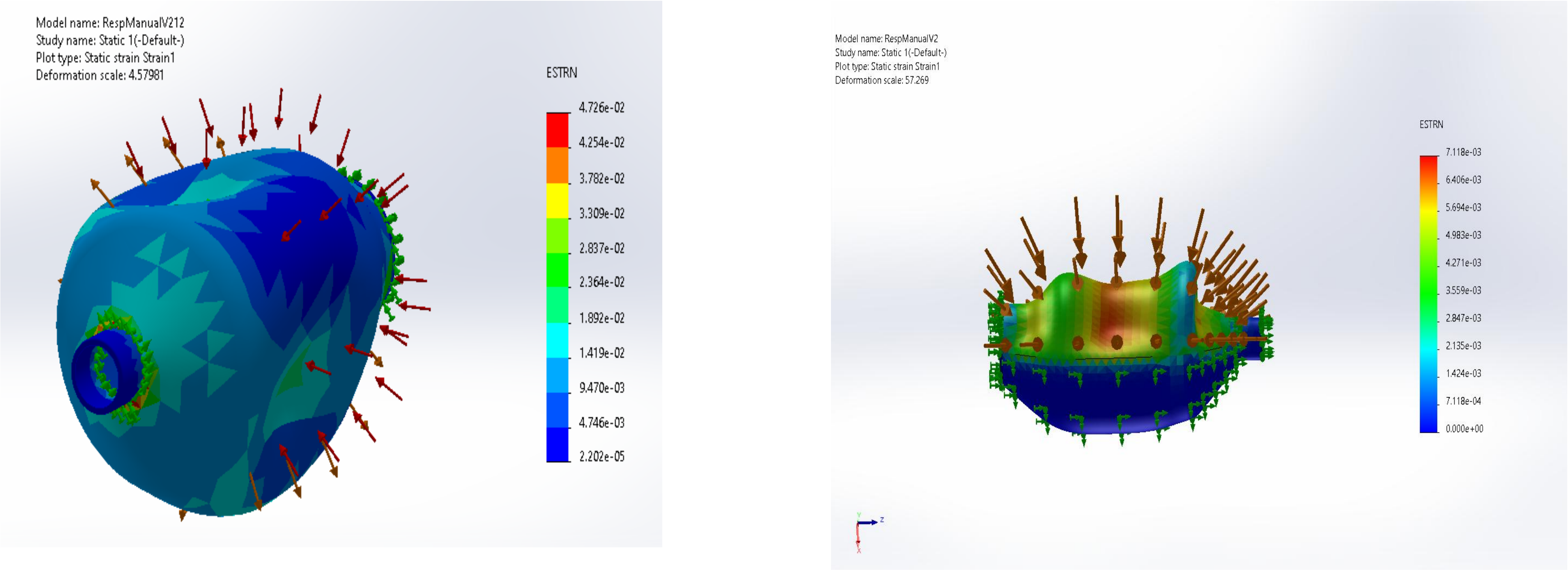


Fig. 10. Stress Curve Comparison between traditional two side pressed MV (blue) and proposed MV model (Red)

Majority: Higher Stress

Nodes 4000-8000: Lower Stress

Result: ESTRN



(a) (b)

Fig. 11. Comparison between (a) traditional two-side pressed MV and (b) proposed MV model equivalent strain

Result: Von mises Stress

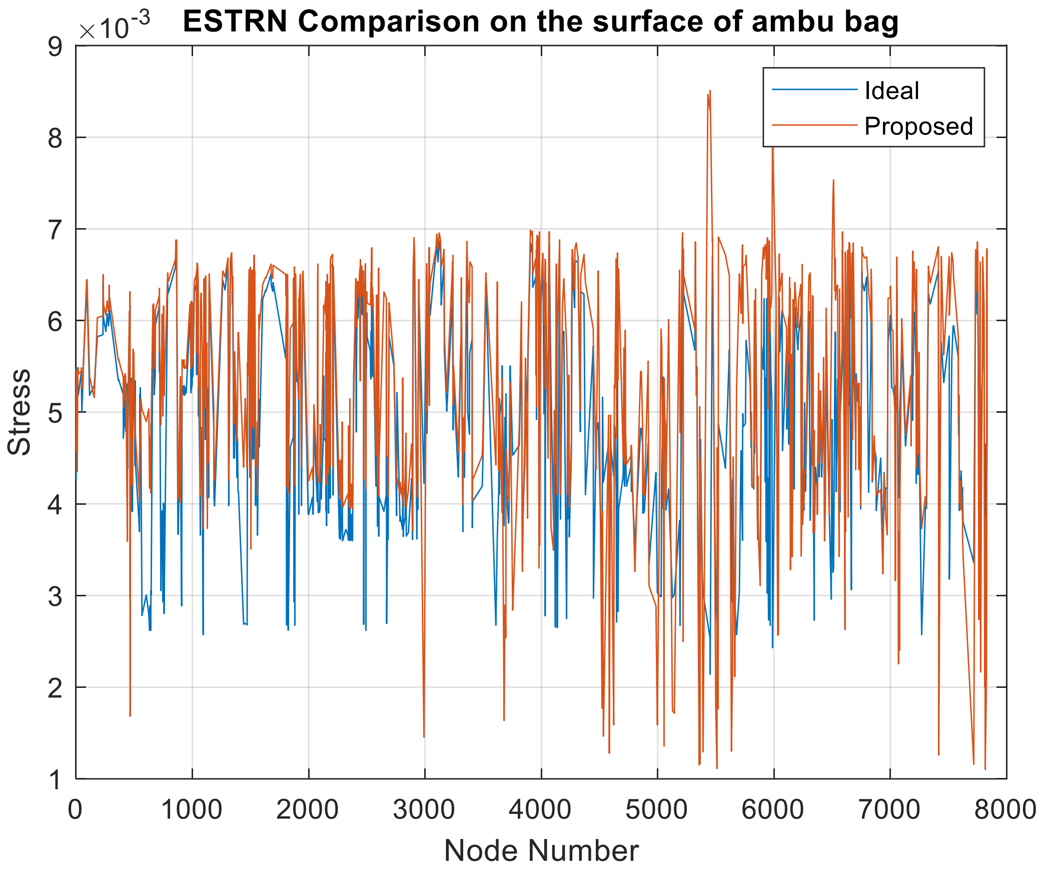


Fig. 12. ESTRN Comparison between traditional two side pressed MV (blue) and proposed MV model (Red)

