Analysis of Intra-Aortic Axial Pump for Heart Assist

E. Abo-Serie[1], E. Oran[2], B. Oran[2] and R. Cirstea[1]

[1] Coventry University, UK
[2] Misal Design Company, Turkey

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- **What are Ventricular Assist Devices (VADs) and why**
- **Historical development of VADs**
- **Current problems and innovations**
- **Sizing of the pump**
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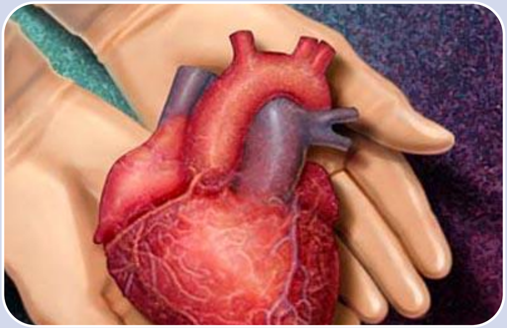
Heart Failure

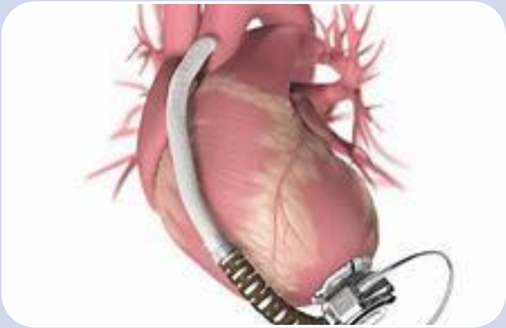
"Each year 550,000 new patients are diagnosed with end-stage heart failure in the US"
"The annual US Market share is 50 billion dollars"

Over half a million people in the UK living with heart failure

Heart failure means that the heart is not pumping blood around the body as effectively as it should.
Having **heart failure** doesn't mean that the heart has stopped working, but that the heart needs some support to help it work better

Heart Failure Control and Treatment





Medication

Just help to improve symptoms, keep and prevent condition from getting worse

Transplant

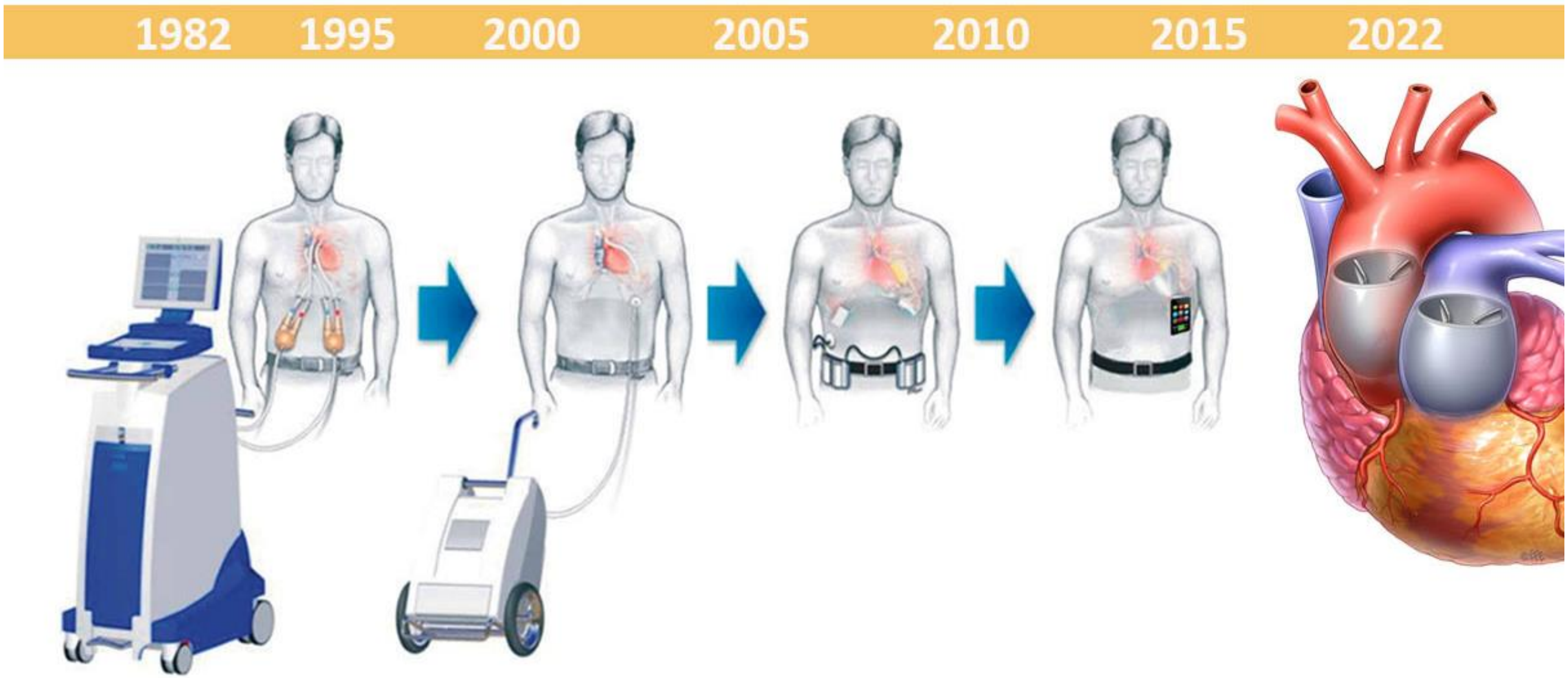
There are limited donors

Mechanical Pumps

Ventricular Assist Device (VAD)

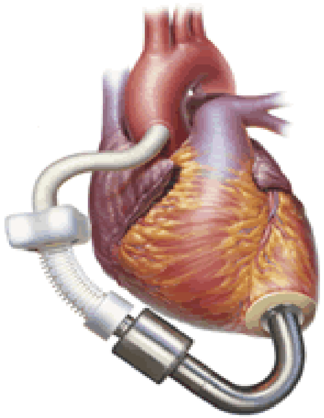
Developing technology

Development of VADs



Problems with the Current VADs

- Bigger and complex design with high metal load in the human body
- Long and complex invasive procedure
- Rotates at a very high speed with higher turbulent blood flow
- High rate blood damage with high rate haemolysis risk in patients with heart failure
- Large blood-surface contact area with high rate cerebral stroke risk
- High energy consumption with short battery life
- Difficult to use wireless energy transfer systems because of high energy consumption



