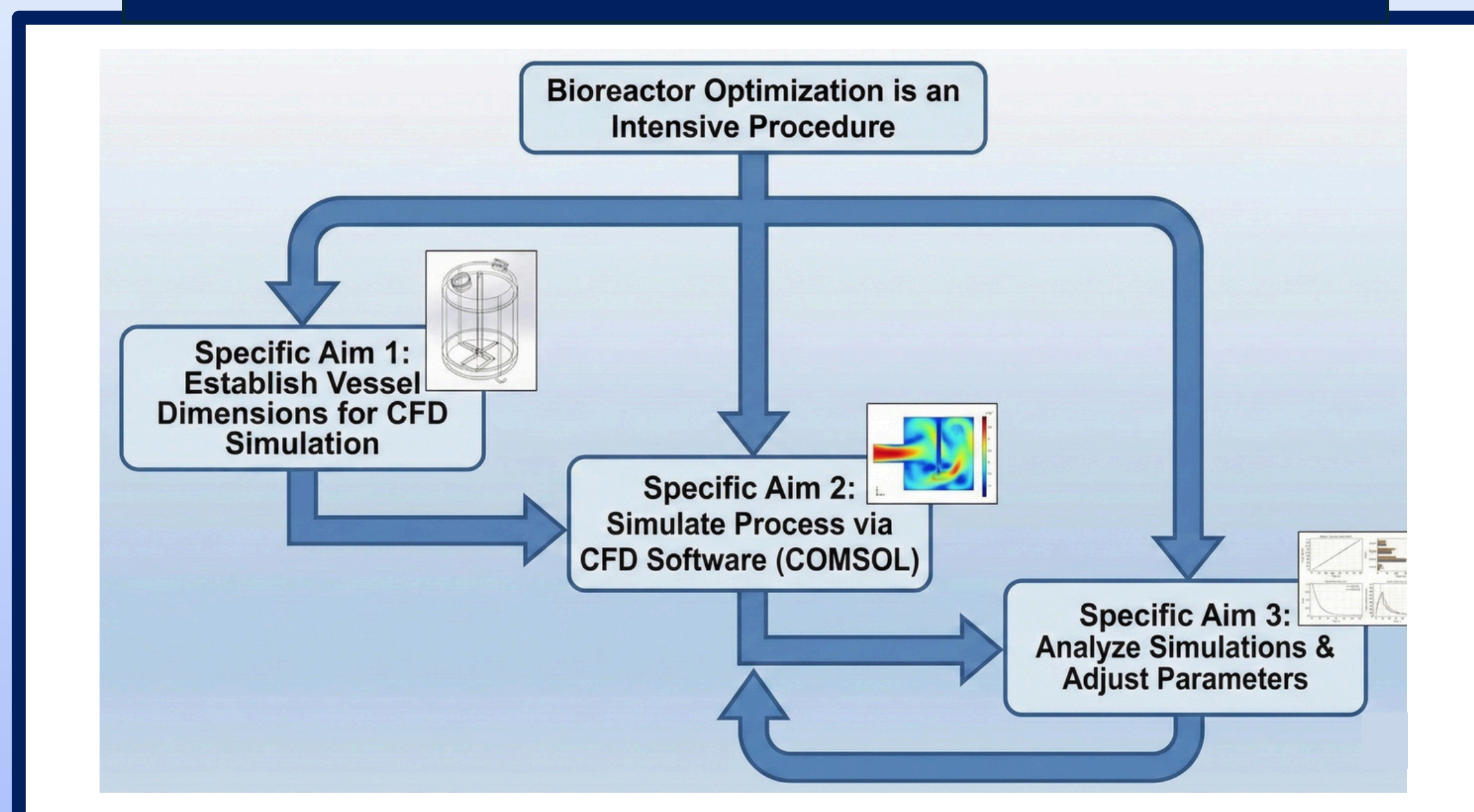


# Optimization of a 20,000 Liter Bioreactor Through Computational Fluid Dynamics Simulation Analysis



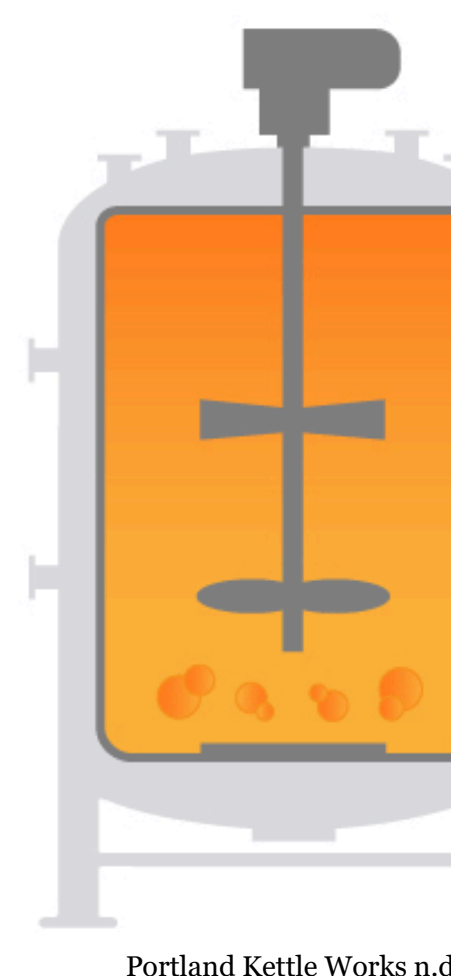
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## VISUAL ABSTRACT



## INTRODUCTION

- Bioreactors need to be finely tuned for the cells they are cultivating.
- Optimizing bioreactors for this purpose can be extremely time and resource intensive, especially for large scale tanks (Buss et. al, 2017).
- Computational Fluid Dynamics (CFD) can simulate the operation and fluid dynamics of a vessel without the need for physical testing.