1. Enhanced Strain Distribution
2. Improved Signal Connectivity

Result: Von mises Stress

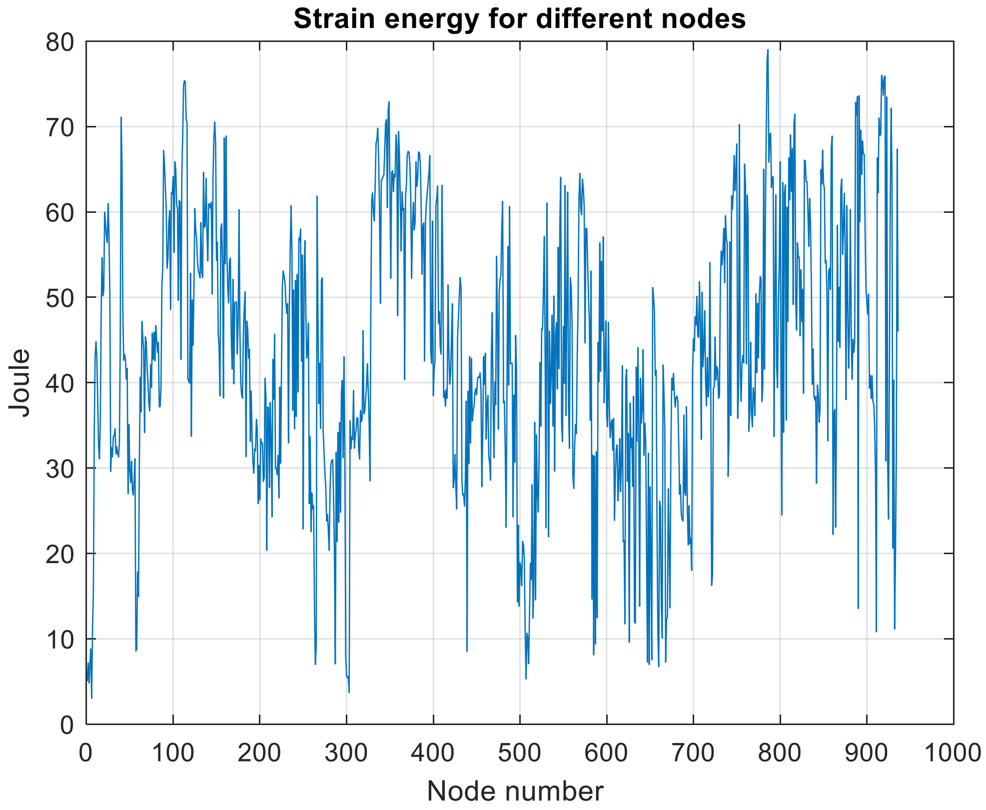
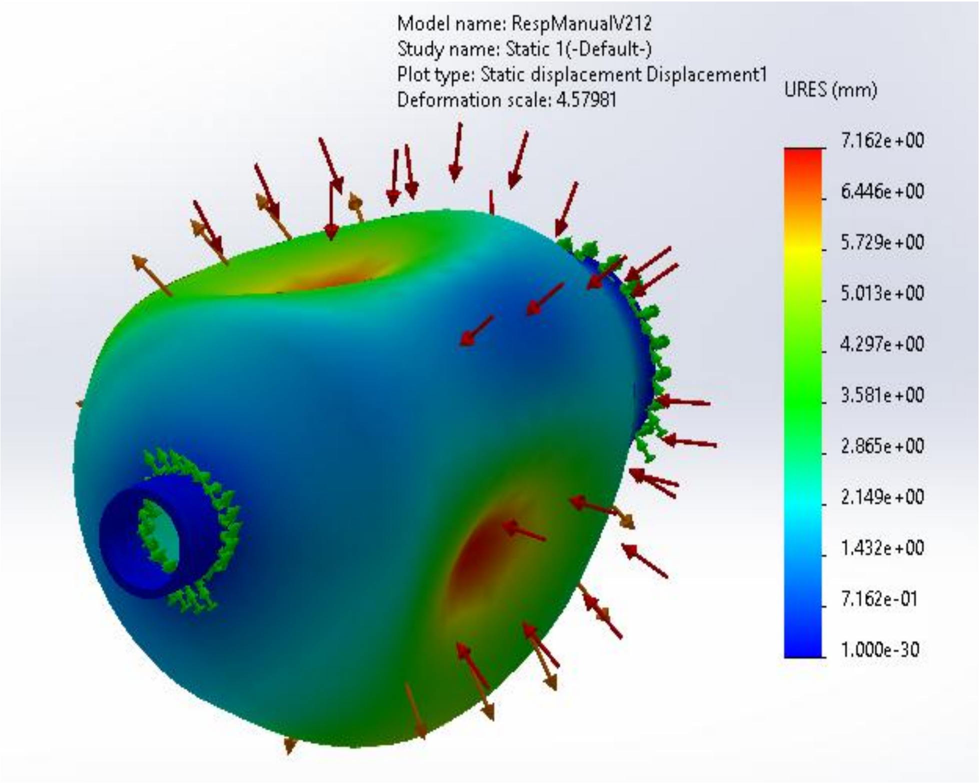


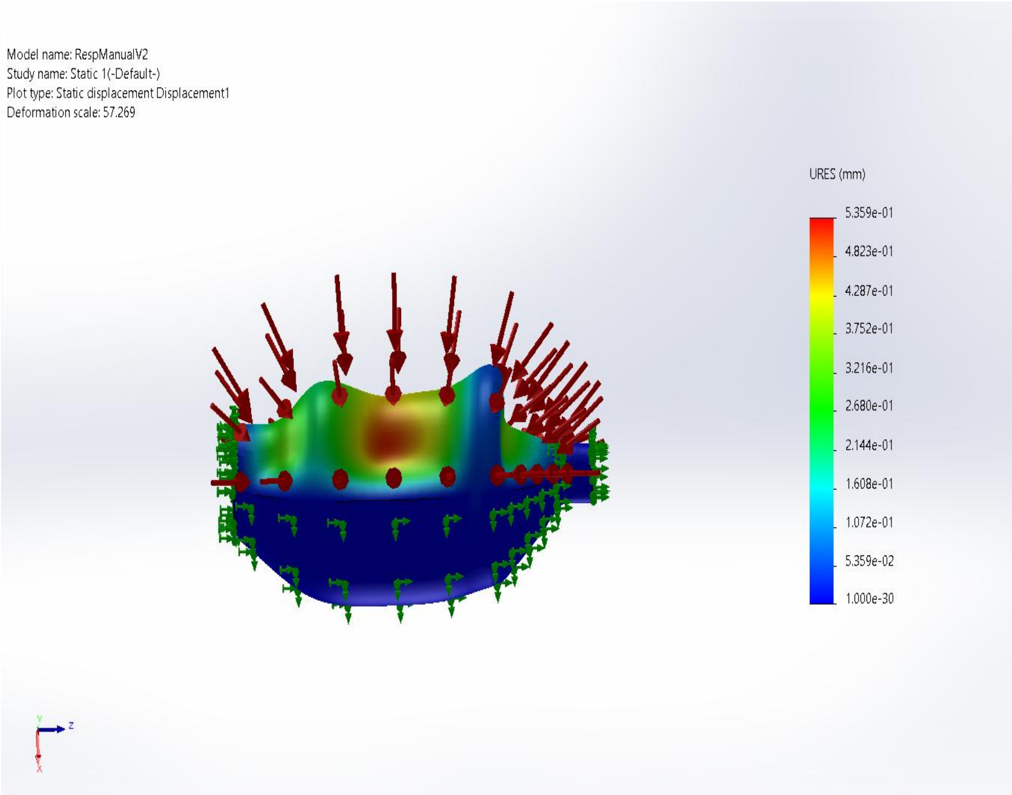
Fig. 13. Equivalent Strain Energy curve for the proposed model.

