A Report

On

INDO-AMERICAN ARTIFICIAL HEART PROJECT (IAAHP) at KITSW

KAKATIYA INSTITUTE OF TECHNOLOGY & SCIENCE, WARANGAL-15
(An Autonomous Institute under Kakatiya University, Warangal)

1. INDO-AMERICAN ARTIFICIAL HEART PROJECT (IAAHP)

- **Indo-American Artificial Heart Project (IAAHP)** has been started in the year 2016 headed by **Dr. Pesaru Sudhakar Reddy**, MD, Professor of Medicine, University of Pittsburgh and Chairman, Science Health Allied Research & Education (SHARE), Pittsburgh, PA, USA.
- Prestigious engineering schools of this region, like BITS Pilani, Hyderabad Campus, CBIT, Hyderabad, SNIST, Hyderabad and KITS, Warangal are working towards design and development of a low cost Artificial Heart for its usage in India.

1.1 INSTITUTIONS / ORGANIZATIONS INVOLVED IN IAAHP

- University of Pittsburgh/ University of Pittsburgh Medical Center (UPMC)
- Cornell University -Cornell
- Mississippi State University - Mississippi
- Integris, Oklahoma
- Inspired Therapeutics
- Kakatiya Institute of Technology & Science, (KITS) Warangal
- Birla Institute of Technology, (BITS) Hyderabad, India
- Chaitanya Bharathi Institute of Technology, (CBIT) Hyderabad
- SreeNidhi Institute of Science & Technology (SNIST) Hyderabad
- Laxven Industries, Hyderabad

1.2 CONTINENTAL USA

1. Greg Burgreen, PhD - Mississippi State University, Associate Research Professor; President, Optimal LLC, Starkville, MS, USA
2. John Woodard, PhD – Chief Technology Officer, Berlin Heart GmbH
3. James Long, MD – Integris, OK, Medical Director for the Institution: NazihZuhdi Transplant Institute– INTEGRIS Baptist Medical Center in Oklahoma City
4. Kurt Dasse, PhD –Co-Founder, President & CEO, Inspired Therapeutics LLC
5. Steve Gregorski, PhD - Artificial Heart Research Specialist, Cornell University
6. Priscilla Petit – co-Founder -Director of Quality & Regulatory, Co-Founder: Inspired Therapeutics LLC

1.3 CONTINENTAL INDIA

1.3.1 Kakatiya Institute of Technology & Science, (KITS) Warangal

1. Dr. K. Eswaraiah, Professor, Team Leader of IAAHP, KITSW
2. Dr. K. Venu Madhav, Associate Professor, Project Member, of IAAHP, KITSW
3. Dr. G. Ganesh Kumar, Associate Professor, Project Member, of IAAHP, KITSW
4. Dr. A. Madhukar Rao, Assistant Professor, Project Member, of IAAHP, KITSW
5. Ms. G. Sumithra, Assistant Professor, Member, IAAHP, KITSW

1.3.2 Birla Institute of Technology, (BITS) Hyderabad, India

1. Dr. Suman Kapur - Senior Professor & Head Dept. of Biological Sciences
2. Dr. Srinivasa Prakash Regalla - Professor, Dept. of Mech. Engg.

1.3.3 Chaitanya Bharathi Institute of Technology, (CBIT) Hyderabad, India

1. Dr. P. Ravinder Reddy - Prof. & HOD, Mechanical & Production Eng.
2. Mr. Rugveda Sunny - Computational Fluid Dynamics

1.3.4 SreeNidhi Institute of Science & Technology (SNIST) Hyderabad

1. Subhananda Rao –Project Manager; Director, Advancement & Research
2. A. Purushotham - Professor, Dept of Mechanical Engg

1.3.5 Laxven Industries, Hyderabad, India

1. Mr. C. Ramesh Reddy – Managing Director; Electromechanical Manufacturing

2. AIM of the project:

The condition of patients with heart failure often declines even with optimal medical treatment. Heart transplantation has traditionally been the preferred treatment of such patients. The lack of donor organs motivated the development of the Total Artificial Heart in the early 60s and development continues to this day. Early artificial hearts such as the pulsatile devices imitates the natural hearts action but yielded poor results due to their large size, invasiveness, complexity, and need for extracorporeal support connections. While debate has continued over the necessity of pulsatile action, rotary pumps with their smaller size and simpler designs, have been steadily gaining popularity as blood pumps for temporary support of an ailing heart. Newer axial blood pumps incorporate several design features such as magnetically levitated rotors, CFD optimized impeller and diffuser blades, bio-compatible materials, and transcutaneous power transmission. These small and robust pumps such as the Left Ventricle Assist Device play an increasing role for those awaiting a heart transplants. The duration of this & temporary support has been increasing to the point where LVAD axial pumps are now being considered as a destination therapy in some cases. Here an attempt is being made to design, manufacture and market an TAH with low cost and higher efficiency for the developing countries like INDIA.

3. Role of KITSW in IAAHP

- Department of Mechanical Engineering is working on **Computational Fluid Dynamics Analysis** using ANSYS work bench for modeling and analysis of Heart Pump and development of prototype model using **3D Printer**.
- Department of Electronics and Instrumentation Engineering have been performing **Mocup Loop Testing** to study the characteristics of blood flow experimentally.
- Department of Electrical and Electronics Engineering is working on **Brushless Direct Current (BLDC) motor control system.**

4. Meeting at Chaitanya Bharathi Institute of Technology, Hyderabad

- An Indo-American Artificial Heart Program Meeting was conducted on 15 March, 2018 at Chaitanya Bharathi Institute of Technology, Hyderabad, to discuss about IAAHP progress.
- Further the work plan was made by the panel members
- Then each group was assigned the work to be performed for the smooth running of the project.
- A decision is made to start a Hangout meeting for discussions on the project issues and developments on every Friday at 6. 30 PM IST sharp without fail.

Persons L-R Dr. James Antaki, Dr. A. Subhananda Rao, Dr. Venu Madhav, Dr. Harvey Borovetz, Dr. P.S. Reddy, Dr. Eswaraiah, Dr. Ganesh Kumar, Srinivasa Prakash Regalla.

Persons L-R Dr. G. Ganesh Kumar, Dr. K. Eswaraiah, Dr. A Subhananda Rao, Dr. Harvey Borovetz, Dr. M. Mal Konda Reddy, Dr. James Antaki, Dr. P. Ravinder Reddy,

<u>5. Meeting at BITS, PILANI, Hyderabad Campus</u>

- An Indo-American Artificial Heart Program Meeting was conducted on 16 March, 2018 at BITS, PILANI, Hyderabad Campus
- The Agenda was to visit the laboratories available and facilities at BITS Pilani.
- Further to discuss about the Mocup Loop experimental test setup installed by Dr. Srinivasa Prakash Regalla.
- A decision was made to draw the H-Q curves for the set-up

<u>IAAHP Members Meet at BITS PILANI, Hyderabad Campus, for project start up updates</u>

Persons L-R Dr. James Antaki, Dr. A. Subhananda Rao, Dr. Venu Madhav, Dr. Harvey Borovetz, Dr. P.S. Reddy, Dr. Eswaraiah, Dr. Ganesh Kumar, Srinivasa Prakash Regalla.

6. <u>3rd International Symposia, Pittsburgh, @ USA 3 Day Symposia at Pittsburgh</u>

An international Symposia was conducted at Pittsburgh from 16-18 June 2018, at University of Pittsburgh Medical Centre (UPMC) for project updates as well as the progress of the work performed by various Institutes and Organizations. A detailed progress presentation about an Indo-American Artificial Heart Program at KITSW was demonstrated one by Dr. K. Venu Madhav and Dr. G. Ganesh Kumar. Dr. K. Venu Madhav has presented about the facilities at KITSW and Dr. G. Ganesh Kumar has presented about the simulation model of Artificial heart pump.

<u>Presentation on IAAHP progress of KITSW during 3rd International Symposia, Pittsburgh, @ USA 3 Day Symposia at Pittsburgh</u>

<u>Persons from L-R</u> : Dr. Venu Madhav, Dr. Ganesh Kumar, Dr. James Antaki, & Dr. P. Ravinder Reddy.

<u>Presentation on IAAHP progress of KITSW during 3rd International Symposia, Washington DC @ USA 3 Day Symposia at Pittsburgh</u>

Persons from L-R: P. Ravinder Reddy, Prof. and Principal, CBIT, Dr. A. Subhananda Rao, Project manager, SNIST. Dr. A. Purushottam, Prof. and Assoc. HOD, Dept. of Mechanical Engineering, SNIST Dr. K. Venu Madhav, Prof. Dept. of Electronics & Instrumentation Engg. KITSW

7.Meeting at KITS, Warangal Campus

- An Indo-American Artificial Heart Program Meeting was conducted on 4 August, 2018 at KITS, Warangal Campus
- The Agenda was to visit the laboratories available and facilities at KITSW.

7.1 Minutes of Meeting

- Dr. K. Ashoka Reddy, Principal, KITS welcomed all the delegates and briefed about facilities and expertise available at KITS Warangal.
- Dr. P.S. Reddy spoke about genesis, importance of the project, consortium of Institutes and Industry working on this,
- The consultancy and Design help will be provided by Professors from USA. He stressed about the need of DOCUMENTATION. He reiterated on punctuality & commitment of each member involved in the project for timely execution.
- Dr. P. Ravinder Reddy, Principal, CBIT summarized the work progress at CBIT on Development of magnetically coupled Centrifugal pump, CFD studies conducted, 3D printed models, Mocup loop etc. and thrown light on the facilities and expertise available at CBIT.
- Dr. K. Eswaraiah and his team from KITSW deliberated on the work progress. Dr. G. Ganesh Kumar from KITSW has presented various pump simulation results considering different number of blades on the impeller and related issues. Mr. Sk. Avez Shariq from KITSW had demonstrated on the issues in designing a centrifugal pump. Members suggested to focus on the design of the pump considering the literature and information available on centrifugal pump.
- With the computer available at the moment with KITSW, it is taking lot of time to execute one run of CFD due to lack of adequate RAM and speed. It was decided to work out on a suitable configuration.

- Dr. P. S. Reddy requested Capt. V. Lakshmikanta Rao to give necessary approval. It was agreed upon.
- Mr. Rugveda demonstrated the various components of Mocup Loop circuit viz. Piping, T-connectors, Pressure Transducers, amplifiers, Flow sensor, DAS box integrating amplifiers with necessary PCB's for processing and isolation of the Data etc. Only one DAS box is available. For other, PCB's need to be procured and integrated. KITSW agreed to procure two sets. Another flow probe received from USA is for higher diameter of pipe. The suitable probe to be obtained.
- Dr. Naveen Reddy presented his experience and precautions to be taken while connecting pressure sensors in the Mock Loop.
- 9. Dr.A.subhananda Rao briefed about the Importance of Documentation and Design control during conceptual/planning phase.
- 10. Meeting adjourned after proposing vote of thanks by Dr. K. Ashoka Reddy.

Persons from L-R Dr. A. Madhukar Rao, Asst. Prof., EEED, KITSW, Dr. G. Ganesh Kumar Assoc. Prof., MED, KITSW, Dr. K. Eswaraiah, Prof and Head, MED, KITSW, Dr. A. Purushotham, Head, MED, SNIST, Sri P. Narayana Reddy, Treasurer, KITSW, Dr. K. Ashoka Reddy, Principal, KITSW, Dr. P.S. Reddy, Professor of Medicine, University of Pittsburgh, Dr. P. Naveen Reddy, Dr. P. Ravinder Reddy, Principal, CBIT, Mr. Rugveda, Research Associate, CBIT, Dr. A. Subhananda Rao, Project manager, SNIST, Dr. Venu Madhav, Associate Prof., EIED, KITSW

Persons from L-R Dr. A. Madhukar Rao, Asst. Prof., EEED, KITSW, Dr. G. Ganesh Kumar Assoc. Prof., MED, KITSW, Dr. K. Eswaraiah, Prof and Head, MED, KITSW, Dr. A. Purushotham, Head, MED, SNIST, Sri P. Narayana Reddy, Treasurer, KITSW, Dr. K. Ashoka Reddy, Principal, KITSW, Dr. P.S. Reddy, Professor of Medicine, University of Pittsburgh, Dr. P. Naveen Reddy, Dr. P. Ravinder Reddy, Principal, CBIT, Mr. Rugveda, Research Associate, CBIT, Dr. A. Subhananda Rao, Project manager, SNIST, Dr. Venu Madhav, Associate Prof., EIED, KITSW

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Persons from R-L

Row-1: Dr. K. Eswaraiah, Prof and Head, MED, KITSW, Sri Narayana Reddy, Treasurer, KITSW, Capt. Laxmikantha Rao, Secretary & Correspondant, KITSW, Dr. P.S. Reddy, Professor of Medicine, University of Pittsburgh, Dr. K. Ashoka Reddy, Principal, KITSW, Sri. Rugveda Sunny, Research Associate CBIT,
Row-2: Dr. G. Ganesh Kumar Assoc. Prof., MED, KITSW, Dr. A. Subhananda Rao, Project manager, SNIST, Dr. P. Ravinder Reddy, Principal, CBIT, Dr. A. Purushotham, Head, MED, SNIST.
Row-3: Dr. K. Venu Madhav, Associate Prof., EIED, KITSW, Dr. A. Madhukar Rao, Asst. Prof., EEED, KITSW, Sri. Avez Shariq, Asst. Prof., MED, KITSW

8.Meeting at KITS, Warangal Campus

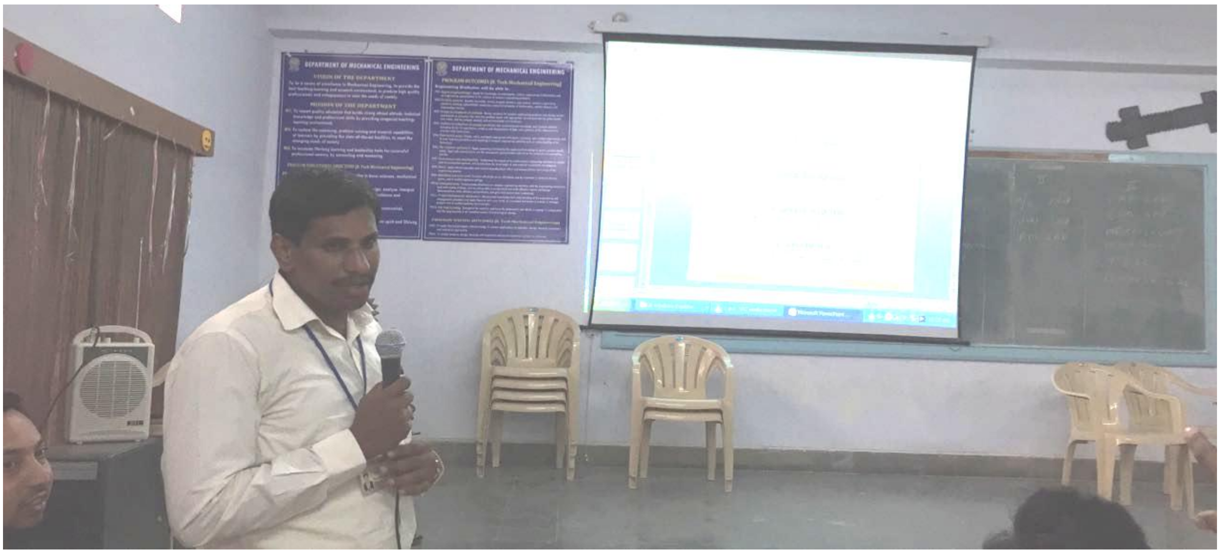
- An Indo-American Artificial Heart Program Meeting was conducted on 4 August, 2018 at KITS, Warangal Campus
- The Agenda was to visit the laboratories available and facilities at KITSW.

Dr. K. Eswaraiah, Prof and Head, MED, KITSW addressing the gathering in the department faculty meeting about IAAHP held on 28.07.2018 in MSH, B-III 210 at 3.30 PM

8. 1 Minutes of Meeting

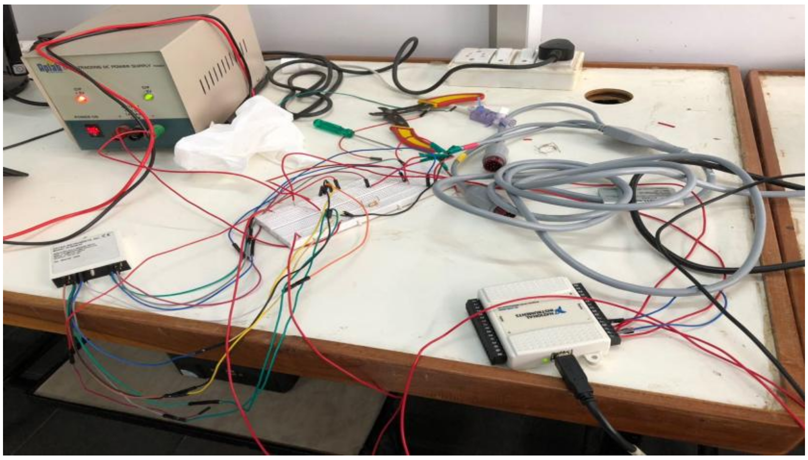
Dr. K. Eswaraiah, Professor and Head, MED, KITSW addressed the departmental meeting about IAAHP. He illuminated about the prominence of this type of high profile projects and stressed on the effect of dedication which is essential for success of this type of projects. He put forth that the management has agreed for a suitable grant and that they expect good results from the faculty involved.

Dr. G. Ganesh Kumar presented a detailed role of CFD analysis for this project. He further enhanced the audience knowledge by discussing about significance of the Governing Differential Equations in their Non-Dimensionalized form and briefed about the work plan and different steps involved in the project. Further, he presented the performance curves of a Centrifugal pump and how the parametric modelling of a pump is to be done. He also spoken about the Non-Newtonian Physics involved and detailed that it plays a significant role in designing the pump. Other faculty enthusiastically suggested that Noise and Vibration analysis will also be essential at a minor level if the natural Heart is to be replaced with an artificial one.



Dr. G. Ganesh Kumar, Associate Professor, MED, KITSW addressing the gathering in the department faculty meeting about IAAHP held on 28.07.2018 in MSH, B-III 210 at 3.30 PM

8.2 Mock-up loop setup in EIED at KITSW for studying the characteristics of flow rate of blood through Artificial pump



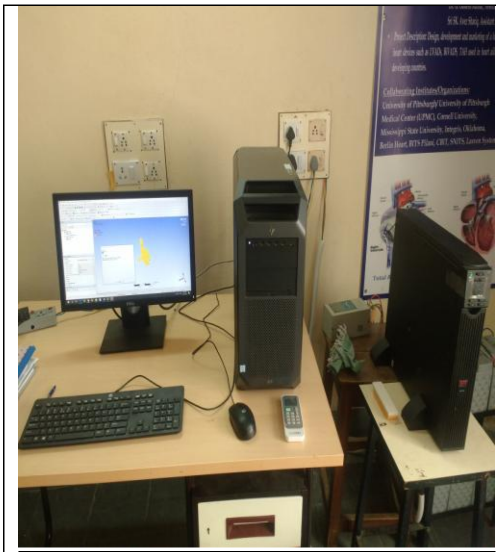
Mocup loop setup in EIED at KITSW for studying the characteristics of flow rate of blood through Artificial pump

9. Research Facilities with cost of the equipment in KITSW

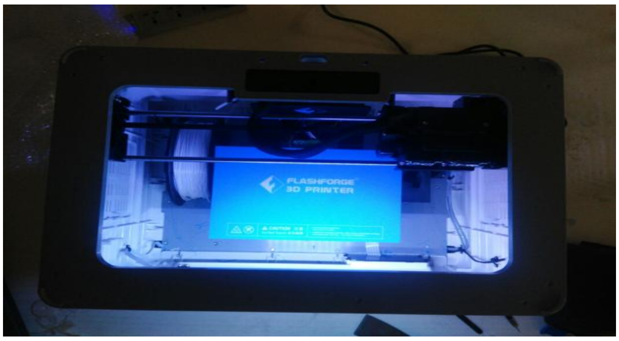
- A center of excellence laboratory was developed with Work Station, Research version of ANSYS 19 with unlimited nodes, Creo 1.0 and 3-D printer.
- An experimental mocup loop test set-up was installed in Department of Electronics and Instrumentation Lab for studying the blood flow characteristics.

S. No	Equipment/Software Details	Cost in Rs.
1.	Work Station	11,00,000/-
2.	ANSYS 19.2	5. 01,500/-
3.	3D Printer	80,000/-
4.	Creo 1.0	3,79,958/-
5.	Mocup LOOP TEST Setup	2,90,000/-
6.	National Instruments (NI) SCXI 1000 Modules	-
7.	NI Data Acquisition Systems	-
8.	NI Signal Conditioning Modules	-
9.	NI Sensors	-
10.	Microcontroller System Development Platform	-
11.	FPGA System Development Platform	-

9. 1 Work Station with specifications

	**Specifications:** **HP Z840 Workstation** 12-Core 4.2GHz Intel Xeon Broadwell E5-2643 v4 [12-cores / 24-threads] 512GB (8x 64GB) of 2400MHz DDR4 ECC Registered RAM 2TB 7200RPM 64MB Cache Hard Drive Slim DVD Burner NVIDIA Quadro P2000 5GB HP Thunderbolt 2 (20GB/s; one port) Windows 10 Professional 64-bit HP Wireless Keyboard 3Dconnexion CAD Mouse

9. 2 3D printer with specifications



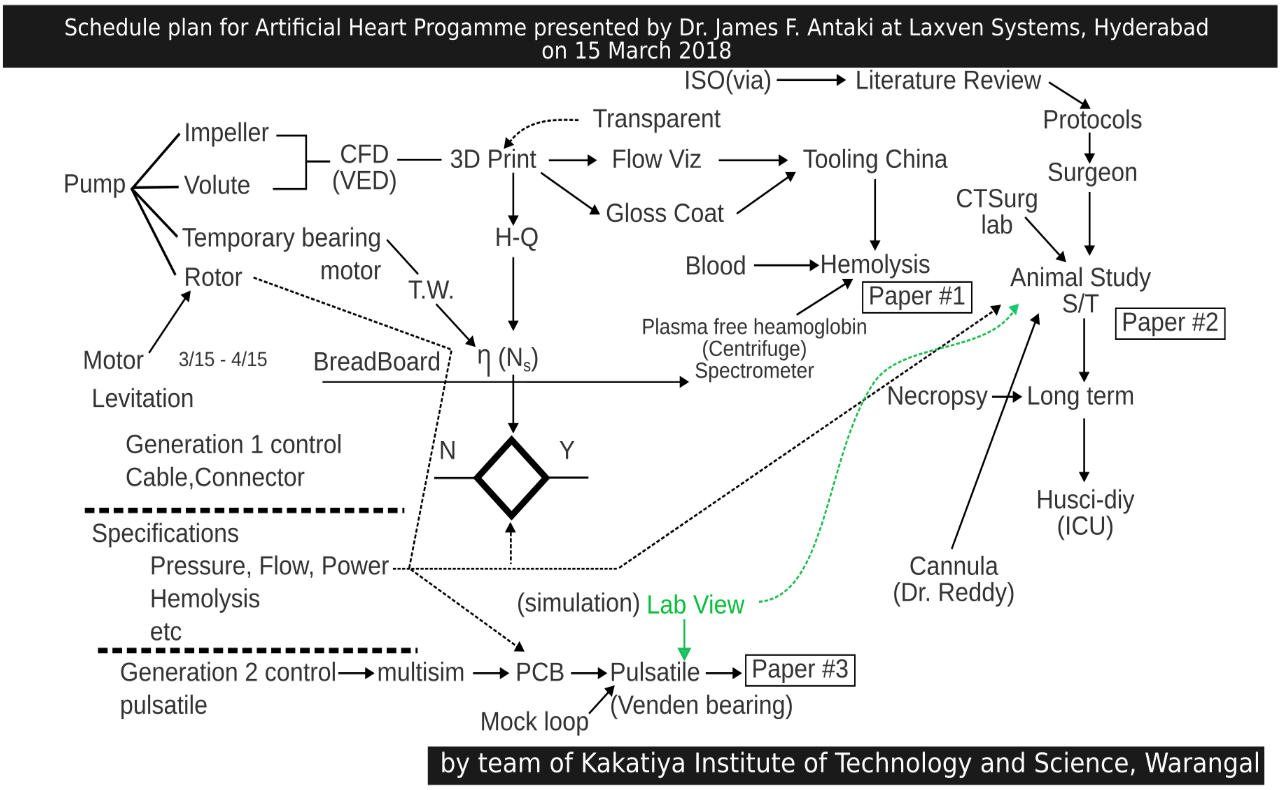
Specifications Weight: 28 Kgs Assembled: yes Dimensions: 485 x 400 x 335 mm Power requirement: AC 100-220 V manual setting 300 W 50/60 Hz LCD control display: yes Warranty: 3 Months manufacturer's warranty Bundled software; Flashprint Supported file types: STL / X3G Supported OS: OSX, Windows	Connectivity: SD Card / USB / Wi-Fi Supported filament: ABS / PLA / Dissolvable filament Layer resolution: 100 microns XY positioning precision: 11 microns Z positioning: 2.5 microns Print technology: Fused Filament Fabrication Filament diameter: 1.75 – 1.8 mm Extruder: Dual extruder Nozzle diameter: 0.4 mm Build Volume: 9.2 x 6.0 x 5.6 in

10. Work in Progress in KITSW:

- A Mocup Loop Test Set-up has been installed in EIED.
- A study on fluid flow characteristics of blood as a non-Newtonian Fluid is performed
- Design Parameters to be considered during analysis
- Preliminary studies on effect of blood flow through pumps were done.

- CFD analysis of blood flow through bend pipes was studied
- Fundamental studies on various characteristics of blood were studied
- CFD analysis of Centrifugal pump is being performed.

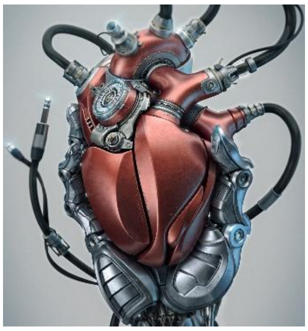
11 Work Plan For IAAHP Project



11. 1 WORK PROGRESS IN MECHANICAL ENGINEERING DEPARTMENT

11. 2 DESIGN OF ARTIFICIAL HEART

There are several critical issues when designing a LVAD. Fluid dynamics of the blood flow must be understood so that enough blood is pumped and no blood clots will be created. Materials must be chosen which are biocompatible otherwise the pump could fail. The efficiency of the motor must be optimized so that minimal heat is generated. Because of possible rejection, the total volume and surface area of the entire device should be kept as small as possible. A typical LVAD weighs around 2.4 lb (1,200 gm) and has a volume of 1.4 pints (660 ml).



11. 3. Design Analysis made at KITSW

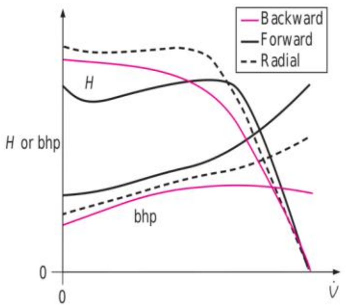
As a part of IAAHP it is proposed to design an Artificial Heart Pump for the purpose, A detailed literature review is done to study the performance parameters of a pump. Based on the studies the following parameters are considered for making analysis of a pump.