Proposed Design

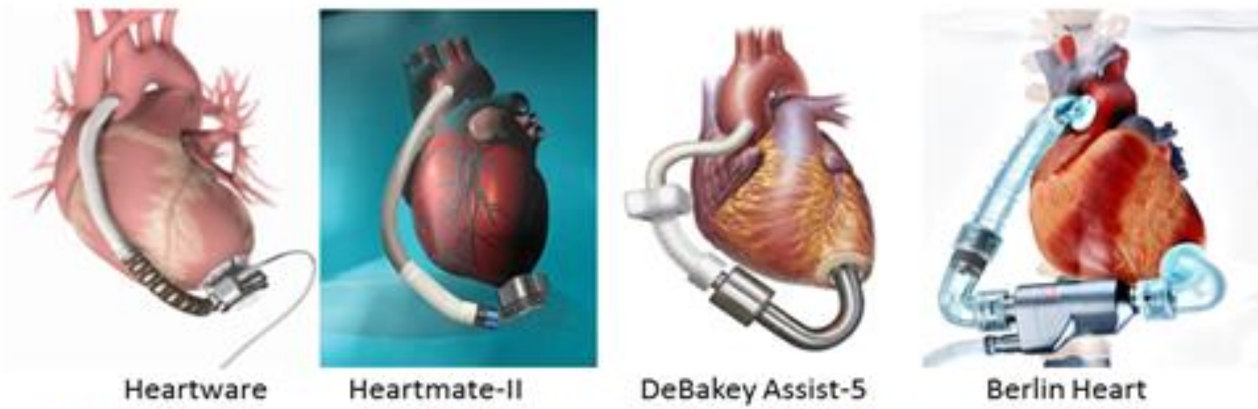


Figure 1: Implantation methods for VADs available in market

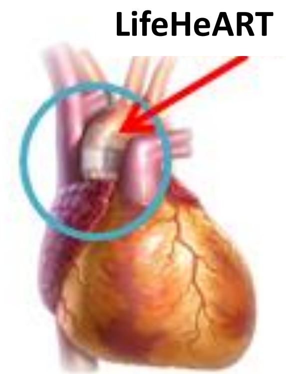


Figure 2: Proposed Design

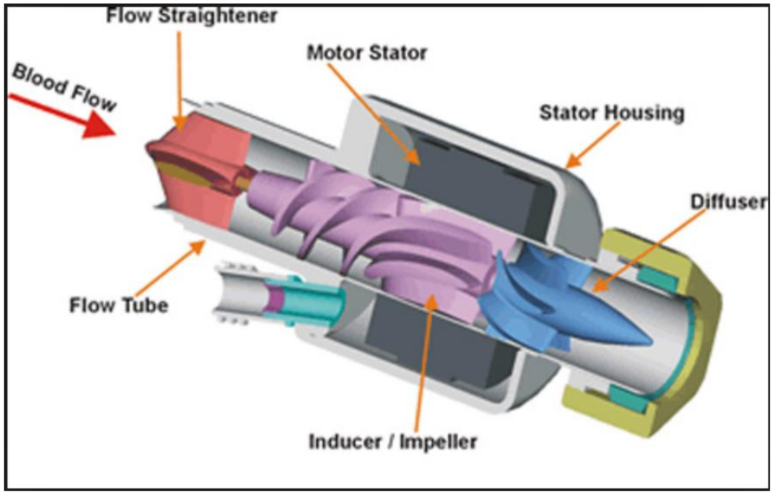
Smaller axial pump inside the aorta, use suspended rotor without central shaft, use the ECG signal of the patient for controlling the rpm for improving quality of life.

Reduced operation size and risk by using minimally invasive implantation techniques, again reducing hospital stay and overall cost of treatment.

Low rpm and therefore low blood damage, fewer bleeding events, therefore reduced need for transfusions, reduced need for anticoagulative drugs, reducing overall cost of treatment.

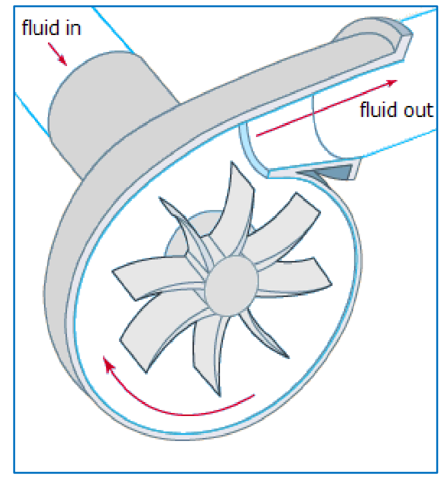
Overview: Heart Types Pumps

Axial pump



- Large surface contact
- High rotational speed
- High power (energy)
- High shear stress & blood damage

Centrifugal pump



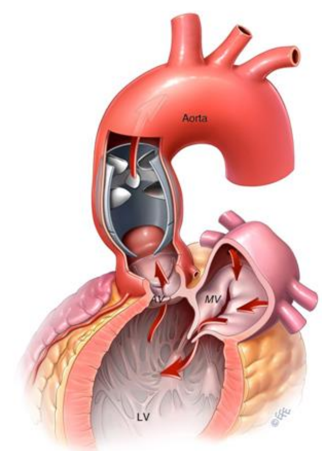
- Shear flow and blood damage
- High turbulence
- Metal load and contact area

Objective

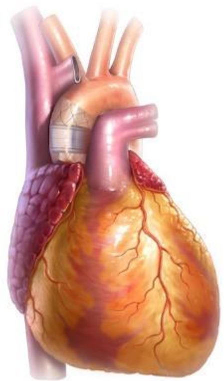
- ➢Perform initial study to design the pump and identify its performance using CFD.

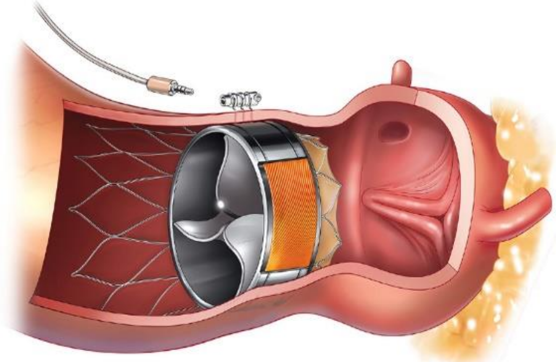
- ➢Understand the interaction between the different design parameters for maximum flow rate and higher hydraulic efficiency.

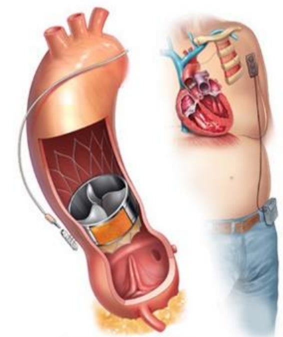
- ➢Identify the challenges for further investigations.

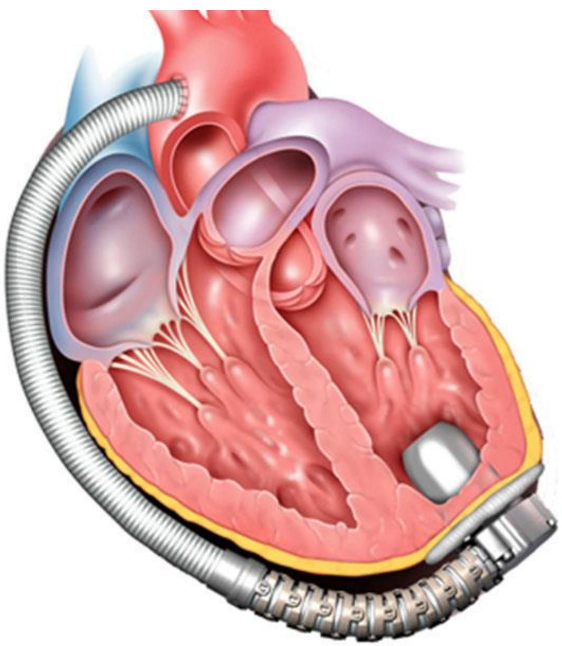


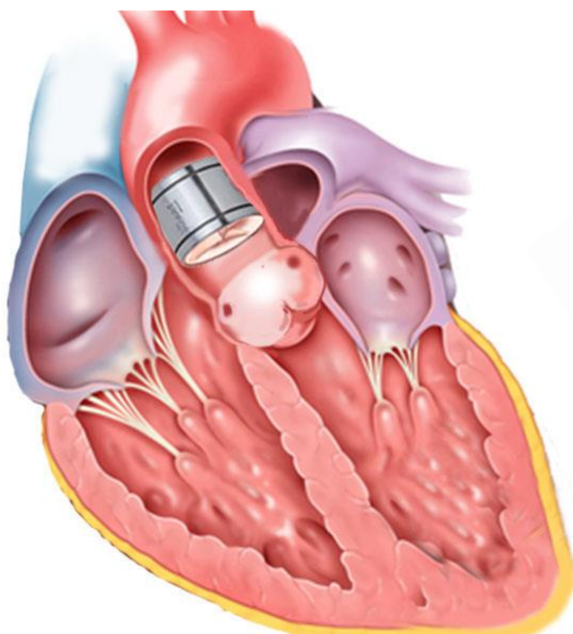
Intraventricular Heartware-mini and LifeheART Device in Aortic Root