1. Strain energy peak: 80 J
2. Periodic curve
3. Spatial load distribution

Result: URES deform



(a)



(b)

Fig. 14. Comparison between (a) traditional two side pressed MV and (b) proposed MV model URES Deformation

Result: URES deform

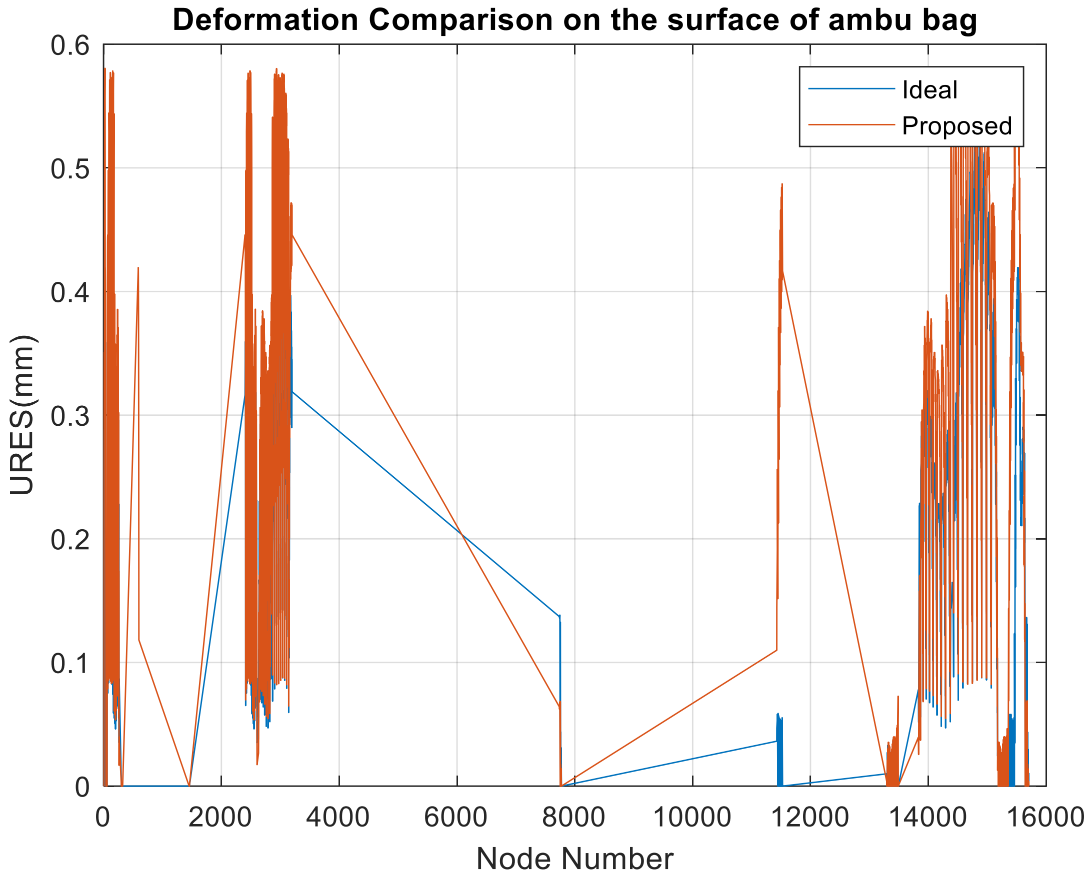
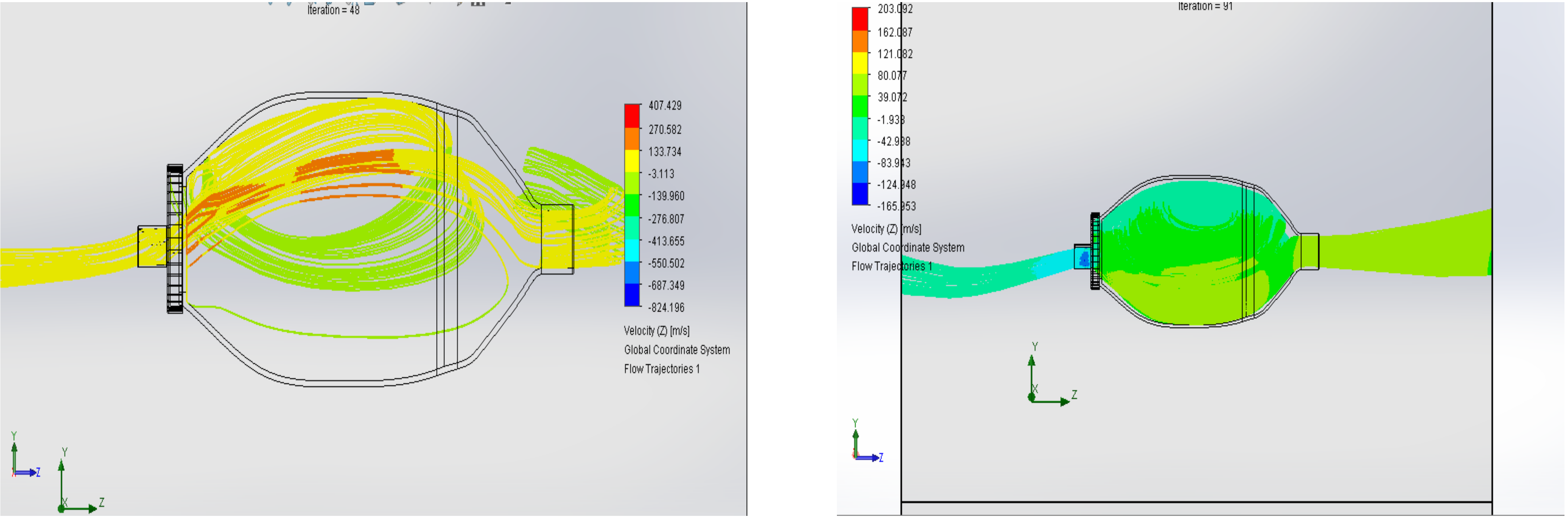


Fig. 15. URES deformation Comparison between traditional two side pressed MV (blue) and proposed MV model (Red)

Node Deformation Analysis Summary:

- Stepwise Straight Line
- Intermediate Node Deformation
- Majority Experiences Greater Deformation
- Nodes 4000 to 8000: Drastically Linear Fall
- Nodes 8000 to 12000: Comparatively Slower Linear Rise
- Node 12000: 90 Degree Rise

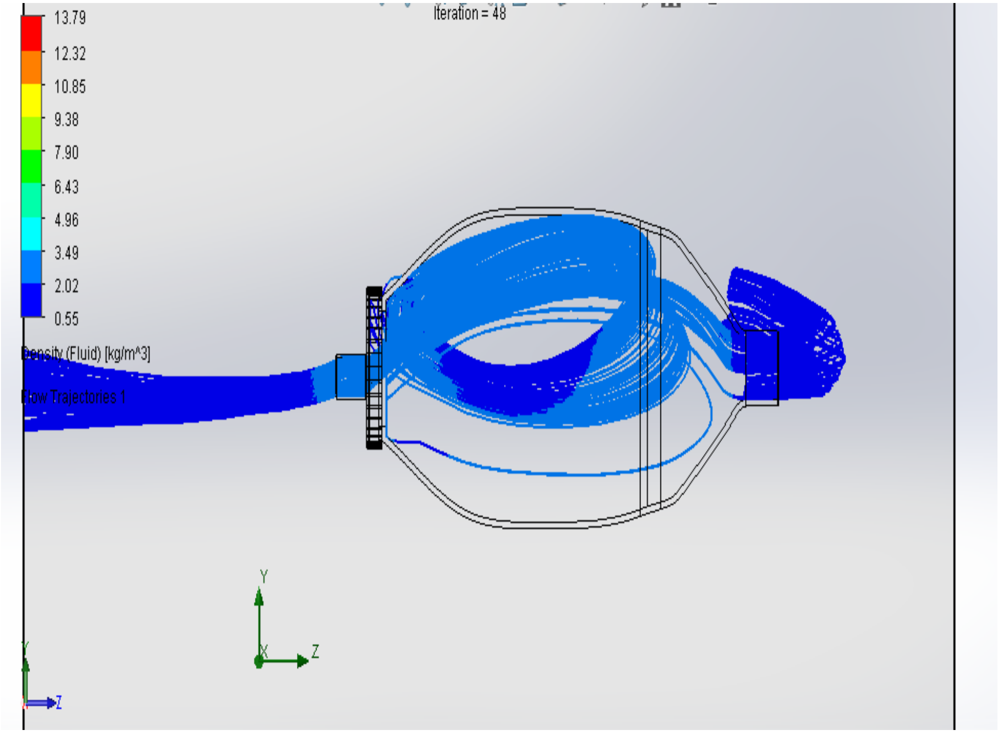
Result: CFD: Flow velocity



(a) (b)