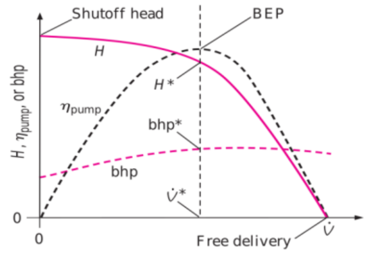
11.3. 1 Design parameters considered during analysis of an Artificial Pump

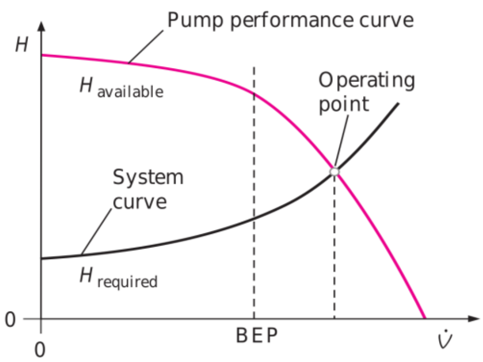
S. No	Input Parameter	Details
1.	Mass flow rate	5 Litres per minute
1.	Speed	5500 rpm
2.	4	10 mm
3.	14^{o} (System Default)	0.83kPa
4.	Density	$1060kg/m^3$
5.	Rotational Speed	5500 rpm

S. No	Input Parameter	Details
7	Volume flow rate	$0.6m^3/hr$
8	Head raised	1.5m
9	Inlet Flow angle	90^{o}
10	Blade angle	22.5^{o}
11	Number of Vanes	6
12	Casing Rotational Angle	22.5^{o}

11.4 STUDY OF VARIOUS PARAMETERS OF FLUID FLOW

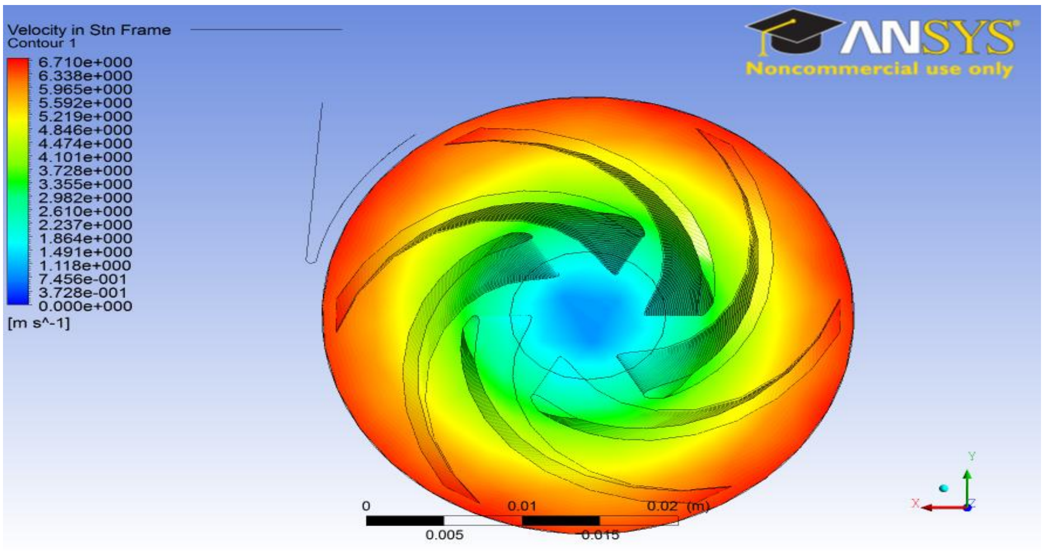




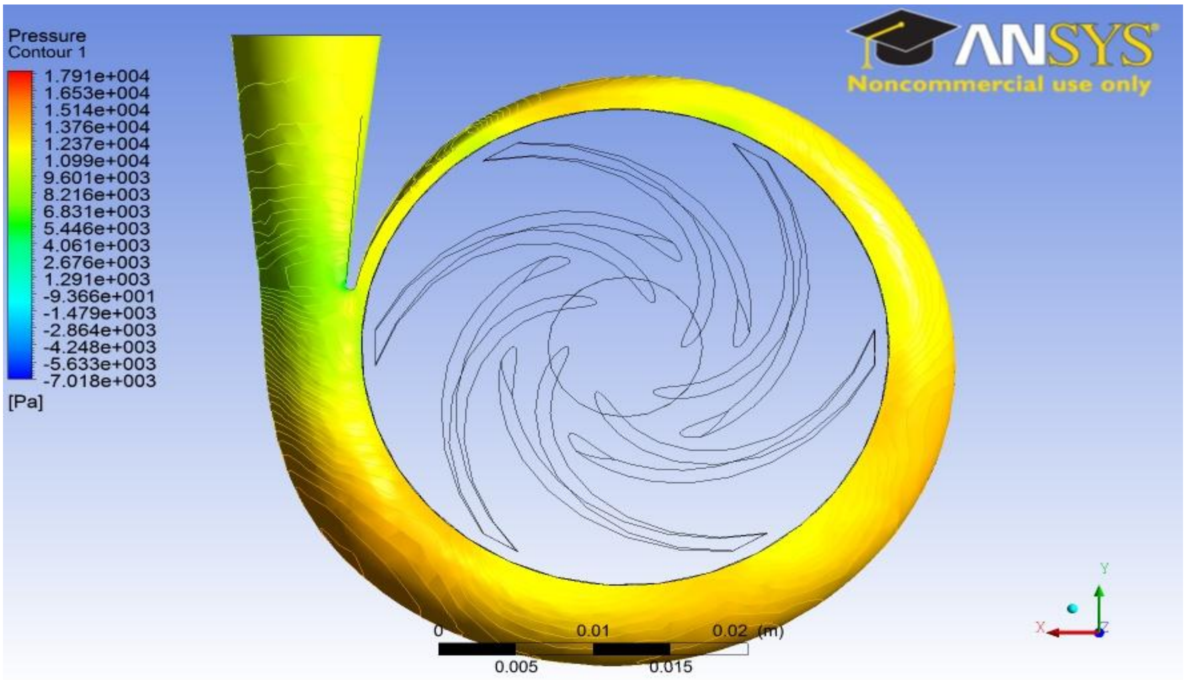


11. 5 Results and Discussion

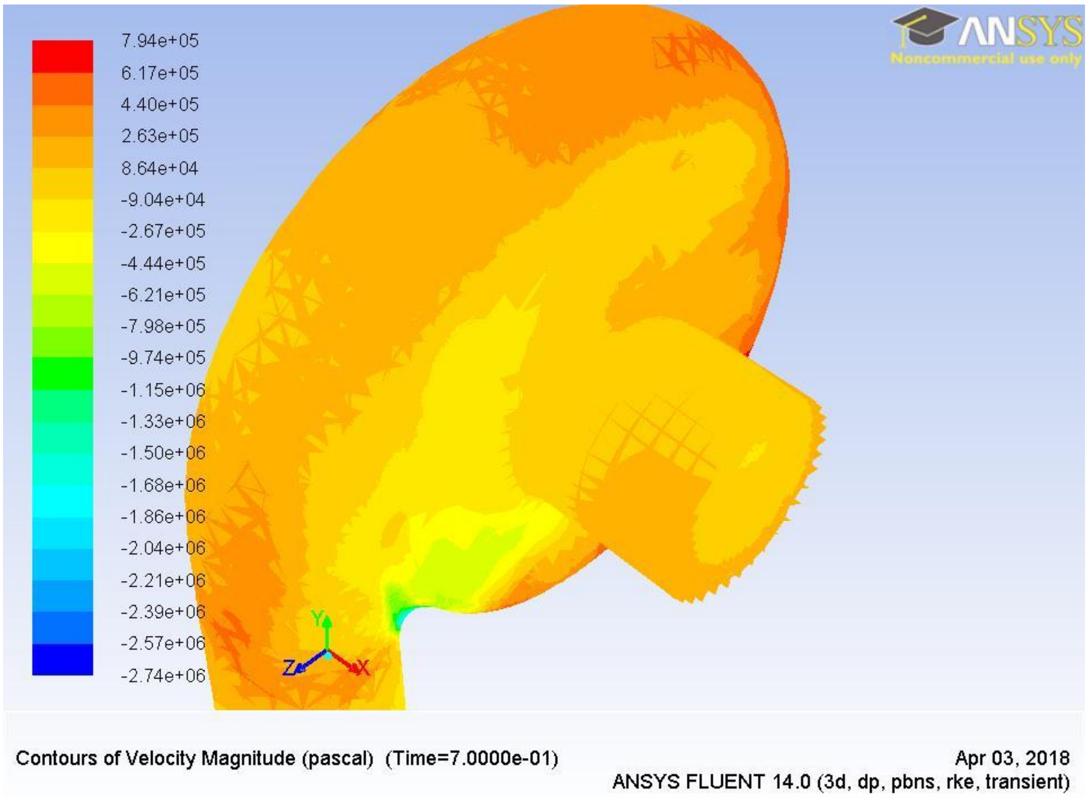
Variation of velocity of fluid across (perpendicular) to the pump surface without the impeller : Volute of Variation of the fluid pressure through the pump



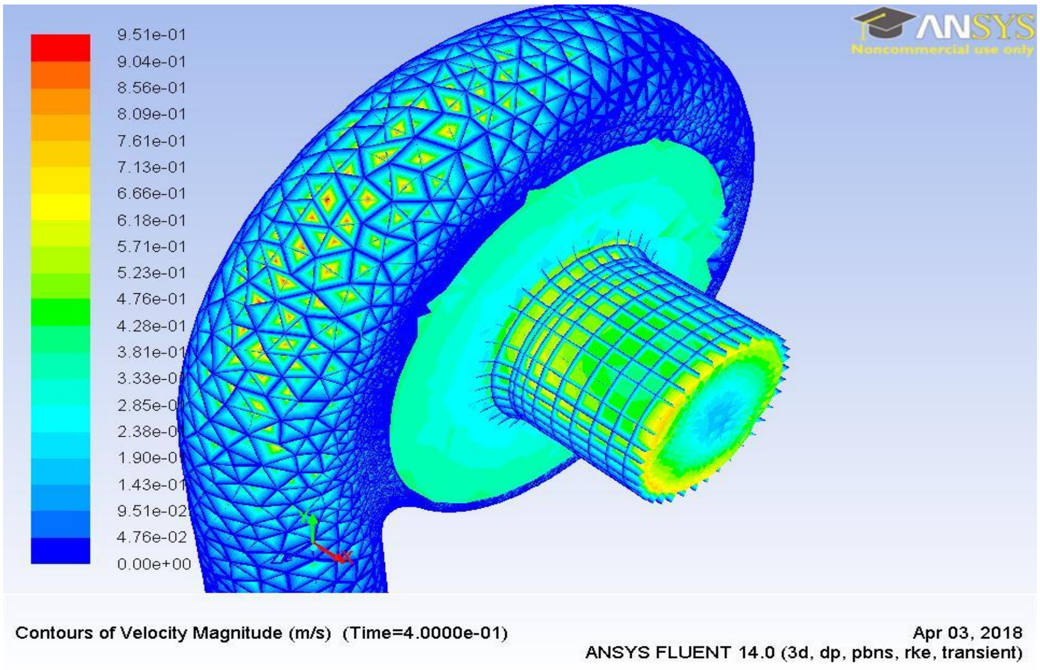
Pressure contours of the fluid through the pump impellers



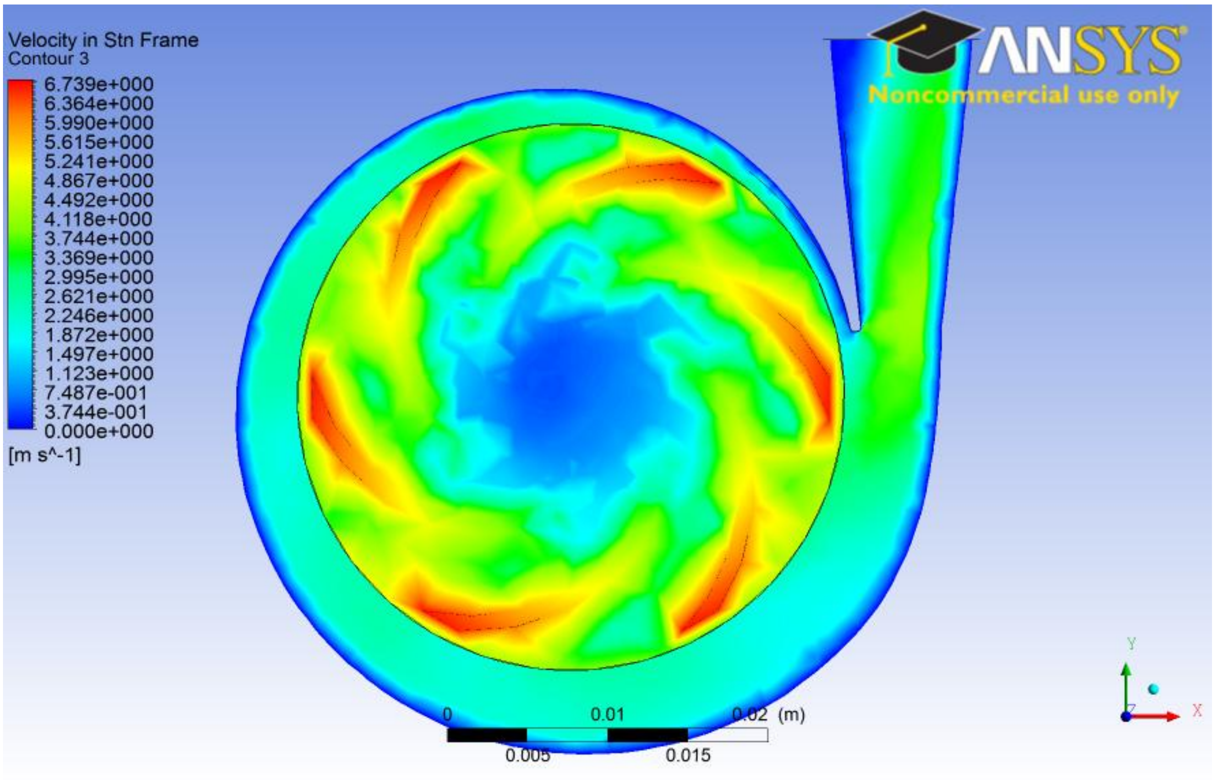
Velocity contours of fluid across the pump with volute 6 blades



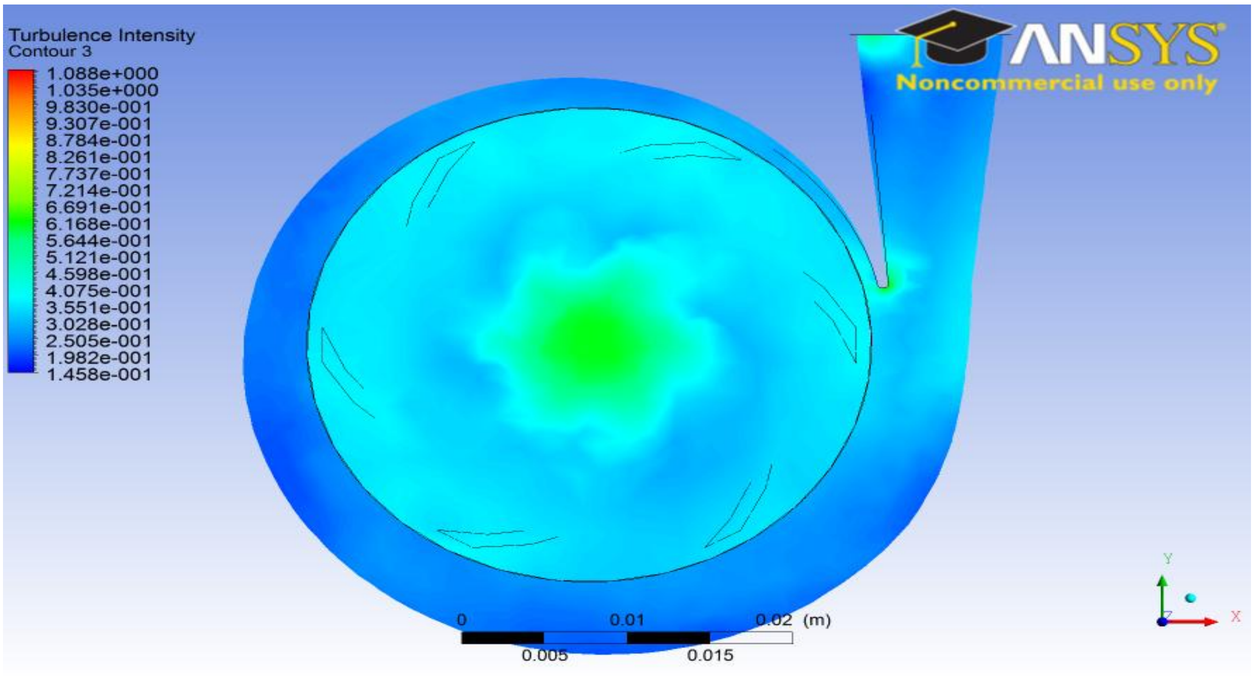
Velocity contours of fluid across the pump with volute



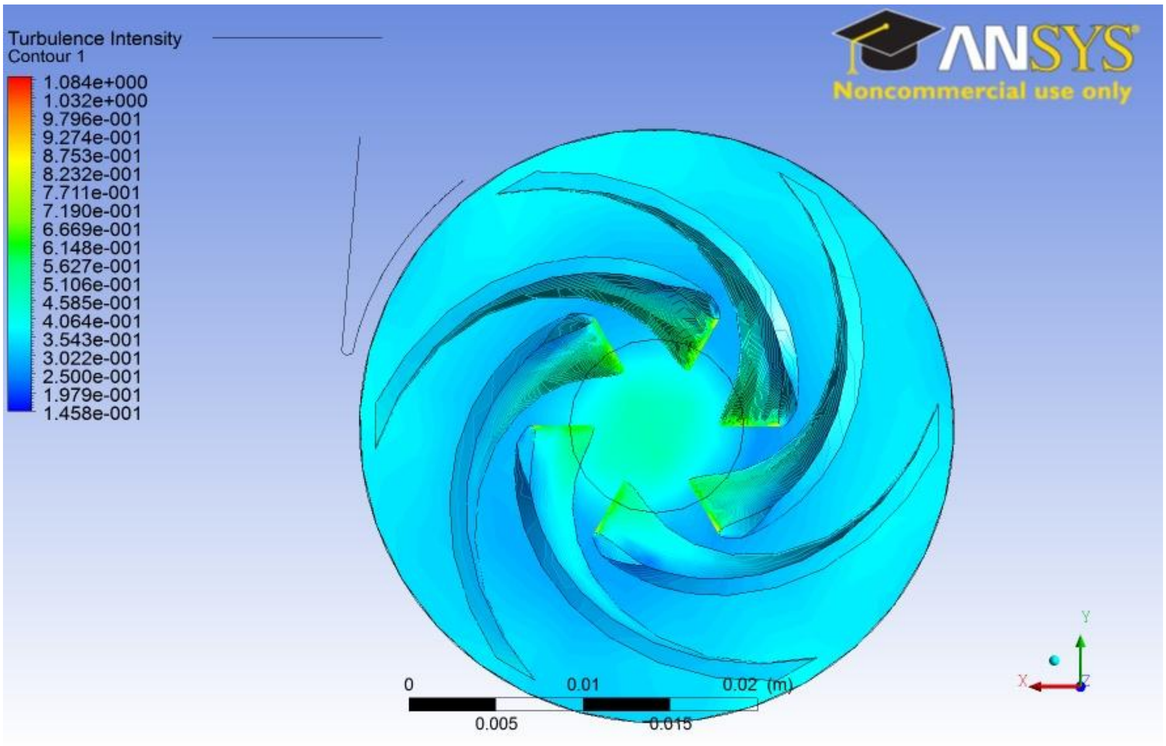
Velocity contours of fluid across the pump with volute



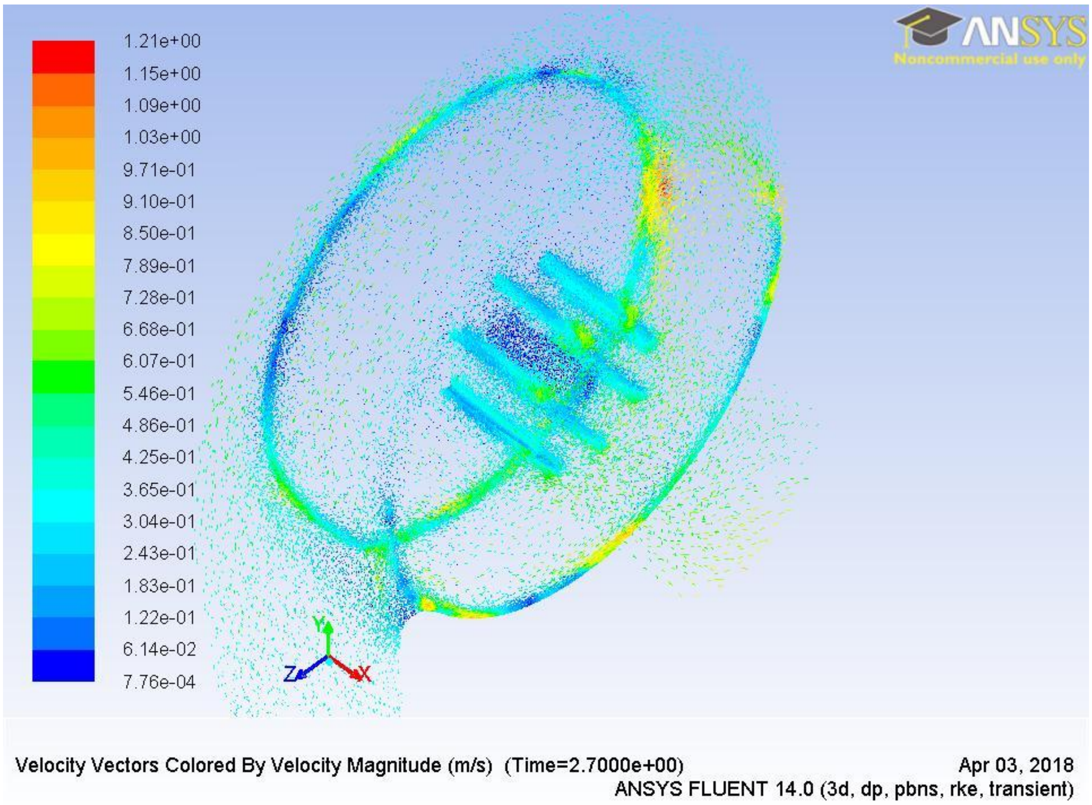
Formation of turbulence in the pump with volute



Formation of turbulence in the pump impellers



Velocity vectors of the fluid in the pump

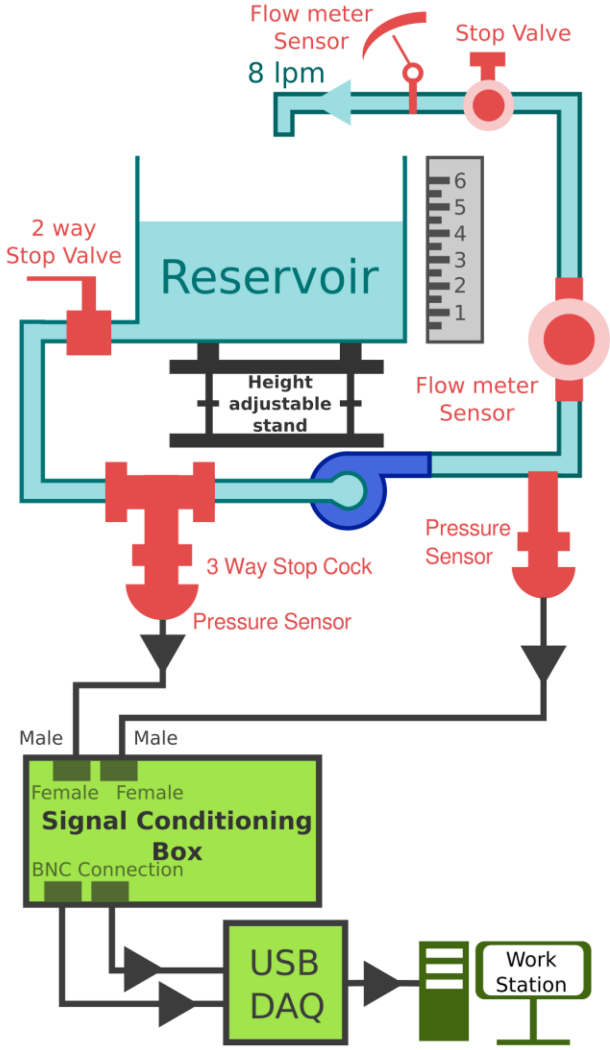


Velocity vectors of the fluid in the pump

12. WORK PROGRESS IN ELECTRONICS AND INSTRUMENTATION ENGINEERING DEPARTMENT

It is proposed to study on the characteristic of a blood like fluid (Glycol) flow properties through pump . Hence, a Mocup Look Test Set up is fabricated. The details of he fabrication and assembly is shown in the following figure for the purpose of testing. A trail runs were performed in the lab using water as a fluid. The details line diagram of the components are shown in the following figure.

12.1 MOCUP LOOP TST SET-UP OREXPERIMENTATION



MOCUP LOOP TST SET-UP OREXPERIMENTATION

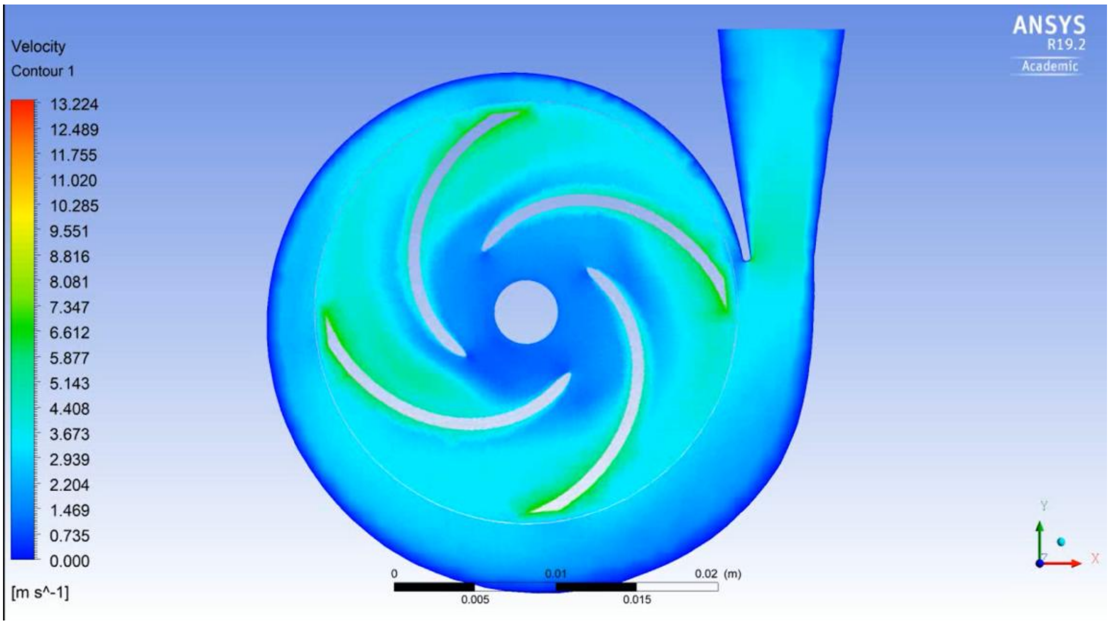
13. <u>WEEKLY PROGRESS REPORT OF THE IAAHP AT KITSW</u>

12-Oct-2018 to 19-Oct-2018

- On 12th October technician from Planet solutions has visited the IAAHP lab to resolve the issues.
- Further on 13th October a meeting was conducted in IAAHP Lab to resolve the issues. The Following Members were present:
  1. Dr. G. Ganesh Kumar, Associate Professor, MED, KITSW
  2. Dr. K. Venu Madhav, Associate Dean, R & D Cell
  3. Sri. Shaik Avez Shariq, Asst. Professor, MED, KITSW
  4. Mr. Suresh,Programmer, CSE
  5. Mr. Srinivas, Planet Solutions

- On 14th , 15th October, Trial runs of CFD analysis was performed for the pump
- On 16th October the work station was installed in IAAHP lab and the inaugurated on the same day at 4.00pm

- On 17th October, Again trail runs were performed to do analysis on CFD software
- On 19th October Completed 1 CFD analysis on the Centrifugal pump. Velocity contours were presented in Google hangouts meeting. Proposed to perform atleast 5 more analysis to plot H-Q curves.



Velocity contours at t=0.01s (when the impeller has completed 360^0 of revolution)

Here, the Pump speed: 5500 rpm & Density : 1060 kg/m^3 were taken as input parameters

20-Oct-2018 to 26-Oct-2018

The following activities were performed in KITSW during this week:

1. The work station Costing about **Rs. 11, 00, 000/-** (Eleven Lakhs only) was installed with UPS of 2KVA APC costing about **Rs. 55000/-** (Fifty Five Thousand Rupees).
2. ANSYS Software (Research Version with CFD Module) was installed which costs **Rs. 5, 01, 000/-** (Five Lakh One Thousand Rupees Only)
3. **Mr. Sk. Avez Shariq** Salary was enhance by **Rs. 10, 000/-** (Ten Thousand Rupees Only) for supporting the IAAHP Group at KITSW.

27-Oct-2018 to 2-Nov-2018

1. Trial runs were performed by KITSW for testing the CFD software with four sample problems (Like Flow through Heated Plate, Water Pipe Flow, Flow through Heat Exchanger and Flow through channel etc.)
2. The Computational Fluid Dynamics analysis was performed using **Fluent ANSYS software** on the workstation using a **four bladed centrifugal pump.**
3. Encountered the issue of usage of Number of cores during the analysis which was identified by the ANSYS Software during telephonic conversation and online

interaction. They admitted that they will handle the issue and resolve the same by next monday. Thus we were able to use only eight cores only.

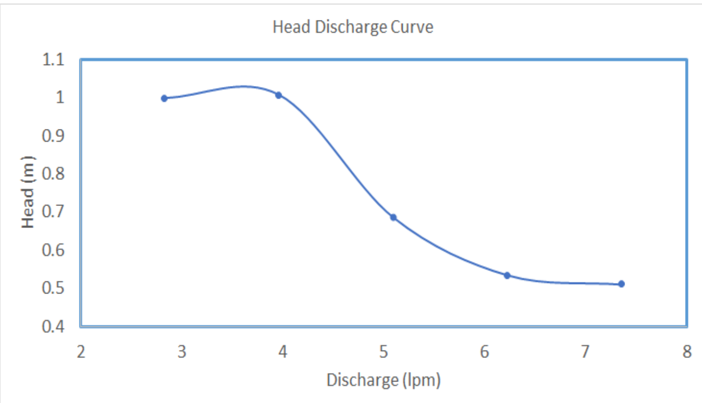
3-Nov-2018 to 9-Nov-2018

1. Due to usage of only eight cores we were able to perform eight different analysis with flow rate varying from 0.05 to 0.15 kg/sec were performed with Blood as a working fluid
2. H-Q Curve was plotted for result analysis the details of which are given below.
3. The following table shows the assumptions and Input parameters considered for the analysis:

Details	**Input or assumptions**
Type of vanes	Backward curved vanes
Number of vanes	4
Density of Blood as per the Literature Survey)	1060 kg/m^3
Type of fluid	Newtonian
Turbulence model	K- Omega (Shear Stress Transport)
Mesh size	1.69 lakhs
Time step	0.0008 s for 35 time steps
Simulation time	0.028 s =2.56 revolutions (about 922^0)

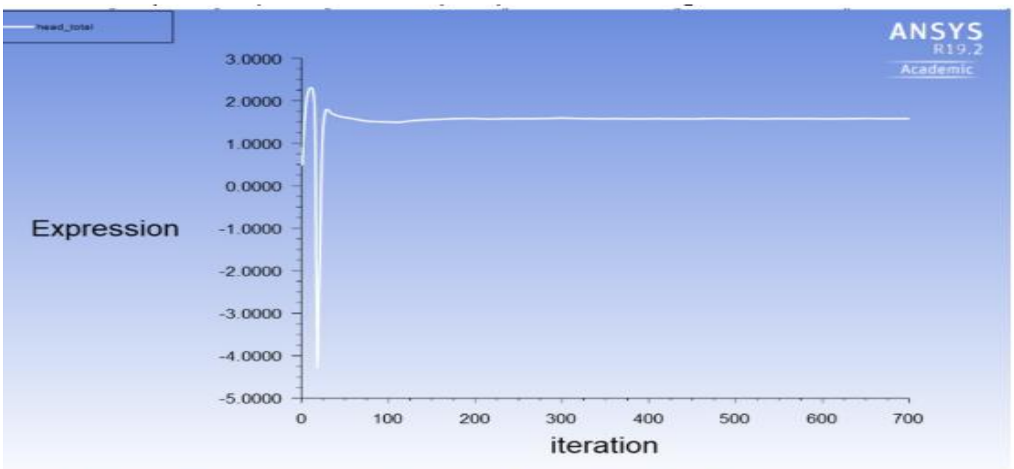
10-Nov-2018 to 16-Nov-2018

- H-Q curves are plotted for the centrifugal pump analysis with flow rate varying from 0.05 to 0.15 kg/sec and are shown in the figure below



The following issues were raised during the CFD analysis of a Centrifugal Pump using Blood as the working fluid:

- Area weighted average of Static Pressure at outlet was observed to be 'Zero' at all times (which is troublesome to find the head generated by the Blood pump).
- Pressure was observed to fluctuate with an amplitude of 0.1 m (which can compromise the accuracy of Head generated).
- CFD simulation was performed on centrifugal pump. The analysis was deliberately terminated for 400 iterations. The analysis did not reach the default convergence criteria in Fluent. However it was observed that head generated was stable over the iterations. This gives the team a hope that the flow has fully developed inside the pump. The following are the results



Graph showing the variation of head with respect to iterations

Graph showing the variation of head with respect to iterations

	A	B	C	D	E	F	G	H	I
1	Name	P1 - param-mass-out	P2 - pressure_inlet_abs-op	P3 - pressure_inlet_total-op	P4 - pressure_outlet_abs-op	P5 - pressure_outlet_total-op	Retain	Retained Data	Note
2	Units	kg s^-1	Pa	Pa	Pa	Pa			
3	DP 0 (Current)	0.15	99539	0	1.1246E+05	16429	☑	✓	
4	DP 1	0.17	99024	0	1.0639E+05	12380	☑	✓	
5	DP 2	0.19	98445	0	1.0066E+05	9002.5	☑	✓	
6	DP 3	0.21	97809	0	93396	4374.9	☑	✓	
7	DP 4	0.23	97114	0	87048	606.46	☑	✓	
8	DP 5	0.13	99989	0	1.181E+05	20182	☑	✓	
9	DP 6	0.11	1.0037E+05	0	1.2099E+05	21910	☑	✓	
10	DP 7	0.09	1.0067E+05	0	1.2262E+05	22957	☑	✓	
11	DP 8	0.07	1.0089E+05	0	1.2406E+05	24114	☑	✓	
12	DP 9	0.05	1.0094E+05	50.898	1.2563E+05	25046	☑	✓	
*							☐		

Table showing the Design point data collected in Ansys Workbench. Inlet pressure anomaly observed at mass flow rate of 0.05 kg/s (=2.83 lpm)

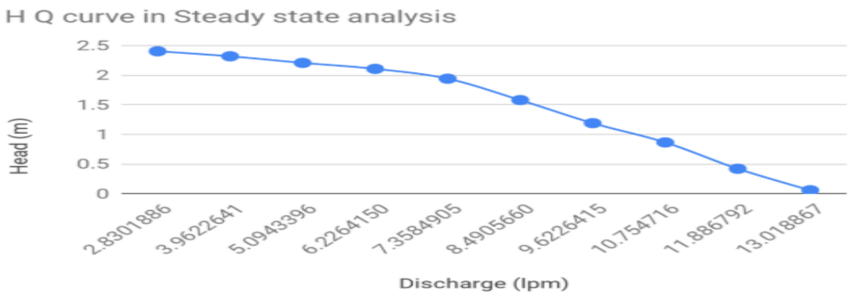


Fig: H-Q Curve for Design Model of a Artificial Heart Pump

10-Nov-2018 to 16-Nov-2018

- 10th November, A new model was proposed by IAAHP-KITSW group for heart pump.