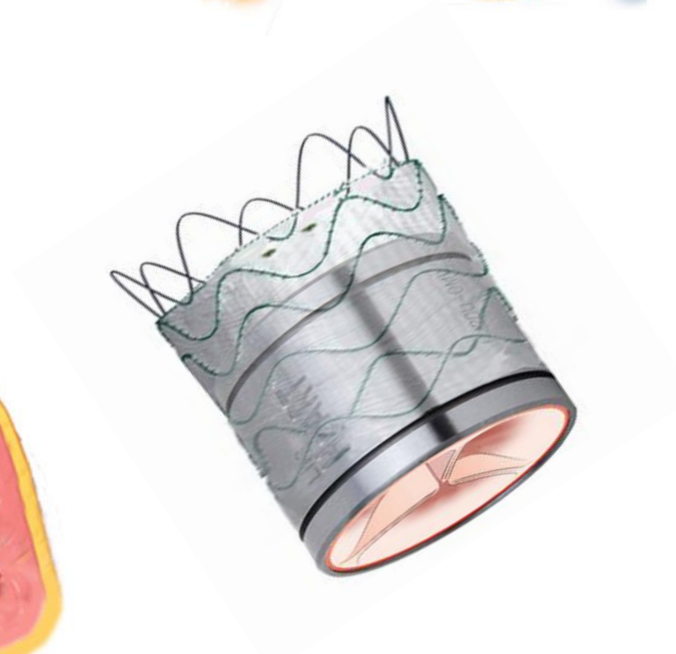








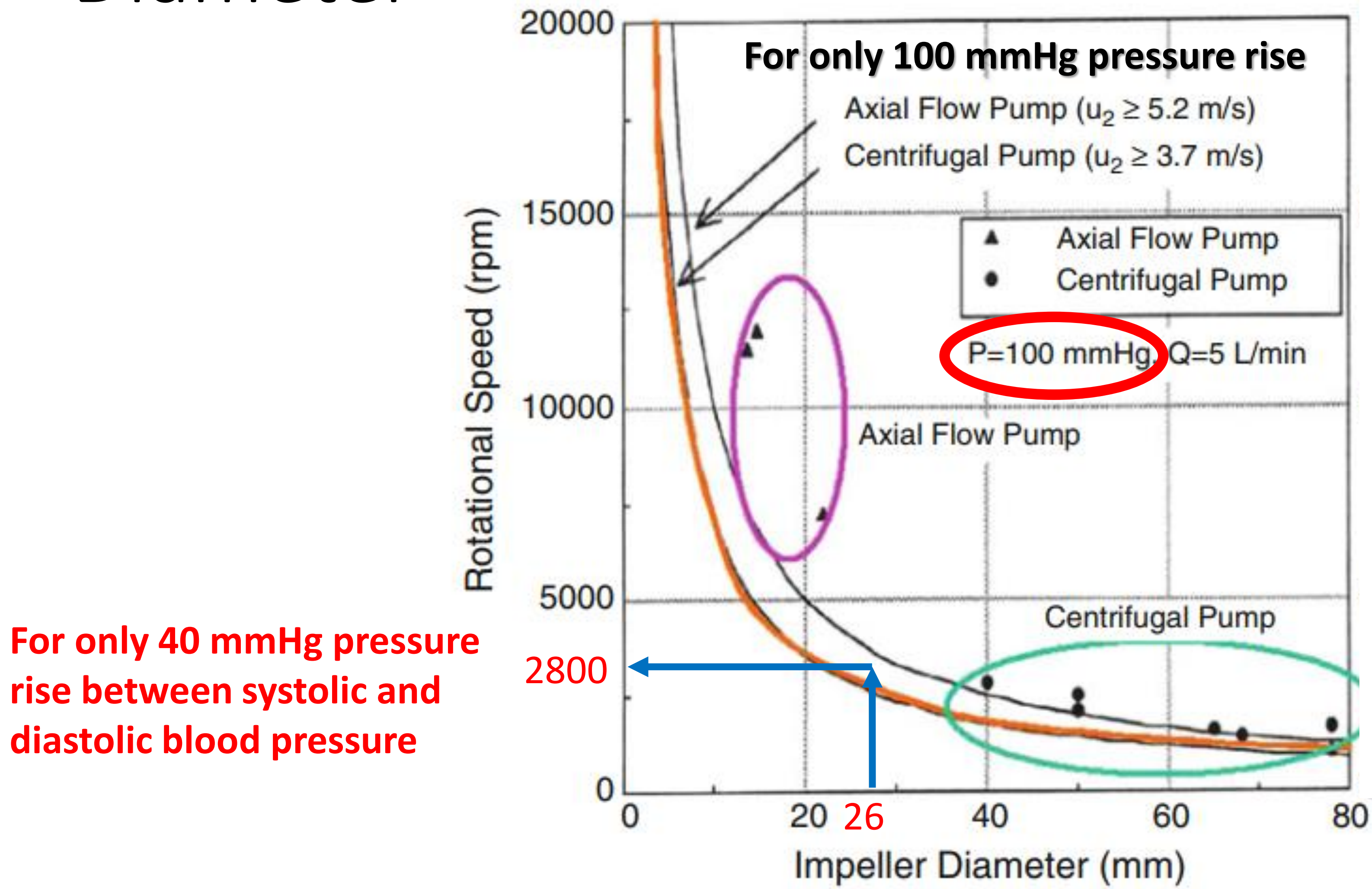




Heartware mini

LifeHeART device with self-expendable stent

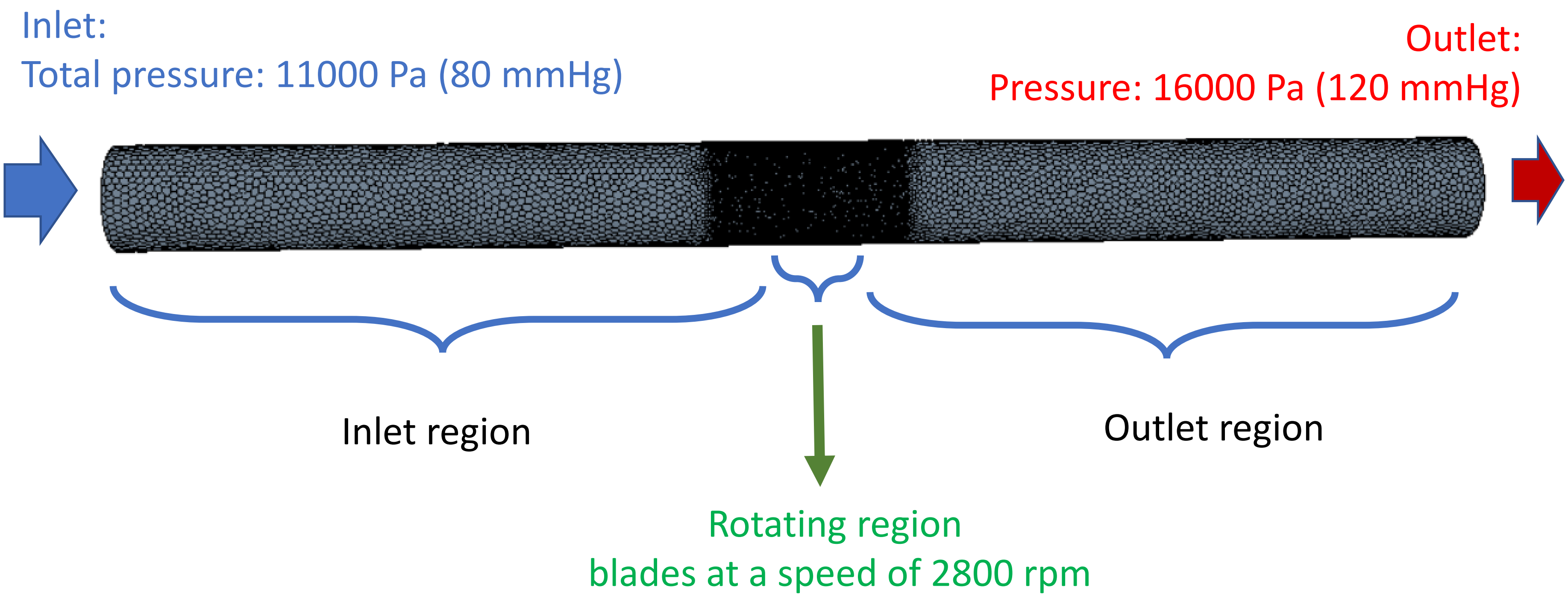
Reducing the Speed by Increasing the Diameter



Design parameters of centrifugal pumps and axial flow pumps

Adapted from Takashi Yamane, '*Mechanism of Artificial Heart*', Springer Japan 2016