Fig. 16. Flow Velocity Comparison between (a) traditional two side pressed MV and (b) proposed MV model

Result: CFD: Fluid Density



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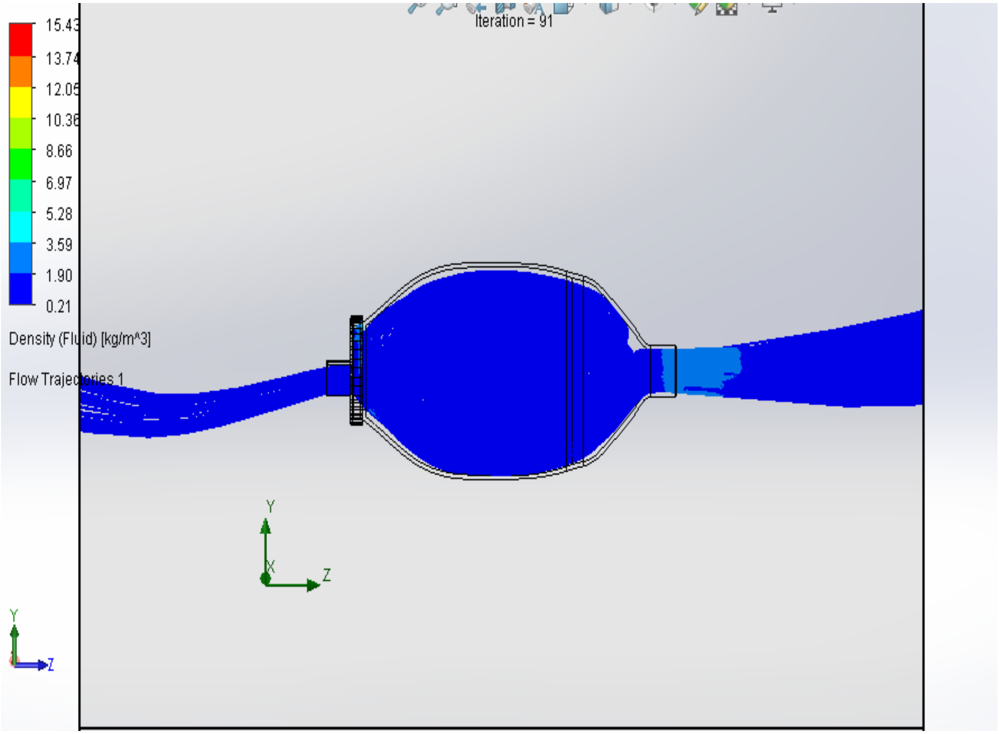
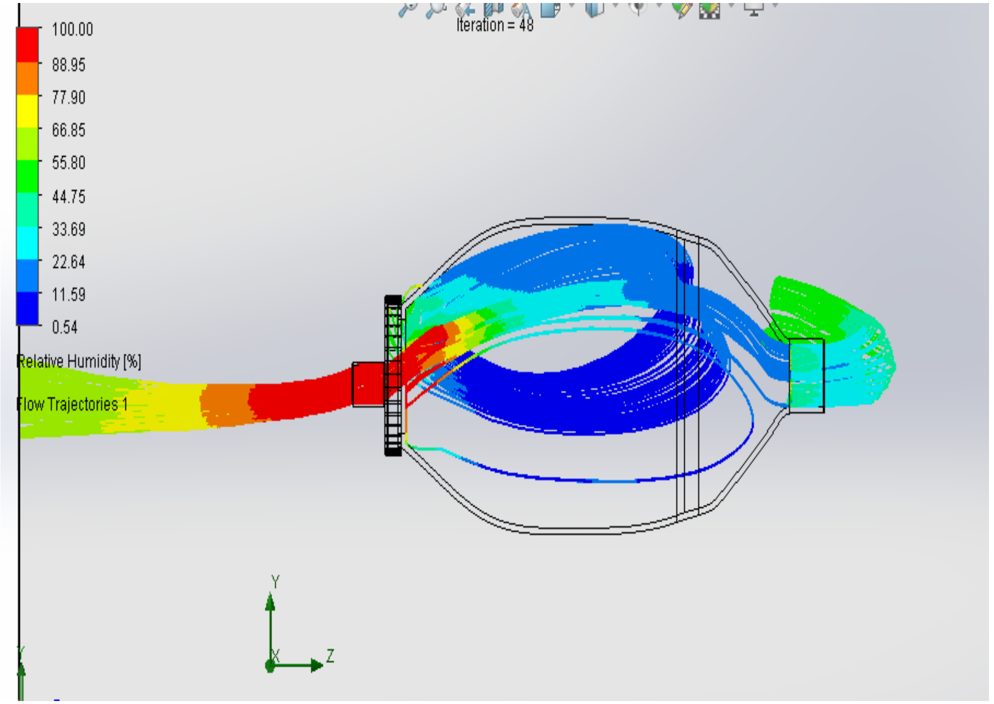


(b)

Fig. 17. Fluid Density comparison between (a) traditional two side pressed MV and (b) proposed MV model