## ENGINEERING OBJECTIVES

**PROBLEM STATEMENT:** Optimizing large-scale bioreactors can be extremely time and resource intensive.

**ENGINEERING GOAL:** To investigate and optimize the operation of a 20,000 liter stirred vessel bioreactor using CFD.

### OBJECTIVE 1

Establish a model accurate to the real bioreactor for simulation

### OBJECTIVE 2

Simulate and analyze factors of bioreactor process performance

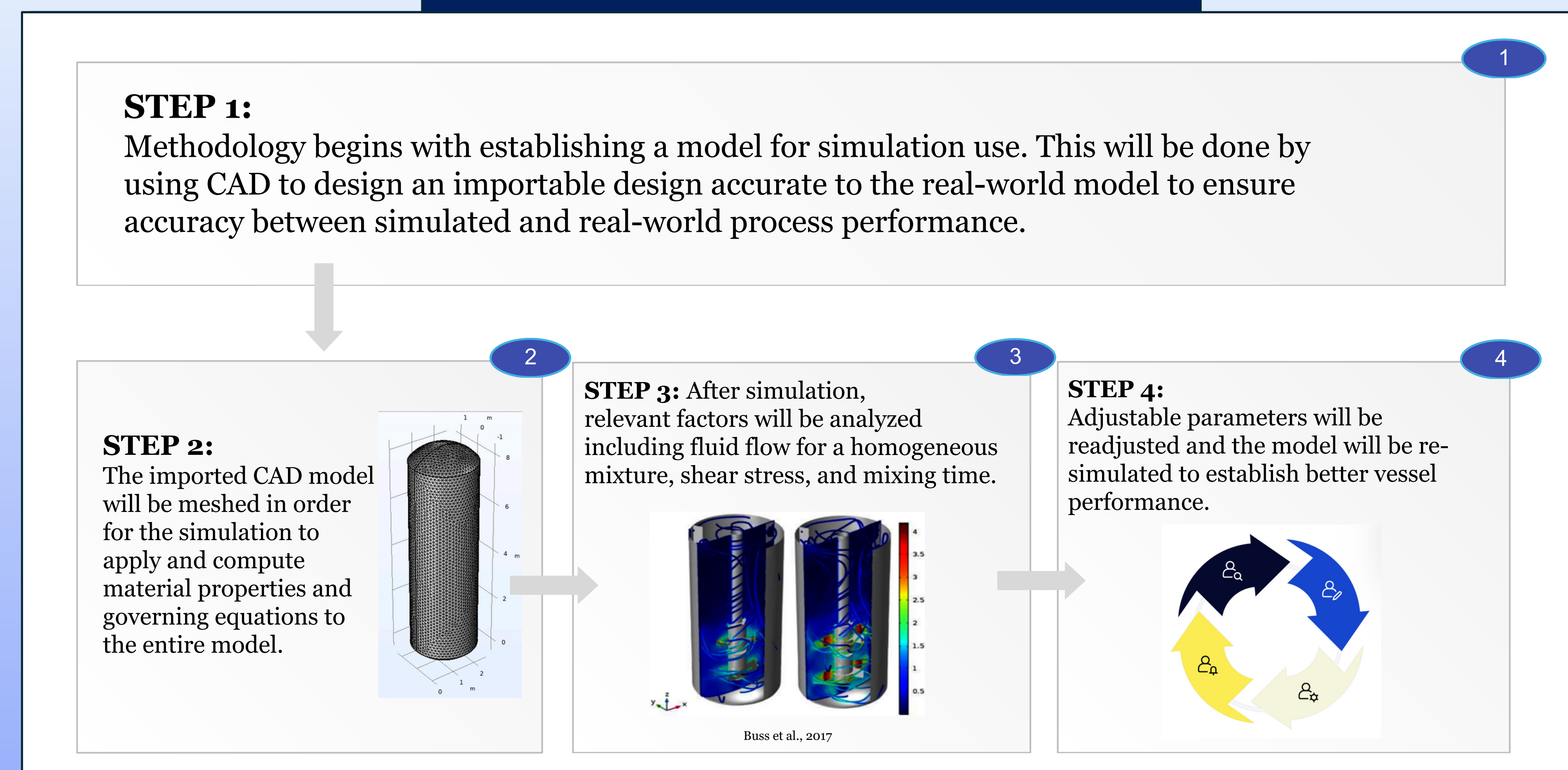
### OBJECTIVE 3

Adjust parameters accordingly for improved process performance

**RESEARCH QUESTION:** How will different impeller configurations affect the mixing time, shear rate, and shear stress of the vessel?

**HYPOTHESIS:** A model with two top axial constant pitch impeller and one radial Smith impeller will result in the best combination of mixing time and shear rate results because of its industry use and researched performance (Vrábel et. al., 2000; Wu et. al., 2023).