CFD Simulations: Boundary Conditions

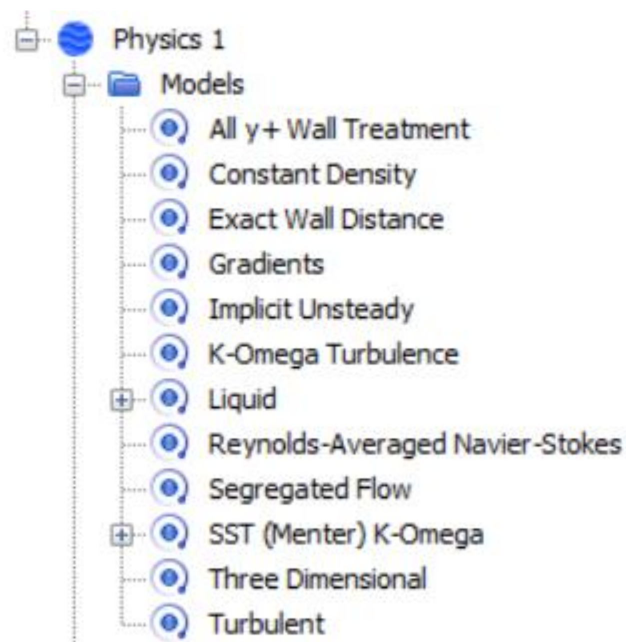


CFD Simulations: Mesh and Physics Models

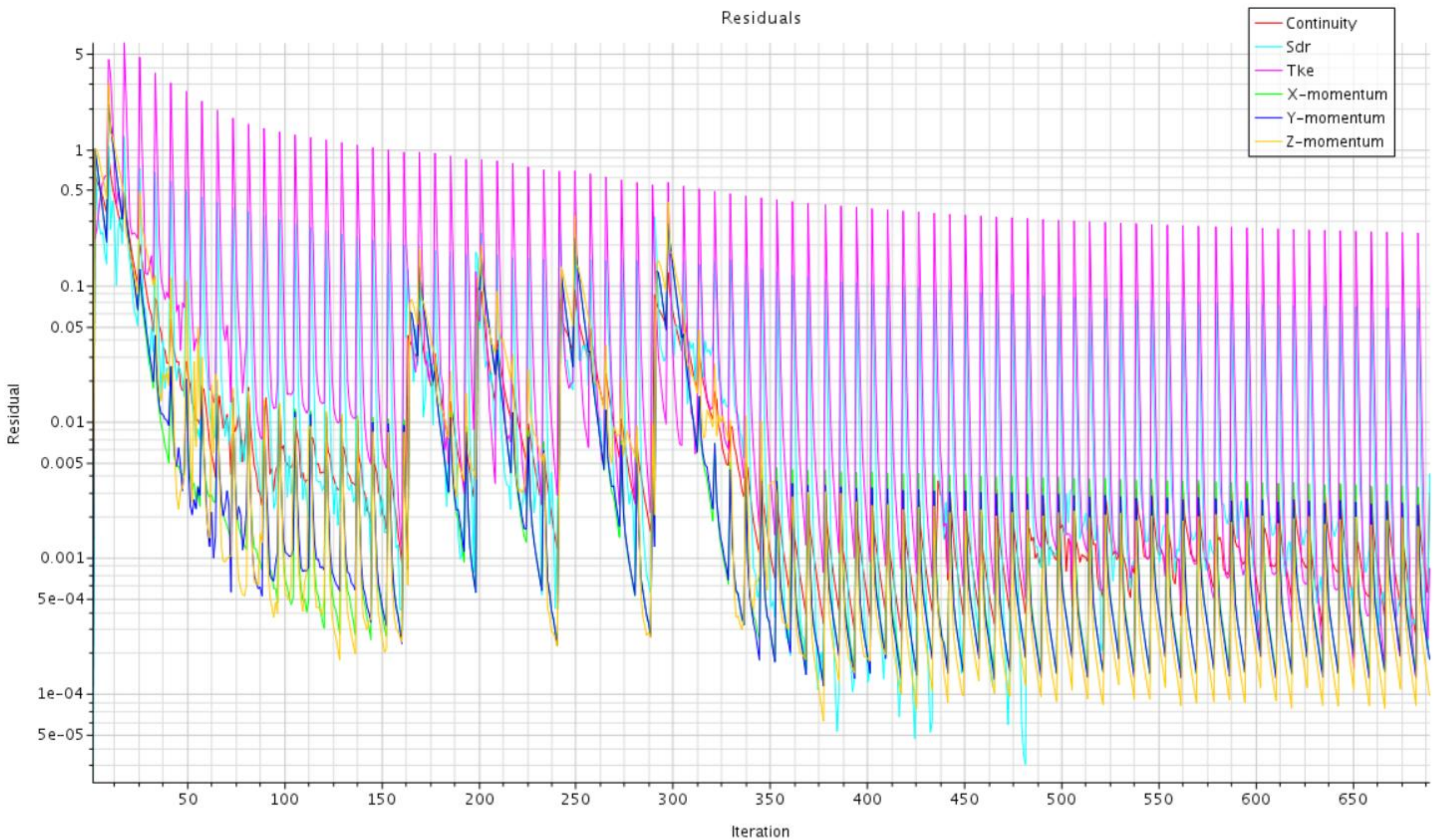
Cell count of 1.4 million cells (with refinement around the blades), polyhedral mesh

Transient Rigid Body Motion model

- Unsteady simulation with a time step 1 μs
- All the simulations were run using k-ω model
- Internal iterations: 8
- Total time: 1 s.

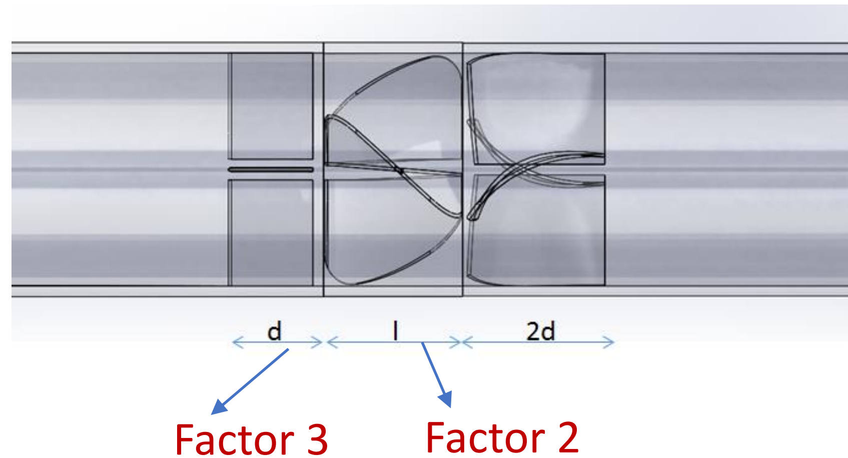


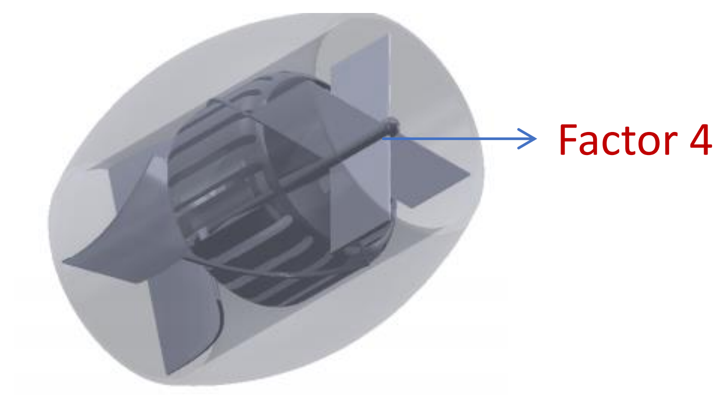
CFD Simulations: Residual Plot



Design of Experiment (Optimization of Impeller)

	Factor-1	Factor-2	Factor-3	Factor-4
	Rotor blade angle (degree)	Rotor length (mm)	Flow straightener & diffuser length (mm)	Center shaft diameter (mm)
		l	**d**	
RUN 1	38	16	4	3
RUN 2	38	12	6	5
RUN 3	38	8	8	5 (shaft)
RUN 4	48	16	6	5 (shaft)
RUN 5	48	12	8	3
RUN 6	48	8	4	5
RUN 7	58	16	8	5
RUN 8	58	12	4	5 (shaft)
RUN 9	58	8	6	3