Result: CFD: Relative humidity



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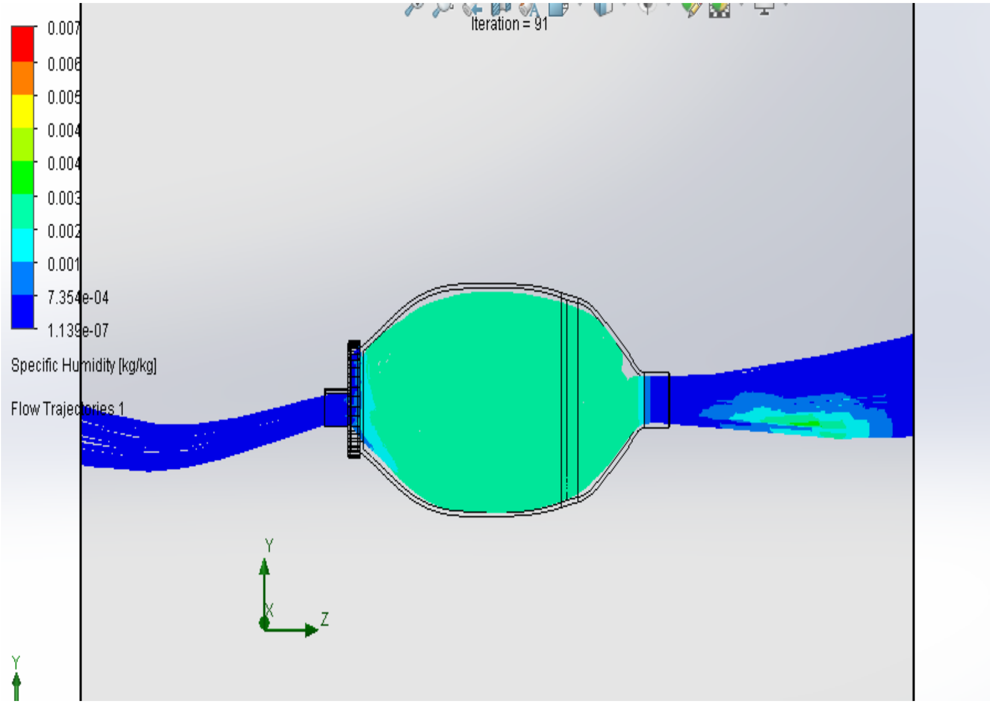
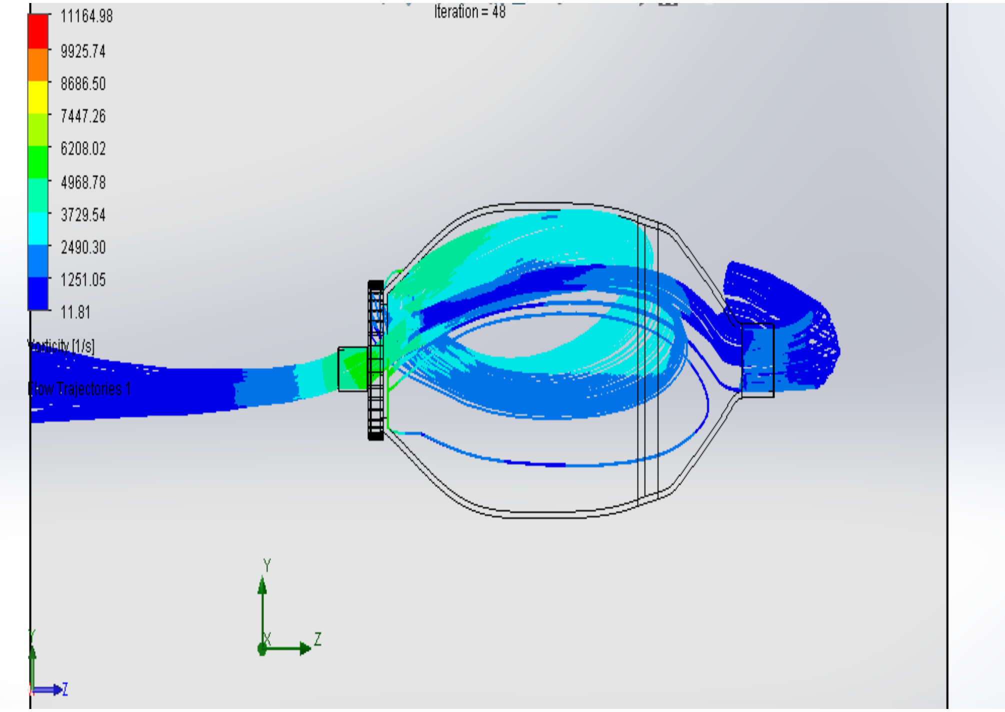


(b)

Fig. 18. Relative humidity comparison between (a) traditional two-side pressed MV and (b) proposed MV model

Result CFD: Fluid vorticity



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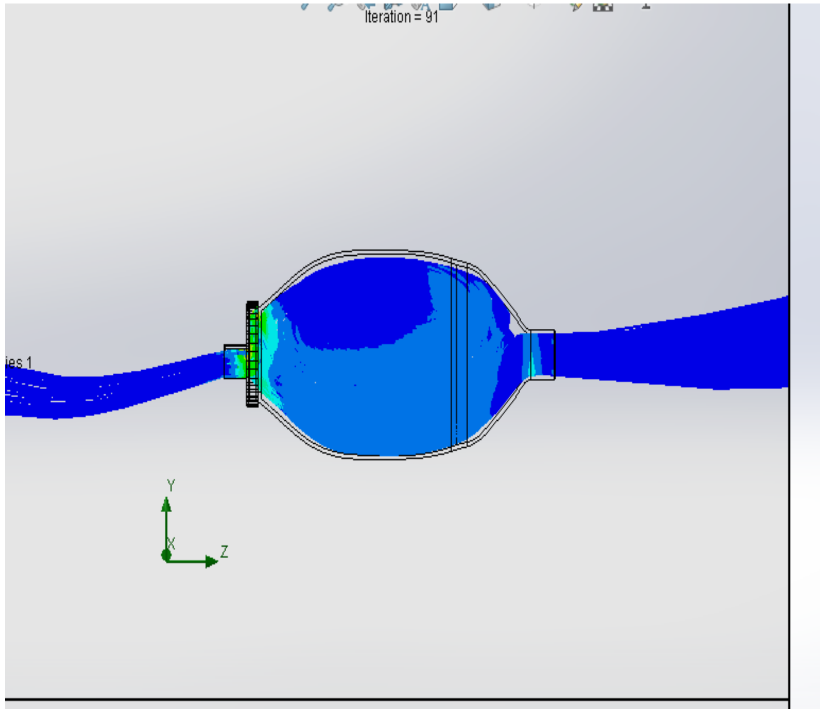
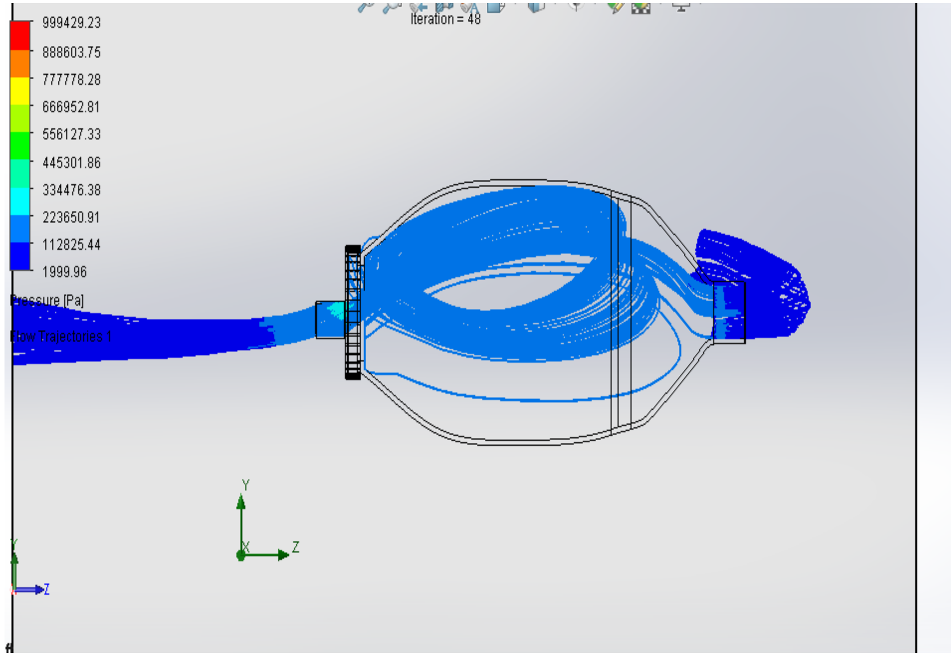


