Journal of Applied Science, Engineering and Technology
e-ISSN: 2722-8363 p-ISSN: 2722-8371
DOI: 10.47355/ASET.V1I2.16

J. ASET

Development of Lung Ventilator for the Treatment of COVID-19 Patient in Indonesia

Putra Adnan Fadilah[1,*], Febriyan Prayoga[2], and M. Triprabowo M[3]

[1] Department of Aero-Propulsion Analysis, Chroma International, Jalan Galunggung No. 37 Bandung 40263, Indonesia

[2] Department of Aero-Structure Analysis, Chroma International, Jalan Galunggung No.37, Bandung 40263, Indonesia

[3] CTO, Chroma International, Jalan Galunggung No.37, Bandung 40263, Indonesia

* Correspondence: putra@chromaintegrated.com

Received: 23.06.2021; Accepted: 22.10.2021; Published: 31.12.2021

Abstract: Development program of local ventilator component, respiratory flow meter (RFM), respiratory blower fan (RBF), and positive end expiratory pressure (PEEP) valve are the main part of contribution to support medical team during COVID-19 virus outbreak that start on March, 2020 in Indonesia. In the COVID-19 pandemic era ventilator become necessary thing to treat Covid patient especially for worst cases patient. With increasing in people who infected by COVID-19 around the world and also in Indonesia, caused the demand of the ventilator system also increased significantly. In Indonesia many research institution and universities have been initiated to develop the emergency ventilator to support the increasing demand. Some companies in Indonesia initiate to develop the component of the lung ventilator to support other research institution therefore to minimize dependency from import product which is in the pandemic era the component such as flow meter and blower fan is difficult to get caused by stock limitation. In this paper we expose the process on development of three essential component part of the lung ventilator, i.e., respiratory flow meter (RFM), respiratory blower fan (RBF), and positive end expiratory pressure (PEEP) valve. The development of these components is using a standard design procedure and utilized with some design software for obtaining the optimum design result.

Keywords: lung ventilator; respiratory flow meter; blower fan; PEEP Valve; COVID-19.

1. Introduction

Development of lung ventilator component (Respiratory Flow Meter, Respiratory Blower Fan, and PEEP Valve) based on the increasing demand of respiratory device that commonly known as ventilator. COVID-19 virus outbreak that increase the demand of ventilator device not only in Indonesia but also around the world [1]. Chroma International as engineering company triggered to support the demand by develop ventilator components such as flow meter and blower fan. Flow meter system in the ventilator device is essentially needed to control and monitoring the air flow through to the patient. We are also developed blower fan as component part of CPAP ventilator, as presented on Fig. 1.

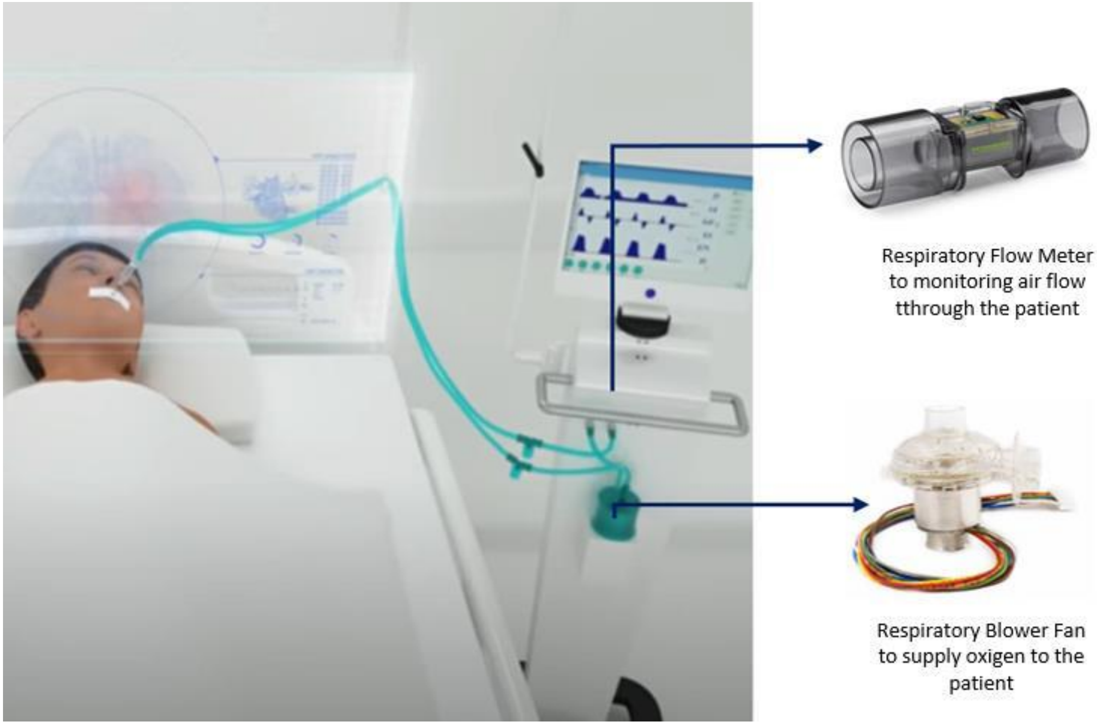

Figure 1. Illustration of RMF and RBF usage to the COVID-19 Patient

The flow meter is a device that use to monitoring the air flow that supply to the patient. In this development Chroma International use two model of flow meter, the first model is venturi-based and the second one is orifice based, as presented on Fig. 2.