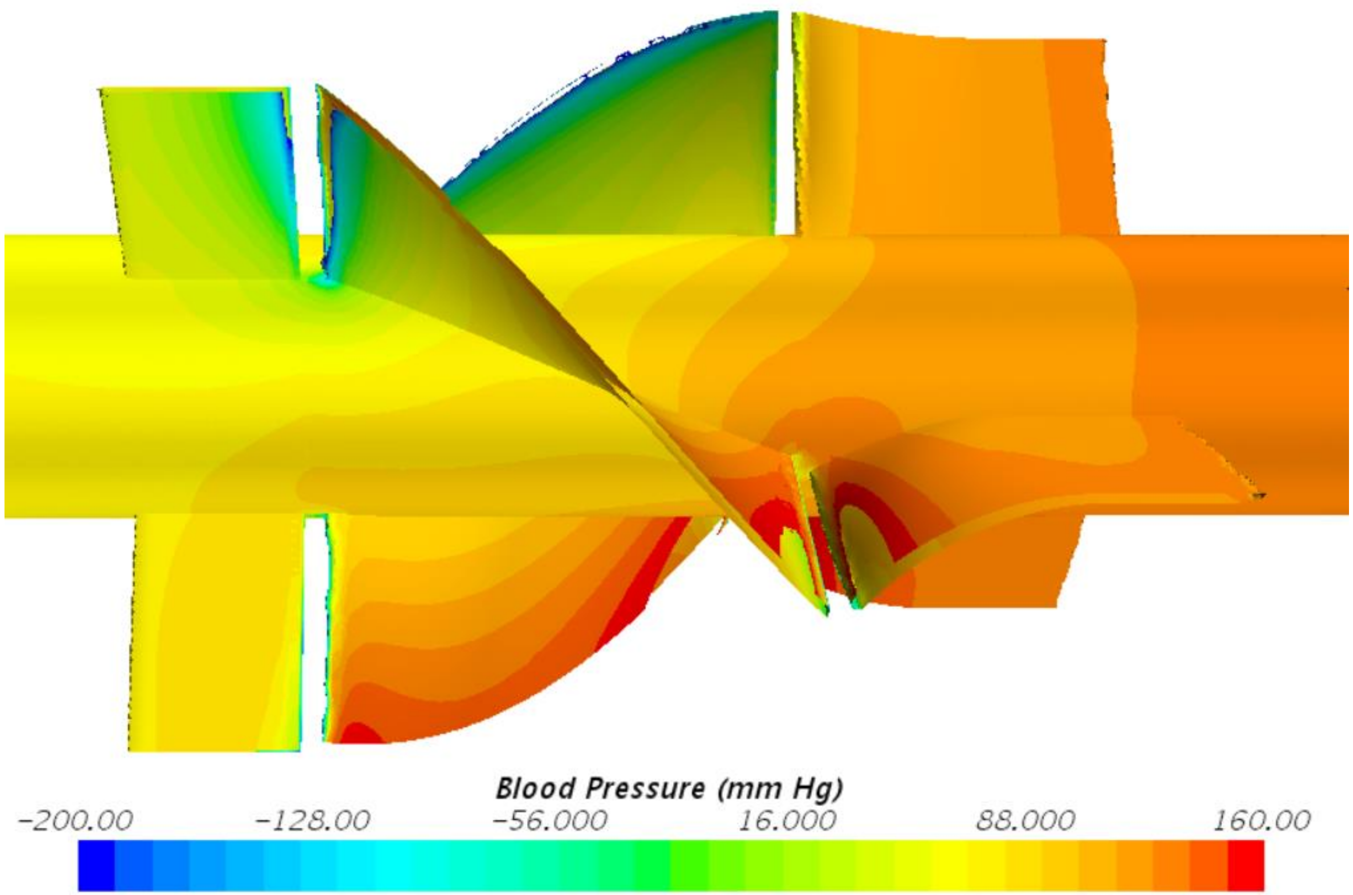




Optimization: Taguchi method, 4 parameters/factors with 3 values for each
Software used: STARCCM+ V10.04, ANSYS BladeGen, Solidworks & Minitab