## METHODOLOGY



## RESULTS

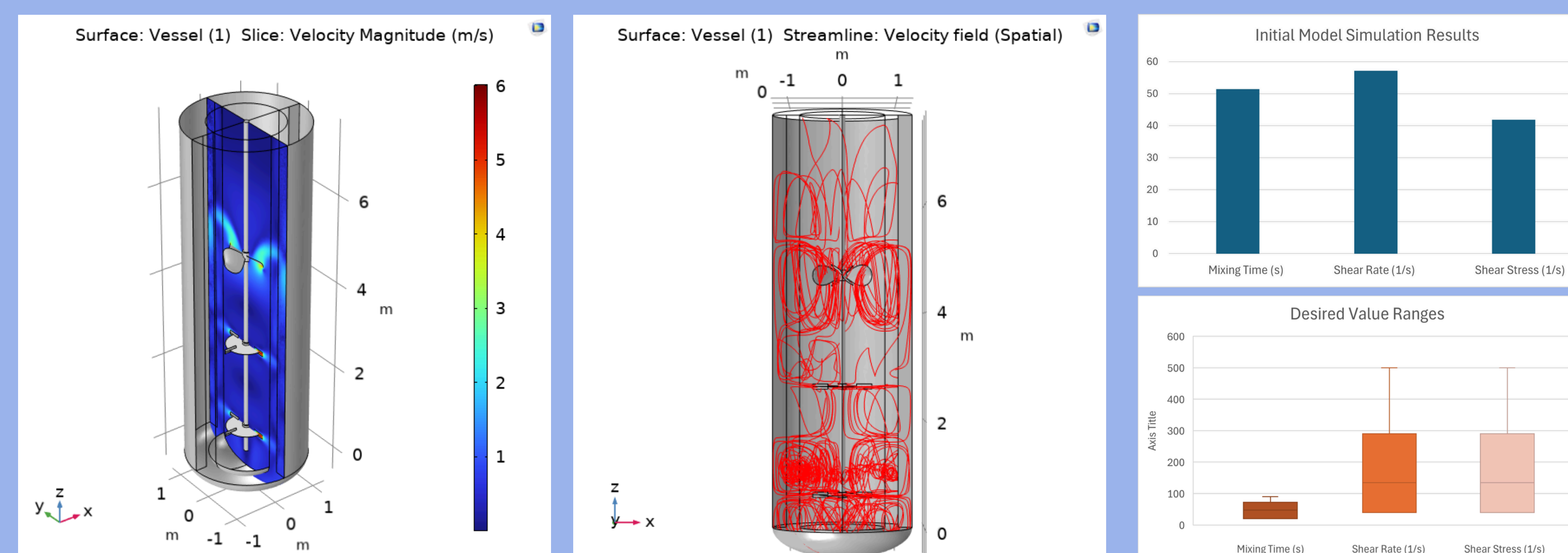


Figure: Simulation results of the base 20kL bioreactor model. a) Slice plot of the velocity magnitude for the model simulated at 100RPM. b) Velocity streamline field to display path of fluid taken. c) Collected simulation values of the initial model's mixing time, shear rate, and shear stress in comparison to a range of desired and reasonable values for each measure.