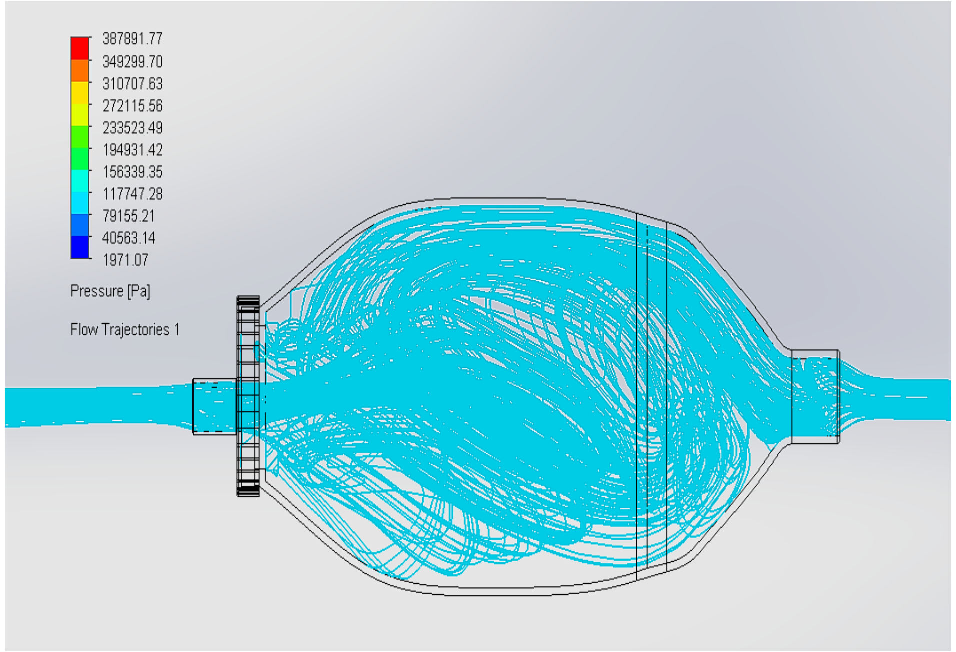
(b)

Fig. 19. Fluid vorticity comparison between (a) traditional two-side pressed MV and (b) proposed MV model along the z-axis

Result CFD: Fluid Pressure



(a)



(b)

Fig. 20. Fluid pressure comparison between (a) traditional two side pressed MV and (b) proposed MV model