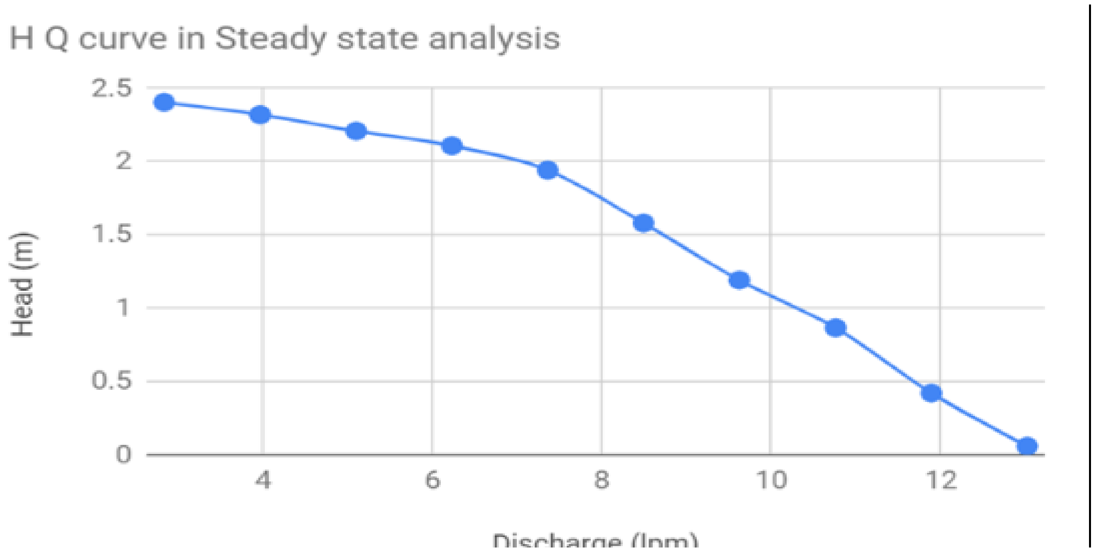
12-Nov-2018:
A one week Short Term Training Program (STTP) on ANSYS was conducted as part of IAAHP. The following 'Hands-on' activities were performed:

Inauguration Function

- Keynote address by Prof. P. Ravinder Reddy garu, Principal CBIT on Finite Element Analysis
- Dr. P. Ravinder Reddy visited Department of Mechanical Engineering and discussed about the progress of IAAHP project in KITSW in IAAHP Lab.
- He has suggested to purchase the 3D printer for fabrication of the project model
- Further he interacted with the faculty of Mechanical Engineering

17-Nov-2018 to 28-Nov-2018

- A CFD Model Analysis was performed on centrifugal pump. The analysis was deliberately terminated for 400 iterations. The analysis did not reach the default convergence criteria in Fluent. However it was observed that head generated was stable over the iterations. This gives the team a hope that the flow has fully developed inside the pump. The following are the results:



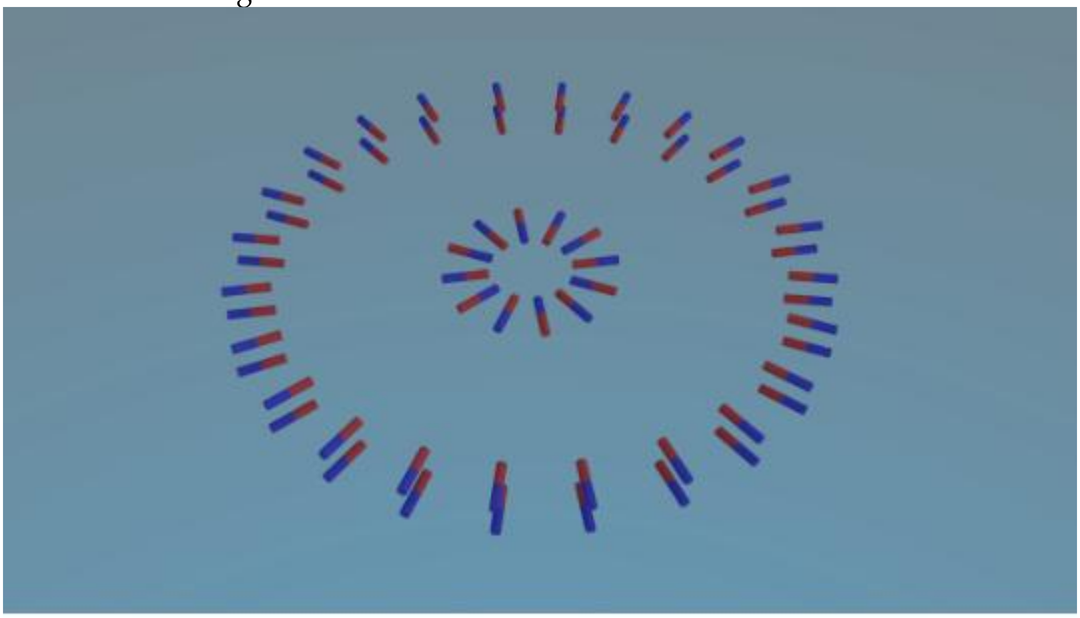
H-Q curve of the pump

From the graph it may be assumed that 7.5 lpm is the Best Efficiency Point

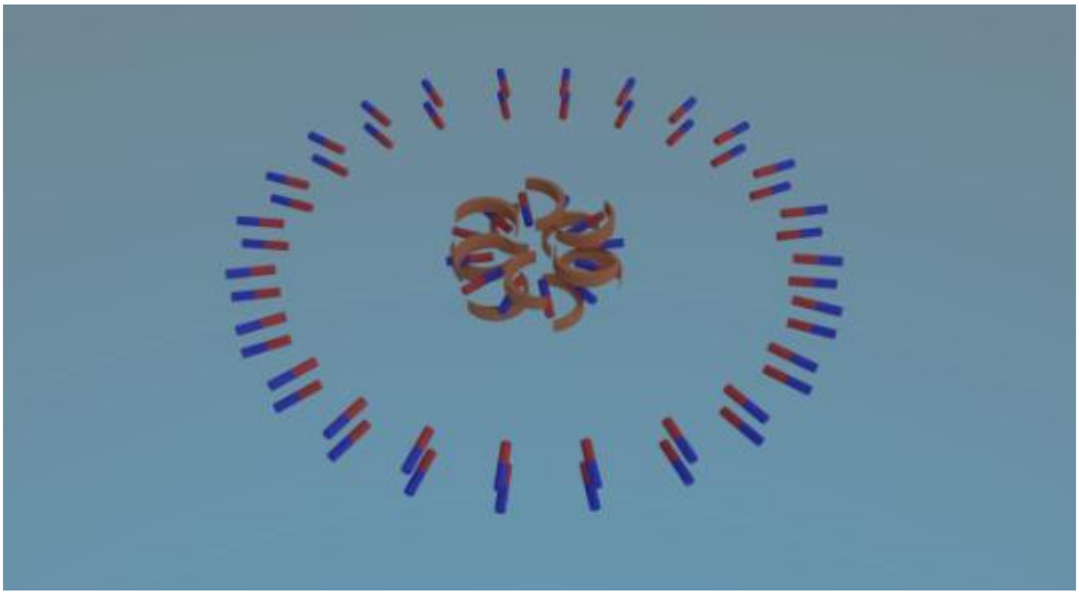
29-Nov-2018 to 7-Dec-018

A conceptual design of completely magnetically levitated centrifugal pump with 2 axial inlets and 1 outlet was designed by IAAHP-KITSW team. It is proposed to apply for the patent of this model. The concept would look as follows:

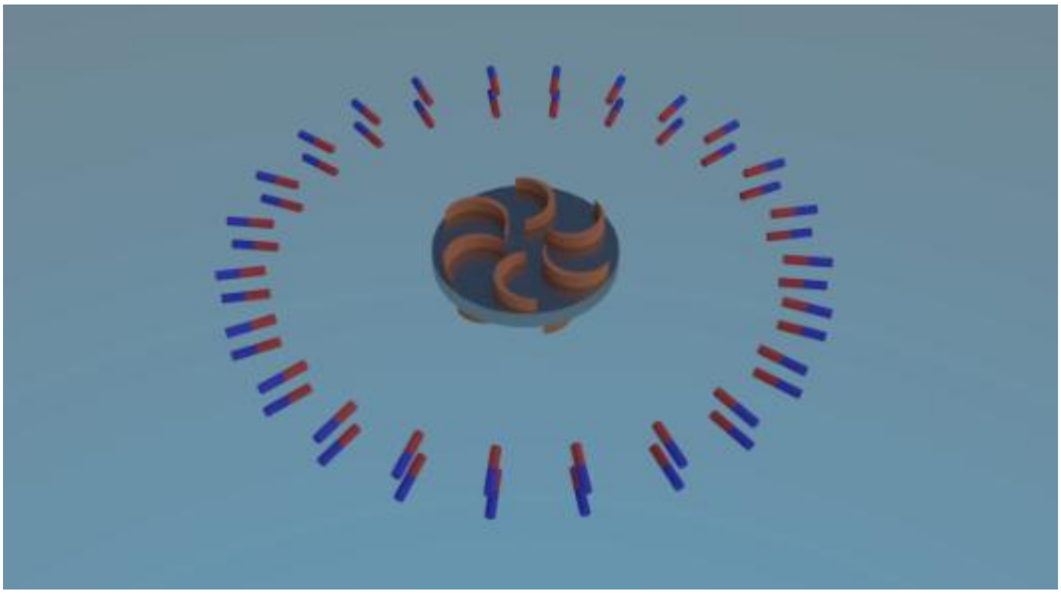
1. Arrangement of magnets. Notice 1 set of magnets in the impeller and a pair of magnets in the rack.



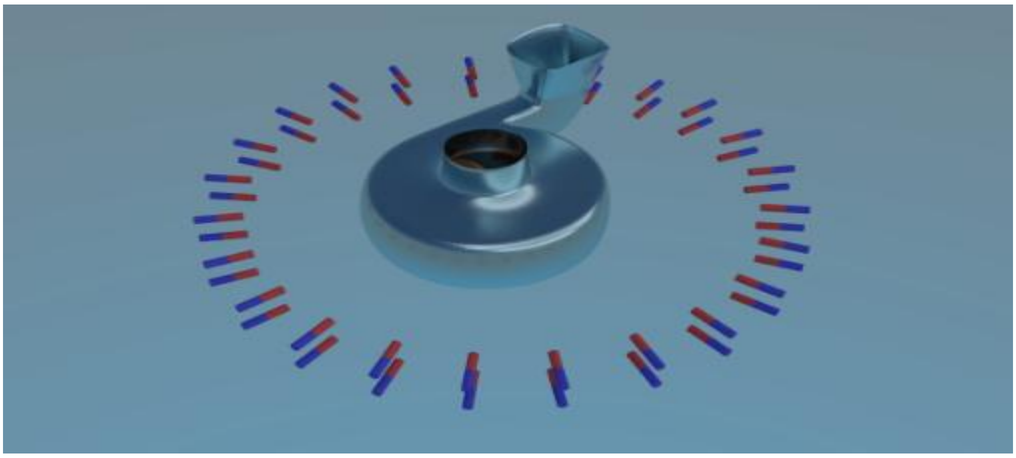
2. Two sets of blades are located above and below the impeller magnets



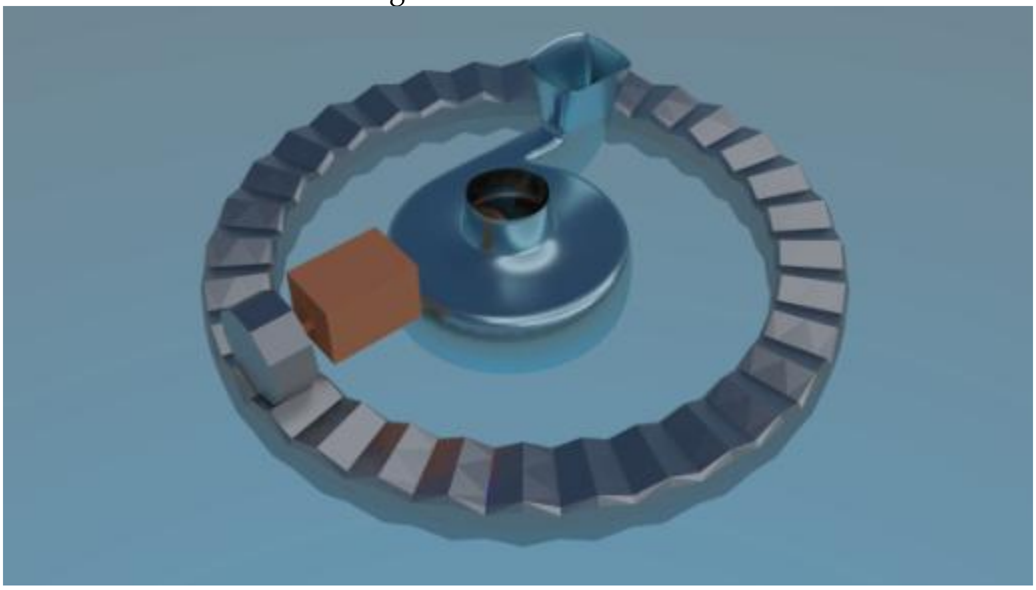
3. With the impeller housing where the magnets are to inserted



4. A model design with Diffuser in the Volute.

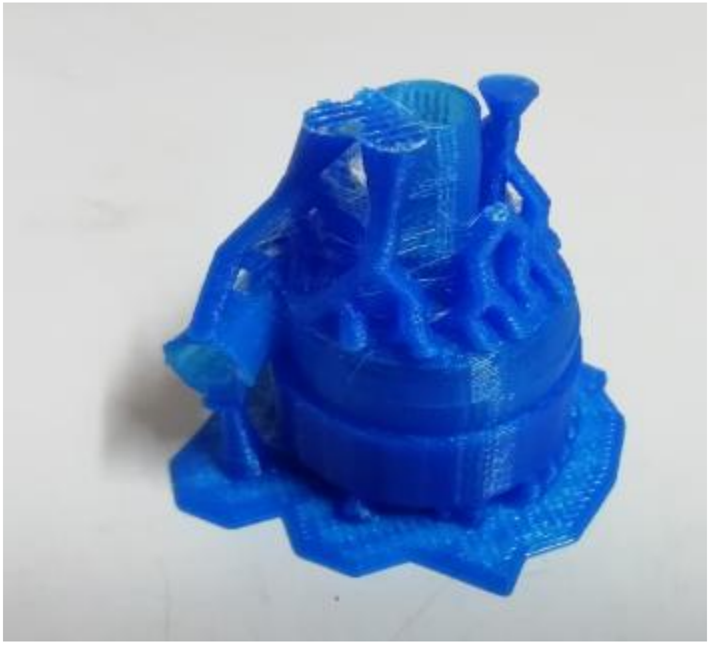


5. Rack and Pinion arrangement for the drive

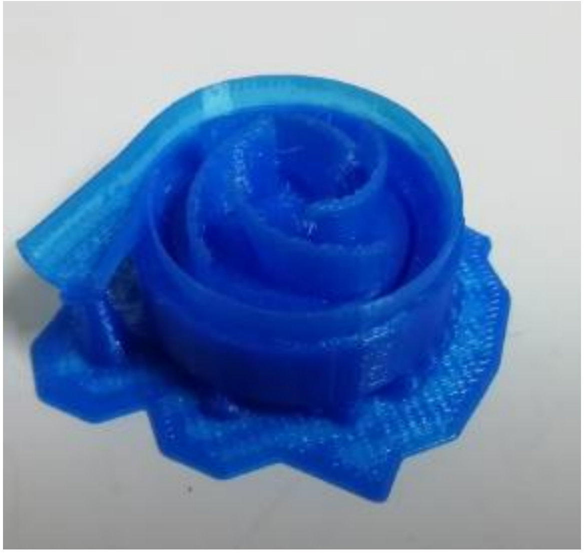


08 Dec- 2018 to 19-Dec-2018

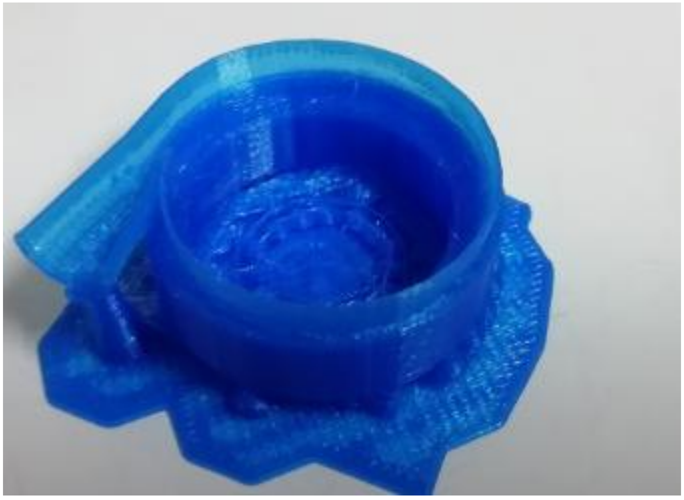
In order to check the tolerances and supports needed and other practical problems that can potentially arise, the prototype was 3D printed on a Fused Deposition Method Printer. Below are the photos:



Completely assembled pump (supports were not removed)



2. Top half of the casing removed (impeller is still inside)



3. Bottom half of the casing

Observations:

1. The surface finish was not as per the requirements.
2. The supports was thick while the casing thickness was very less
3. The 3D printing accuracy was not satisfactory
4. Casing was very thin due to which it has failed in initial conditions.

09-Dec-2018-16-Dec-2018

A meeting was conducted at Guest House in Somajiguda to discuss the progress of the IAAHP in all the institutes.

The following members were present:

1. Dr. P. Sudharakara Reddy, Chairman, IAAHP
2. Dr. K. VenuMadhav, Member, IAAHP, KITSW
3. Dr. G. Ganesh Kumar, Member, IAAHP, KITSW
4. Sri. Sk. AvezShariq, Member, IAAHP, KITSW

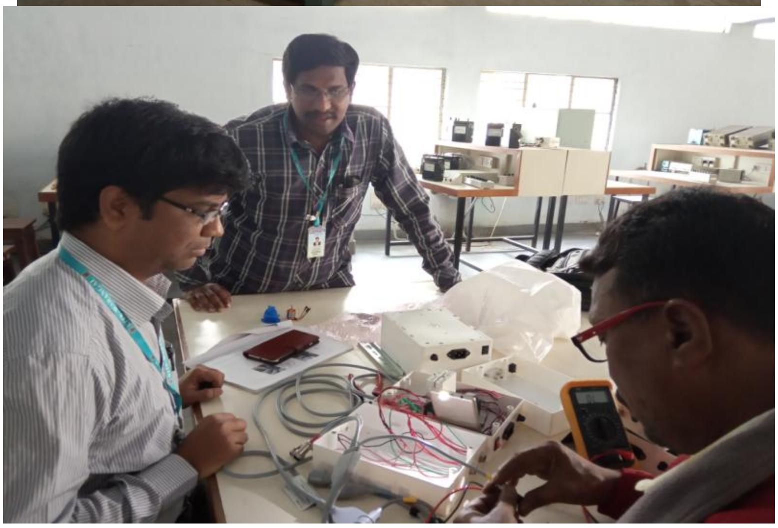
5. Dr. Suman Kapoor, BITS, Pilani.
6. Dr. P. Ravinder Reddy, Principal CBIT
7. Dr. A. Shubananda Rao, Professor, SNITS
8. Mr. Rigveda, Research Associate, CBIT
9. Sri. Chada Ramesh Reddy, LAXVEN Systems.

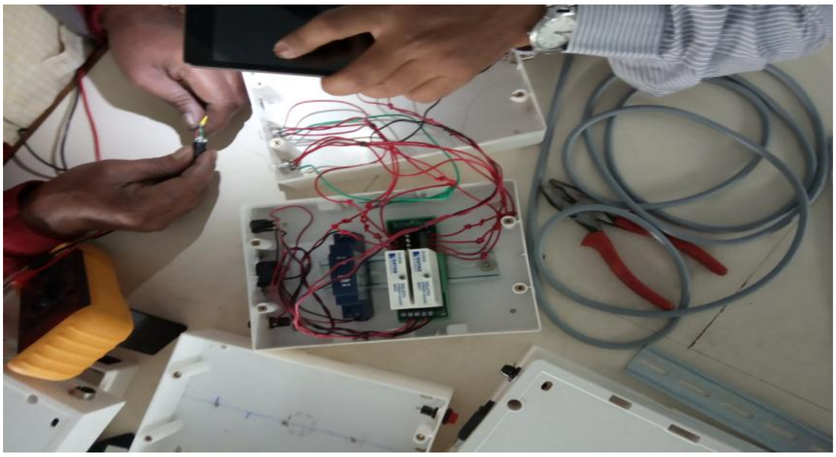
The following discussions were made in the meeting:

1. Dr. P. S Reddy instructed the members to collect the probes and other components for assembling the Mocup Loop Test set-up.
2. It is resolved to make four different Mocup Loop test Set-ups to be fabricated in CBIT, KITSW with similar features for validation of results.
3. The above setup has to be tested with Glycerine as a working media in concerned institutes.
4. Experimentation shall be performed on the test setups assembled at CBIT and KITSW using blood as a working fluid in BITS, Pilani from 17.12.2018 to 20.12.2018 for validation.
5. Dr. P. S. Reddy spoke to Capt. V. Lakshmikantha Rao and instructed the KITSW team to start the process for purchasing an advanced version of a 3D printing machine which costs about 21 Lakhs
6. The meeting ended at 22.10pm.

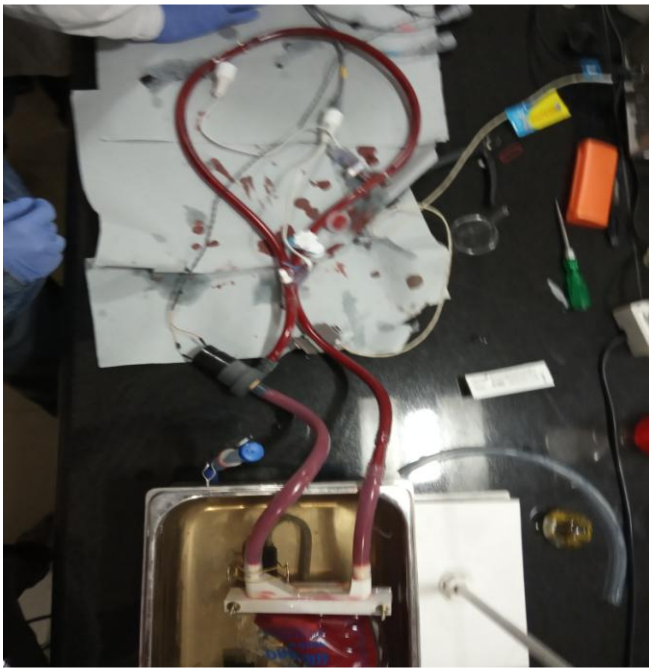
11-16-Dec-2018

1. The Box with DIN connectors and swiches were assembled for the experimentation
2. The Experimental connections were given and are assembled in EIE department with the pump.



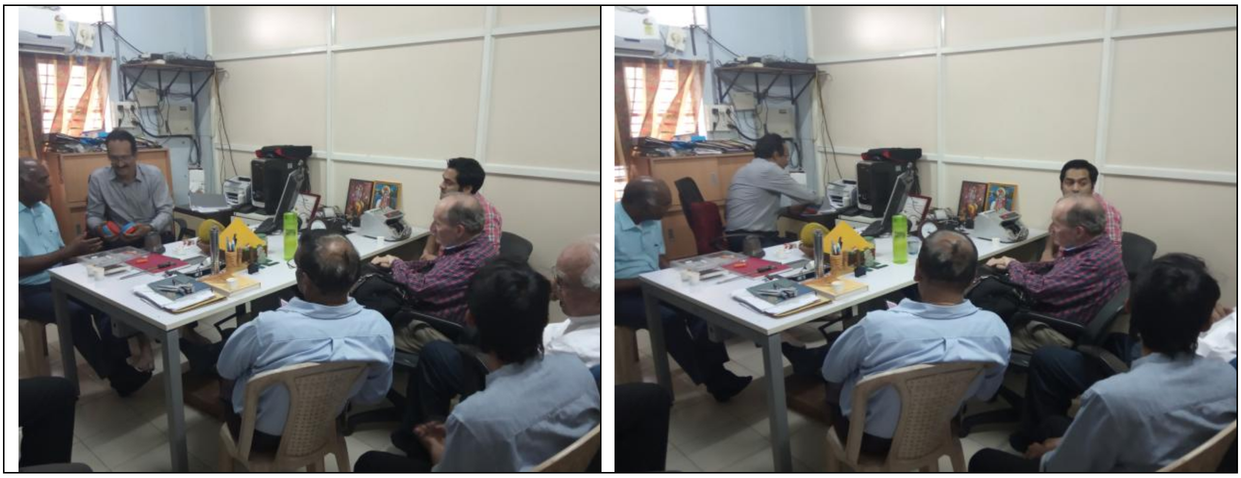


3. Test was performed with water in EIE department
4. Then the set was taken to BITS, Pilani, Hyderabad, Campus for testing



5. Interacted with members during testing.

During the visit to Laxven Systems on 5th January to test the Magnetic Levitated Pump



During the visit to Karthik Moulds, Hyderabad, on 5th January to test the Magnetic Levitated Pump

Meeting on 18th January at Guest House to discuss on the protocol to perform Haemolysis test at BITS, Pilani using Human blood

Testing of Blood at Medi-City before performing Haemolysis Test for Haemoglobin content

Centrifuging Testing of Blood at Medi-City before performing Haemolysis Test for Haemoglobin content

Assembling the test set-up at BITS, Pilani, for Haemolysis Test

Meeting at Guest House to discuss about the challenges in the test results

Second day - Haemolysis Testing at BITS, Pilani

Expert Lecture in WIGH-19 at BITS, Pilani

14.Mockup loop test up at KITSW

Further from 15 Jan 2019 Mockup loop test up was installed in the department of EIE for the experimentation

Mock-up Loop Test Set up installed at KITSW

The CFD analysis was performed at KITSW for different configurations (viz., 4, 6 Bladed Pumps) and levitation pump.

15. Six Bladed Centrifugal Pump designed at KITSW

- Two different types of pumps were designed for the purpose the results were satisfactory. The following figures shows the model of the pump.

15.1. Design of the centrifugal pump

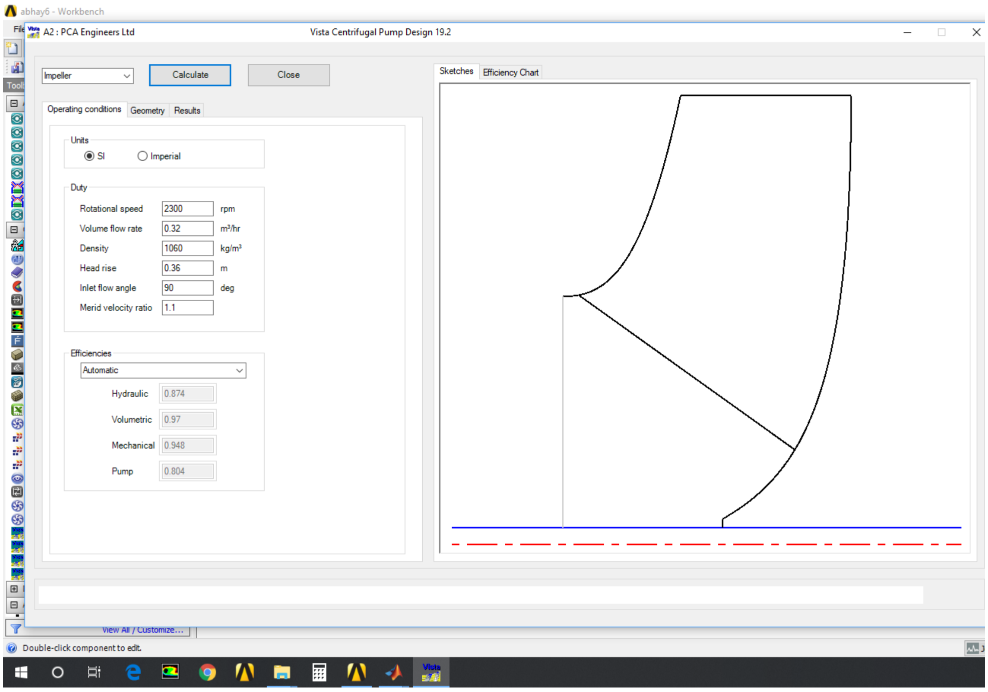
Design parameters considered for six blade and volute in ANSYS CPD

Details/ Range of Parameters	Input or assumptions
Type of vanes	Backward curved vanes
Number of vanes	4 and six
Density of Blood (as per the Literature Survey)	1060 kg/m^3
Type of fluid	Non-Newtonian
Turbulence model	K- Epsilon (Shear Stress Transport) -Realizable with scalable wall function
Mesh size	0.4 mm
Method	Coupled
Angle of Blade	22.5^o
Speed	2000-7500 RPM
Mass Flow Rate	5-10 Liters/min
Exit Pressure outlet	20000/ 150 mm of Hg
No. of iterations	1000-1500
Inlet Diameter	12 mm
Outlet diameter	10
No. Magnets	3 for impeller and 6 for hub
Volute Hub Diameter	28.63 mm
Brushless DC Motor Capacity	10000KVA
Weight in Kg	200g
Toque	6-15 Nm

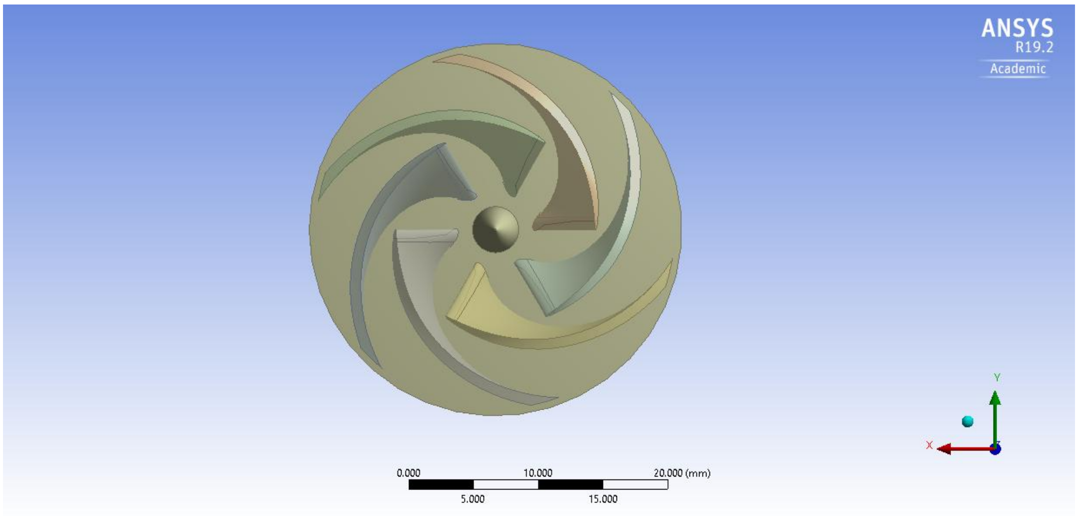
Viscosity	0.0035 kg/m s
Methods	Couple –Pseudo Transient & warped face gradient correction

<u>15.1.1 For Blade</u>:

- Designing of the blade of the impeller in ANSYS Fluent CPD by considering the following parameter
- Speed –2300 rpm
- Volume flow rate- 0.32 m^3/hr
- Density – 1060 kg/m^3
- Head rise – 0.36m
- Inlet flow angle- 90
-

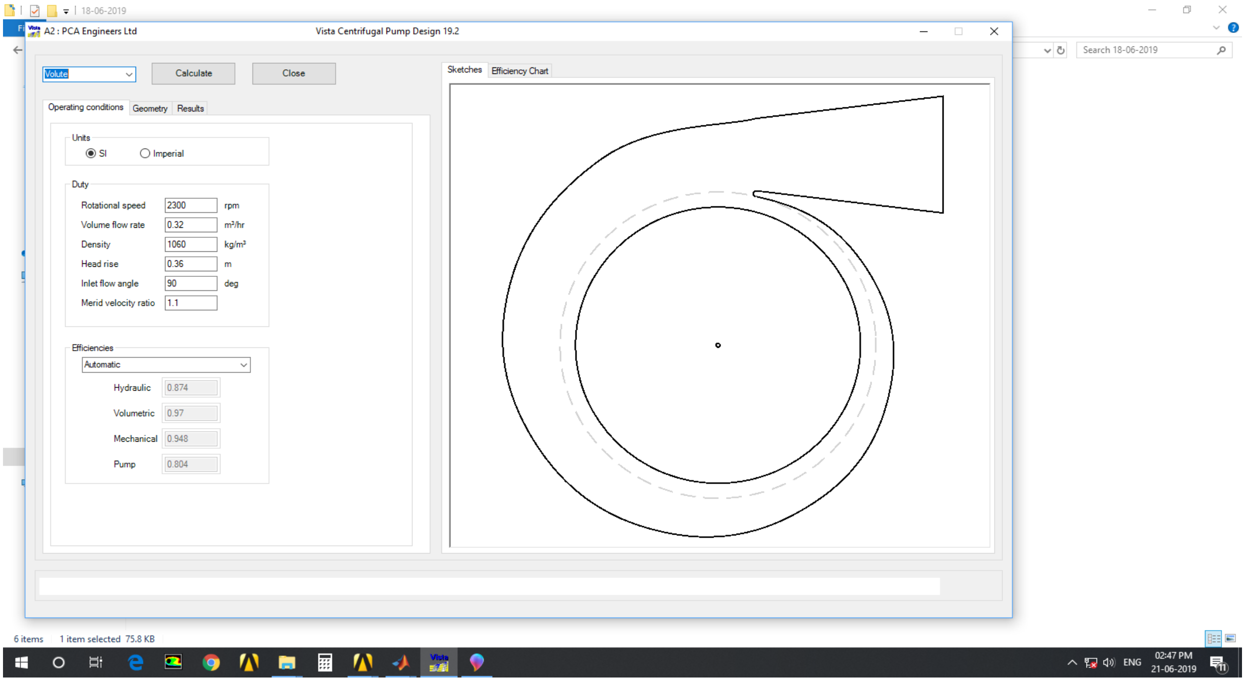


- Using this parameters, geometry of the impeller is created .