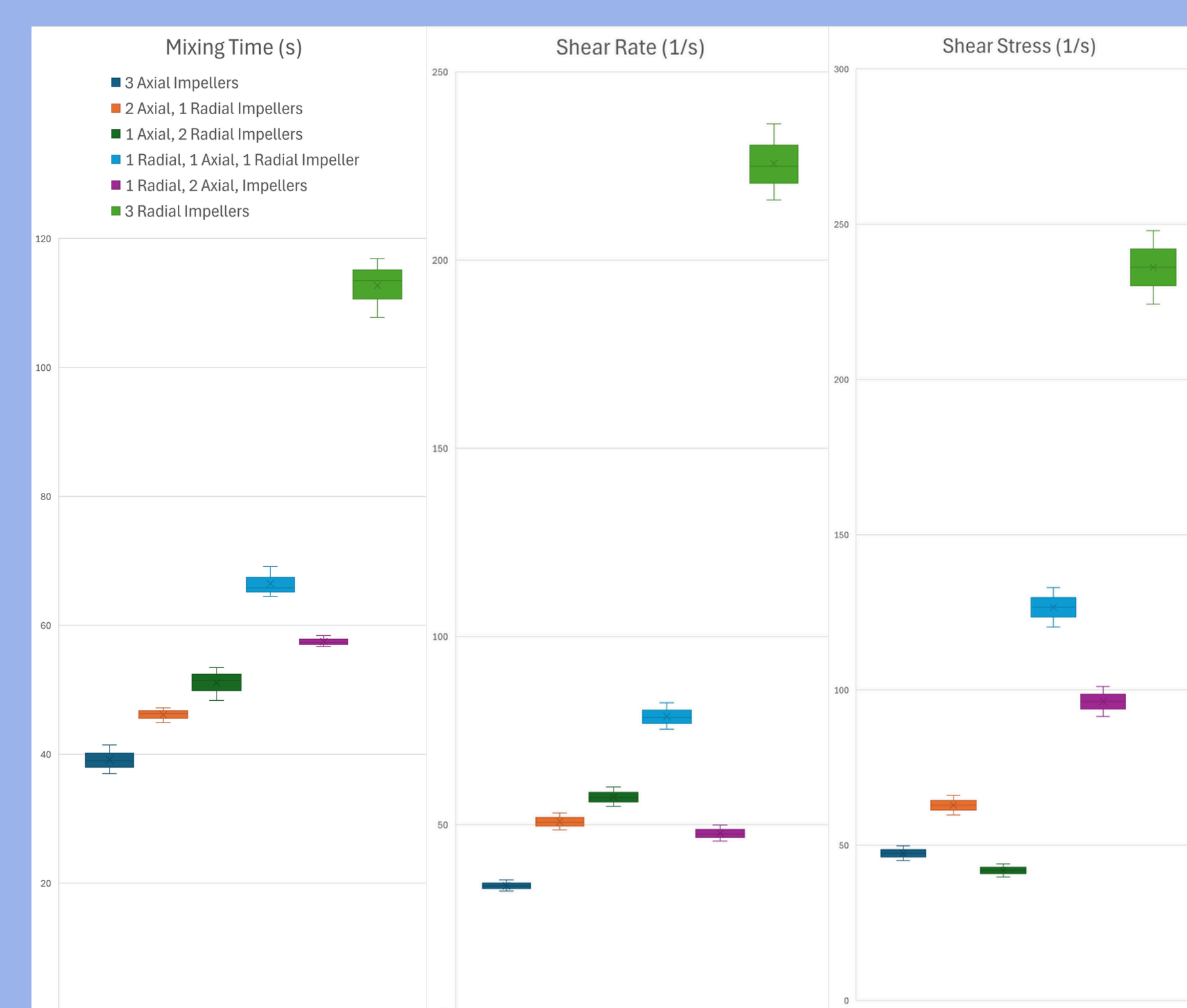


Figure 2: Box and whisker plot comparison between the initial bioreactor model results and five experimental configurations for mixing time, shear stress, and shear rate. Box and whisker plots were achieved by running a mesh dependent study, where each model's simulation was reiterated at normal and fine mesh levels to confirm the validity of the initially collected results in the initial simulation.

Design Criteria Matrix						
Criteria & Criteria Weight	3 Axial Impellers	2 Axial, 1 Radial Impeller	1 Axial, 2 Radial Impellers	1 Radial, 1 Axial, 1 Radial Impeller	1 Radial, 2 Axial Impellers	3 Radial Impellers
Mixing Time (8)	10	9	8	7	8	0
Shear Rate (7)	10	9	9	8	9	5
Shear Stress (9)	10	9	10	8	8	5
<b>TOTAL:</b>	<b>240</b>	<b>225</b>	<b>217</b>	<b>184</b>	<b>199</b>	<b>80</b>

Figure 3: Design criteria matrix and pugh chart for objective comparison of the three different metrics measured in this project across each experimental design.

## CONCLUSION

- Current depictions of base model fluid flow show reasonable and practical results that display promise for in-field operation.
- Of the five experimental models, each exhibits similar traits that can each be used for vessel operation with the sole exception being the three radial Smith impeller configuration.
- The three radial Smith impeller exhibits a lackluster mixing time combined with a higher potential to damage cells, providing evidence that the configuration is not suitable for real-world implementation, supporting literature such as Post (2010).
- The three axial constant pitch impellers exhibit the lowest mixing times and shear rate because of the enhanced axial vortex fluid motions. This model shows promise in optimizing mixing in the vessel without negatively damaging the well-being of mixed cells which supports fluid dynamics literature.
- The base model design does interestingly show an approximately 11% lower value for shear stress compared to the triple axial configuration, yet both impeller arrangements fall within reasonable and desired values for all three metrics.

## SIGNIFICANCE

- Many pharmaceuticals are produced with bioreactors.
- Optimizing without physical testing is especially impactful for large scale bioreactors that can be difficult or impossible to physically adjust.
- By saving time and resources, the production costs of pharmaceuticals can be decreased.

## FUTURE WORK

### Further analysis of bioreactor process performance:

- Expand study to incorporate more iterations of the currently analyzed metrics.
- Conduct simulations on vessel gas aeration for practical connections to oxygen distribution in the tank.

### Additional research contributions and novelty:

- Analyze the nonlinear relationship between upscale of identical smaller scale bioreactors to the current model.