Evaluating Clean Bench Designs Using CFD and Particle Tracing

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INTRODUCTION

At the Kansas City National Security Campus (KCNSC), simulation analysts are often called upon to evaluate designs and manufacturing processes performed in the plant. Precision mechanisms need to be assembled on clean benches that provide laminar airflow to prevent dust contamination. Mechanism engineers modified the layout of the bench to include computer monitors to improve the efficiency and ergonomics for operators using the bench. We ran CFD and particle tracing simulations to understand whether these obstructions disrupt the laminar airflow causing risk of particle accumulation.

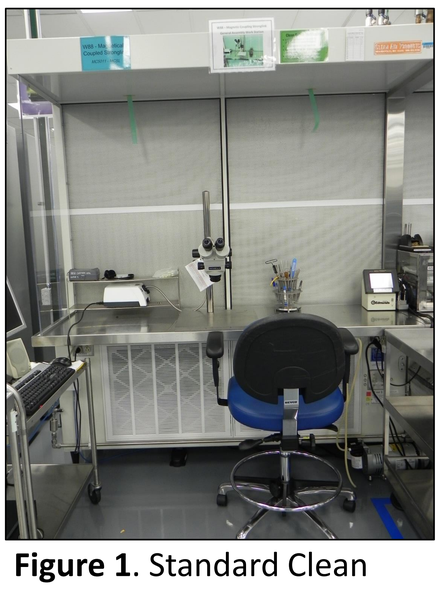

Figure 1. Standard Clean Bench Layout

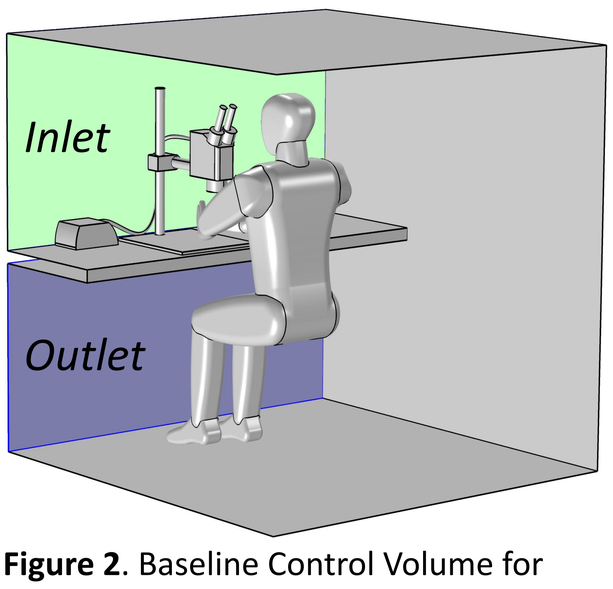

Figure 2. Baseline Control Volume for CFD Analysis

COMPUTATIONAL METHODS

Clean benches are designed to circulate filtered air across the top of the working surface. The air pressure and velocity fields were computed using the CFD module with an inlet velocity of 0.5 m/s and an outlet pressure of 0 Pa. These fields were then used by the Particle Tracing module to predict unique particulate behavior.

Laminar Flow

$$\rho\frac{\partial \mathbf{u}}{\partial t}+\rho(\mathbf{u}\cdot\nabla)\mathbf{u} = \nabla\cdot\left[-p\mathbf{I}+\mu\left(\nabla\mathbf{u}+(\nabla\mathbf{u})^{\mathrm{T}}\right)\right]+\mathrm{F}$$