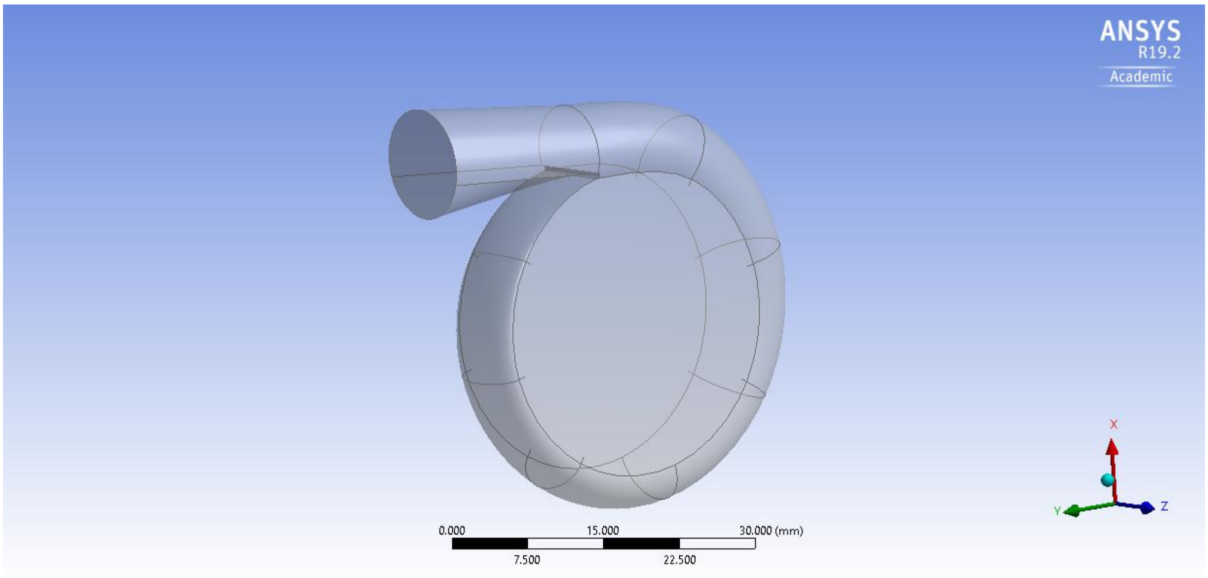


15.1.2 For volute :

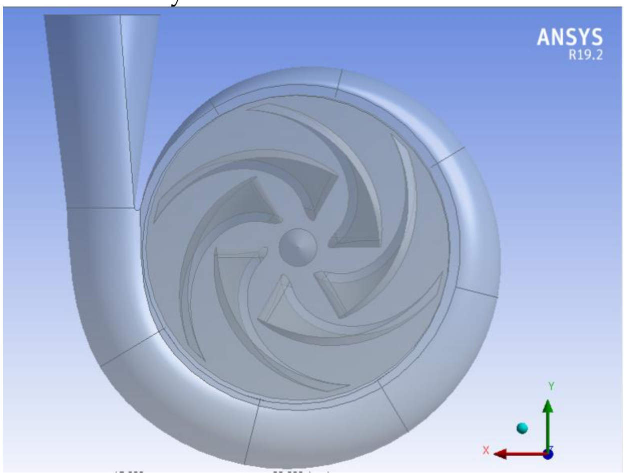
- By considering the following parameters , volute is created .
- Speed –2300 rpm
- Volume flow rate- 0.32 m^3/hr
- Density – 1060 kg/m^3
- Head rise – 0.36m
- Inlet flow angle- 90
- No of blades- 6
- Outer diameter – 11 mm

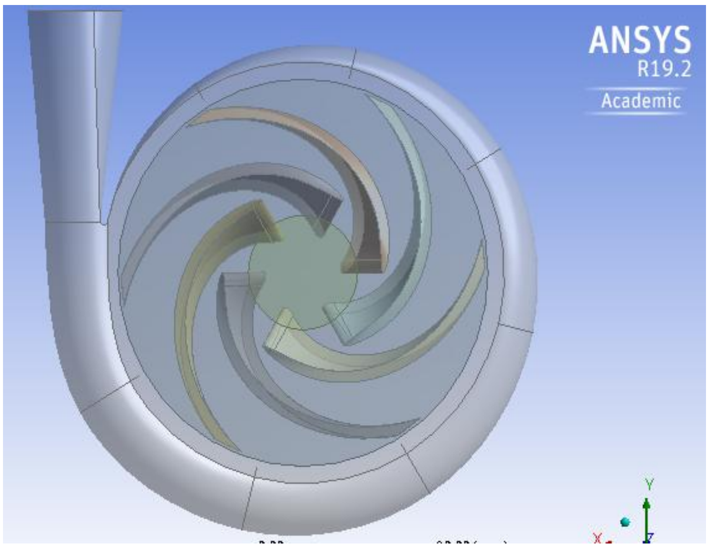


- Using this parameters, volute is created by providing casing to it.

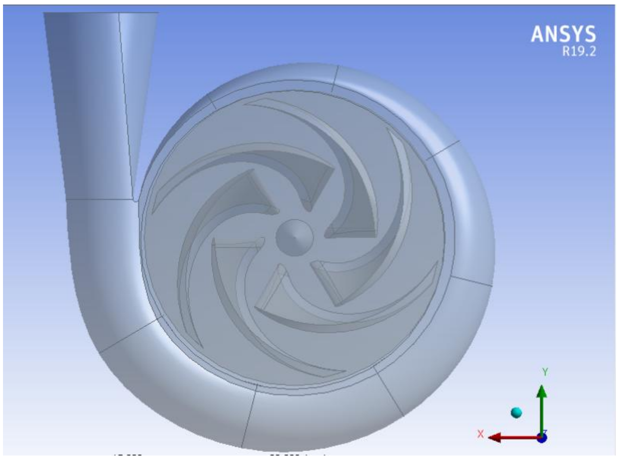


- Following simulations are done by considering geometry of blade and volute by applying meshing and boundary conditions.



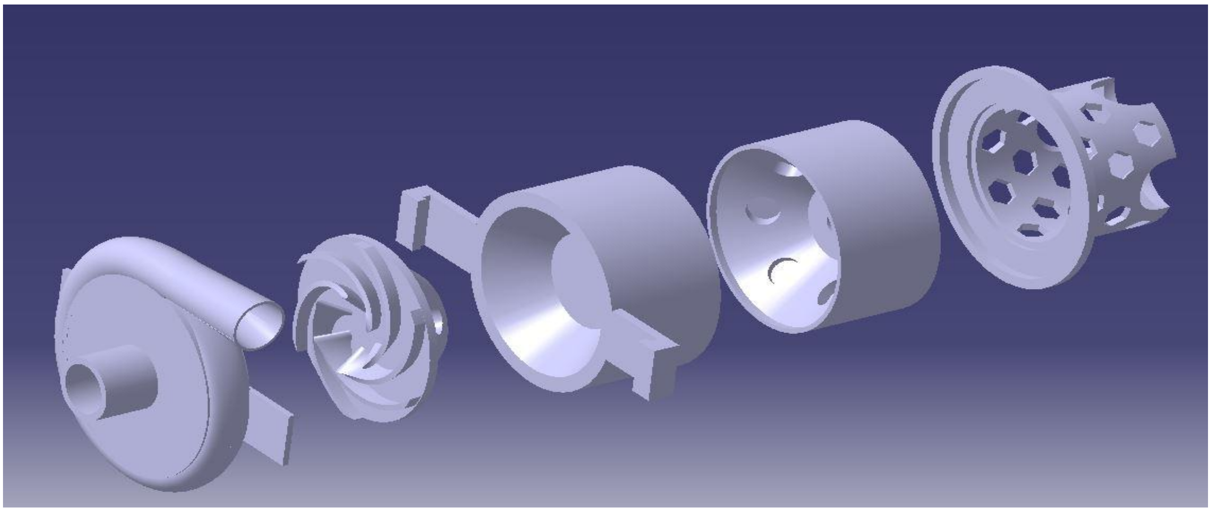


6 blades with impeller diameter 40 mm



6 blades with impeller diameter 28.63 mm

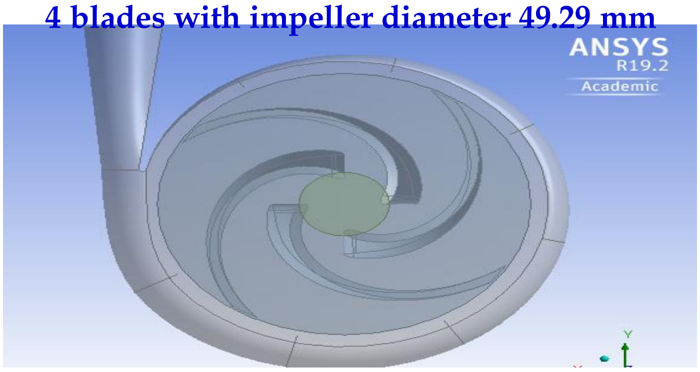
Six bladed designed model of Centrifugal pump assembly (Exploded view)



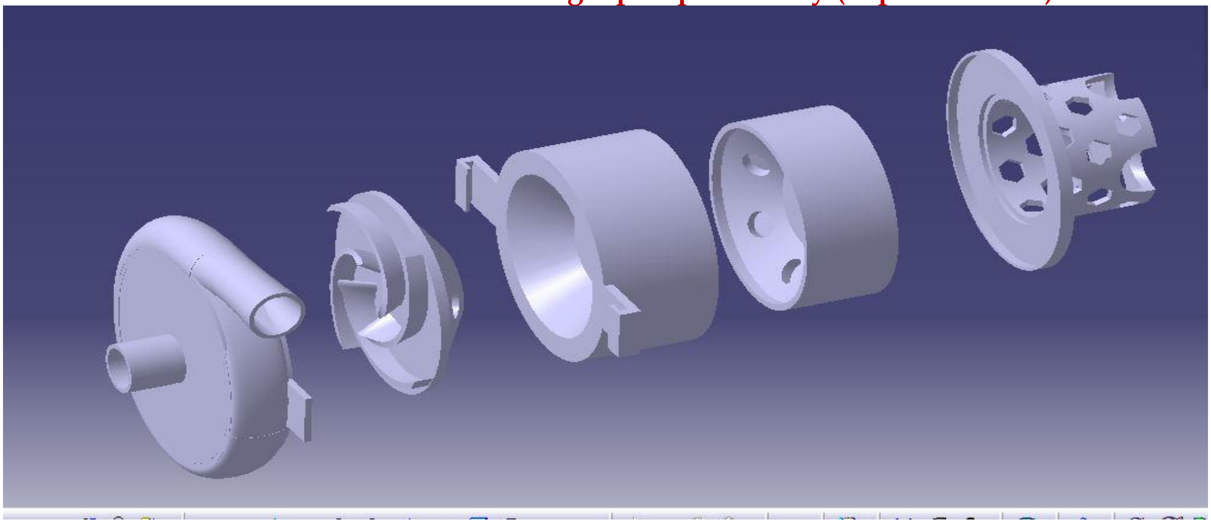
Parts of centrifugal pump :
1.Volute casing
2.impeller
3.Base Casing
4. Magnet case
5.Motor case

- A four bladed pump was designed for the purpose the results were as below The following figure shows the model of the pump.

4 blades with impeller diameter 49.29 mm



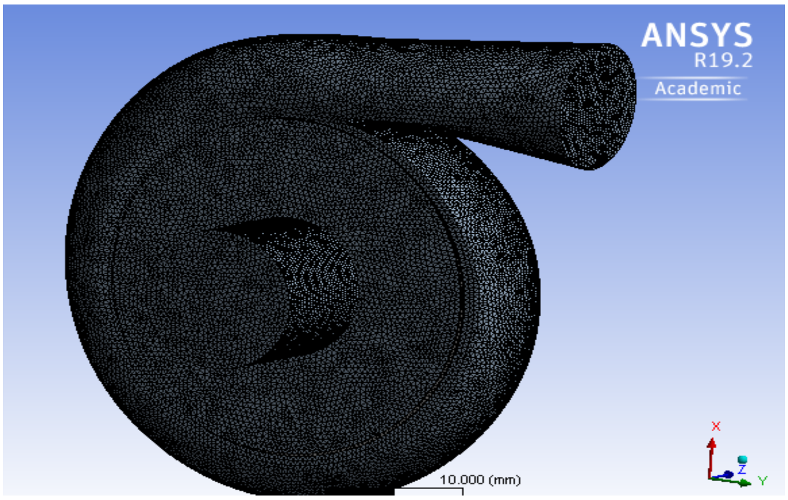
Four bladed model of Centrifugal pump assembly (Exploded view)



Parts of centrifugal pump :
1.Volute casing
2.impeller
3.Base Casing
4. Magnet case
5.Motor case

Meshing: The mesh size considered for the study was 0.4 mm with 1516382 elements

The following figure shows the sample of a meshed pump



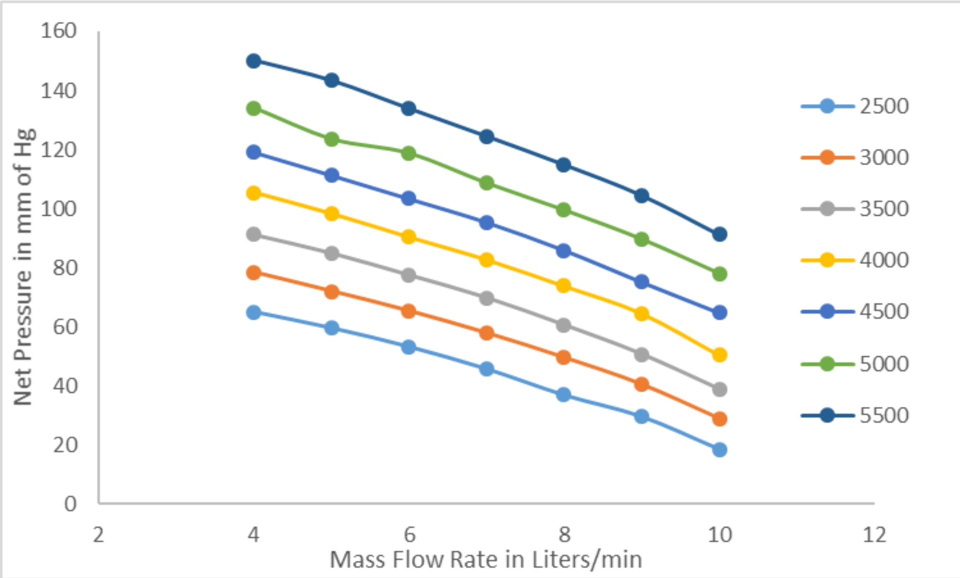
With body sizing of 0.4mm and element of 1516382

15.2. Results obtained from the Analysis of a Six Bladed Pump:

Speed	Mass Flow Rate in L/min	Mass Flow Rate in kg/s	Pressure inlet in Pa	Pressure outlet in Pa	Net Pressure in Pa	Net Pressure in mm of Hg
2500	4	0.07064	11756.299	20308.616	8552.317	64.9976092
2500	5	0.0883	12646.041	20482.321	7836.28	59.555728
2500	6	0.105996	13690.105	20690.834	7000.729	53.2055404
2500	7	0.123662	14923.735	20935.656	6011.921	45.6905996
2500	8	0.141328	16368.902	21216.73	4847.828	36.8434928
2500	9	0.158994	17654.905	21544.404	3889.499	29.5601924
2500	10	0.1766	19465.251	21903.797	2438.546	18.5329496
3000	4	0.07064	10009.204	20311.921	10302.717	78.3006492
3000	5	0.0883	11018.962	20483.158	9464.196	71.9278896
3000	6	0.105996	12105.418	20691.75	8586.332	65.2561232
3000	7	0.123662	13333.703	20938.073	7604.37	57.793212
3000	8	0.141328	14706.844	21223.393	6516.549	49.5257724
3000	9	0.158994	16224.264	21546.569	5322.305	40.449518
3000	10	0.1766	18103.954	21904.419	3800.465	28.883534
3500	4	0.07064	8315.7635	20311.92	11996.1565	91.1707894
3500	5	0.0883	9308.8939	20484.038	11175.1441	84.93109516
3500	6	0.105996	10494.376	20694.421	10200.045	77.520342
3500	7	0.123662	11753.813	20939.989	9186.176	69.8149376
3500	8	0.141328	13249.591	21223.618	7974.027	60.6026052
3500	9	0.158994	14881.043	21546.98	6665.937	50.6611212
3500	10	0.1766	16797.422	21902.114	5104.692	38.7956592
4000	4	0.07064	6442.5515	20311.362	13868.8105	105.4029598
4000	5	0.0883	7553.3627	20485.023	12931.6603	98.28061828
4000	6	0.105996	8808.8176	20694.035	11885.2174	90.32765224
4000	7	0.123662	10064.198	20941.543	10877.345	82.667822
4000	8	0.141328	11518.038	21226.443	9708.405	73.783878
4000	9	0.158994	13058.996	21549.328	8490.332	64.5265232
4000	10	0.1766	15264.867	21902.129	6637.262	50.4431912
4500	4	0.07064	4652.6085	20311.185	15658.5765	119.0051814
4500	5	0.0883	5848.1039	20483.221	14635.1171	111.22689
4500	6	0.105996	7102.5736	20694.257	13591.6834	103.2967938
4500	7	0.123662	8402.4634	20945.318	12542.8546	95.32569496
4500	8	0.141328	9926.4466	21225.771	11299.3244	85.87486544
4500	9	0.158994	11671.271	21549.523	9878.252	75.0747152
4500	10	0.1766	13400.166	21908.329	8508.163	64.6620388
5000	4	0.07064	2670.4572	20311.131	17640.6738	134.0691209
5000	5	0.0883	4227.1598	20485.553	16258.3932	123.5637883
5000	6	0.105996	5075.1392	20694.002	15618.8628	118.7033573
5000	7	0.123662	6649.6026	20941.572	14291.9694	108.6189674
5000	8	0.141328	8135.4233	21227.738	13092.3147	99.50159172

5000	9	0.158994	9749.8073	21548.76	11798.9527	89.67204052
5000	10	0.1766	11635.753	21907.49	10271.737	78.0652012
5500	4	0.07064	566.39492	20310.373	19743.97808	150.0542334
5500	5	0.0883	1636.295	20485.777	18849.482	143.2560632
5500	6	0.105996	3084.4596	20696.442	17611.9824	133.8510662
5500	7	0.123662	4565.2418	20943.268	16378.0262	124.4729991
5500	8	0.141328	6110.2192	21228.843	15118.6238	114.9015409
5500	9	0.158994	7792.3158	21552.13	13759.8142	104.5745879
5500	10	0.1766	9892.6061	21909.272	12016.6659	91.32666084

The following Figure shows the H-Q Curve:

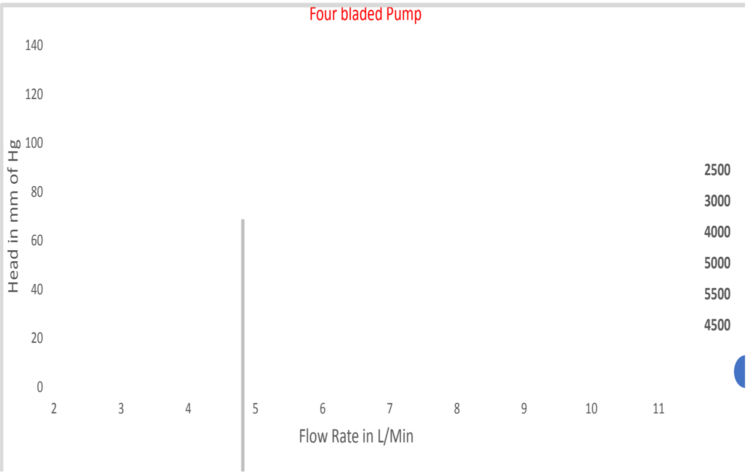


15.3. Results obtained from the Analysis of a Four Bladed Pump:

Speed	Mass Flow Rate in Litres/min	Mass Flow Rate in kg/s	Pressure inlet in Pa	Pressure outlet in Pa	Net Pressure in Pa	Net Pressure in mm of Hg
2000	4	0.07064	15989.5	20331.418	4341.914	32.9985464
2000	5	0.0883	17045.16	20513.968	3468.806	26.3629256
2000	6	0.105996	18142.72	20734.628	2591.905	19.698478
2000	7	0.123662	19526.25	20994.405	1468.158	11.1580008
2000	8	0.141328	20941.02	21298.781	357.758	2.7189608
2500	4	0.07064	14803.41	20331.79	5528.38	42.015688
2500	5	0.0883	15740.35	20513.619	4773.265	36.276814
2500	6	0.105996	16896.18	20735.284	3839.108	29.1772208
2500	7	0.123662	18399.13	20996.446	2597.321	19.7396396
2500	8	0.141328	19751.75	21297.735	1545.989	11.7495164
2500	9	0.158994	21402.95	21644.364	241.417	1.8347692
3000	4	0.07064	13458.18	20331.698	6873.52	52.238752
3000	5	0.0883	14631.36	20514.92	5883.563	44.7150788
3000	6	0.105996	15774.6	20738.439	4963.843	37.7252068
3000	7	0.123662	17137.68	20999.256	3861.577	29.3479852
3000	8	0.141328	18625.77	21301.374	2675.606	20.3346056
3000	9	0.158994	20285.19	21643.747	1358.554	10.3250104
3000	10	0.1766	22026.16	22028.834	2.679	0.0203604
4000	4	0.07064	10409.16	20330.802	9921.647	75.4045172
4000	5	0.0883	11609.95	20515.869	8905.919	67.6849844
4000	6	0.105996	13058.48	20741.034	7682.555	58.387418
4000	7	0.123662	14214.93	21003.037	6788.112	51.5896512
4000	8	0.141328	15806.05	21304.969	5498.922	41.7918072
4000	9	0.158994	17394.46	21649.042	4254.583	32.3348308
4000	10	0.1766	19496.76	22028.851	2532.095	19.243922
4500	4	0.07064	8727.589	20333.677	11606.09	88.20627184
4500	5	0.0883	10300.04	20515.165	10215.12	77.6349424
4500	6	0.105996	11588.71	20741.619	9152.91	69.562116
4500	7	0.123662	12649.55	20997.735	8348.183	63.4461908
4500	8	0.141328	14142.09	21299.55	7157.461	54.3967036
4500	9	0.158994	15720.05	21656.378	5936.325	45.11607
4500	10	0.1766	17730.84	22028.043	4297.202	32.6587352
5000	4	0.07064	6464.004	20331.316	13867.31	105.391572
5000	5	0.0883	8556.215	20517.762	11961.55	90.9077572
5000	6	0.105996	9066.453	20741.124	11674.67	88.7275034
5000	7	0.123662	10852	21008.655	10156.66	77.1905856
5000	8	0.141328	12800.48	21308.634	8508.157	64.6619932

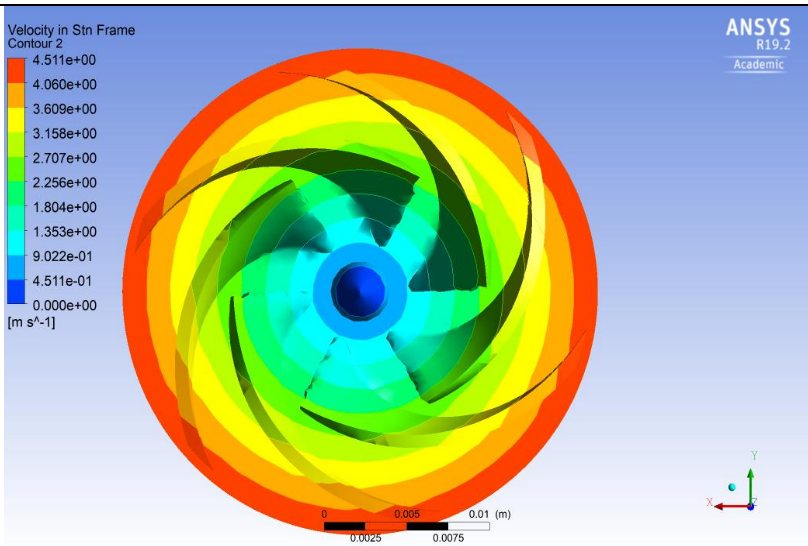
5000	9	0.158994	13726.43	21648.712	7922.281	60.2093356
5000	10	0.1766	15744.32	22028.144	6283.823	47.7570548
5500	4	0.07064	4106.299	20331.306	16225.01	123.3100532
5500	5	0.0883	6470.983	20515.36	14044.38	106.737266
5500	6	0.105996	7703.053	20737.389	13034.34	99.06095436
5500	7	0.123662	9309.652	21003.988	11694.34	88.87695132
5500	8	0.141328	10238.66	21300.389	11061.73	84.0691404
5500	9	0.158994	11701.58	21653.27	9951.693	75.6328668
5500	10	0.1766	13956.45	22023.001	8066.549	61.3057724

The following Figure shows the H-Q Curve

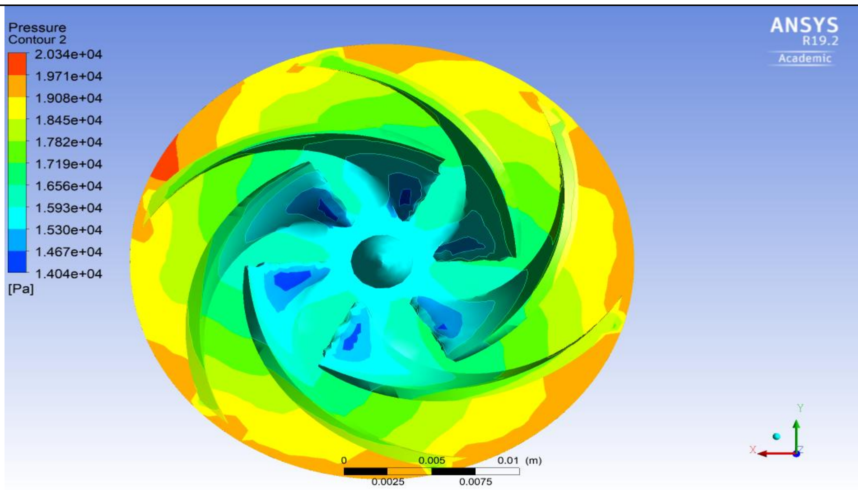


<u>16. Parametric Studies of Four and Six Bladed Pumps</u>

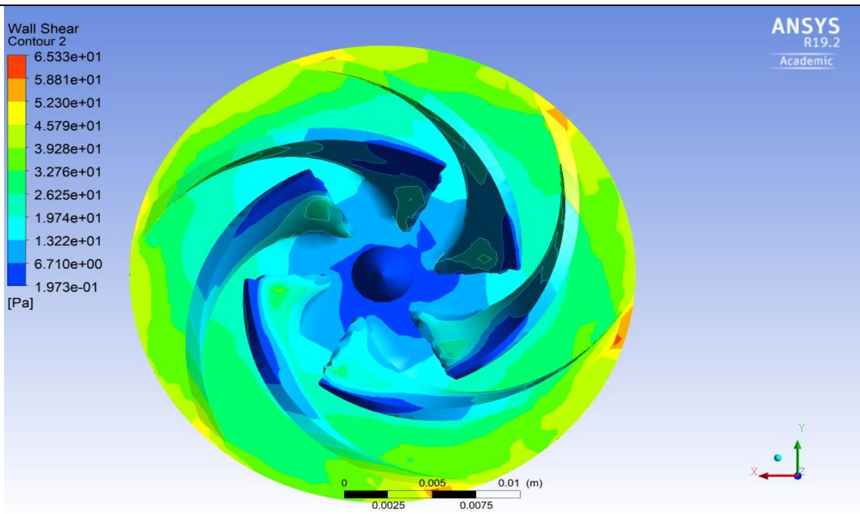
16.1. Six Bladed Pump:



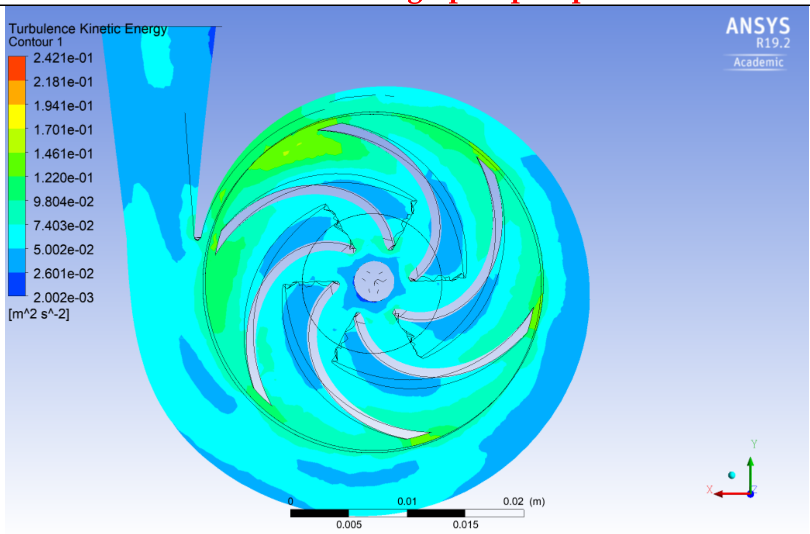
Velocity variation of fluid through pump impellers without volute



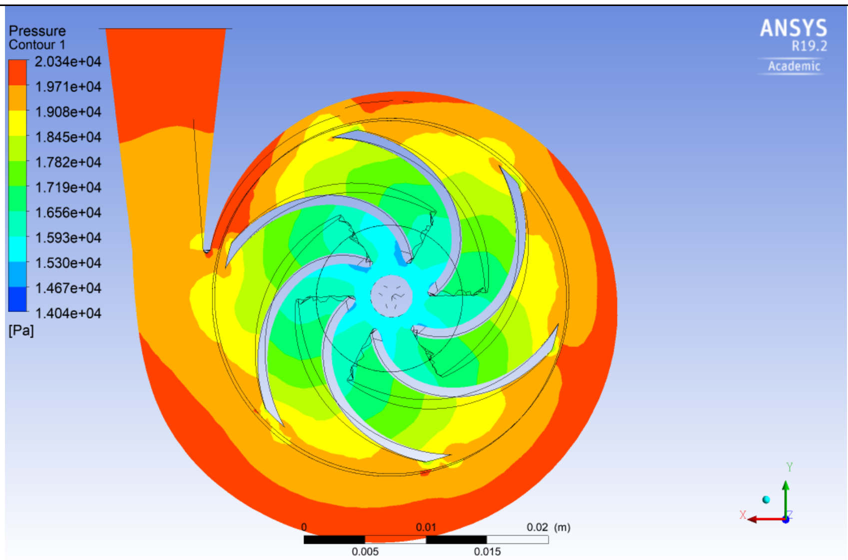
Pressure variation of fluid through pump impellers without volute



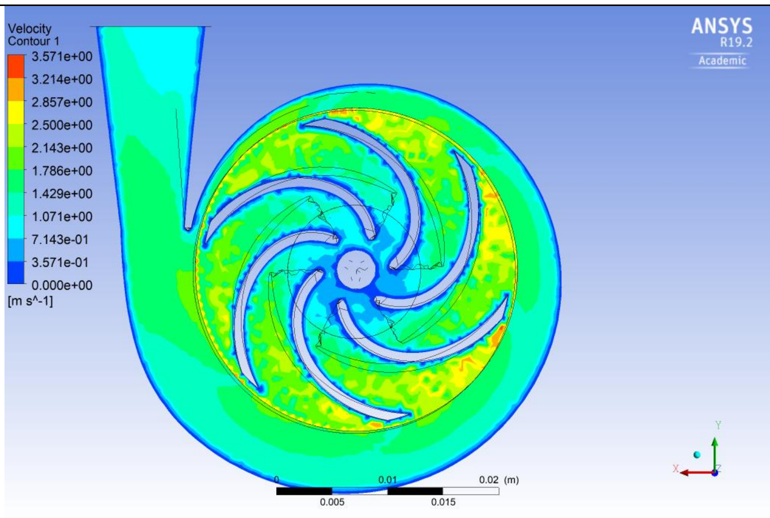
Wall shear variation of fluid through pump impellers without volute



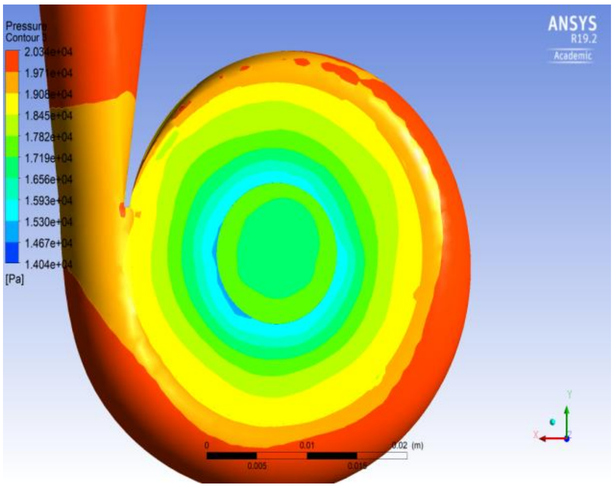
Turbulence k-ε variation of fluid through pump



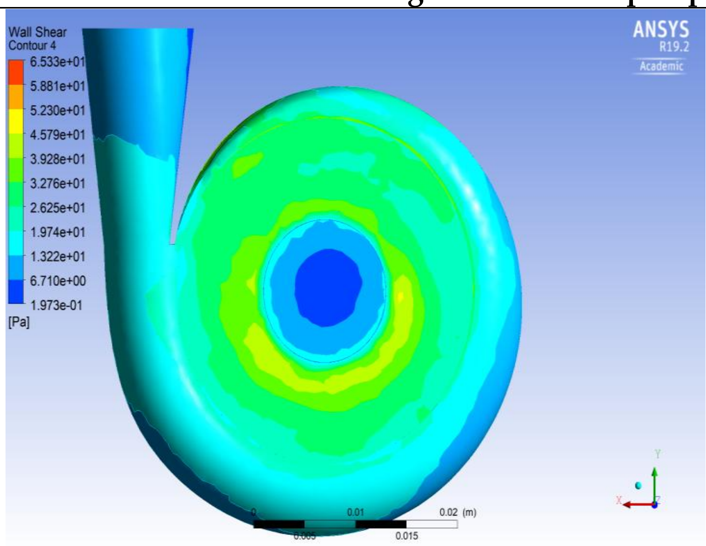
Pressure contour variation of fluid through pump



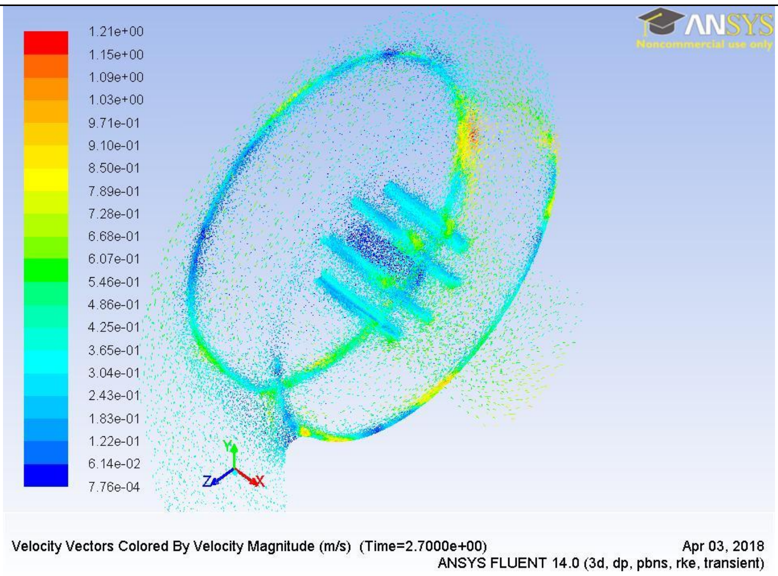
Velocity contour variation of fluid through pump



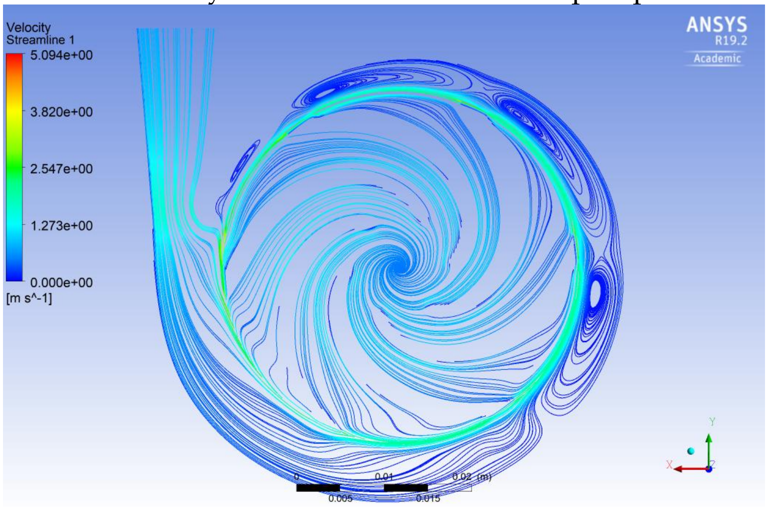
Max pressure shear is 203400 Pa
Pressure and Wall shear through volute of the pump



Max Wall shear is 65.33 Pa
Pressure and Wall shear through volute of the pump

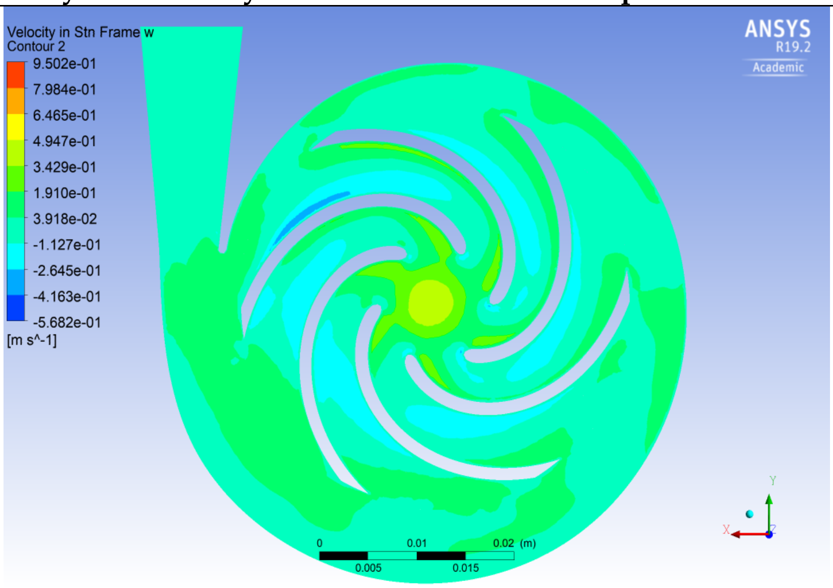


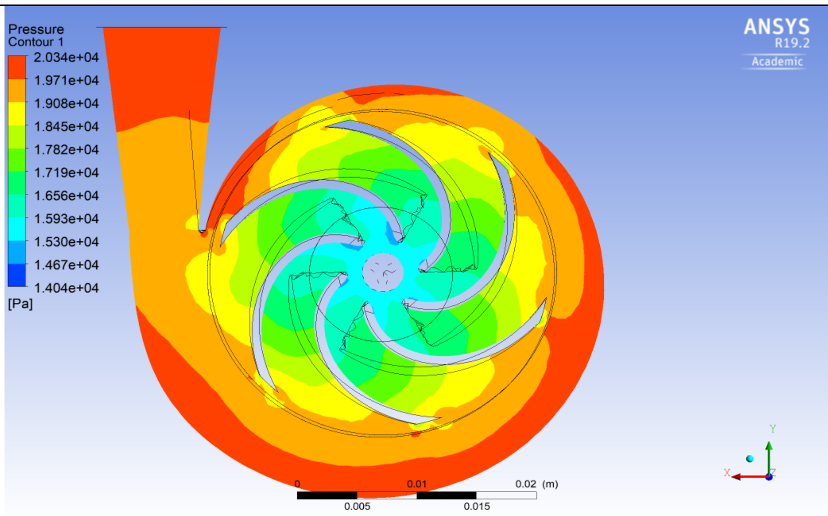
Velocity vectors of the fluid in the pump



Streamline

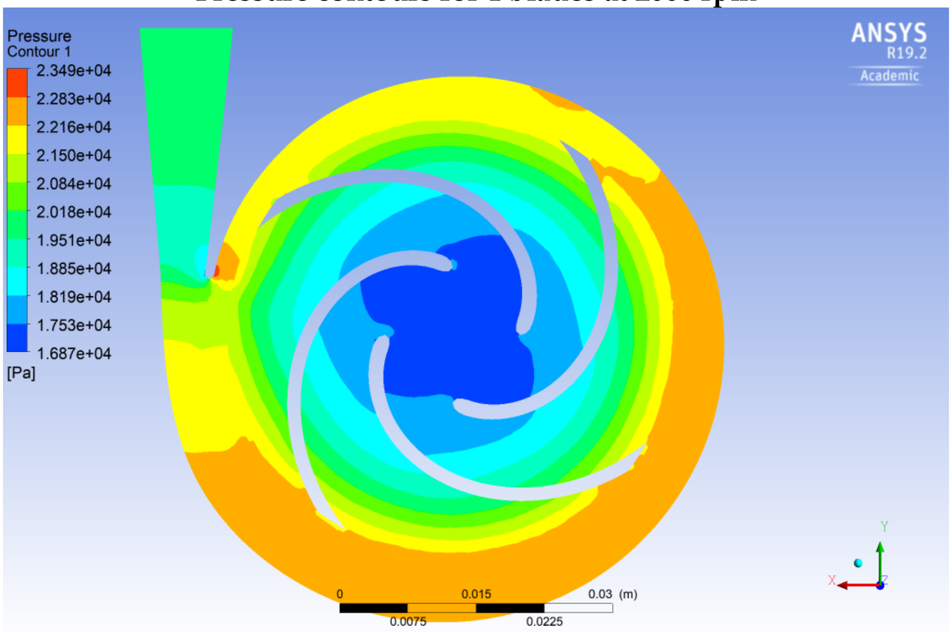
Velocity in Stationery frame for 6 blades with impeller of 39.10 mm



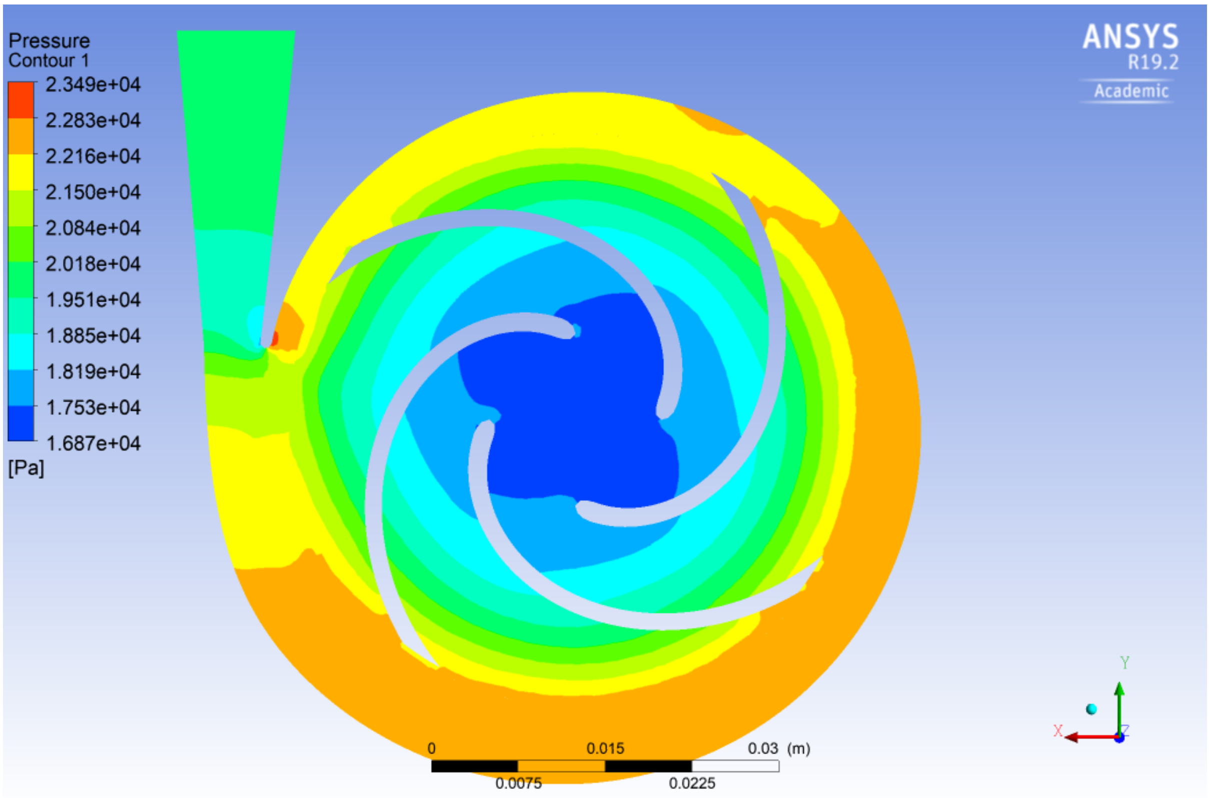


16.2. FOUR BLADED PUMP

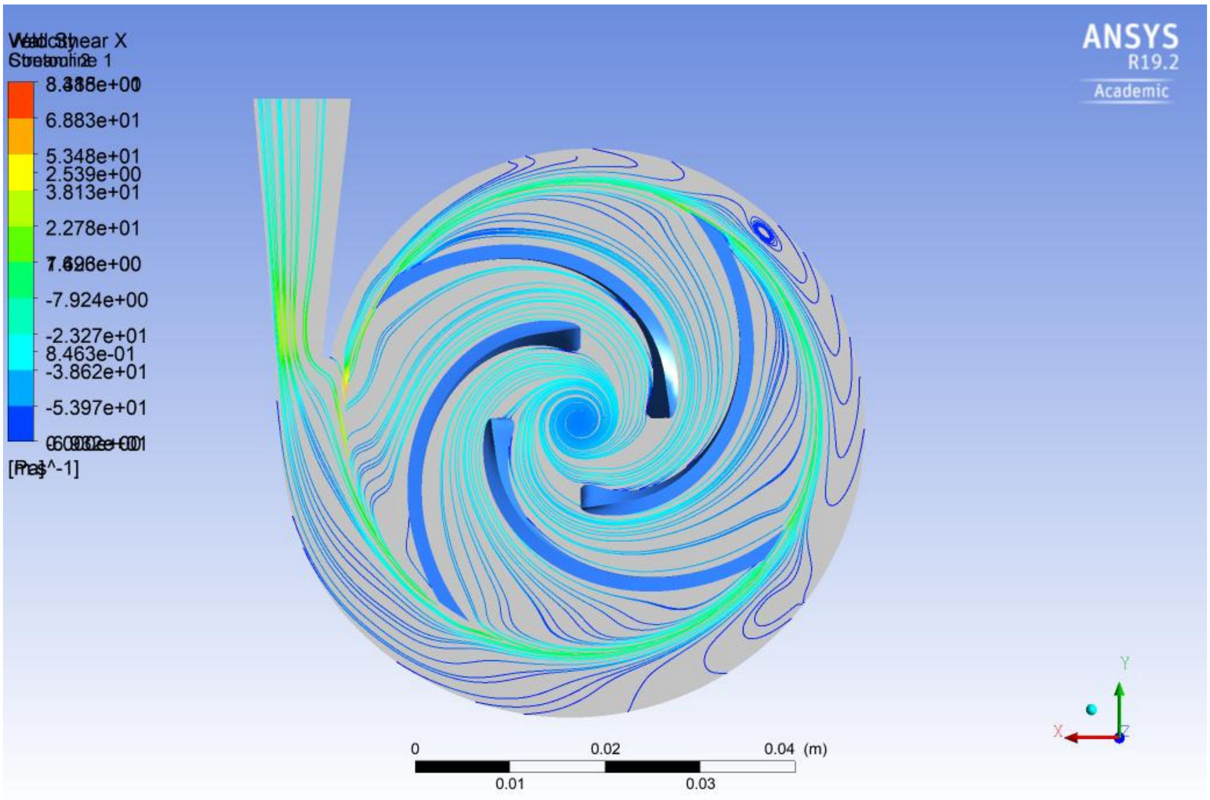
Pressure contours for 4 blades at 2000 rpm



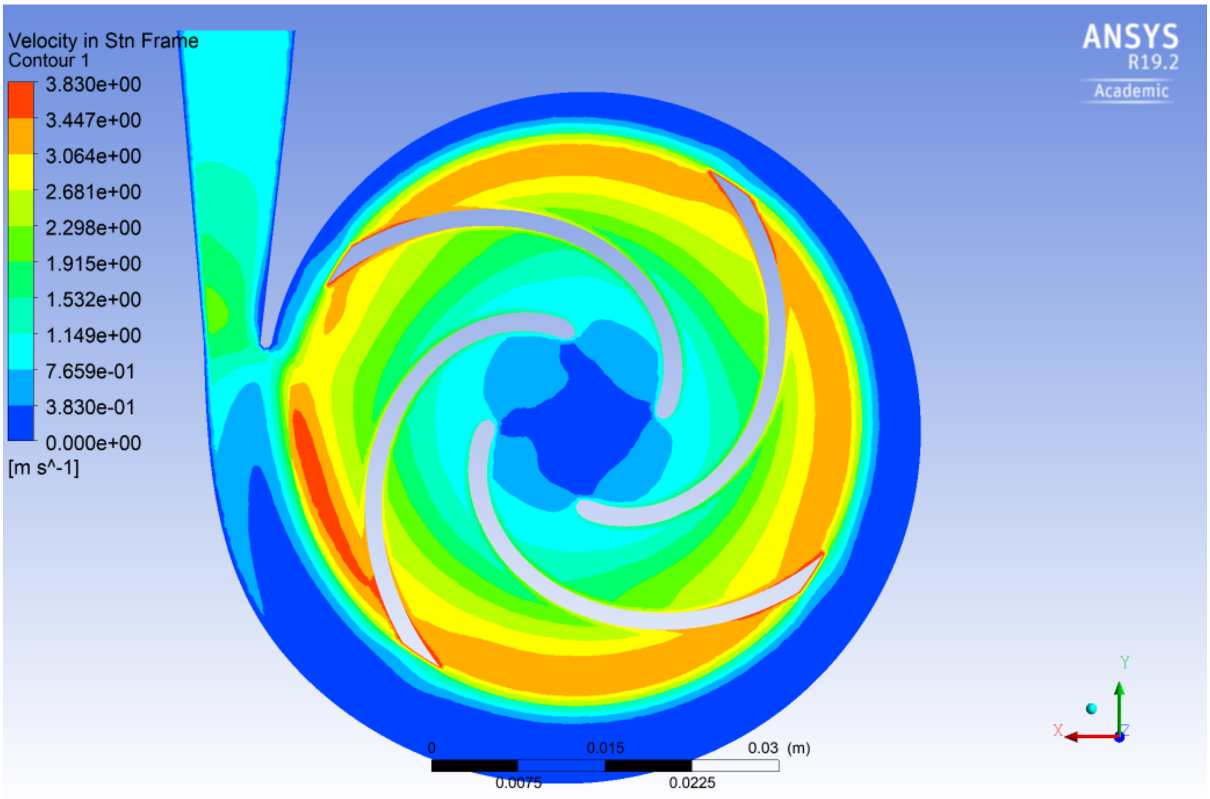
Pressure contours for 4 blades at 2000 rpm



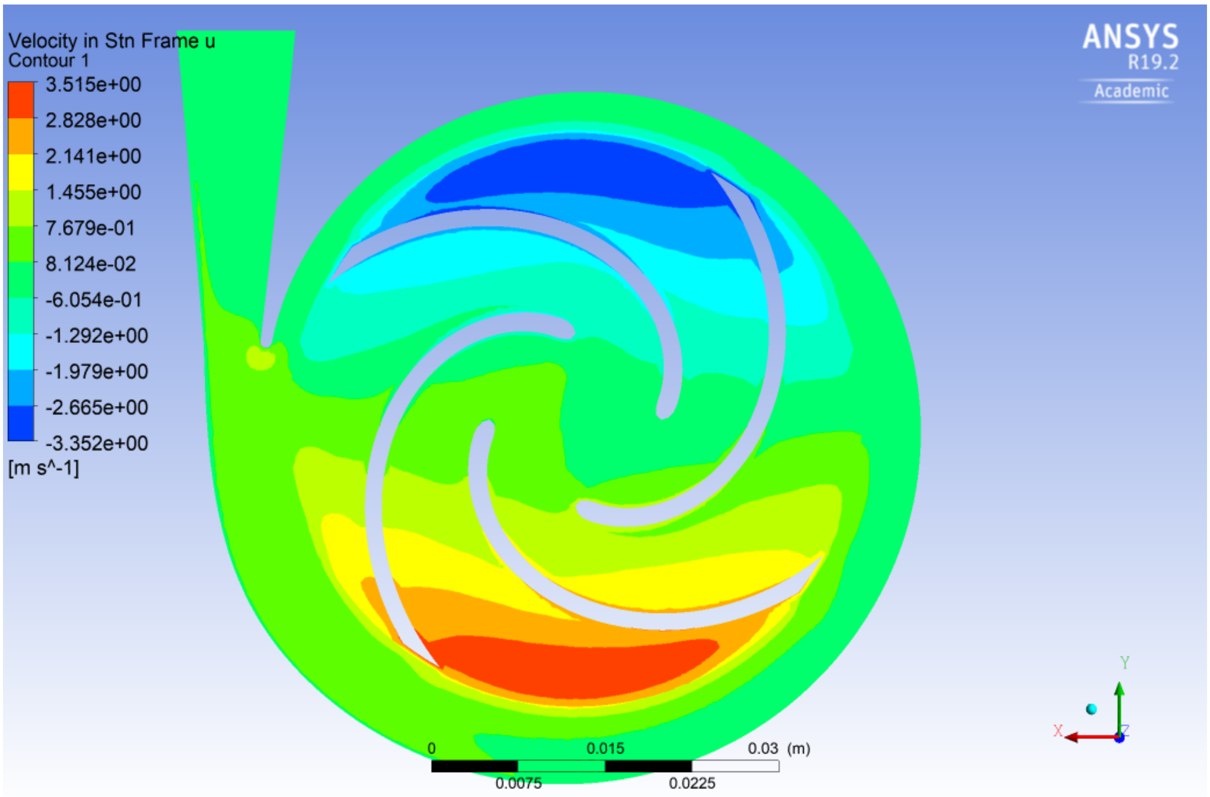
Pressure contour at 2000 rpm

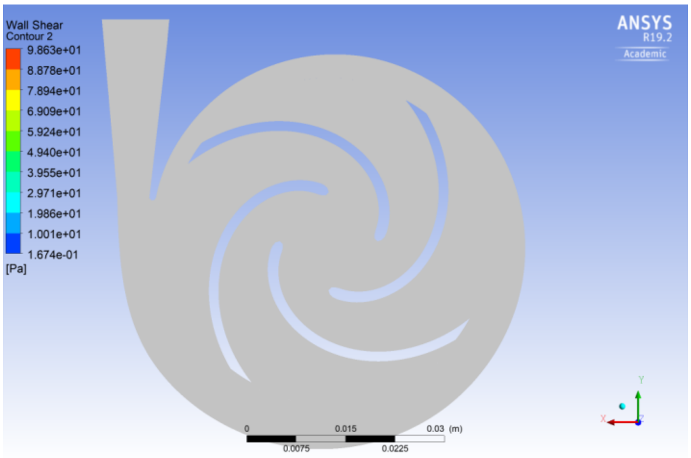


Stream line at 2000 rpm



Velocity in Stationary frame contour at 2000 rpm



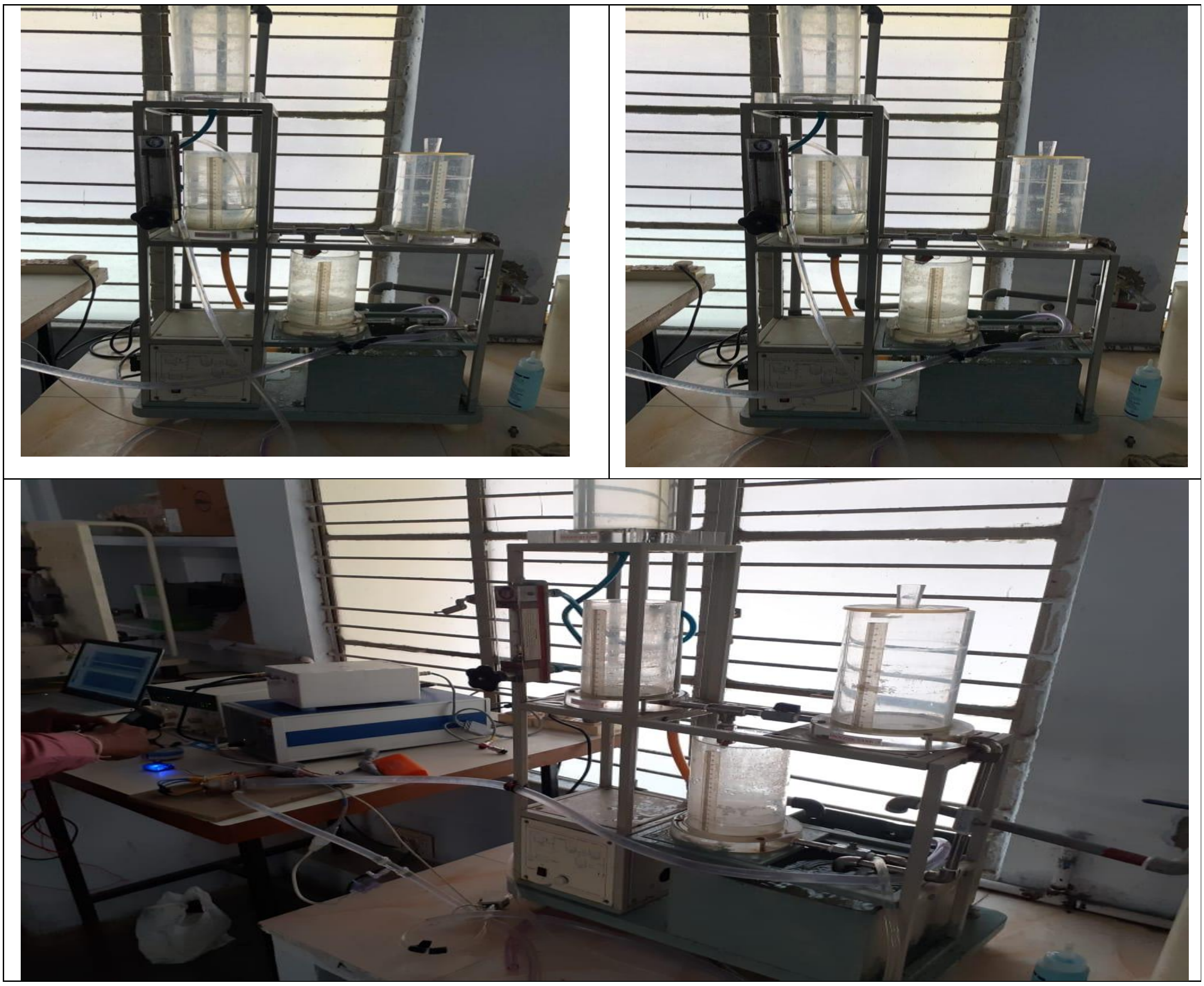


Wall Shear at 2000 rpm is 98.30 Pa

16.3. Comparison of 6 blades and 4 blades Pump

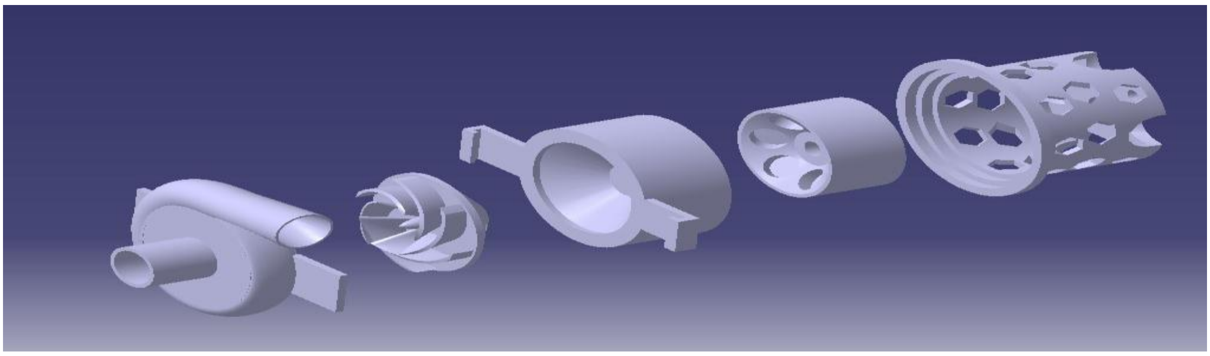
Speed	Mass Flow Rate in Liters/min	Net Pressure in mm of Hg
For 4 blades with impeller Dia. 49.21		
5000	5	90.90776
5500	6	99.06095
5000	4	105.3916
5500	5	106.7373
5500	4	123.3101
For 6 blades with impeller Dia. 39.10		
5500	8	114.9015
5000	6	118.7034
4500	4	119.0052
5000	5	123.5638
5500	7	124.473
For 6 blades with impeller Dia. 28.63		
5500	10	103.5216
4500	7	120.566
4500	6	117.9535
4500	5	133.378
4500	4	131.2673