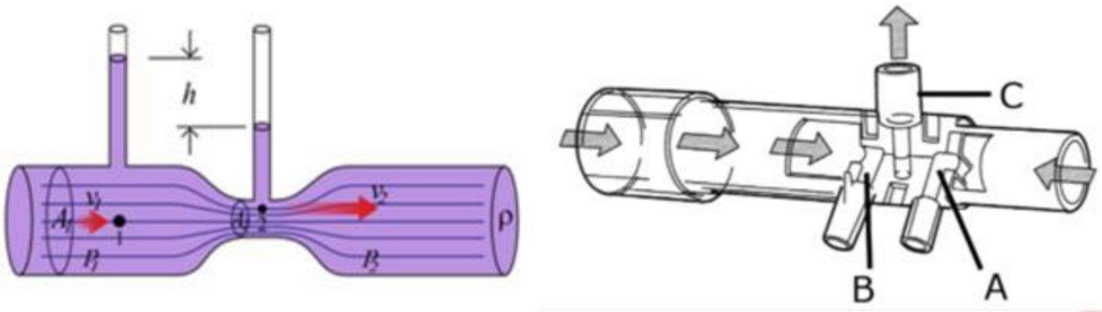

Figure 2. Venturi based flow meter (left) and orifice-based flow meter (right)

Venturi based flow meter using Bernoulli law basic that the fluid flow can be derive from pressure difference at the two station that have two difference velocity [2]. Venturi based flow meter using gradual difference area to produce difference pressure for orifice-based flow meter using step area difference to make pressure loss / pressure difference at the pressure tap. In the orifice flow meter based on flow enter the flow meter through section B to measure the static pressure and at the station A will be measured total pressure.

The difference between station A and B will give dynamic pressure that proportional to air flow velocity. Station C is used for additional sensor to measure Oxygen (O_2) and Carbon dioxide (CO_2) level. Equation (1) to (3) are the standard equation for designing flow meter.

$$Q = v_1 A_1 = v_2 A_2 \tag{1}$$

$$P_1 - P_2 \frac{P}{2}\left(v_2^2 - v_1^2\right) \tag{2}$$

$$Q = A_2 \sqrt{\frac{2(P_1 - P_2)}{\rho\left(1 - \left(\frac{A_s}{A_1}\right)2\right)}} = A_2 \sqrt{\frac{2}{\rho\left(1 - \left(\frac{A_2}{A_1}\right)2\right)}} * \sqrt{\Delta P} \tag{3}$$

The respiratory blower fan (RBF) that is developed by us aim to support the massive development of emergency ventilator in Indonesia due to COVID-19 virus outbreak. RBF basically is a flow supply device that using standard radial blade commonly known as centrifugal flow pump [3]. In the medical device component, RBF usually used as oxygen pump. Chroma designed RBF beside being used as oxygen flow pump not rule out the possibility to be used as a substitute for ambu-bag, as presented on Fig. 3.

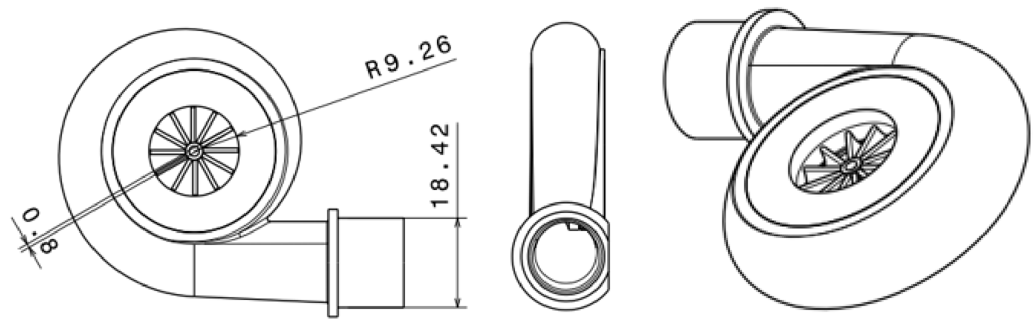

Figure 3. Design of the respiratory blower fan (RBF)

The blower blade design using standard design procedure to obtain the optimal geometry of the blower blade [3-4]. Equation and relation that used to make initial model of the blower blade (see Fig. 4) and based on the calculation using equations (4) to (12) below.