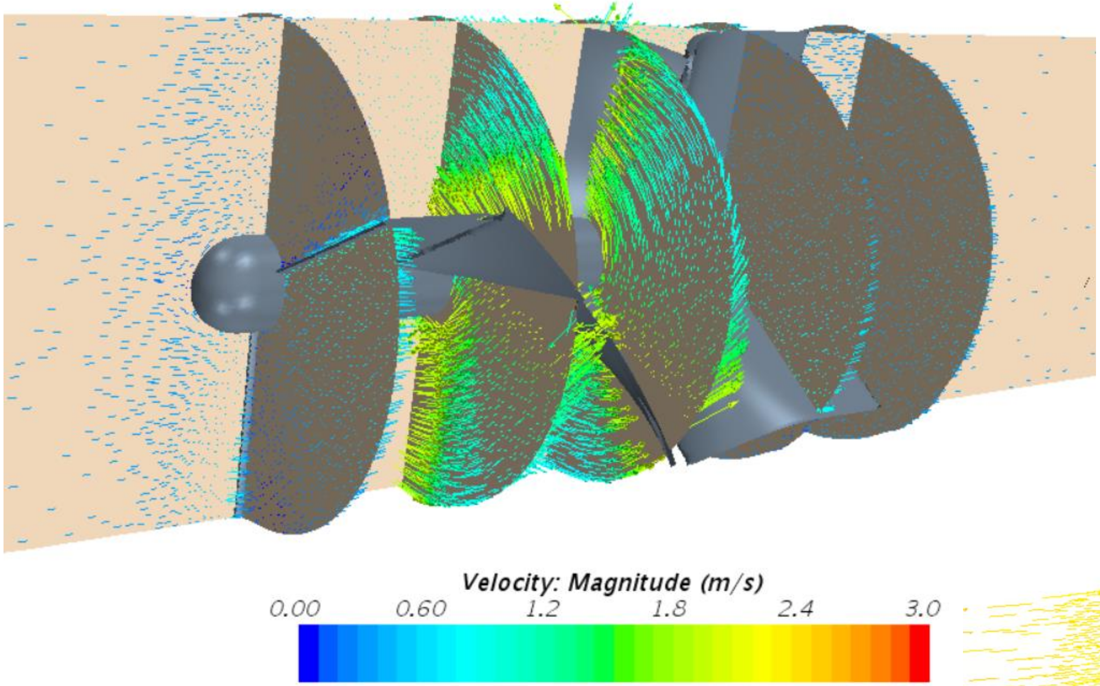
Typical Pressure Distribution

Time = 0.68 ms

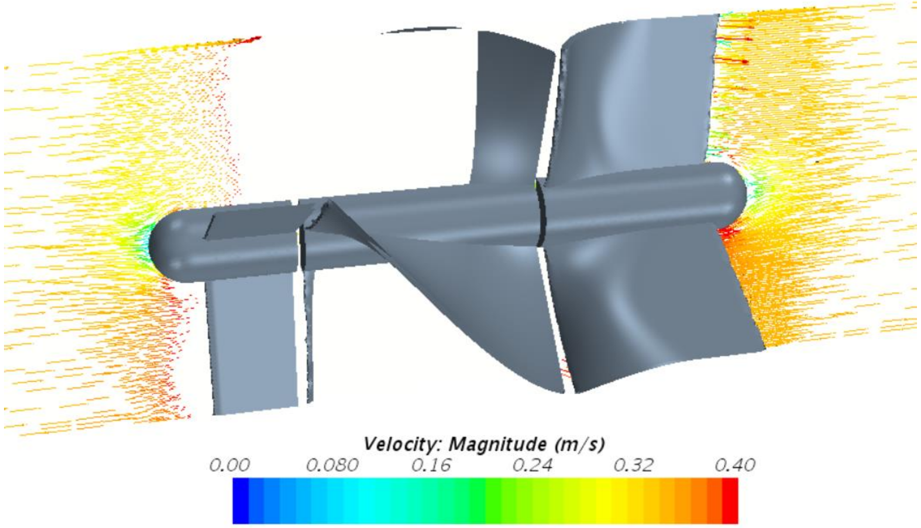


Typical Velocity Vector

Velocity vector at various sections

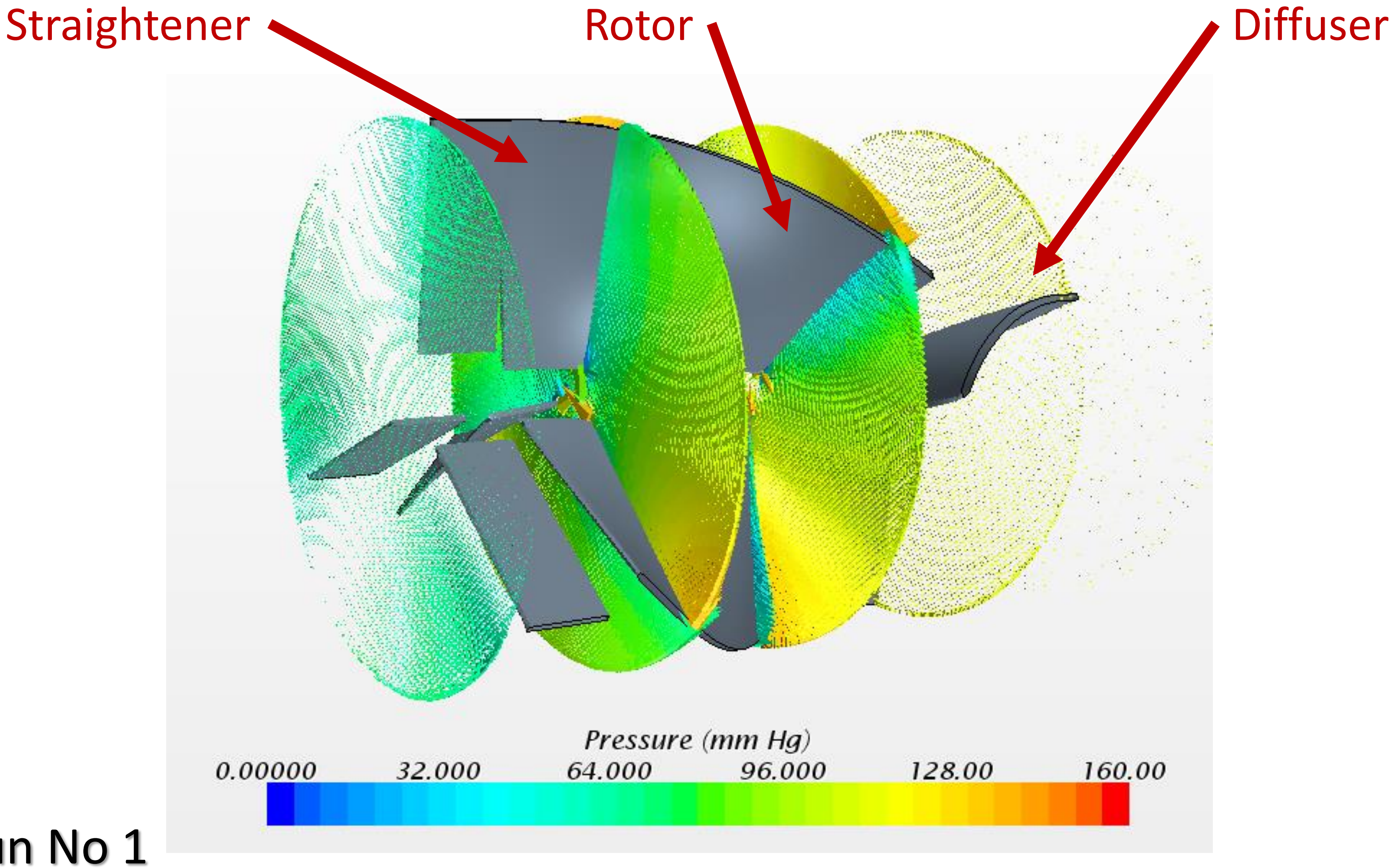


The exit flow has minimum rotation masking the velocity vectors in the blade area



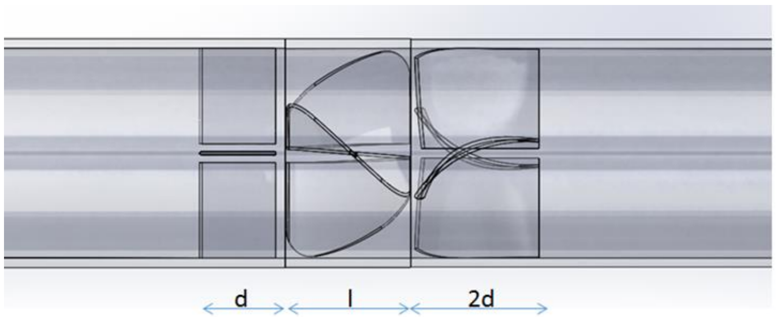
Flow rate was calculated based on 5000 Pa pressure difference between flow inlet and outlet.