Result CFD: Fluid Pressure

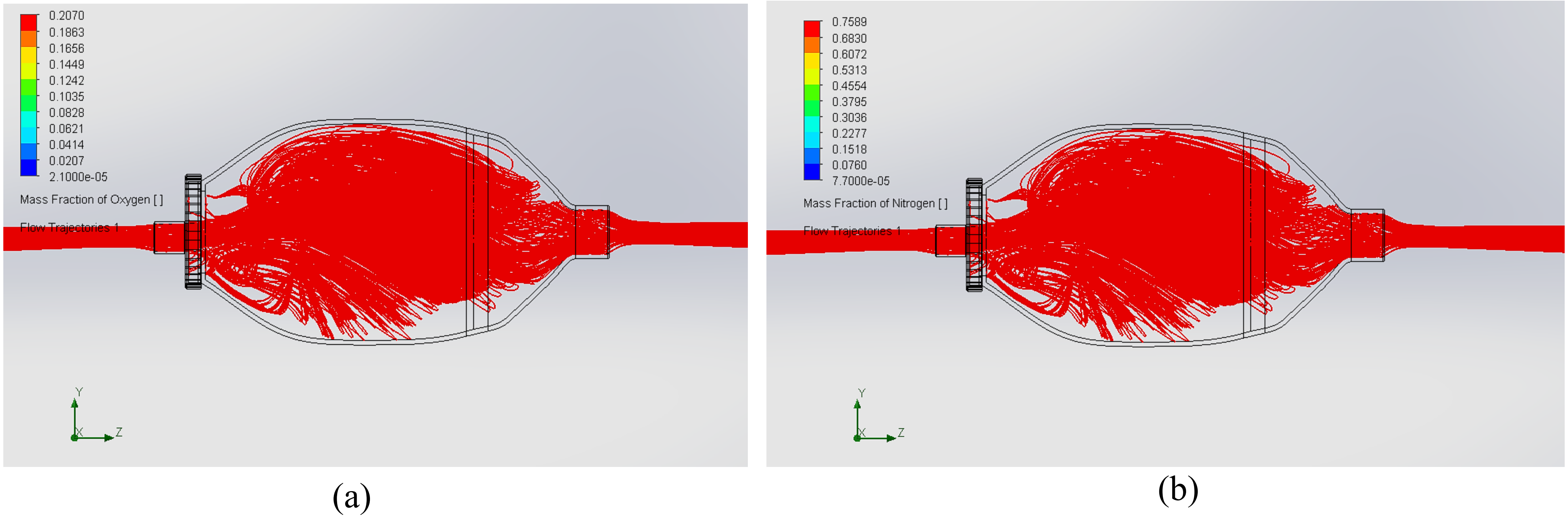


Fig. 21. Mass fraction of proposed MV model (a) Oxygen and (b) Nitrogen

Result: CFD: Fluid Pressure

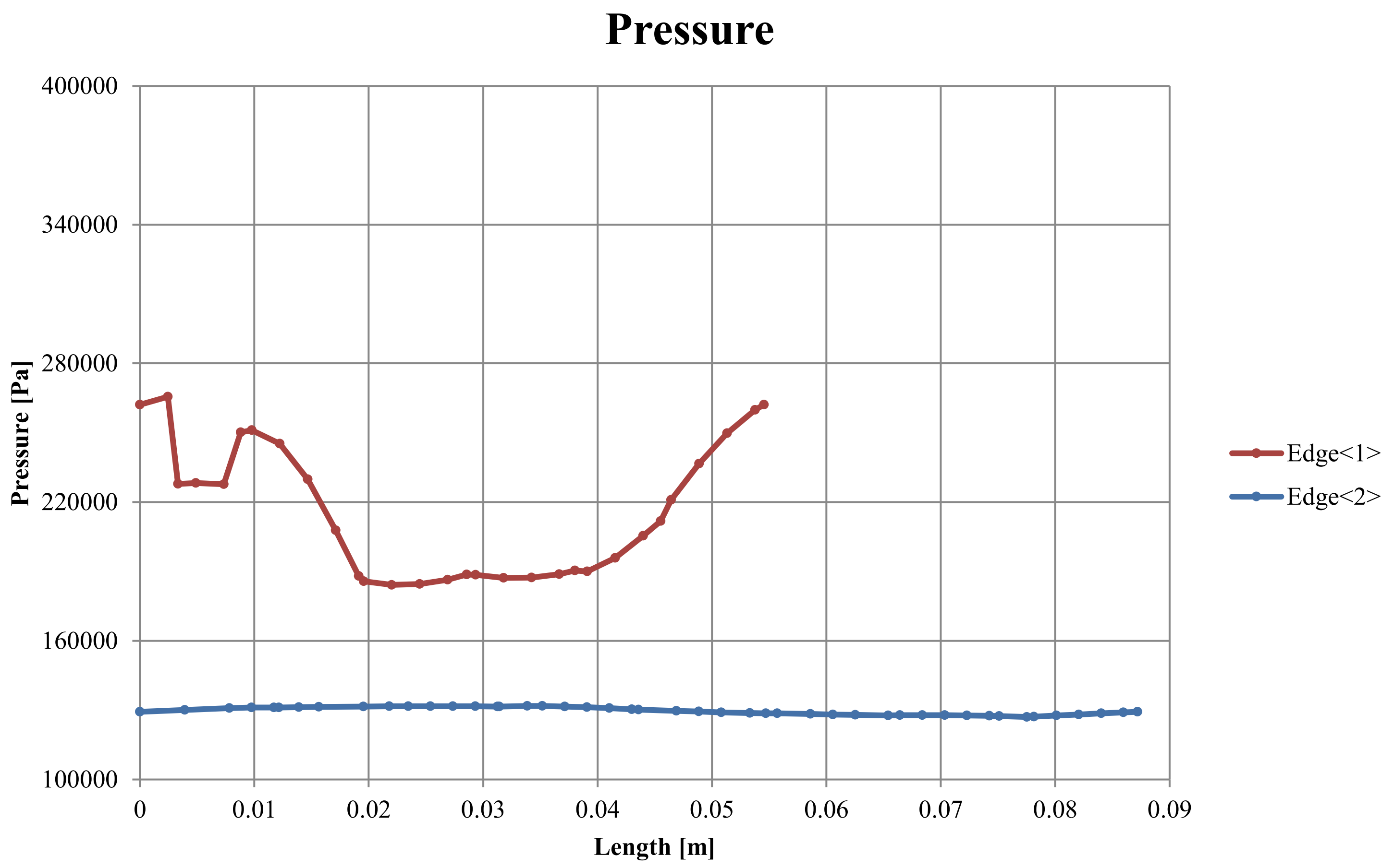


Fig. 22. Air Pressure Comparison of the proposed MV model between Outlet (blue) and Inlet (Red)

Result: Implemented Device: Outlet pressure

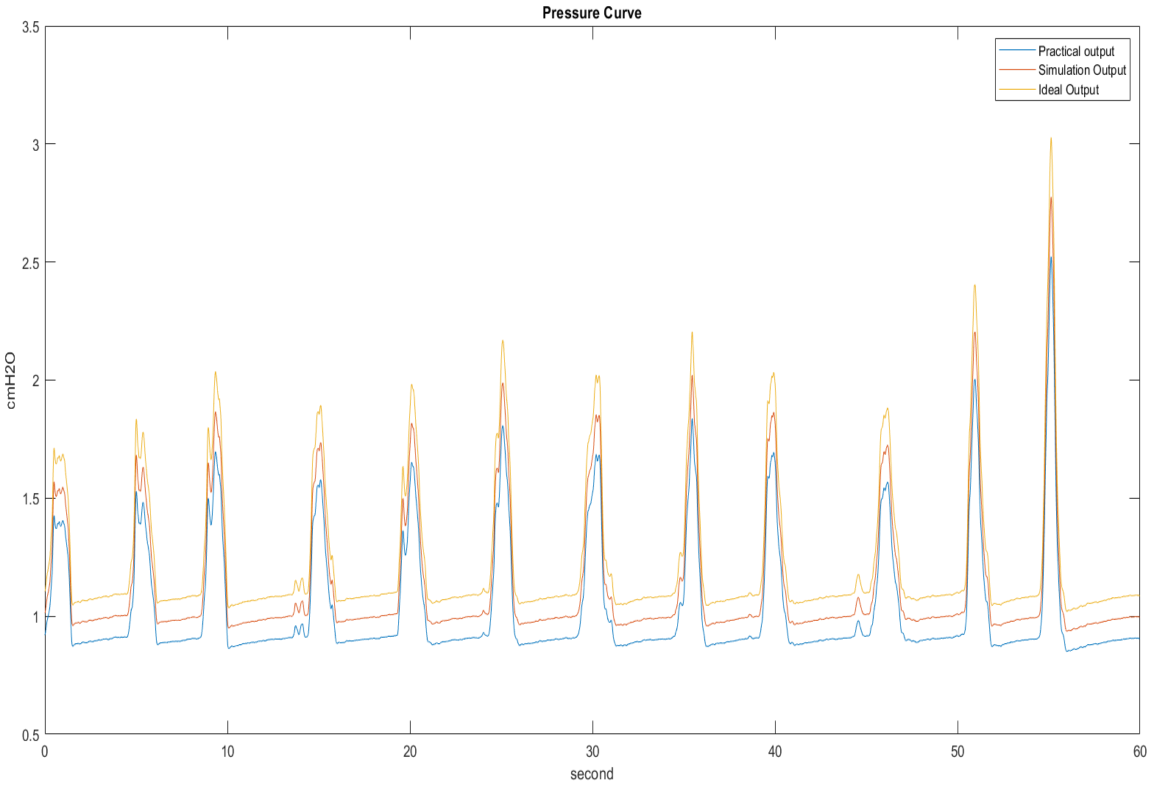


Fig. 23. Implemented MV Air Pressure (blue) Comparison with normal case (orange) and simulated result (red)