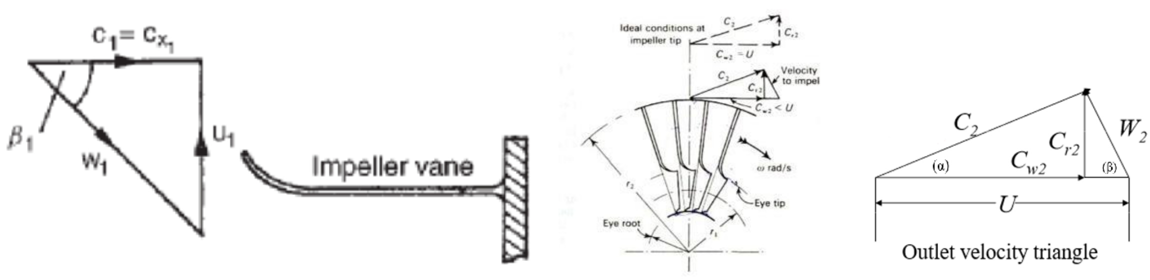

Figure 4. Basis Calculation for Respiratory Blower Blade

The flow angle (β1) at hub is denoted by: $\beta_h = \tan^{-1}\left(\frac{2\pi r i_h N}{C_1}\right)$ (4)

The flow angle (β2) at hub is denoted by: $\beta_t = \tan^{-1}\left(\frac{2\pi r i_h N}{C_1}\right)$ (5)

For the initial calculation may by take assumption: $C_1 = C_{r2}$,

Therefore, the velocity at impeller exducer can be derived as: $C_{w2} = \sigma U$

Where, σ, is slip factor in the initial design value of the slip factor between 0.8-0.9.

Hence that, it can be written as follow: $U = \pi\, r_e\, N$ (6)

For the predicting of flow angle entering diffuser, we can use the equation;

$$\alpha = tan^{-1}\left(C_{r2} / C_{w2} \right) \quad (7)$$

Another geometry parameters that can be calculated by initial design equation is depth of the exducer, by using this following equation and relations; $b = A/\pi\, De$ (8)

where,

$$A = \text{mass flow rate} / \rho_2\, C_{r2} \quad (9)$$

$$\rho_2 = P_2 / RT_2 \quad (10)$$

For the density and static pressure at impeller exduer obtained by parametric cycle calculation using aero-thermo relation. For calculating the blade number, we can use approach equation as following;

$$\sigma = 1 - \frac{0.63\, ^{\pi}/_{Z}}{1 - \emptyset 2 tan^{-1} \beta_2} \quad (11)$$

where,

$$\emptyset = C_{r2} / U_2 \quad (12)$$

2. Materials and Methods

The methodology that used in this study is numerical methodology using CFD (Computational Fluid Dynamic). CFD is used to predict the performance of RFM and RBF. For RFM design methodology, in the first step design of the flow meter obtained from standard venturi design then the initial design converts in to 3D model with CAD software. The 3D model then calculated using CFD with input of various mass flow rate. Result of the simulation will compare the pressure difference of the pressure tap convert to the mass flow rate and mass flow rate that input as simulation boundary condition. For designing RBF (Respiratory Blower Fan), use almost same procedure, first the geometry requirements is obtained by make comparison study with another typical respiratory blower that has already on the market. To make initial concept of the blower (blade and volute) use standard analytical calculation to get the initial model. Initial concept of the design blower than convert in to 3D model. Three-dimensional model of the designed blower is simulated with CFD to predict the initial performance. Optimization is done to obtain the most optimum design for RMF and RBF.

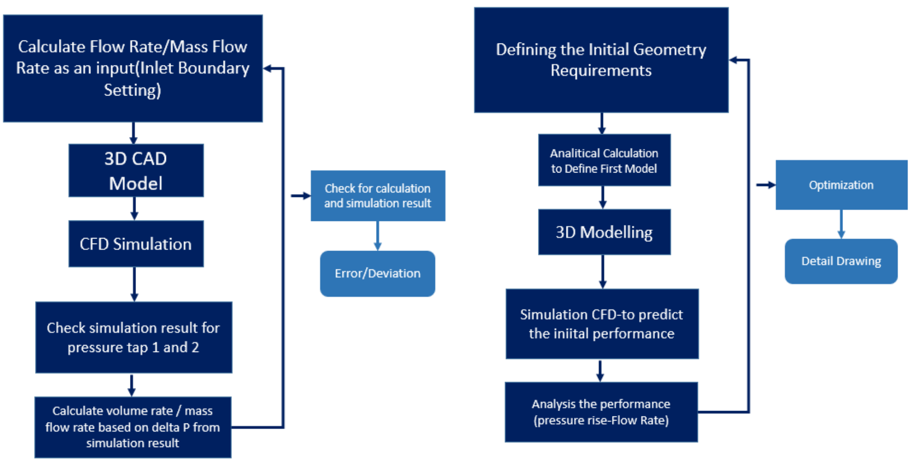

Figure 5. Chart diagram of the design process for RFM (left) and RBF (right)

2.1 Model Geometry Respiratory Flow Meter

The geometry model is build using CAD software to make the 3D model for respiratory flow meter. The respiratory flow meter build in the two difference models [2,4]. As previously described that the company develop two type respiratory flow meter, venturi based and orifice based. The 3D CAD model is depicted in the Fig. 6 and 7.