Further from 15 Jan 2019 mock-up loop test up was installed in the department of EIE for the experimentation



Mock-up Loop Test Set up installed at KITSW

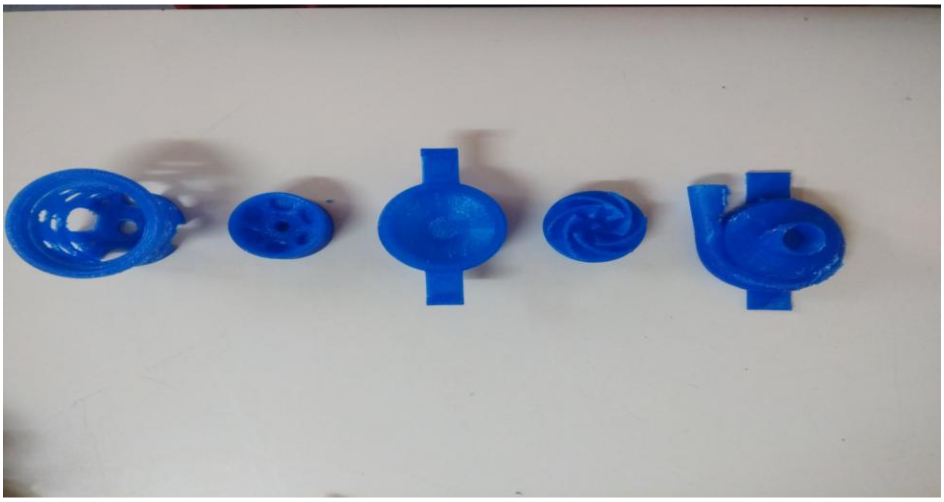
16.4. 3D Solid models of 6 blades Impeller and volute:
In CATIA, solid models of impeller, volute and remaining parts related to centrifugal pump are designed . All parts are designed and assembled in CATIA V5R20.



Centrifugal pump with 6 blades with smaller diameter

16.4.1. 3D printing of the 6 blade models:

The models which are designed in CATIA software , are printed in 3D printing machine . The machine used is Flashforge Dreamer 3D printing machine.



Individual parts of centrifugal pump

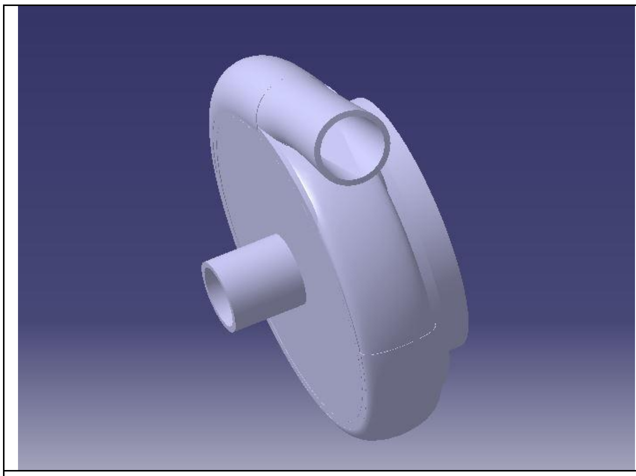
Individual parts of centrifugal pump (6 blades)

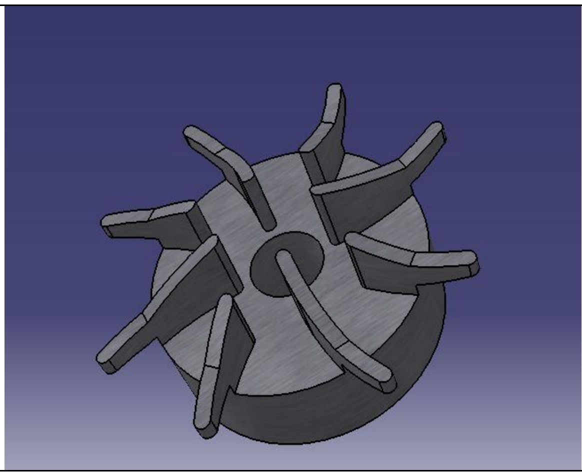
17. Design of the Levitation pump

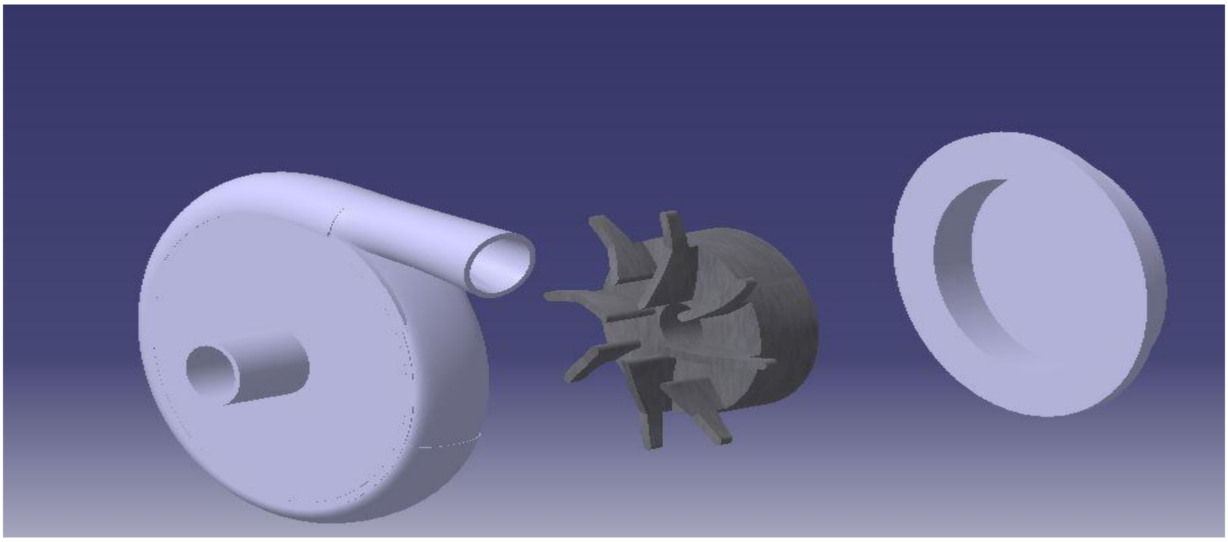
The pump consists of impeller and casing which consists of eight blades.

LEVITATION PUMP OF LAXVEN SYSTEMS

SIMULATION MODEL OF A LEVITATION PUMP



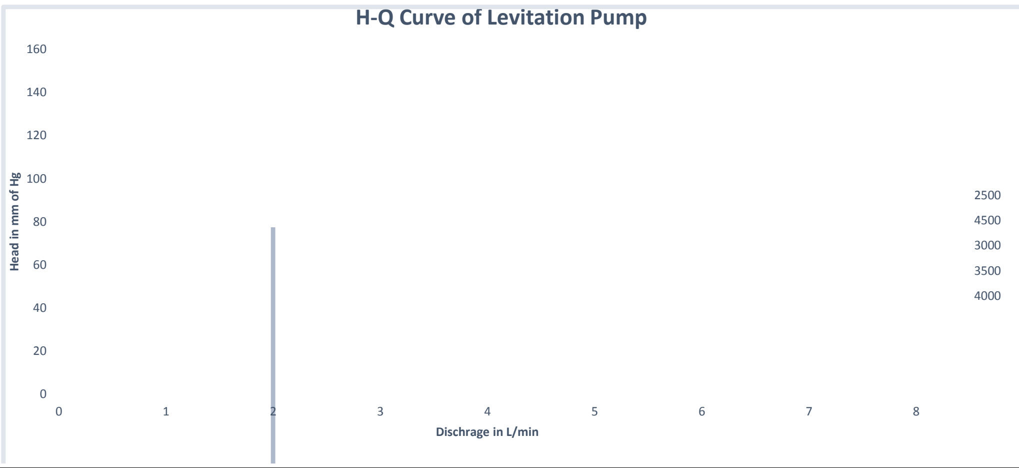




17.1. Results obtained from the Analysis of a Levitation Pump:

Speed	Mass Flow Rate in Liters/min	Mass Flow Rate in kg/s	Pressure inlet in Pa	Pressure oulet in Pa	Net Pressure in mm of Hg
2500	4	0.07064	20347.85	16131.68	32.04288
2500	5	0.0883	20856	17000	29.3056
2500	6	0.105996	20825.16	17829.32	22.76844

2500	7	0.123662	21143.737	18736.214	18.29717
	4	0.07064	20355.47	2069.932	138.9701
4500	5	0.08833	20568.71	3003.16	133.4982
4500	6	0.105996	20806.14	4815.408	121.5295
4500	7	0.123662	21102.87	6509.785	110.9074
3000	4	0.07064	20349.26	13648.13	50.92858
3000	5	0.08833	20550.8	14395.21	46.78249
3000	6	0.105996	20816.29	15546.7	40.04894
3000	7	0.123662	21123.54	16509.14	35.06944
3500	4	0.07064	20356	10059.12	78.25628
3500	5	0.08833	20547.14	11165.36	71.30154
3500	6	0.105996	20804.37	12659.15	61.90367
3500	7	0.123662	21118.32	13688.35	56.46783
4000	4	0.07064	20364.32	6510.64	105.2879
4000	5	0.08833	20555.35	7780.089	97.09195
4000	6	0.105996	20793.458	9172.7881	88.31709
4000	7	0.123662	21108.416	10331.747	81.90268



Upcoming events

- Flow Modelling using CFD
- 3D printing of the designs
- Mock loop testing
- Design modifications for betterment

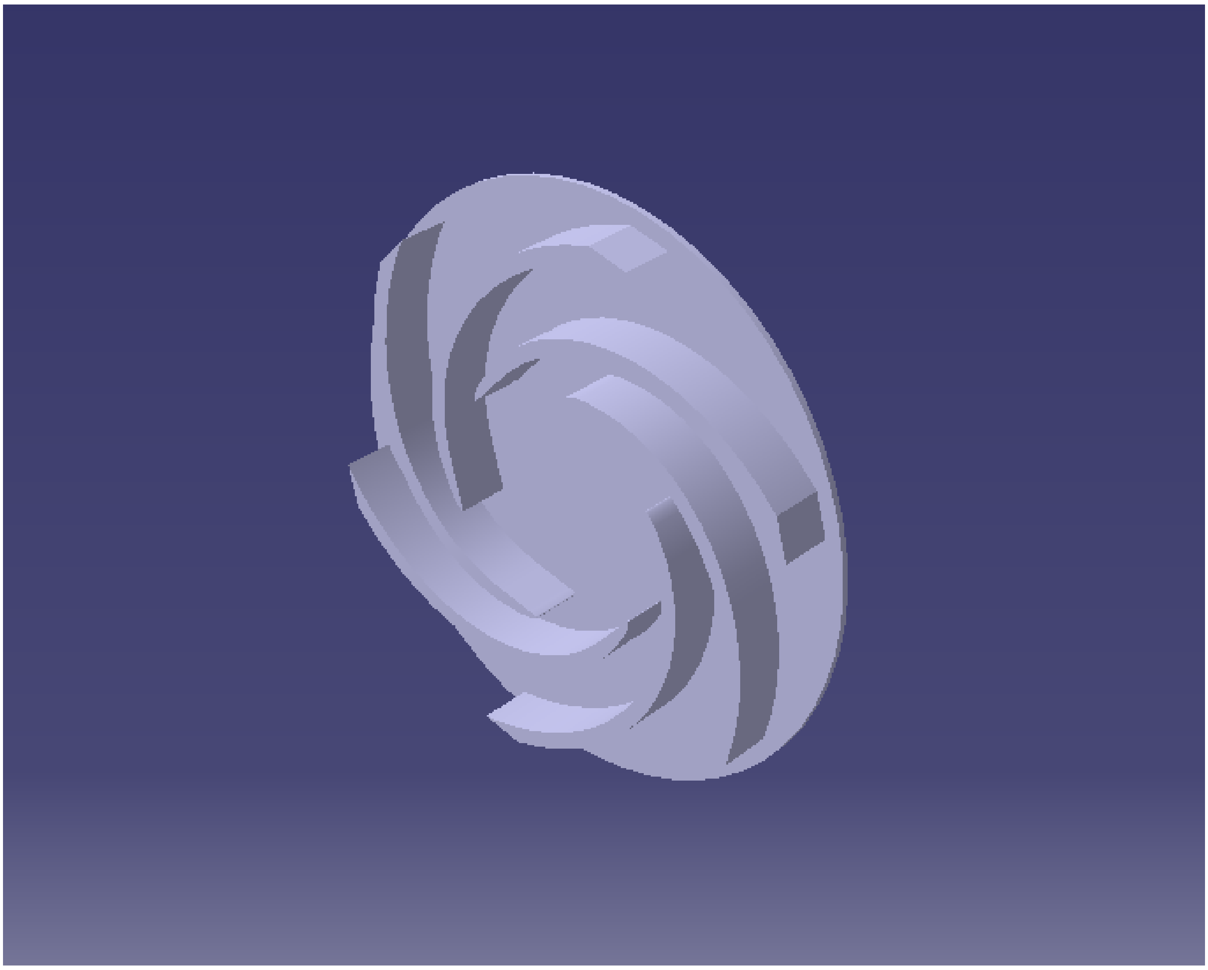
Future plans:

- Procurement of latest 3d Printers
- Simulation and fabrication of a complete pump
- Modeling of wireless power transmission

18 . 2D sketch Analysis

Done on 25/7/2019

2D sketch of 6 blades were done in CATIA, by projecting on to the new datum plane.

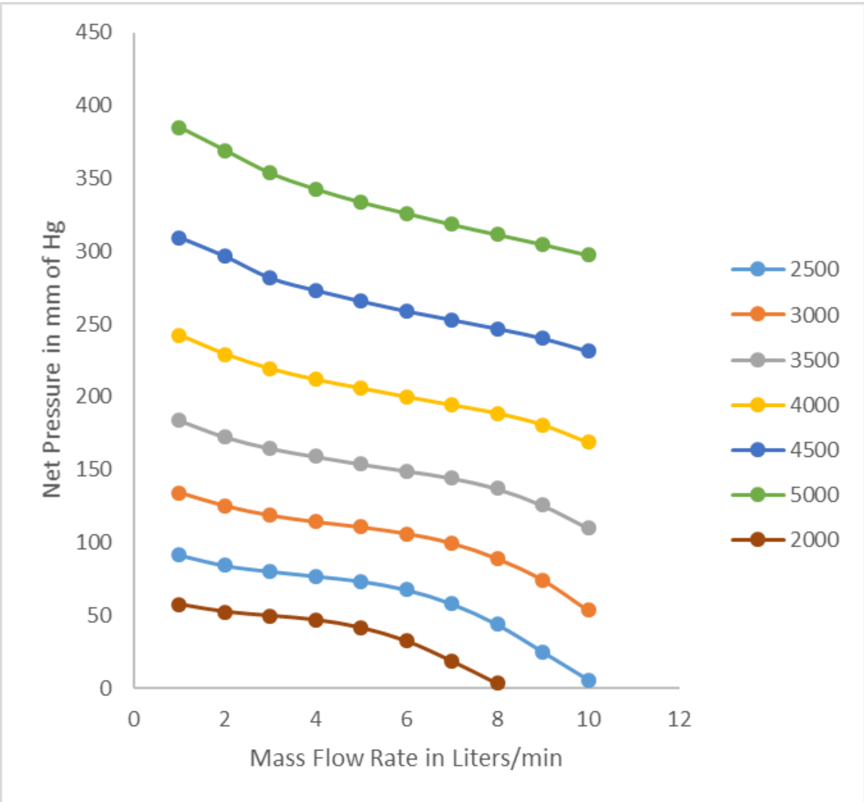


Analysis of the 2D Sketch were done in ANSYS ,following are the results

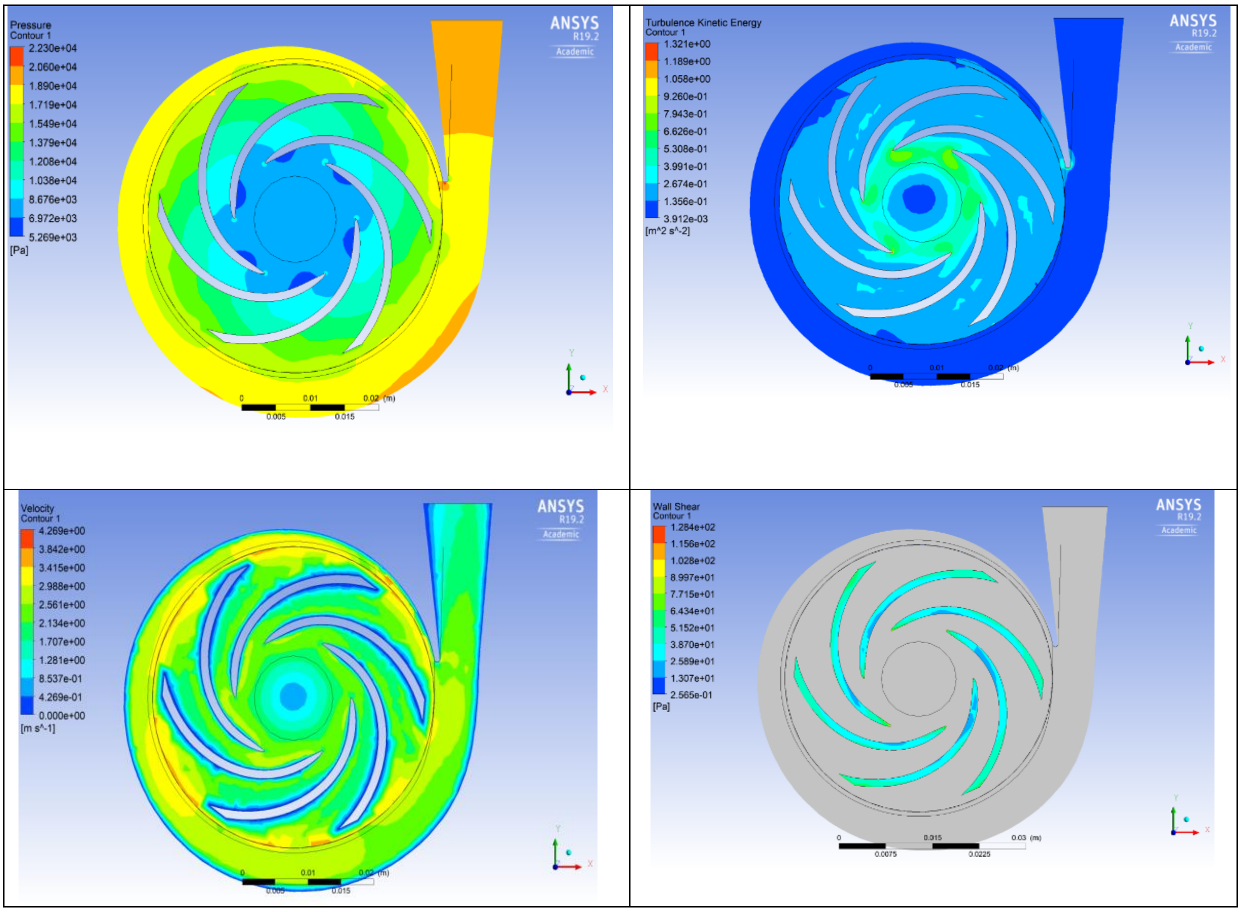
Speed	Mass Flow Rate in Liters/min	Mass Flow Rate in kg/s	Pressure inlet in Pa	Pressure outlet in Pa	Net Pressure in Pa	Net Pressure in mm of Hg
2000	10	0.1766	27311.544	23206.726	-4104.818	-31.1966168
2000	9	0.158994	24213.249	22484.325	-1728.924	-13.1398224
2000	8	0.141328	21454.547	21900.413	445.866	3.3885816
2000	7	0.123662	18900.063	21367.22	2467.157	18.7503932
2000	6	0.105996	16613.826	20879.158	4265.332	32.4165232
2000	5	0.0883	15071.19	20534.084	5462.894	41.5179944
2000	4	0.07064	14160.592	20328.057	6167.465	46.872734
2000	3	0.053	13648.089	20187.649	6539.56	49.700656

2000	2	0.03533333	13191.185	20088.365	6897.18	52.418568
2000	1	0.01766667	12468.787	20022.982	7554.195	57.411882
2500	10	0.17666667	22316.415	23055.581	739.166	5.6176616
2500	9	0.158994	19084.415	22349.957	3265.542	24.8181192
2500	8	0.141328	15926.907	21667.871	5740.964	43.6313264
2500	7	0.123662	13509.632	21124.347	7614.715	57.871834
2500	6	0.105996	11871.354	20759.25	8887.896	67.5480096
2500	5	0.0883	10847.981	20511.742	9663.761	73.4445836
2500	4	0.07064	10217.503	20335.164	10117.661	76.8942236
2500	3	0.053	9643.0593	20199.533	10556.4737	80.22920012
2500	2	0.03533333	9003.3472	20092.86	11089.5128	84.28029728
2500	1	0.01766667	7987.4773	20027.299	12039.8217	91.50264492
3000	10	0.1766	15657.899	22701.276	7043.377	53.5296652
3000	9	0.158994	12212.879	21991.011	9778.132	74.3138032
3000	8	0.141328	9715.5825	21420.913	11705.3305	88.9605118
3000	7	0.123662	7926.495	21022.551	13096.056	99.5300256
3000	6	0.105996	6771.5082	20736.701	13965.1928	106.1354653
3000	5	0.0883	5973.2662	20522.74	14549.4738	110.5760009
3000	4	0.07064	5327.8517	20353.052	15025.2003	114.1915223
3000	3	0.053	4600.2436	20209.301	15609.0574	118.6288362
3000	2	0.03533333	3634.0906	20102.026	16467.9354	125.156309
3000	1	0.01766667	2369.6824	20034.468	17664.7856	134.2523706
3500	10	0.1766	7859.4483	22333.168	14473.7197	110.0002697
3500	9	0.158994	5229.0003	21755.006	16526.0057	125.5976433
3500	8	0.141328	3307.3974	21329.226	18021.8286	136.9658974
3500	7	0.123662	2024.4867	21003.066	18978.5793	144.2372027
3500	6	0.105996	1119.397	20754.654	19635.257	149.2279532
3500	5	0.0883	305.76984	20554.829	20249.05916	153.8928496
3500	4	0.07064	-553.65891	20374.472	20928.13091	159.0537949
3500	3	0.053	-1444.5973	20219.584	21664.1813	164.6477779
3500	2	0.03533333	-2590.9652	20108.843	22699.8082	172.5185423
3500	1	0.01766667	-4152.2778	20039.092	24191.3698	183.8544105
4000	10	0.1766	-87.08193	22123.687	22210.76893	168.8018439
4000	9	0.158994	-2122.4201	21672.978	23795.3981	180.8450256
4000	8	0.141328	-3534.5387	21309.149	24843.6877	188.8120265
4000	7	0.123662	-4557.0538	21026.346	25583.3998	194.4338385
4000	6	0.105996	-5520.5886	20797.924	26318.5126	200.0206958
4000	5	0.0883	-6510.0158	20585.666	27095.6818	205.9271817
4000	4	0.07064	-7489.2284	20386.343	27875.5714	211.8543426
4000	3	0.053	-8609.5666	20244.926	28854.4926	219.2941438

4000	2	0.03533333	-10061.54	20119.569	30181.109	229.3764284
4000	1	0.01766667	-11832.516	20042.969	31875.485	242.253686
4500	10	0.1766	-8374.5224	22058.443	30432.9654	231.290537
4500	9	0.158994	-9955.5298	21655.462	31610.9918	240.2435377
4500	8	0.141328	-11144.544	21336.704	32481.248	246.8574848
4500	7	0.123662	-12194.487	21079.73	33274.217	252.8840492
4500	6	0.105996	-13217.436	20836.967	34054.403	258.8134628
4500	5	0.0883	-14337.928	20607.703	34945.631	265.5867956
4500	4	0.07064	-15519.546	20408.905	35928.451	273.0562276
4500	3	0.053	-16783.269	20261.046	37044.315	281.536794
4500	2	0.03533333	-18881.646	20130.621	39012.267	296.4932292
4500	1	0.01766667	-20662.254	20044.594	40706.848	309.3720448
5000	10	0.1766	-17117.162	22042.64	39159.802	297.6144952
5000	9	0.158994	-18424.067	21690.672	40114.739	304.8720164
5000	8	0.141328	-19596.584	21407.287	41003.871	311.6294196
5000	7	0.123662	-20763.755	21143.807	41907.562	318.4974712
5000	6	0.105996	-22033.221	20875.052	42908.273	326.1028748
5000	5	0.0883	-23277.607	20627.443	43905.05	333.67838
5000	4	0.07064	-24628.568	20453.144	45081.712	342.6210112
5000	3	0.053	-26255.689	20265.007	46520.696	353.5572896
5000	2	0.03533333	-28433.379	20144.477	48577.856	369.1917056
5000	1	0.01766667	-30590.339	20044.709	50635.048	384.8263648



Contours of 2D sketch analysis:

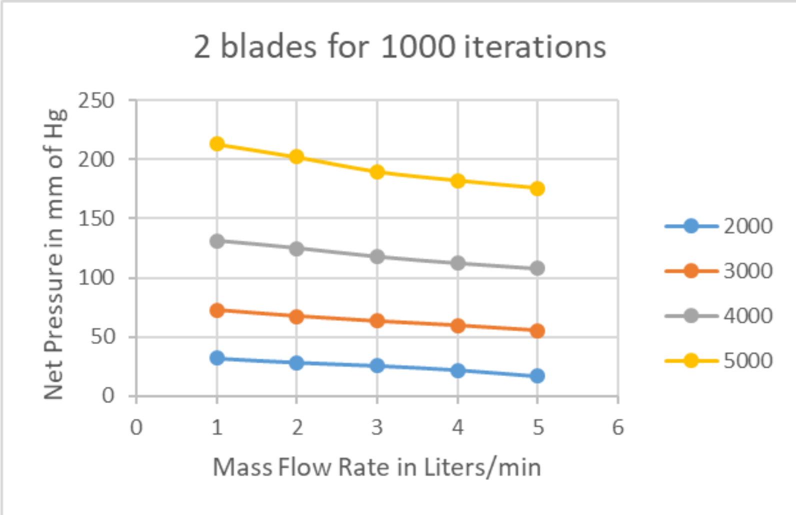


19. Analysis of different blades of 2D sketch:

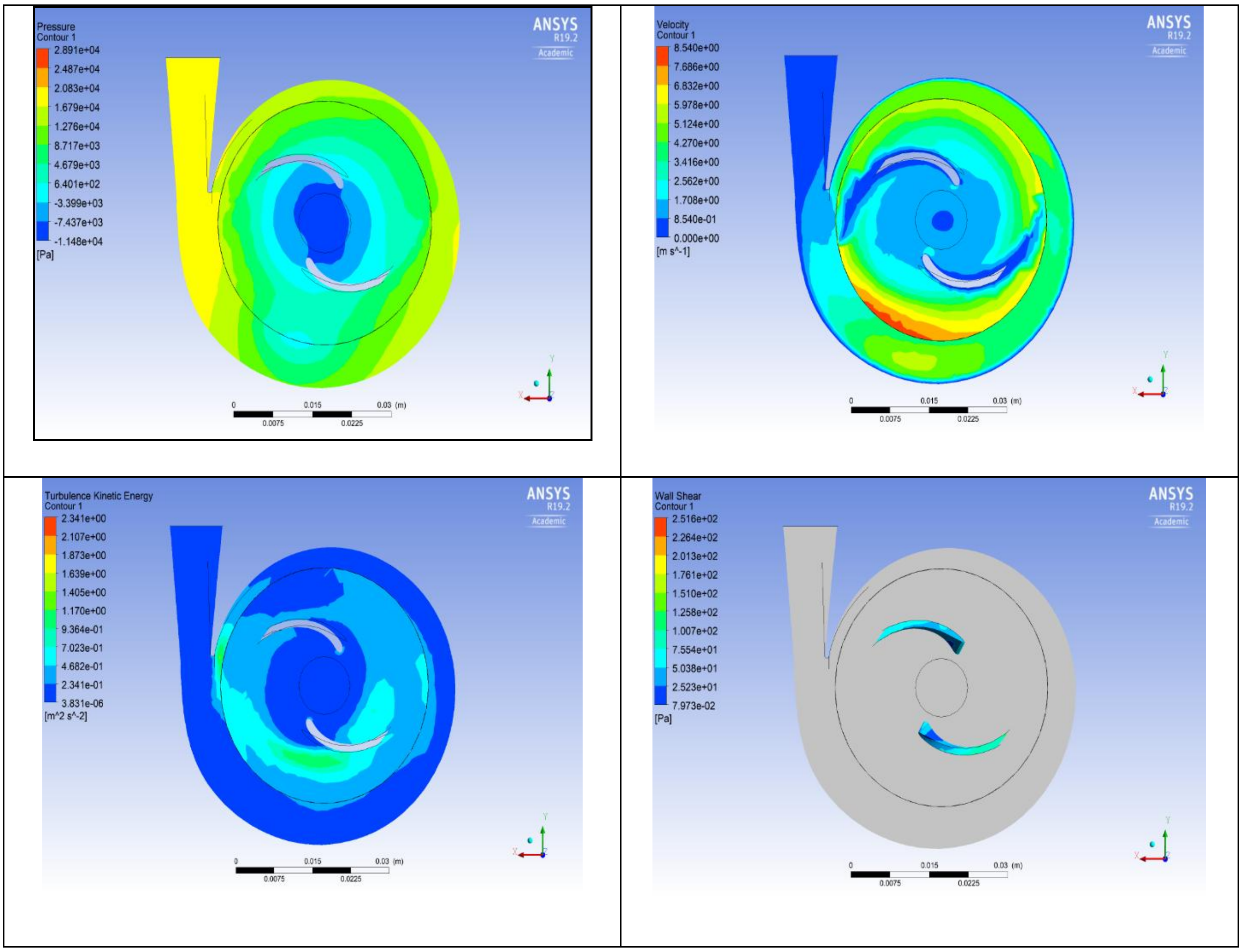
31/07/2019 to 09/08/2019:

<u>Done on 31-7-2019 - 2D sketch with 2 blades:</u>

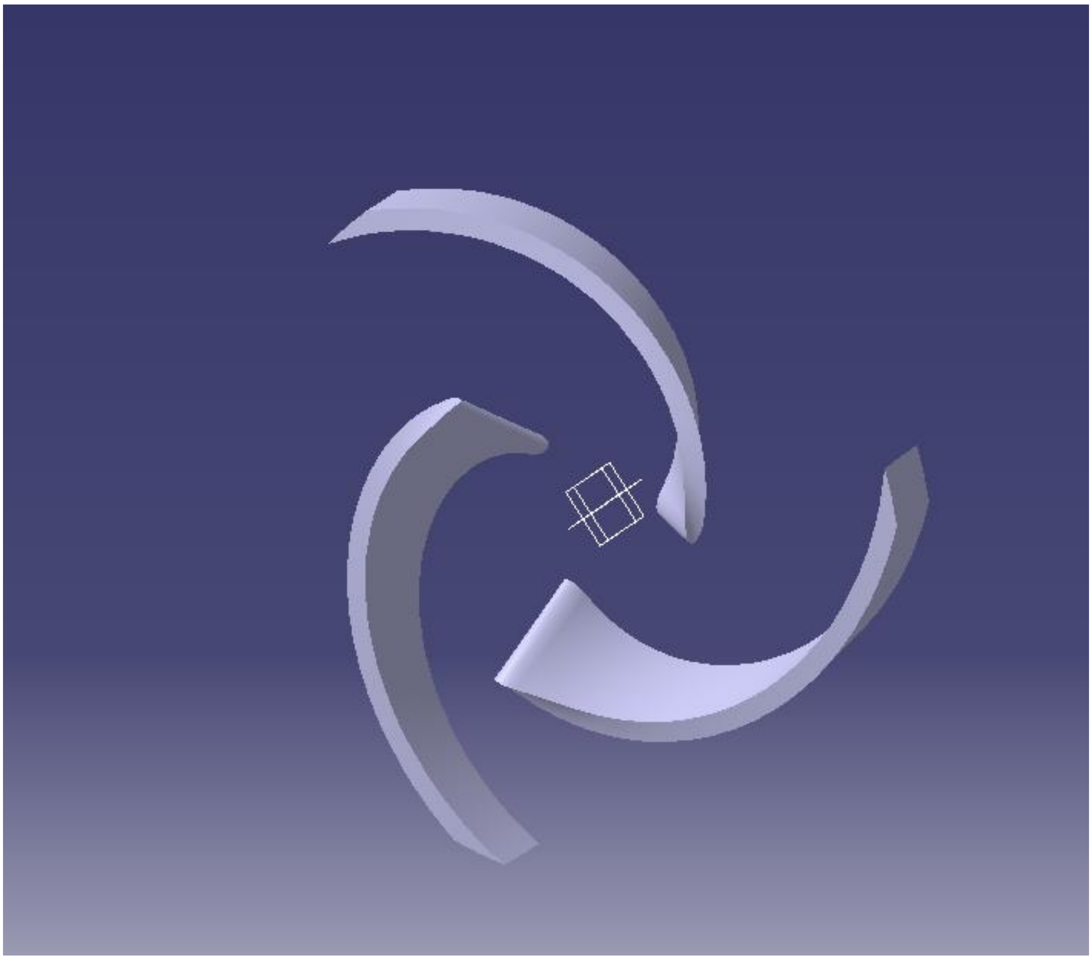
Speed	Mass Flow Rate in Liters/min	Mass Flow Rate in kg/s	Pressure inlet in Pa	Pressure outlet in Pa	Net Pressure in Pa	Net Pressure in mm of Hg
2000	5	0.0883	18442.64	20629.838	2187.198	16.6227048
2000	4	0.07064	17464.518	20355.527	2891.009	21.9716684
2000	3	0.053	16817.867	20185.604	3367.737	25.5948012
2000	2	0.035333333	16362.336	20085.815	3723.479	28.2984404
2000	1	0.017666667	15822.42	20022.297	4199.877	31.9190652
3000	5	0.0883	13246.503	20517.596	7271.093	55.2603068
3000	4	0.07064	12489.009	20333.222	7844.213	59.6160188
3000	3	0.053	11882.307	20202.721	8320.414	63.2351464
3000	2	0.035333333	11209.92	20093.691	8883.771	67.5166596
3000	1	0.017666667	10453.289	20023.422	9570.133	72.7330108
					0	0
4000	5	0.0883	6353.974	20527.817	14173.843	107.7212068
4000	4	0.07064	5577.8423	20362.381	14784.5387	112.3624941
4000	3	0.053	4723.2653	20218.489	15495.2237	117.7637001
4000	2	0.035333333	3650.3861	20097.379	16446.9929	124.997146
4000	1	0.017666667	2774.5526	20028.991	17254.4384	131.1337318
					0	0
5000	5	0.0883	-2574.9378	20566.325	23141.2628	175.8735973
5000	4	0.07064	-3597.7673	20389.261	23987.0283	182.3014151
5000	3	0.053	-4746.6893	20224.912	24971.6013	189.7841699
5000	2	0.035333333	-6515.0883	20100.154	26615.2423	202.2758415
5000	1	0.017666667	-8033.6637	20035.156	28068.8197	213.3230297
					0	0



Contour for 2Blades

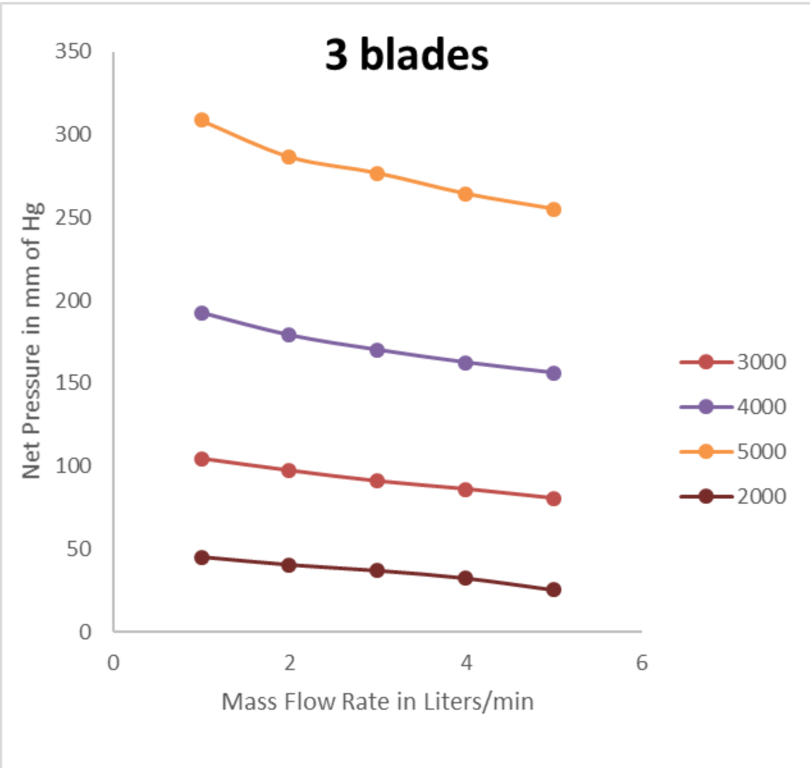


3 blades simulation:

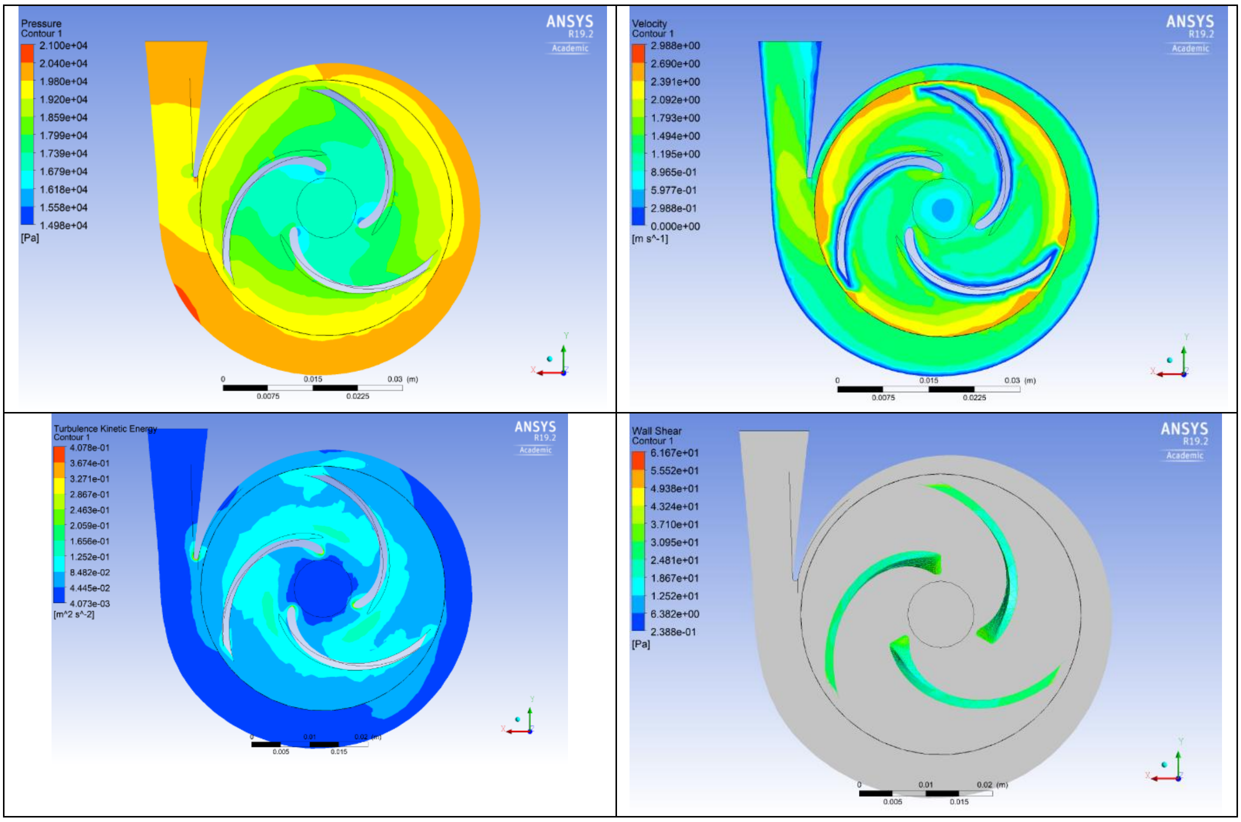


Speed	Mass Flow Rate in Liters/min	Mass Flow Rate in kg/s	Pressure inlet in Pa	Pressure outlet in Pa	Net Pressure in Pa	Net Pressure in mm of Hg
2000	5	0.0883	17211.321	20584.843	3373.522	25.6387672
2000	4	0.07064	16044.031	20330.536	4286.505	32.577438
2000	3	0.053	15313.148	20189.334	4876.186	37.0590136
2000	2	0.035333333	14763.974	20089.609	5325.635	40.474826
2000	1	0.017666667	14093.56	20023.048	5929.488	45.0641088
					0	0
3000	5	0.0883	9898.555	20521.017	10622.462	80.7307112
3000	4	0.07064	9002.8062	20348.562	11345.7558	86.22774408
3000	3	0.053	8238.976	20211.793	11972.817	90.9934092

3000	2	0.035333333	7288.871	20093.298	12804.427	97.3136452
3000	1	0.017666667	6296.5727	20037.589	13741.0163	104.4317239
					0	0
4000	5	0.0883	43.776963	20577.416	20533.63904	156.0556567
4000	4	0.07064	-972.61415	20393.106	21365.72015	162.3794731
4000	3	0.053	-2146.8667	20218.721	22365.5877	169.9784665
4000	2	0.035333333	-3416.9778	20127.365	23544.3428	178.9370053
4000	1	0.017666667	-5281.8653	20050.115	25331.9803	192.5230503
					0	0
5000	5	0.0883	-12913.287	20628.516	33541.803	254.9177028
5000	4	0.07064	-14359.578	20404.549	34764.127	264.2073652
5000	3	0.053	-16145.773	20265.058	36410.831	276.7223156
5000	2	0.035333333	-17550.166	20152.283	37702.449	286.5386124
5000	1	0.017666667	-20555.93	20056.746	40612.676	308.6563376

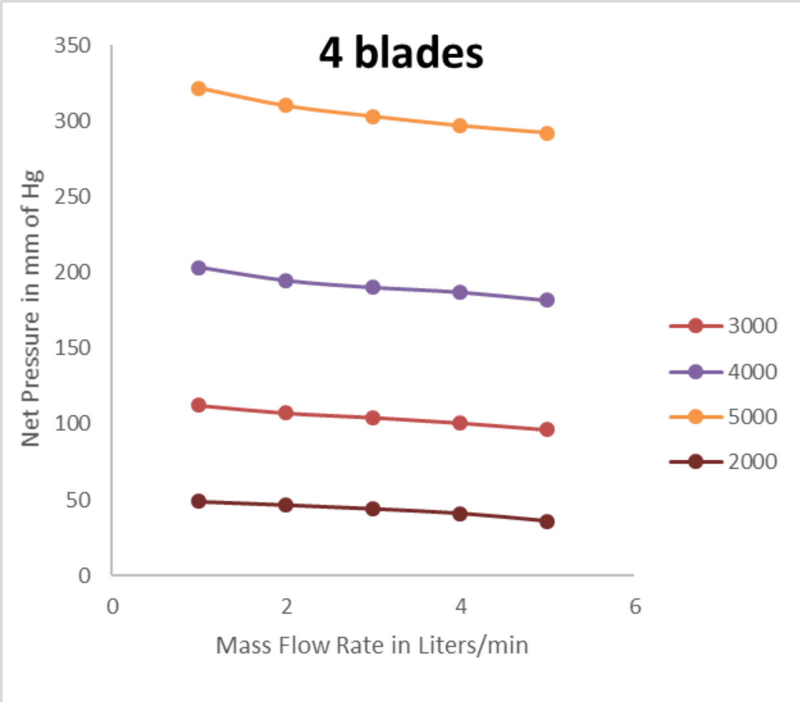


Contour of 3Blades

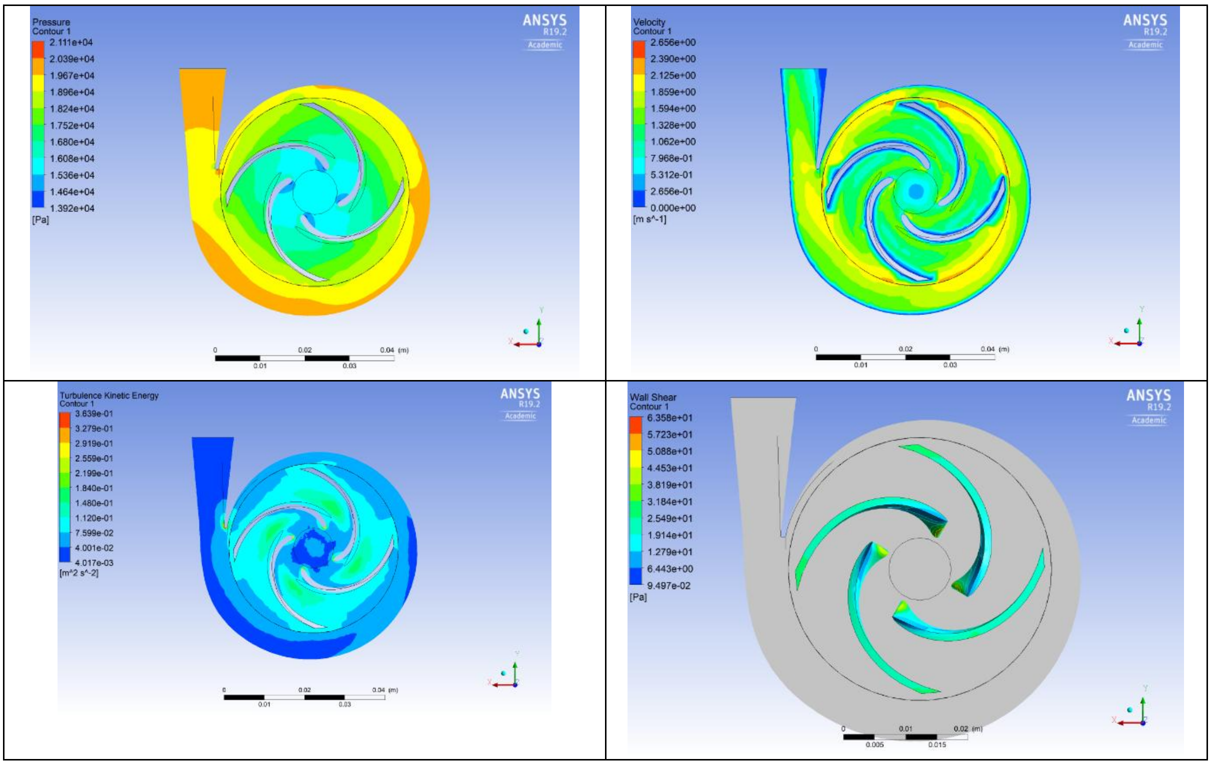


4 blades simulation

Speed	Mass Flow Rate in Liters/min	Mass Flow Rate in kg/s	Pressure inlet in Pa	Pressure oulet in Pa	Net Pressure in Pa	Net Pressure in mm of Hg
2000	5	0.0883	15848.957	20575.047	4726.09	35.918284
2000	4	0.07064	14925.446	20338.201	5412.755	41.136938
2000	3	0.053	14399.258	20202.505	5803.247	44.1046772
2000	2	0.03533333	13954.134	20087.45	6133.316	46.6132016
2000	1	0.01766667	13597.42	20028.657	6431.237	48.8774012
					0	0
3000	5	0.0883	7891.8349	20563.358	12671.5231	96.30357556
3000	4	0.07064	7111.8918	20375.076	13263.1842	100.8001999
3000	3	0.053	6465.7558	20204.344	13738.5882	104.4132703
3000	2	0.03533333	5986.977	20106.807	14119.83	107.310708
3000	1	0.01766667	5254.6861	20042.528	14787.8419	112.3875984
					0	0
4000	5	0.0883	-3342.0256	20583.426	23925.4516	181.8334322
4000	4	0.07064	-4256.1202	20377.762	24633.8822	187.2175047
4000	3	0.053	-4805.4161	20228.868	25034.2841	190.2605592
4000	2	0.03533333	-5476.5201	20154.711	25631.2311	194.7973564
4000	1	0.01766667	-6712.1285	20050.785	26762.9135	203.3981426
					0	0
5000	5	0.0883	-17824.111	20614.208	38438.319	292.1312244
5000	4	0.07064	-18656.158	20407.479	39063.637	296.8836412
5000	3	0.053	-19562.076	20310.391	39872.467	303.0307492
5000	2	0.03533333	-20618.326	20177.724	40796.05	310.04998
5000	1	0.01766667	-22292.103	20060	42352.103	321.8759828

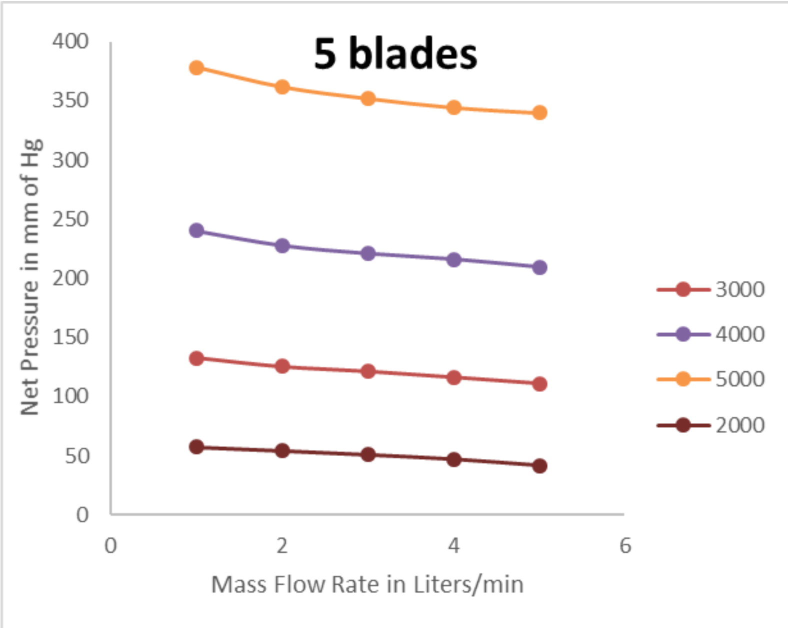


Contour for 4 blades

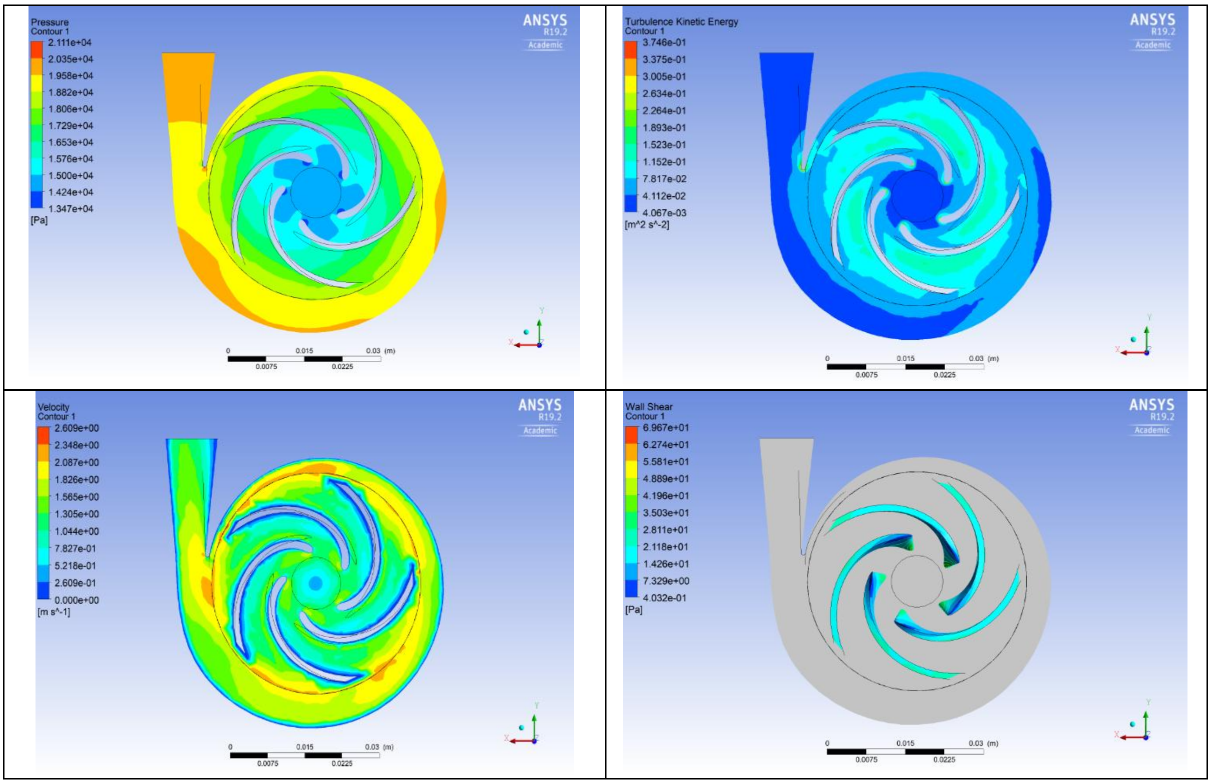


5 blades simulation done on 5-8-2019

Speed	Mass Flow Rate in Liters/min	Mass Flow Rate in kg/s	Pressure inlet in Pa	Pressure outlet in Pa	Net Pressure in Pa	Net Pressure in mm of Hg
2000	5	0.0883	15056.683	20528.061	5471.378	41.5824728
2000	4	0.07064	14146.403	20329.276	6182.873	46.9898348
2000	3	0.053	13522.777	20195.748	6672.971	50.7145796
2000	2	0.03533333	12987.052	20098.304	7111.252	54.0455152
2000	1	0.01766667	12518.866	20037.487	7518.621	57.1415196
					0	0
3000	5	0.0883	5928.0973	20538.959	14610.8617	111.0425489
3000	4	0.07064	5066.675	20371.529	15304.854	116.3168904
3000	3	0.053	4292.3728	20250.239	15957.8662	121.2797831
3000	2	0.03533333	3669.7831	20149.647	16479.8639	125.2469656
3000	1	0.01766667	2571.385	20040.027	17468.642	132.7616792
					0	0
4000	5	0.0883	-6890.6027	20631.073	27521.6757	209.1647353
4000	4	0.07064	-7936.9506	20471.416	28408.3666	215.9035862
4000	3	0.053	-8723.9372	20319.888	29043.8252	220.7330715
4000	2	0.03533333	-9755.1121	20197.137	29952.2491	227.6370932
4000	1	0.01766667	-11561.841	20043.85	31605.691	240.2032516
					0	0
5000	5	0.0883	-23913.341	20758.763	44672.104	339.5079904
5000	4	0.07064	-24709.123	20552.604	45261.727	343.9891252
5000	3	0.053	-25861.557	20407.709	46269.266	351.6464216
5000	2	0.03533333	-27292.522	20263.621	47556.143	361.4266868
5000	1	0.01766667	-29686.267	20050.759	49737.026	378.0013976

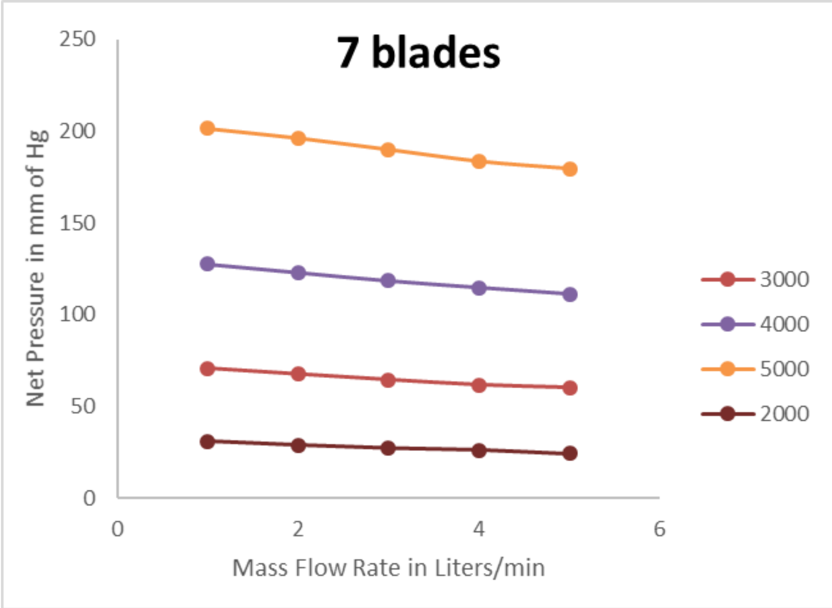


Contours for 5 blades

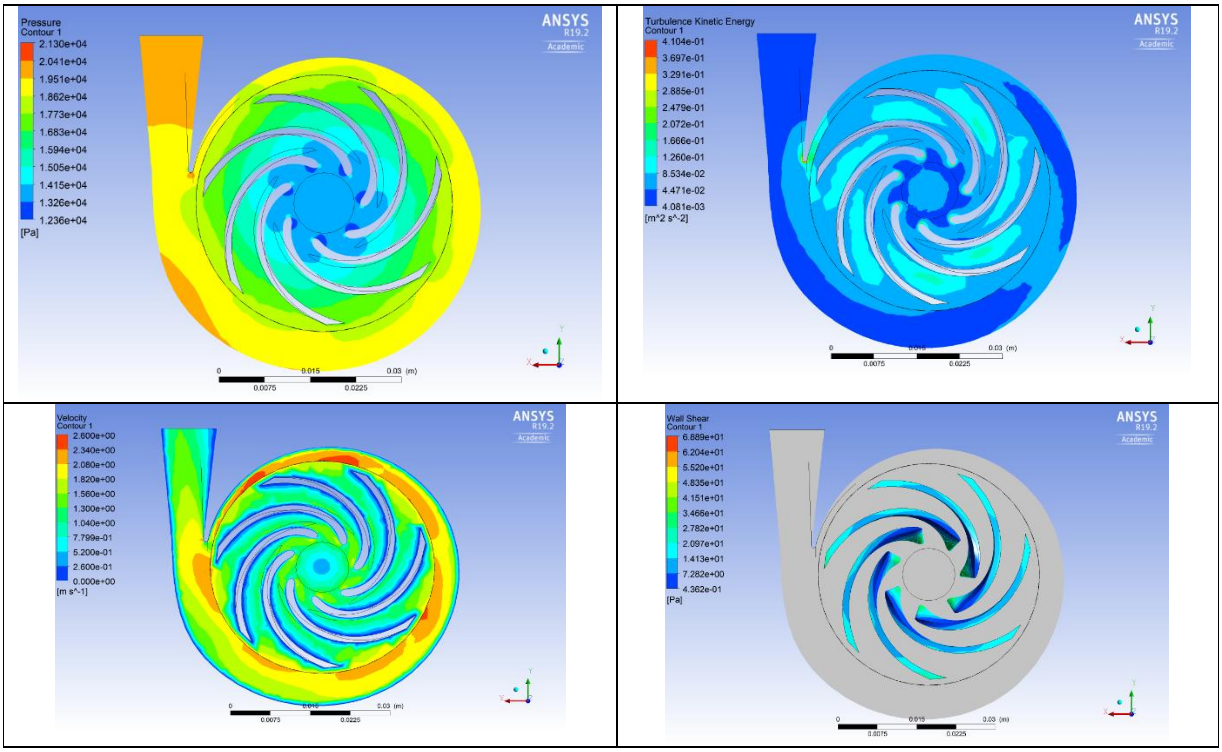


7 blades simulation done on 6-8-2019

Speed	Mass Flow Rate in Liters/min	Mass Flow Rate in kg/s	Pressure inlet in Pa	Pressure outlet in Pa	Net Pressure in Pa	Net Pressure in mm of Hg
2000	5	0.0883	17350.789	20528.824	3178.035	24.153066
2000	4	0.07064	16875.926	20327.304	3451.378	26.2304728
2000	3	0.053	16625.056	20202.175	3577.119	27.1861044
2000	2	0.03533333	16320.236	20110.354	3790.118	28.8048968
2000	1	0.01766667	15987.996	20037.252	4049.256	30.7743456
					0	0
3000	5	0.0883	12635.464	20552.396	7916.932	60.1686832
3000	4	0.07064	12312.941	20428.96	8116.019	61.6817444
3000	3	0.053	11792.743	20270.595	8477.852	64.4316752
3000	2	0.03533333	11266.104	20146.241	8880.137	67.4890412
3000	1	0.01766667	10756.387	20043.908	9287.521	70.5851596
					0	0
4000	5	0.0883	6114.8332	20748.488	14633.6548	111.2157765
4000	4	0.07064	5403.718	20501.973	15098.255	114.746738
4000	3	0.053	4723.1181	20309.207	15586.0889	118.4542756
4000	2	0.03533333	3980.2347	20162.885	16182.6503	122.9881423
4000	1	0.01766667	3260.1315	20052.402	16792.2705	127.6212558
					0	0
5000	5	0.0883	-2830.3333	20801.988	23632.3213	179.6056419
5000	4	0.07064	-3532.2146	20619.803	24152.0176	183.5553338
5000	3	0.053	-4634.6211	20360.806	24995.4271	189.965246
5000	2	0.03533333	-5637.671	20175.487	25813.158	196.1800008
5000	1	0.01766667	-6430.099	20062.677	26492.776	201.3450976
					0	0