Typical Flow Velocity

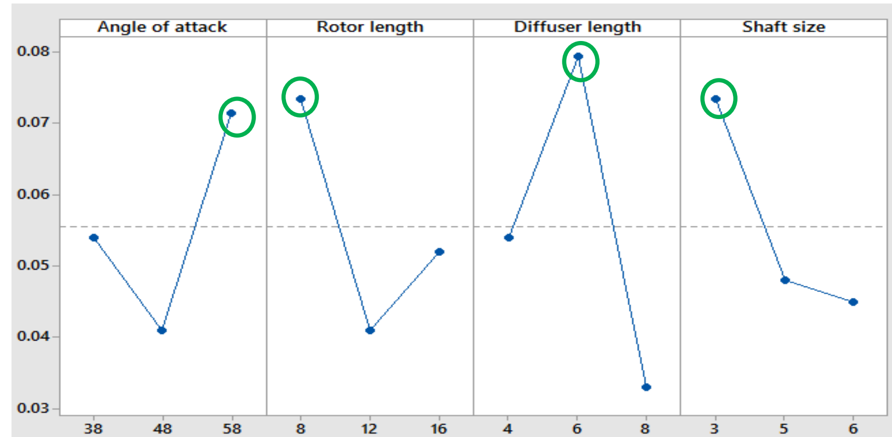


Run No 1

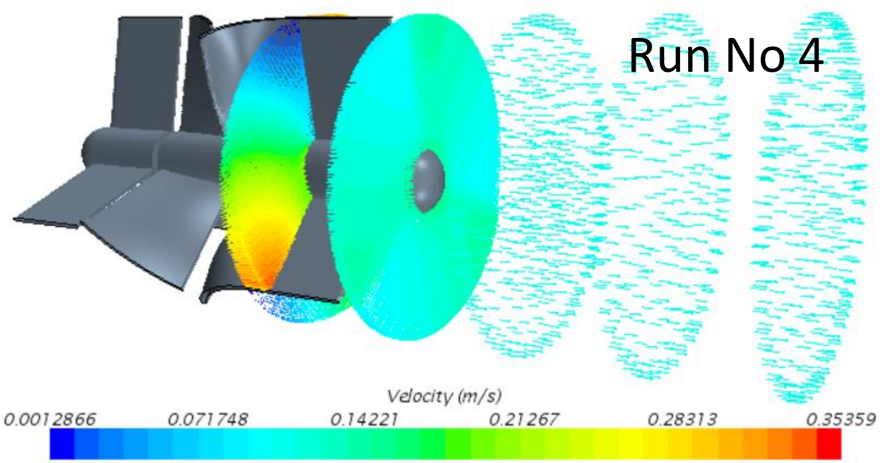
Sample of CFD & Optimization Results

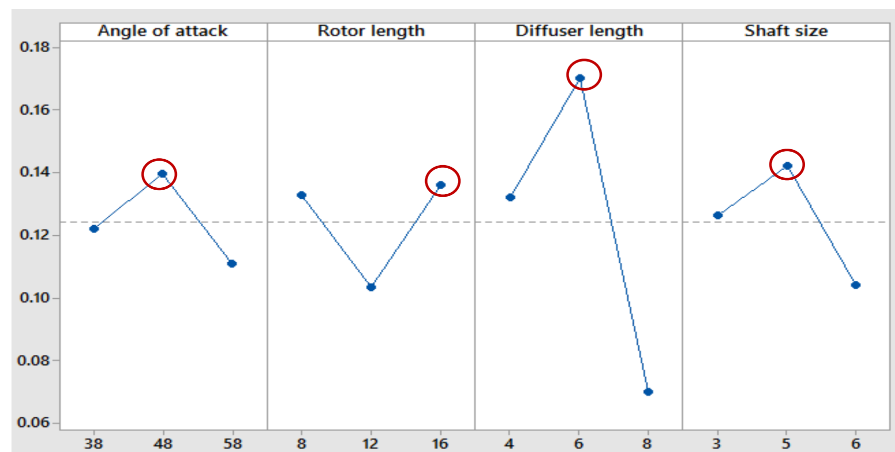


Uniform flow velocity at exit



Effect of different value of the three parameters on **pump efficiency;**





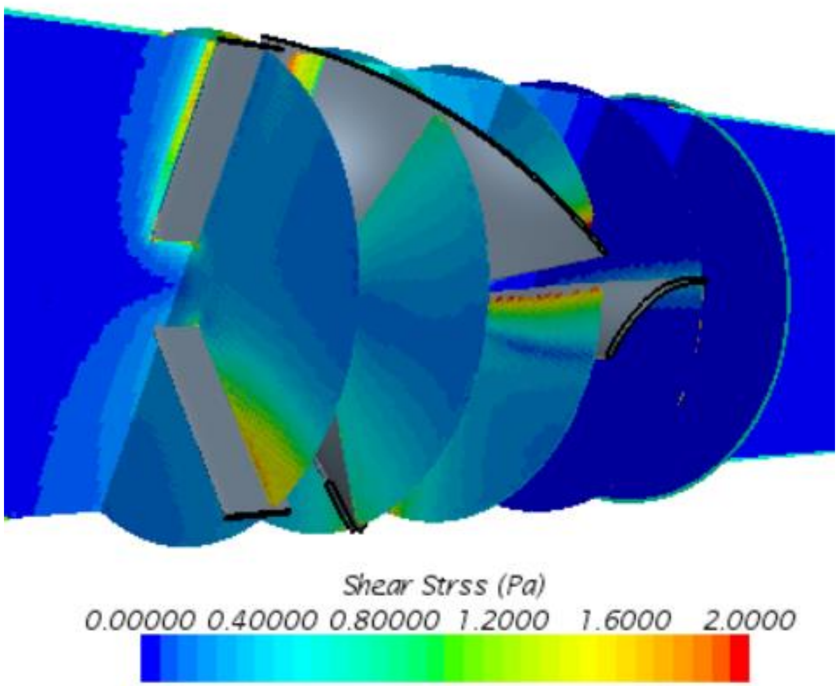
Effect of different value of the three parameters for **Maximum flow rate;**

Best cases

Run 9 Run 4

Blood Damage Index & Comparison

Shear stress =strain rate x dynamic viscosity



Shear stress was calculated at each cell.

Run No 1

Blood Damage index Di was calculated using the Mitoh et al equation (2003)

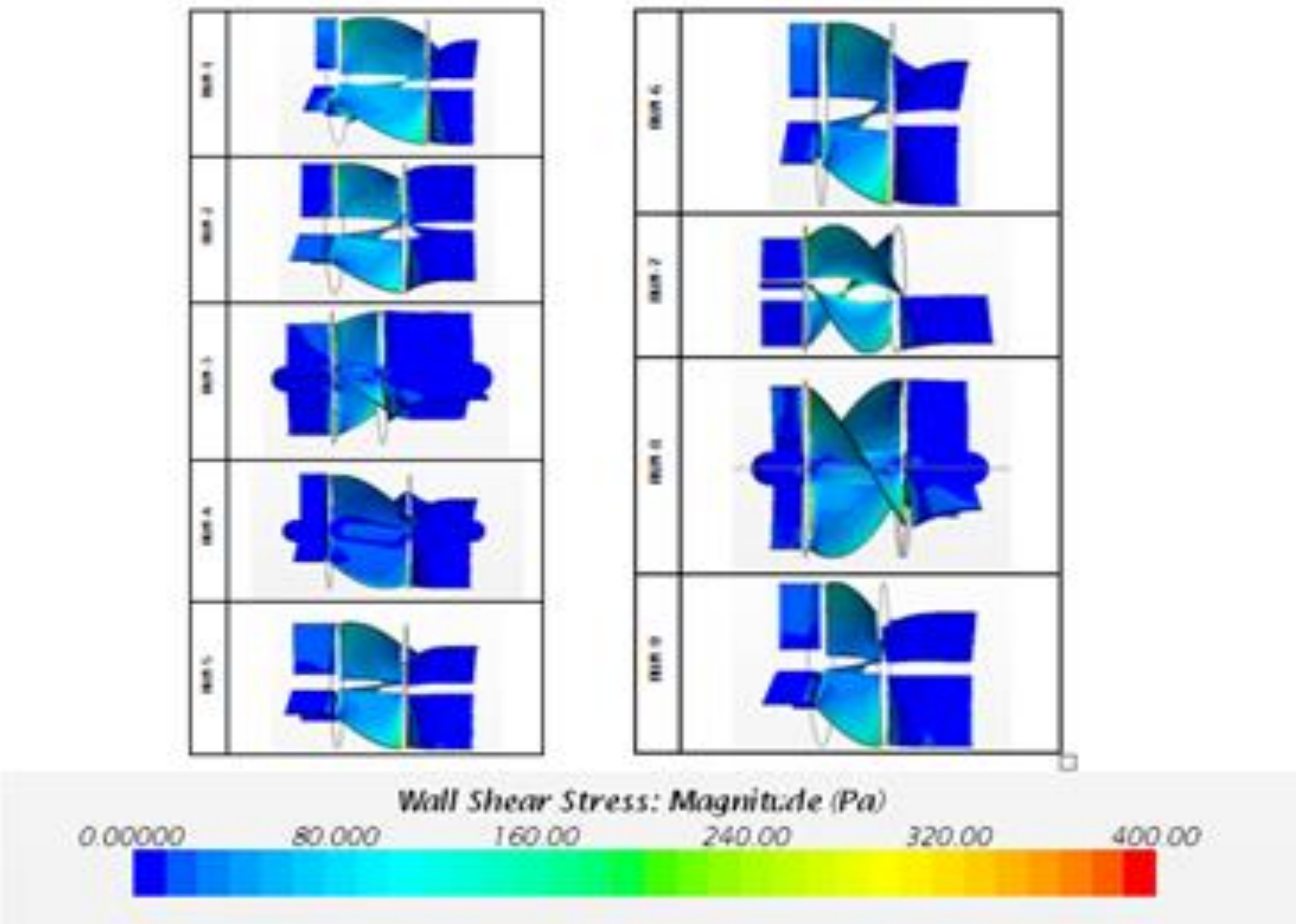
$$d_{p,i} = 3.62 \times 10^{-7} \times \tau_t^{2.416} \times \Delta t^{0.785}$$

Di= 0.14 %

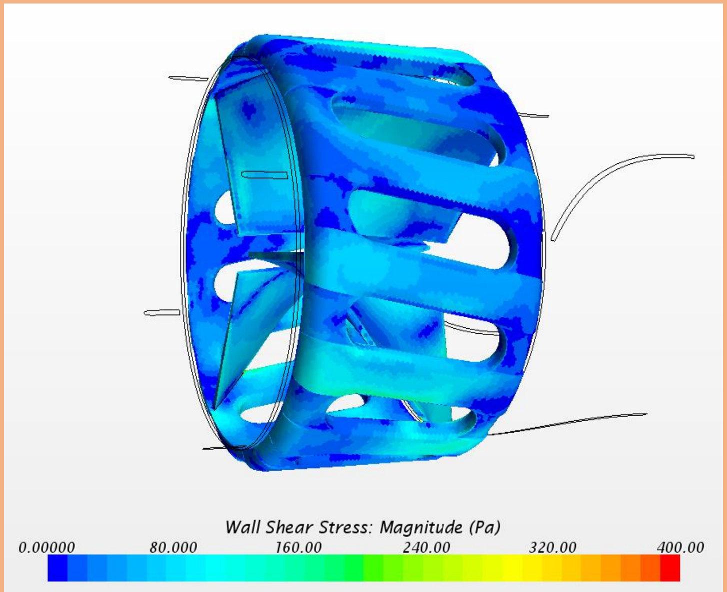
For Run number 1

The shear stresses acting on the blood in humans lie within a range of 0.1–1 Pa in healthy human veins and 1–20 Pa in healthy human arteries.