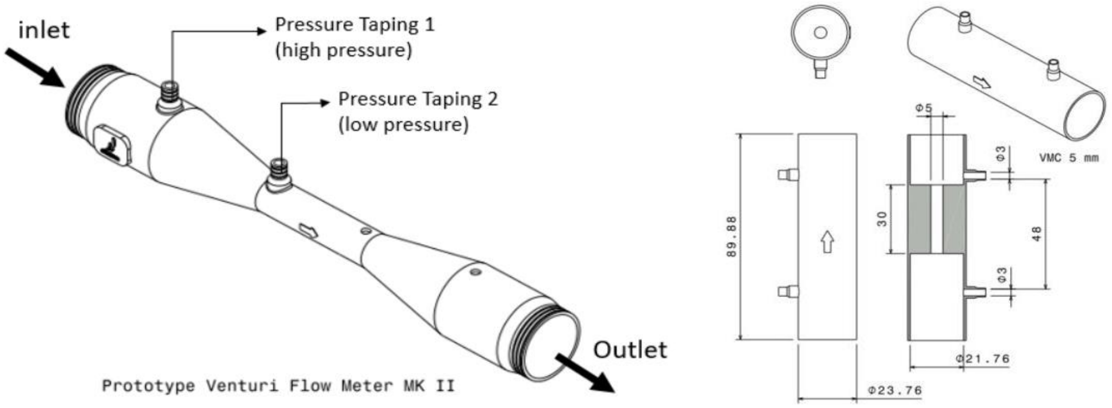

Figure 6. 3D Model of RFM (model venturi based (left) and orifice based (right)

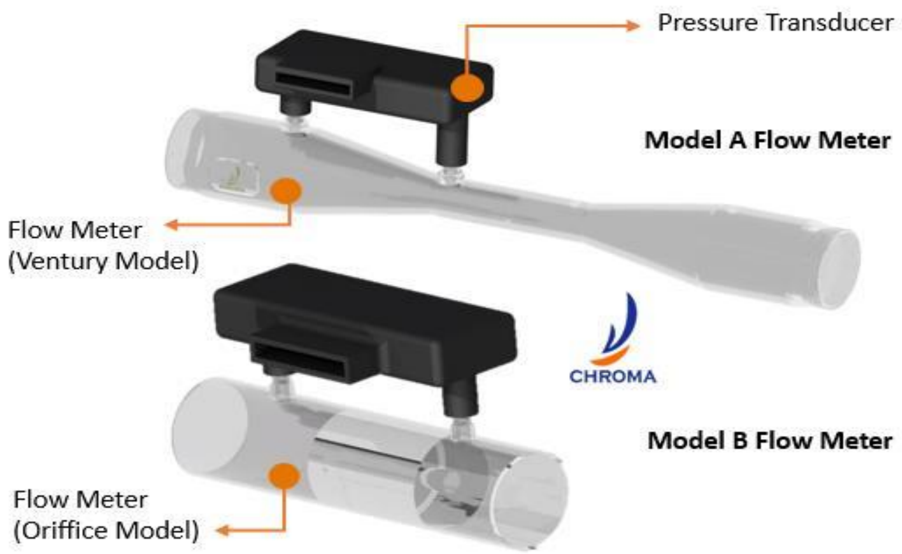

Figure 7. Model RFM with pressure transducer developed by Chroma International

2.2 Model Geometry Respiratory Blower Fan

Same with RFM, the Respiratory Blower Fan (RBF) build in various model to assess which one is give the best result. For the RBF there are three models of blade that develop. The difference blade model is obtained using CFD based optimization. The blade model consists of radial blade model and backswept blade model, as on Fig. 8 and 9.