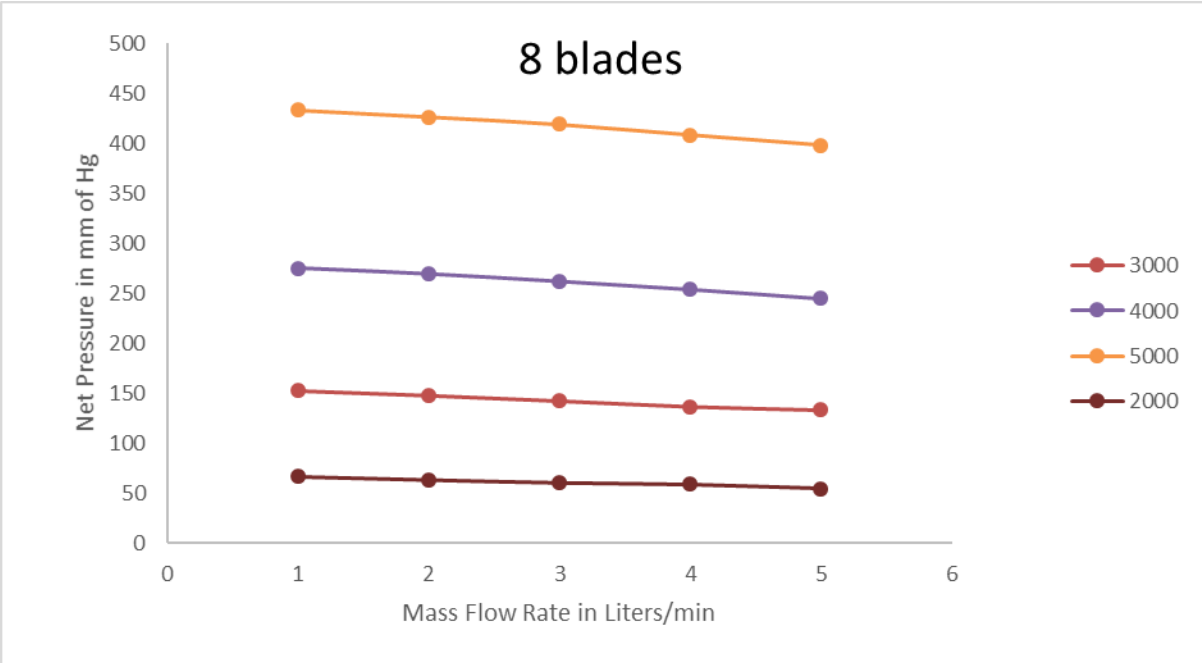


Contours for 7 blades

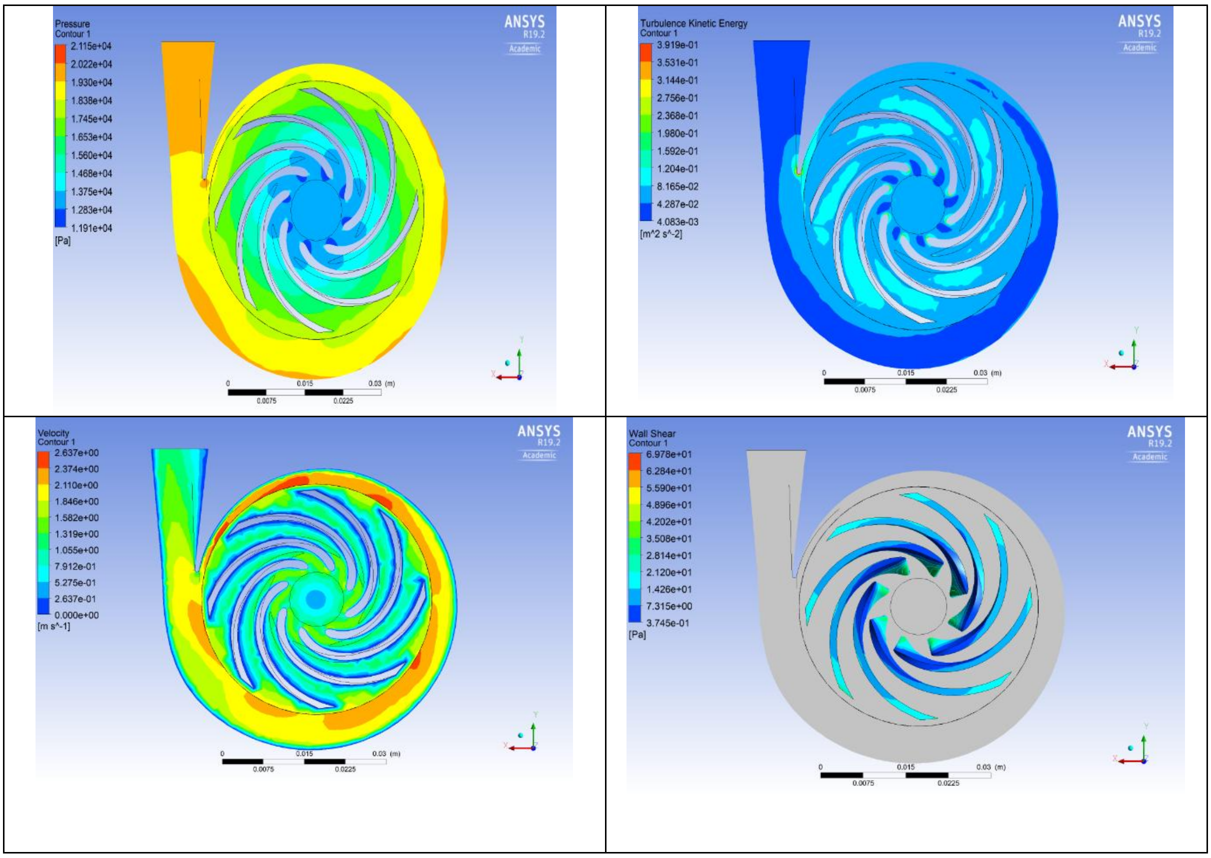


8 blades simulation done on 6-8-2019

Speed	Mass Flow Rate in Liters/min	Mass Flow Rate in kg/s	Pressure inlet in Pa	Pressure outlet in Pa	Net Pressure in Pa	Net Pressure in mm of Hg
2000	5	0.0883	13315.983	20525.764	7209.781	54.7943356
2000	4	0.07064	12589.521	20335.126	7745.605	58.866598
2000	3	0.053	12227.743	20205.121	7977.378	60.6280728
2000	2	0.03533333	11720.48	20093.642	8373.162	63.6360312
2000	1	0.01766667	11229.344	20037.429	8808.085	66.941446
					0	0
3000	5	0.0883	3043.8652	20595.828	17551.9628	133.3949173
3000	4	0.07064	2390.5085	20400.672	18010.1635	136.8772426
3000	3	0.053	1468.1834	20233.773	18765.5896	142.618481
3000	2	0.03533333	659.58173	20149.883	19490.30127	148.1262897
3000	1	0.01766667	-69.951885	20044.469	20114.42089	152.8695987
					0	0
4000	5	0.0883	-11585.27	20670.321	32255.591	245.1424916
4000	4	0.07064	-13009.549	20433.475	33443.024	254.1669824
4000	3	0.053	-14169.41	20319.61	34489.02	262.116552
4000	2	0.03533333	-15278.899	20166.919	35445.818	269.3882168
4000	1	0.01766667	-16139.745	20050.714	36190.459	275.0474884
					0	0
5000	5	0.0883	-31700.708	20690.838	52391.546	398.1757496
5000	4	0.07064	-33204.031	20538.641	53742.672	408.4443072
5000	3	0.053	-34760.893	20369.799	55130.692	418.9932592
5000	2	0.03533333	-35943.588	20176.133	56119.721	426.5098796
5000	1	0.01766667	-36957.915	20056.638	57014.553	433.3106028

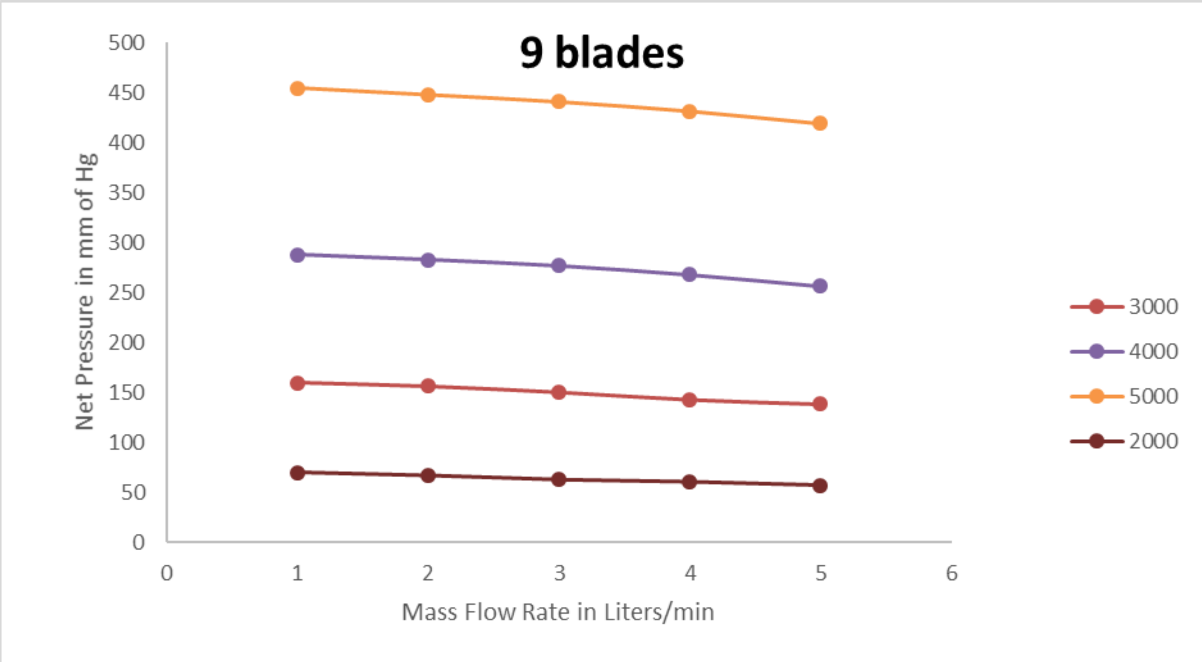


Contours for 8 blades

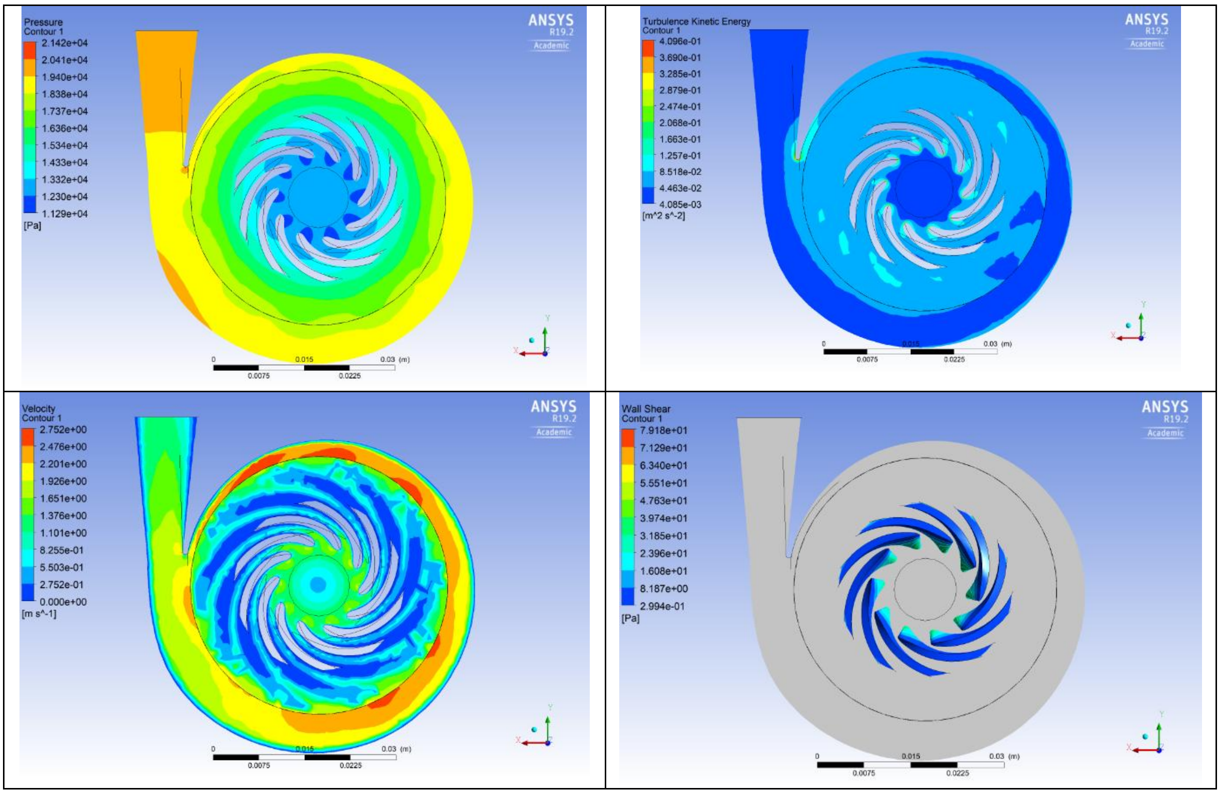


9 blades simulation done on 7-8-2019

Speed	Mass Flow Rate in Liters/min	Mass Flow Rate in kg/s	Pressure inlet in Pa	Pressure oulet in Pa	Net Pressure in Pa	Net Pressure in mm of Hg
2000	5	0.0883	13012.964	20517.936	7504.972	57.0377872
2000	4	0.07064	12382.56	20331.548	7948.988	60.4123088
2000	3	0.053	11961.864	20200.803	8238.939	62.6159364
2000	2	0.03533333	11318.05	20099.253	8781.203	66.7371428
2000	1	0.01766667	10852.084	20037.532	9185.448	69.8094048
					0	0
3000	5	0.0883	2363.2636	20574.895	18211.6314	138.4083986
3000	4	0.07064	1593.1116	20388.763	18795.6514	142.8469506
3000	3	0.053	478.85064	20248.545	19769.69436	150.2496771
3000	2	0.03533333	-397.04675	20154.151	20551.19775	156.1891029
3000	1	0.01766667	-991.53203	20041.48	21033.01203	159.8508914
					0	0
4000	5	0.0883	-13047.519	20672.038	33719.557	256.2686332
4000	4	0.07064	-14771.877	20460.277	35232.154	267.7643704
4000	3	0.053	-16083.519	20340.269	36423.788	276.8207888
4000	2	0.03533333	-17071.763	20163.973	37235.736	282.9915936
4000	1	0.01766667	-17853.435	20047.86	37901.295	288.049842
					0	0
5000	5	0.0883	-34402.264	20746.224	55148.488	419.1285088
5000	4	0.07064	-36181.366	20585.353	56766.719	431.4270644
5000	3	0.053	-37636.978	20360.794	57997.772	440.7830672
5000	2	0.03533333	-38749.585	20169.769	58919.354	447.7870904
5000	1	0.01766667	-39757.939	20053.051	59810.99	454.563524

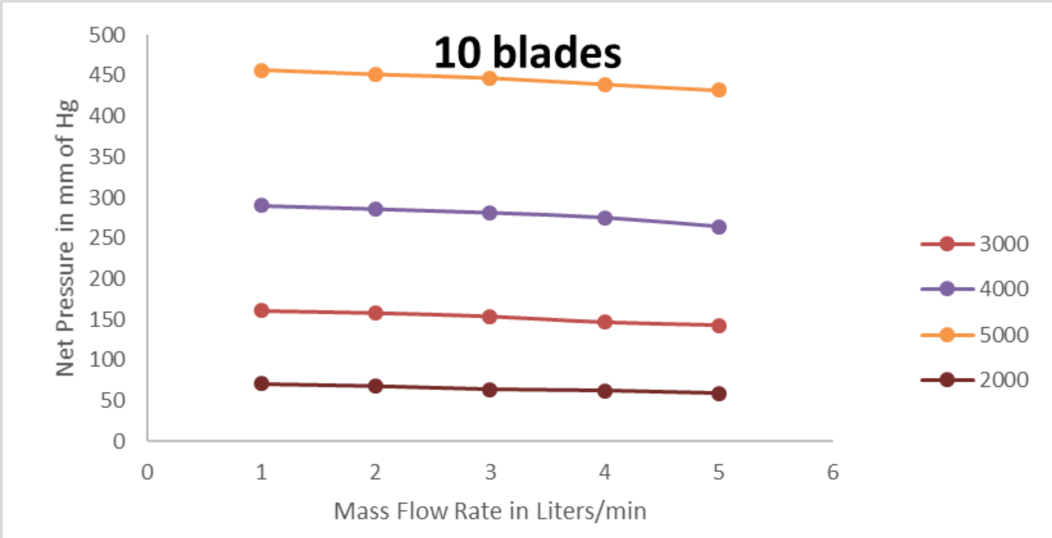


Contours for 9 blades

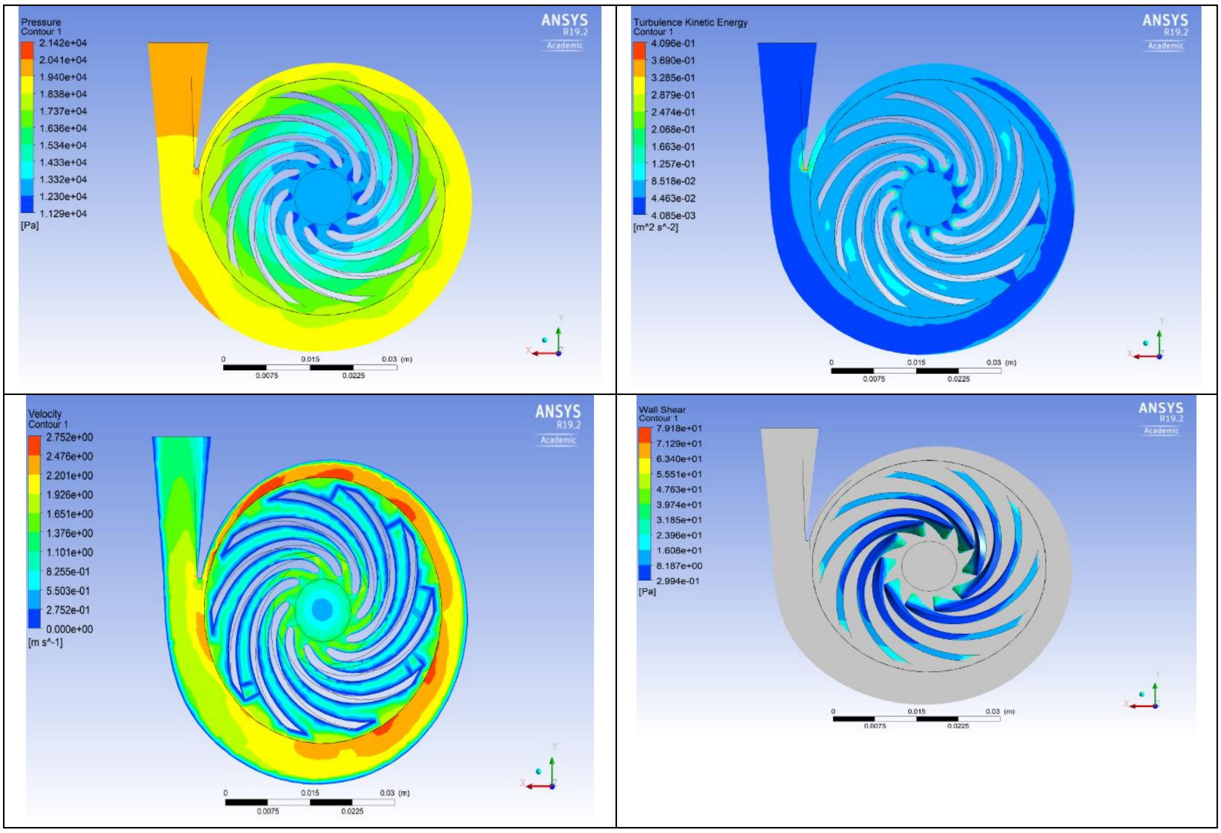


10 blades simulation done on 8-8-2019

Speed	Mass Flow Rate in Liters/min	Mass Flow Rate in kg/s	Pressure inlet in Pa	Pressure outlet in Pa	Net Pressure in Pa	Net Pressure in mm of Hg
2000	5	0.0883	12727.852	20520.459	7792.607	59.2238132
2000	4	0.07064	12096.437	20340.586	8244.149	62.6555324
2000	3	0.053	11756.245	20206.29	8450.045	64.220342
2000	2	0.03533333	11106.363	20098.243	8991.88	68.338288
2000	1	0.01766667	10711.96	20038.475	9326.515	70.881514
					0	0
3000	5	0.0883	1858.9815	20603.396	18744.4145	142.4575502
3000	4	0.07064	1162.2936	20416.993	19254.6994	146.3357154
3000	3	0.053	-23.239401	20242.871	20266.1104	154.022439
3000	2	0.03533333	-698.06372	20153.947	20852.01072	158.4752815
3000	1	0.01766667	-1171.395	20045.065	21216.46	161.245096
					0	0
4000	5	0.0883	-14029.788	20696.072	34725.86	263.916536
4000	4	0.07064	-15778.859	20443.268	36222.127	275.2881652
4000	3	0.053	-16684.323	20333.712	37018.035	281.337066
4000	2	0.03533333	-17464.835	20167.003	37631.838	286.0019688
4000	1	0.01766667	-18113.989	20051.105	38165.094	290.0547144
					0	0
5000	5	0.0883	-36135.678	20708.361	56844.039	432.0146964
5000	4	0.07064	-37249.736	20574.466	57824.202	439.4639352
5000	3	0.053	-38464.637	20374.207	58838.844	447.1752144
5000	2	0.03533333	-39253.777	20175.62	59429.397	451.6634172
5000	1	0.01766667	-40063.014	20058.735	60121.749	456.9252924
					0	0



Contours for 10 blades



Done on 7-9-2019: 3d printing of new model impeller with 6 blades having 3 magnets

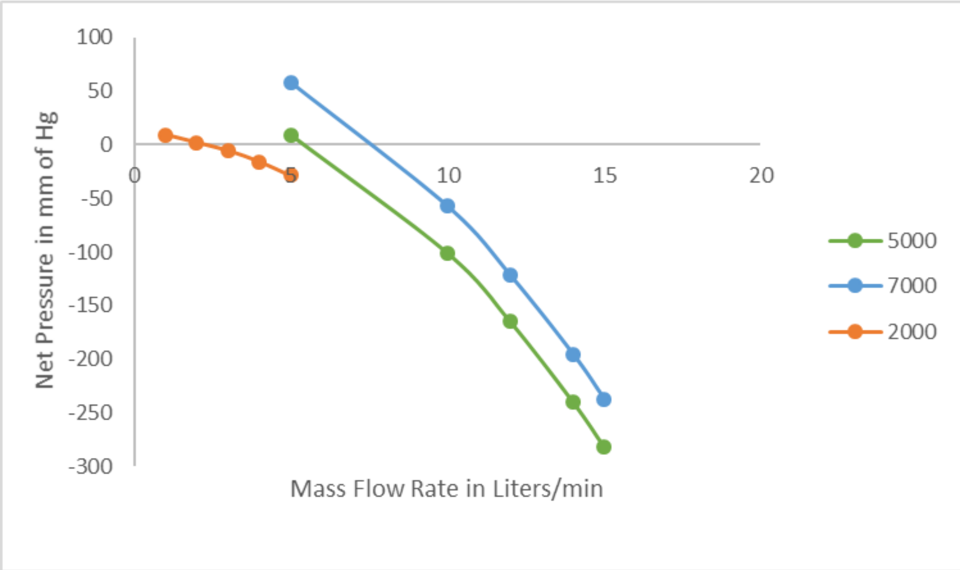
3D printing of different samples of impellers were taken, As there is less magnetic force between the parts it should be re-designed again.

Analysis of Previous models which are designed in CATIA:

6/9/2019 to 20/9/2019: Analysis results of P1 model

Speed	Mass Flow Rate in Litres/min	Mass Flow Rate in kg/s	Pressure inlet in Pa	Pressure outlet in Pa	Net Pressure in Pa	Net Pressure in mm of Hg
2000	5	0.0883	23783.835	20000	-3783.835	-28.757146
2000	4	0.07064	22071.369	20000	-2071.369	-15.7424044
2000	3	0.053	20726.688	20000	-726.688	-5.5228288
2000	2	0.035333333	19748.624	20000	251.376	1.9104576
2000	1	0.017666667	18801.787	20000	1198.213	9.1064188
2000	0.8	0.014133333	18569.728	20000	1430.272	10.8700672
2000	0.6	0.0106	18363.128	20000	1636.872	12.4402272
2000	0.4	0.007066667	18162.06	20000	1837.94	13.968344
2000	0.2	0.003533333	17984.161	20000	2015.839	15.3203764
					0	0
5000	5	0.0883	19181.369	20397.575	1216.206	9.2431656
5000	10	0.176666667	34808.538	21511.429	-13297.109	-101.0580284
5000	12	0.212	43930.822	22237.631	-21693.191	-164.8682516
5000	14	0.247333333	54595.045	23038.657	-31556.388	-239.8285488
5000	15	0.265	60586.936	23487.126	-37099.81	-281.958556
7000	5	0.0883	12766.17	20430.392	7664.222	58.2480872
7000	10	0.176666667	29006.419	21475.729	-7530.69	-57.233244
7000	12	0.212	38141.33	22128.34	-16012.99	-121.698724
7000	14	0.247333333	48642.245	22957.343	-25684.902	-195.2052552
7000	15	0.265	54654.588	23443.174	-	-

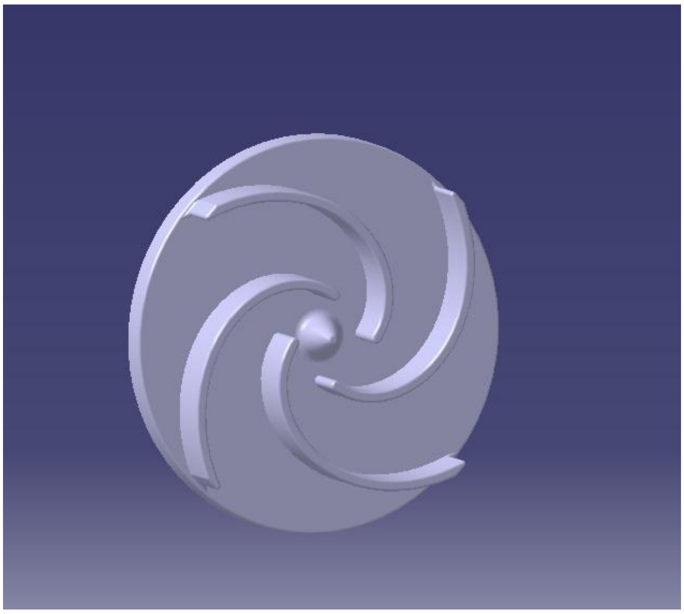
					31211.414	237.2067464



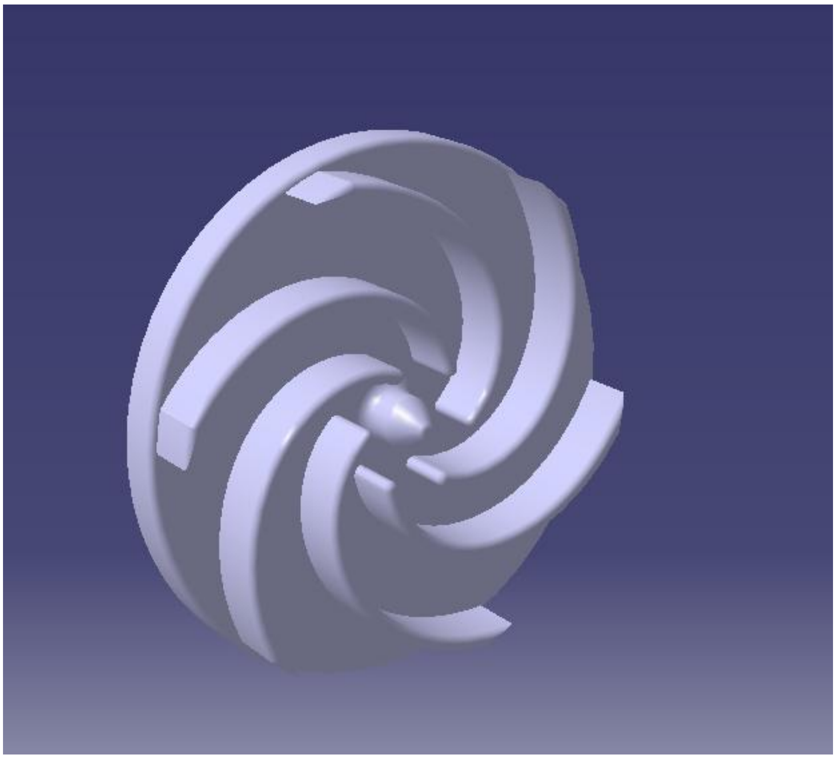
Remarks:

This model was unsuccessful as there is a negative pressure difference and it is not considered further.

20. Re-model: Previous models are re-designed by applying fillets at corners-25/9/2019:



P5 Model



P6 model

Analysis of the models are yet to be done in ANSYS.