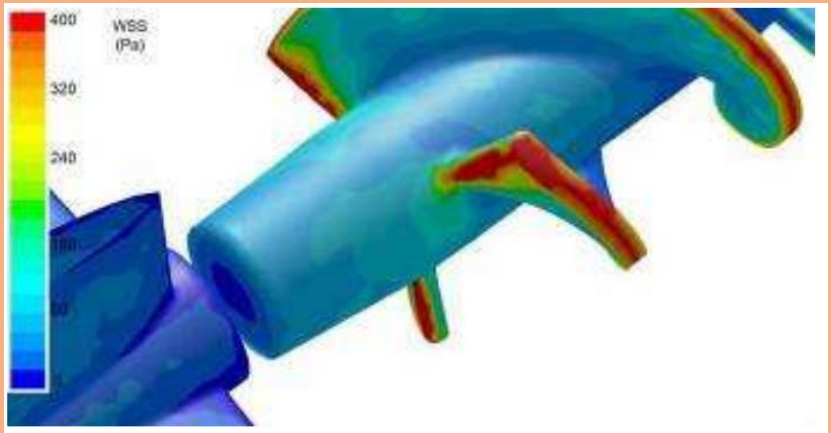
Wall Shear Stress Distribution



Comparison with Literature



Wall Shear Stress Distribution of Run-1



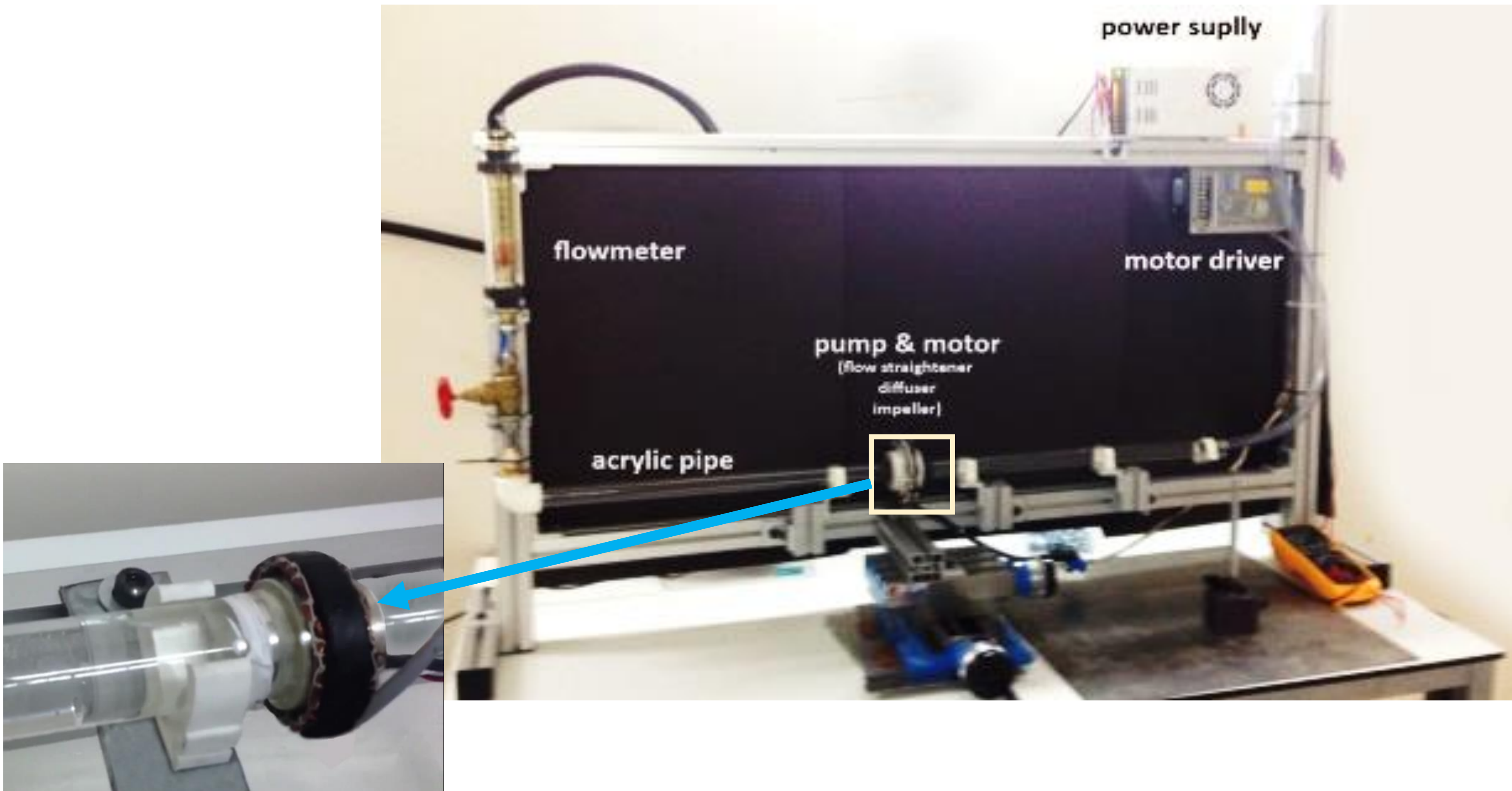
*«Tubitak Project no: 106M309 Desing analyses and manufacture of an artificial heart pump», İstanbul 2010. N. EGRICAN, S. KÜÇÜKAKSU, M. AKGÜN,I. LAZOĞLU,N.CIBLAK, E. AN, E. SORGÜVEN , K. ŞAFAK ,A. FETHIOKYAR, C. UÇAK ,M. ŞEHRLIOĞLU

Wall Shear Stress Distribution of an axial type blood pump from literature

The wall shear stress for all the 9 runs shows that the rotor is exposed to the highest shear; however, it is significantly lower compared to other pumps that are available in the market and also in literature.

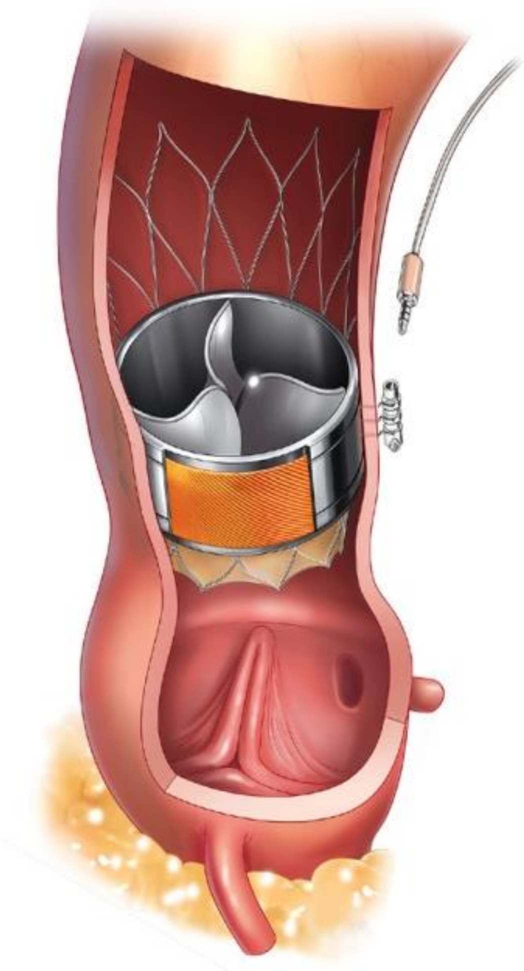
Technology Validation on Test Rig

Testing using water is currently under development



Conclusions

- The new proposed pump with a larger diameter can achieve the necessary flow rate and head with relatively much lower rotational speed.
- Shear stress and blood damage index showed significantly lower values.
- The optimization process needs further work to have a closer range for the parameter values.
- It was noticed that also the distance between the straightener and rotor creates too much turbulence and may need further investigations.



Questions

Thank you for listening