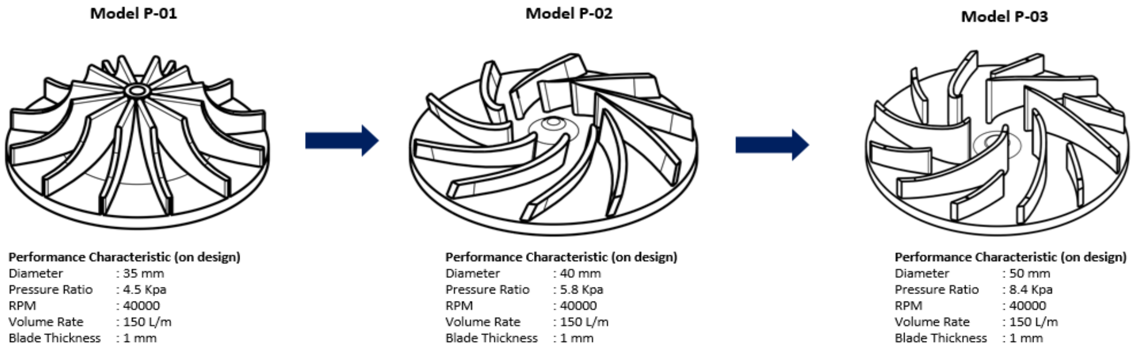

Figure 8. Variation of Blower Blade that has been developed

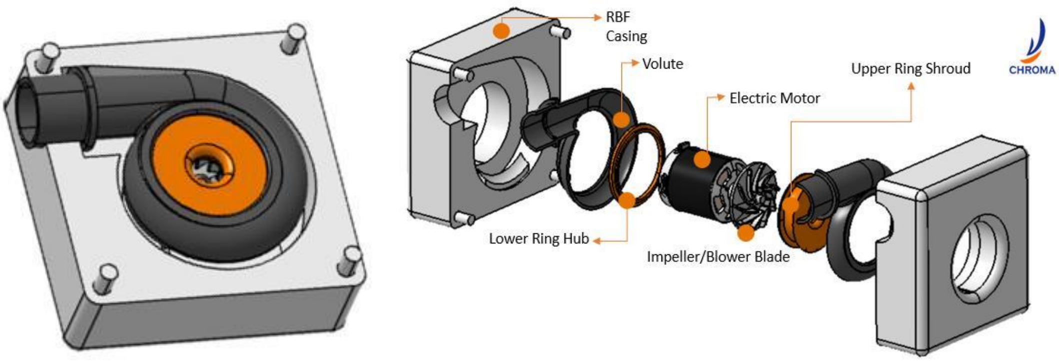

Figure 9. Prototype and the complete part of developed RBF

2.3 CFD Simulation

CFD (Computational Fluid Dynamic) simulation was used to predict the characteristic performance both of RFM and RBF. With CFD it can be obtained the best result of the design. For the RFM, simulation is quite simple only check the pressure difference at the two pressures tap at designed flow meter. For the RBF simulation conducted in the two steps, first for the blower blade, and the final simulation is for the full configuration with volute included in the domain. For the RBF simulation, using double domain to modelling the flow through the blower blade then flows in the volute, as on Fig. 10 and 11.

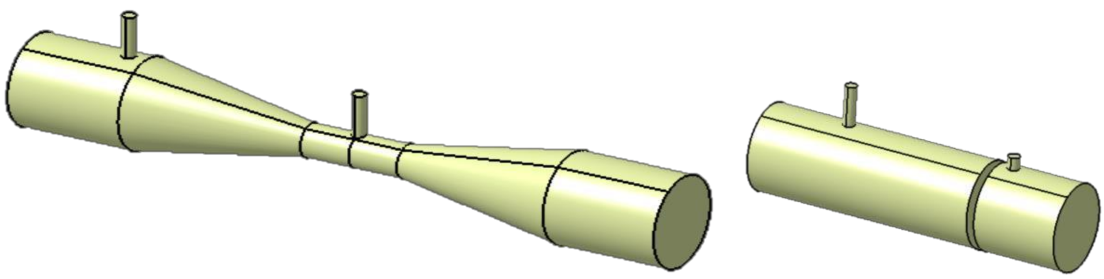

Figure 10. Domain simulation for the respiratory flow meter (venturi based (left) and orifice based (right)

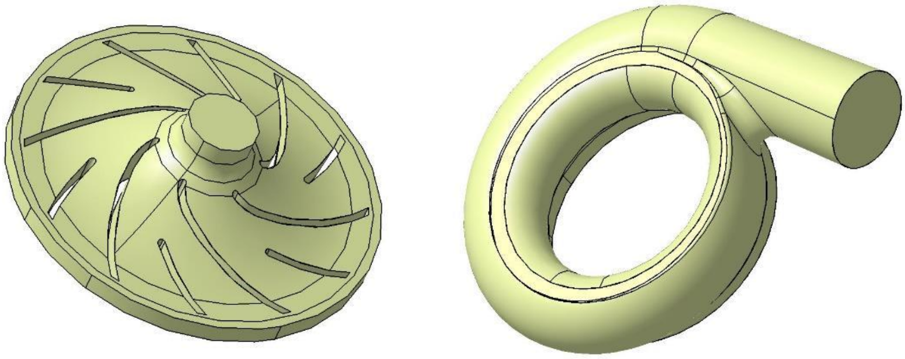

Figure 11. Domain Simulation for Chroma Respiratory Blower Fan

2.4 CFD-Simulation setting and the Boundary condition

The CFD simulation setting was dedicated for the RFM and RBF is mostly difference. For the RFM the simulation setting is very simple just set the input mass flowrate at the inlet and set the outlet condition. RBF simulation setting relatively have more complex setting caused of it has double domain configuration. Double domain configuration use to model the rotational flow around the blower blade and stationary flow when the fluid through the volute domain. The RBF simulation setting require RPM input, information about center rotational axis, and information about where the interface is defined in the geometry model.