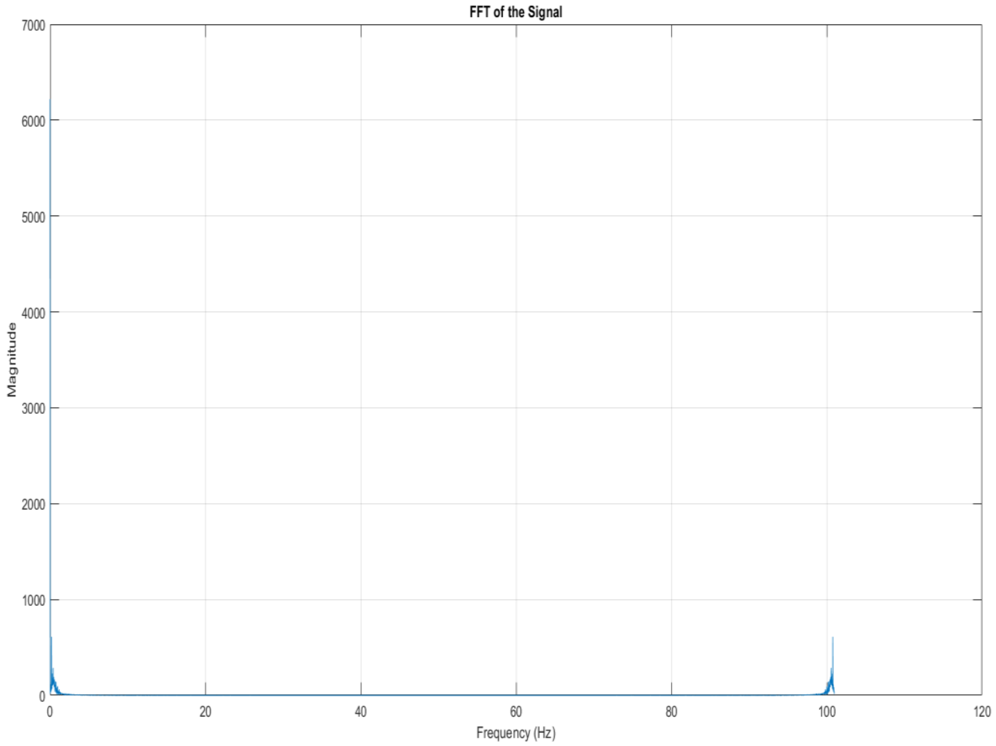


Fig. 24. FFT of outlet pressure curve

Result: Implemented Device: air volume

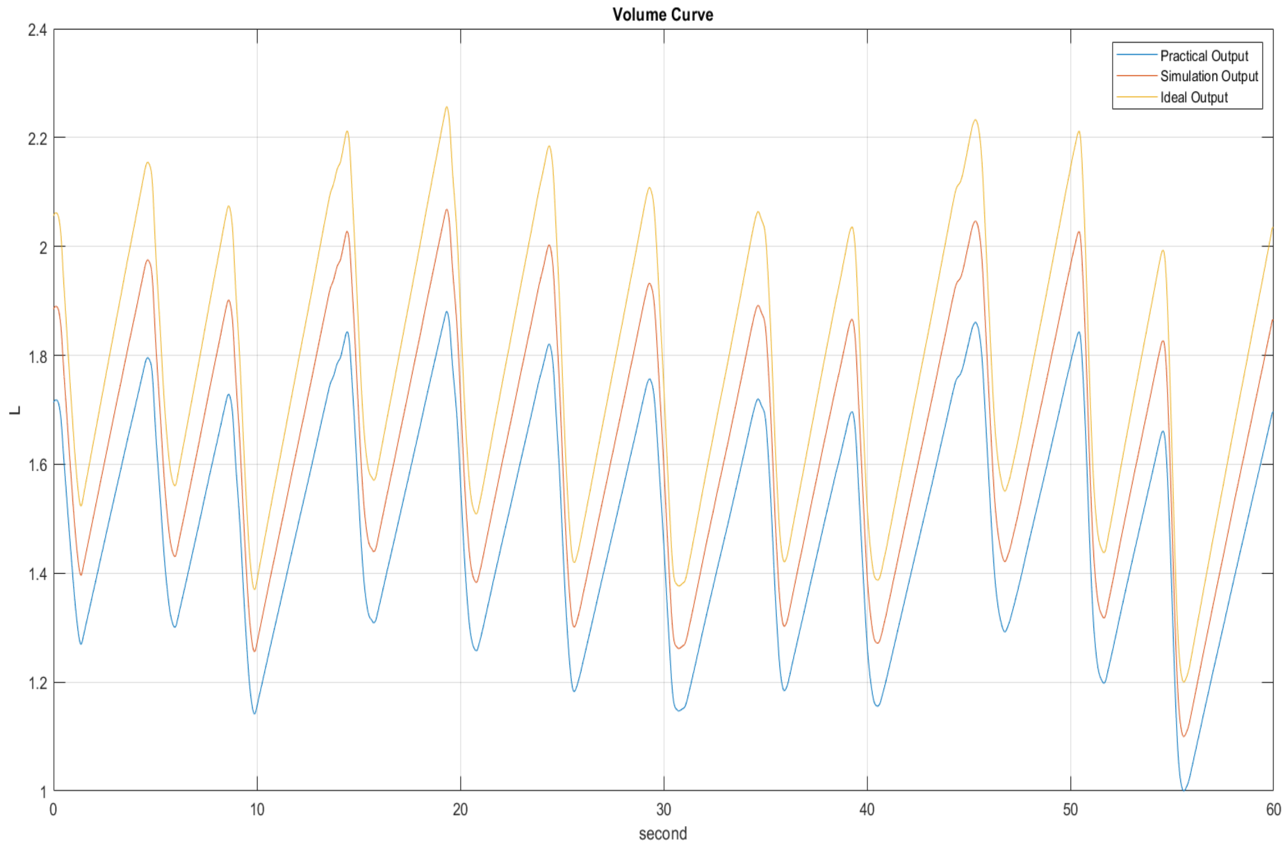


Fig. 24. Implemented MV Air Volume (blue) Comparison with normal case (orange) and simulated result (red).

Result: Implemented Device: Air FLOW Rate

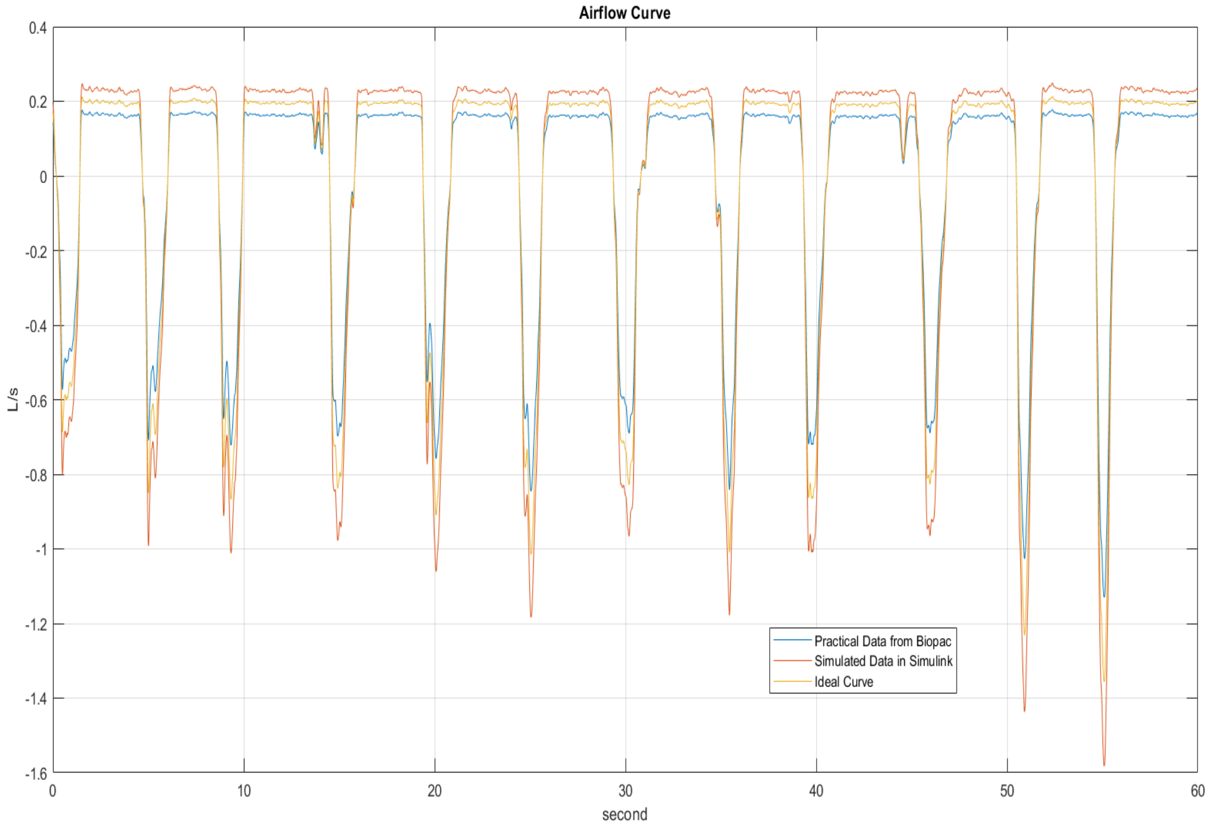


Fig. 26. Implemented MV Air flow rate (blue) Comparison with normal case (orange) and simulated result (red)

Result: Integrated

Parameter	Max Value extracted from implemented device
Pressure	3 cmH_2O
Volume	1.2 L /breathe
Airflow Rate	12.6 L/min

Result: Accuracy

Add table name:

Analysis name	Accuracy with respected to ideal result	Accuracy with respected to simulated result
Pressure Analysis	95.32	97.21
Volume Analysis	92.12	95.61
Airflow Analysis	94.09	96.31
Average	93.84	96.37

Conclusion

- Thesis model outperforms previous research.
- Mechanical study shows better load handling capacity than traditional both sides pressed ambu bag-based MV.
- Motion study shows better dynamics and motor performance in the output.
- CFD shows a better fluid flow profile through the ambu bag almost in every case.
- The implemented device has gained 93.84 % accuracy according to the physiological ideal value.
- The implemented device has gained a 96.37% success rate in implementation for the simulation study.

References

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[6] H. Lewith and J. J. Pandit, “Lung ventilation and the physiology of breathing,” *Surgery (Oxford)*, vol. 38, no. 5, pp. 233–239, May 2020.

Thank You