The boundary condition of this simulation divided by the condition for RFM (Respiratory Flow Meter) and for RBF (Respiratory Blower Fan). Boundary Condition for the Respiratory Flow Meter as follow:

Inlet condition : Mass flow rate at the inlet surface
Wall : Default setting (smooth condition)
Outlet condition : Average static condition (using standard atmospheric condition)

While the Boundary Condition for Respiratory Blower Fan as follow:

Inlet condition : Mass flow
Wall : Default setting for shroud, hub, blade, and volute
Outlet condition : Average static condition (using standard atmospheric condition)
RPM : for the blower blade (vary from 20000-40000 RMP)

2.5 Convergence Criteria

The used criteria of convergence in the simulation is residual growth of mass and momentum as shown in Figure 14. The residual is one of the most fundamental measures of an iterative solutions convergence, as it directly quantifies the error in the solution of the system equation. In a CFD analysis, the residual measures the local imbalance of a conserved variable in each control volume. For complicated problems, however, it is not always possible to achieve residual levels as low as -6 (global residual scale in NUMECA).

However, if the global residual curve cannot reach certain low level, the convergence of the simulation still can be assessed by monitoring integrated quantities such as force, drag, mass flow or average temperature, the simulation is convergence when the integrated quantities value is not much. Fluctuate anymore. Figure below shown the convergence history of integrated quantities that represented by mass flow, as on Fig. 12.

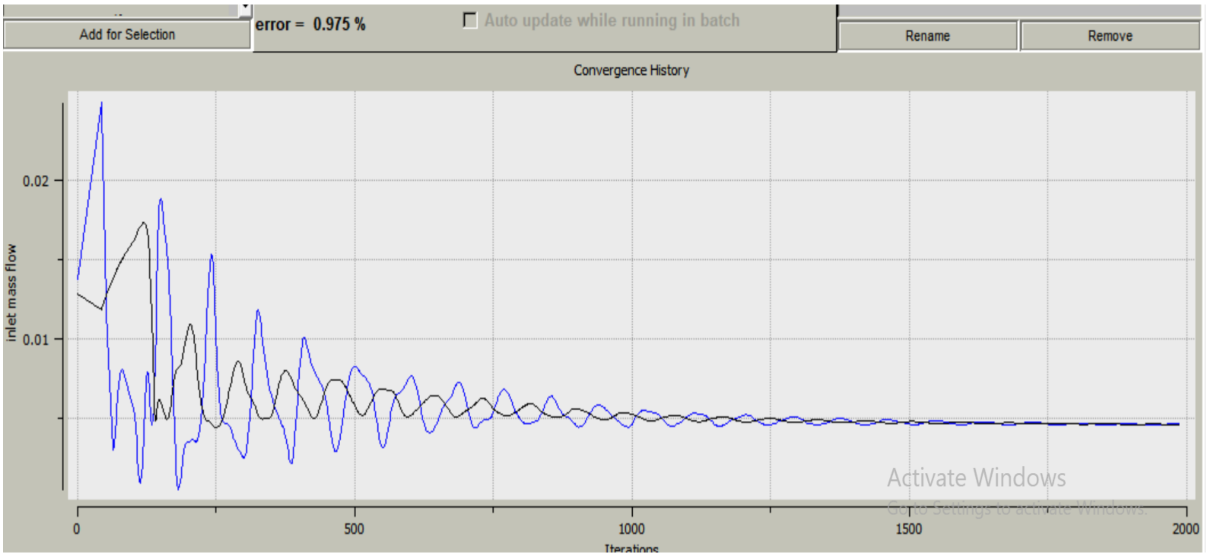

Figure 12. Convergence History Curve of CFD Simulation

3. Results

In this section will be discuss about the simulation result from RFM and RBF. For the simulation result will be depicted as table and curve prediction performance.

3.1 Respiratory Flow Meter

Respiratory flow meter is simulated with various mass flow rate to assess the linearity of the differential pressure measurement. Here is the table and curve performance of the designed respiratory flow meter, as on Table 1 and 2 below.

Table 1. RFM Venturi Based Simulation Result

Input	**Calculated**				Error Deviation (%)
Volume Rate (L/min)	P Tap 1	P Tap 2	Delta P (Pa)	Volume Rate Based on Delta P (L/min)	
2	0.1377	-0.1393	0.277	2.046	2.1
4	0.4243	-0.6529	1.0727	4.026	0.7
6	0.7976	-1.565	2.3626	5.964	0.9
8	1.336	-2.853	4.189	7.92	0.9
10	2.165	-4.449	6.614	9.96	0.1

Table 2. RFM Orifice Based Simulation Result

Input	Calculated				Error
Volume Rate (L/min)	P Tap 1	P Tap 2	Delta P (Pa)	Volume Rate Based on Delta P (L/min)	Deviation (%)
2	3.376	-1.526	4.902	2.376	16.4
4	12.94	-0.6057	13.54	3.942	2.1
6	31.55	-1.201	32.75	6.18	3.4
8	43.43	-2.181	45.61	7.26	8.3
10	67.43	-3.309	70.74	9.06	9.6

In the figure below depicted the predicted flow meter measurement curve (Fig. 13).

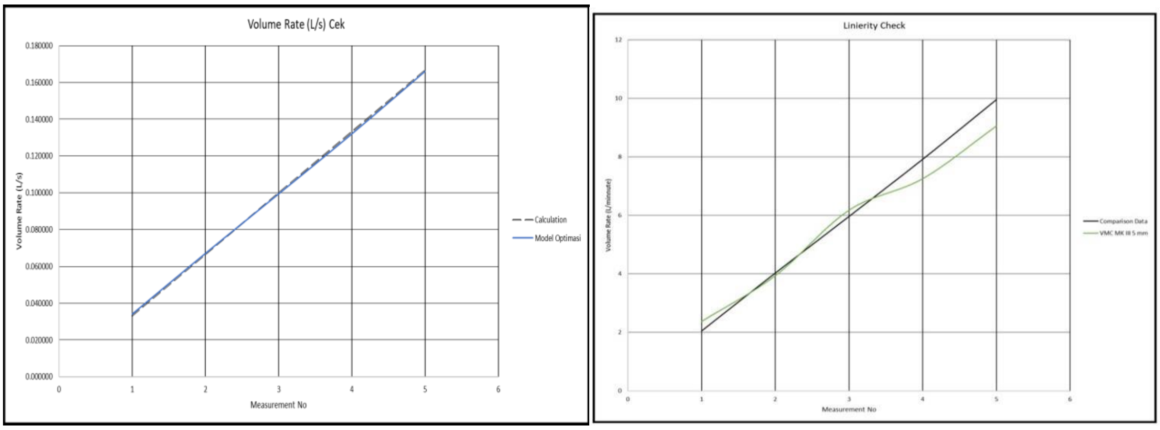

Figure 13. Comparison Between Ventury Based Flow Meter and Orifice Based Flow Meter

3.2 Respiratory Blower Fan

Here is the simulation result of the various model of blower blade that will be applied on respiratory blower fan model design [5]. Simulation is done using NUMECA FINE/Turbo kind of dedicated software for turbomachinery platform. Monitoring is done by compare the inlet and outlet of the mass flow, simulation is convergence when the deviation between inlet and outlet around 1%, as on Fig. 14.

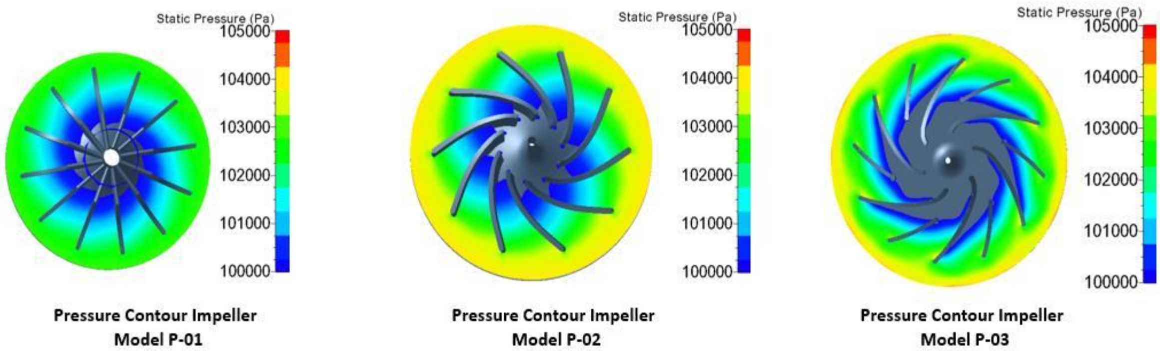

Figure 14. Power-On CFD Simulation Domain Area

In the blower blade simulation, the setting of the impeller (blower blade) is set up with various RPM start from 30000-40000 RPM. The predictive performance of the full configuration blower fan is depicted in the figure 15 and 16.

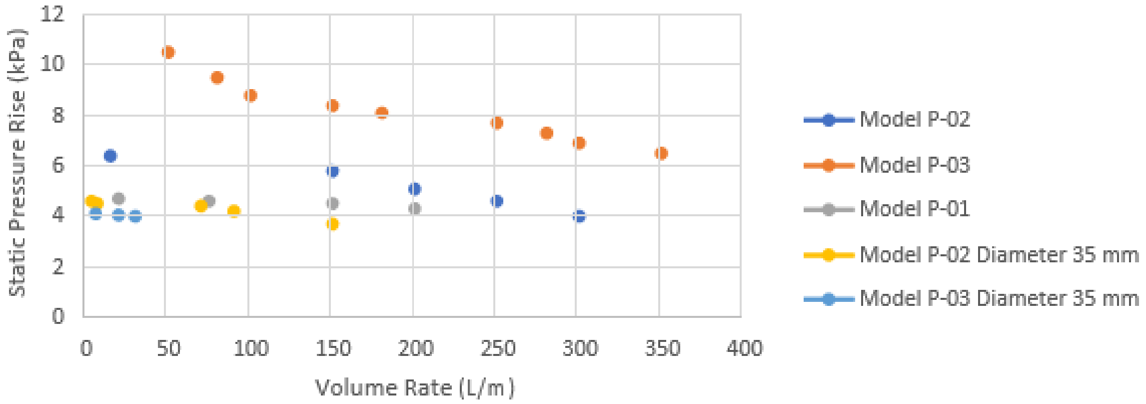

Figure 15. Blower Blade Predictive Performance Curve

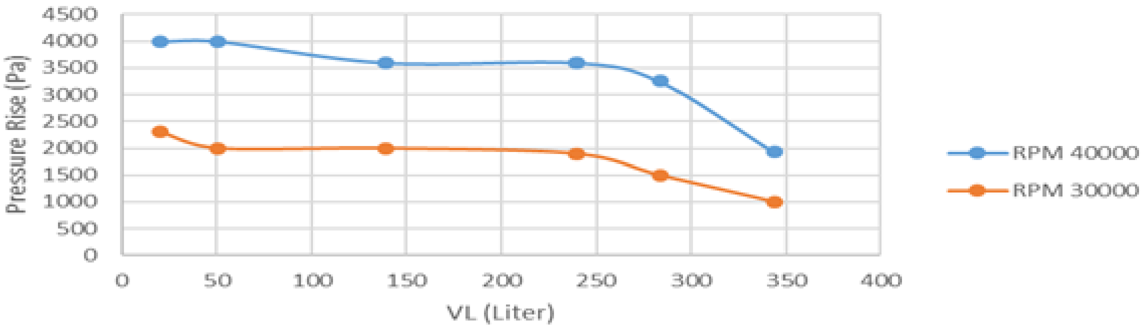

Figure 16. Full Configuration Performance Curve for Model P-02 Blower Blade

4. Discussion

Here is the prototyping of respiratory flow meter and respiratory blower fan designed by Chroma International. Using 3D print SLA technology to make smooth and precision result of the prototype as on Fig. 17 and 18.

Figure 17. Respiratory Blower Fan (RBF) prototype

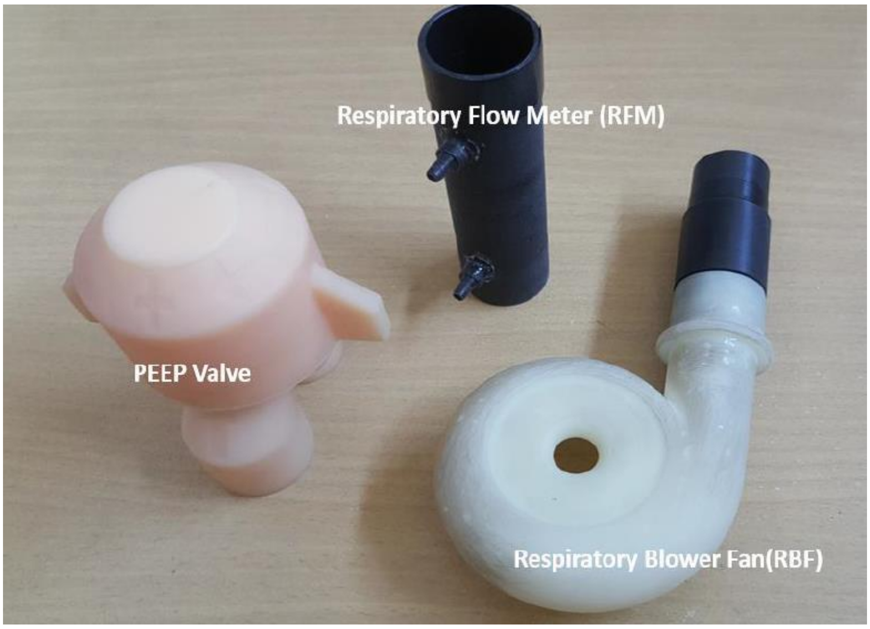

Figure 18. Prototype of RFM, RBF, and PEEP Valve that has been developed

This study shows a potential development of three essential component part of the lung ventilator for Covid-19 diseases treatment, they are: respiratory flow meter (RFM), respiratory blower fan (RBF), and positive end expiratory pressure (PEEP) valve. The production of those component was using a standard design procedure with utilizing design software for obtaining the optimum design results.

5. Conclusions

To support the increasing ventilator demand caused by COVID-19 virus outbreak, Chroma International developed local ventilator components such as RFM (Respiratory Flow Meter), RBF (Respiratory Blower Fan) and PEEP Valve. RFM and RBF is designed by standard engineering process using state of the art CAE software tools to obtained the most optimum design geometry configuration. The development of these components starting from October 2020 has already entering prototyping and testing process.

References

1. Q.H. Nagpurwala, "Design of Centrifugal Compressor," M S Ramaiah School of Advance Studies, part 1-2, RMD510
2. Justin Jongsik Oh, "The Effect of Blade Fillets on Aerodynamic Performance of a High-pressure Ratio Centrifugal Compressor", In, 1964, pp. 15-64.
3. Dadang Furqon E, "Small Centrifugal Compressor Performance Trend Prediction based on Computational Fluid Dynamic", Journal of Physics, 2018.
4. Firman Hartono, "Parametric Cycle Analysis", Bahan Ajar Kelas Aeropropulsi, 2015.

J Peterson, and R W Glenny, "Gas exchange and ventilation-perfusion relationship", European Respiratory Journal 44, pp. 1023-1041, 2014.