$$\rho\nabla\cdot(\mathbf{u})=0$$

Particle Tracing for Fluid Flow

$$\mathbf{F}_{\mathrm{t}}=\frac{d(m_p\mathbf{v})}{dt}$$

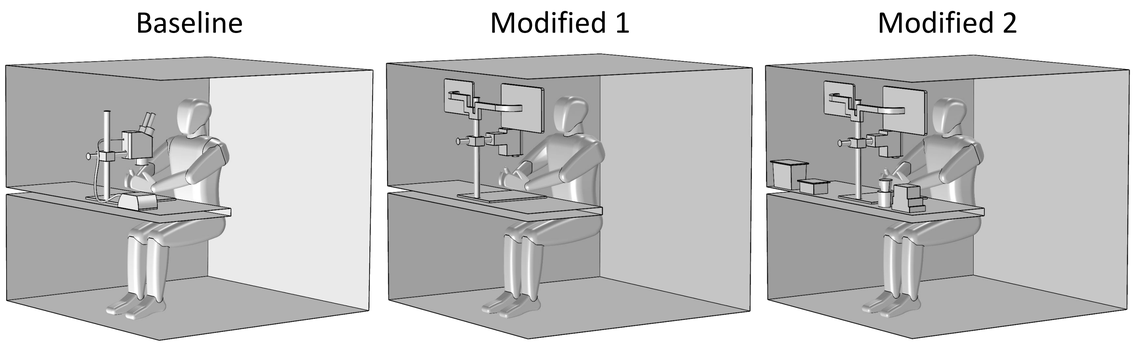

Figure 3. Modified bench layouts were compared against the baseline with particles released from various zones

RESULTS

Fluid velocity plots were compared against the baseline for each of the modified bench layouts. Furthermore, the transmission probability of particles finishing on the bench surface was recorded in **Table 1**.

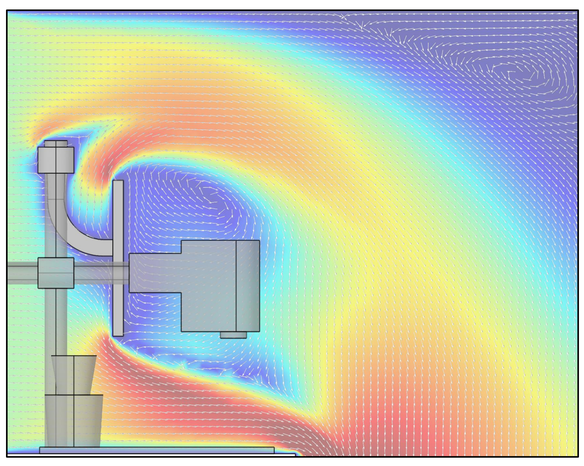

Figure 4. Fluid velocity with cut plane midway through monitor (scaled 0 m/s to 0.5 m/s)

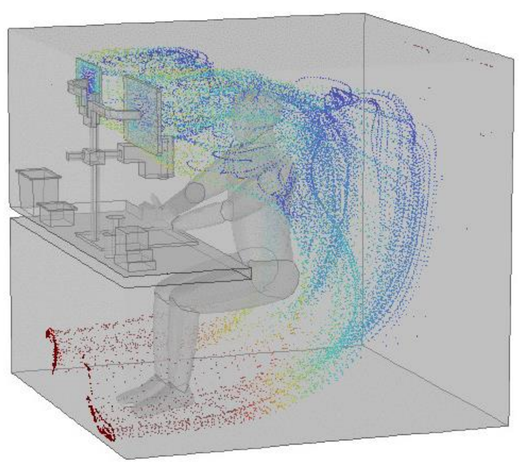

Figure 5. 10-micron particles released from monitors

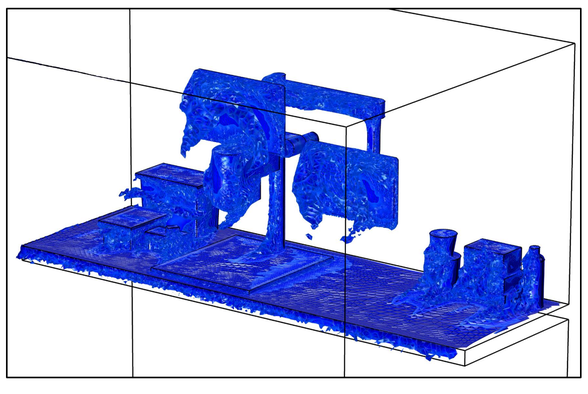

Figure 6. Fluid velocity less than 0.1 m/s

Table 1. Particle accumulation on bench surface transmission probability

	Transmission Probability		
Bench Layout	Zone 1	Zone 2	Zone 3
Baseline	4.8%	-	-
Modified 1	5.1%	<0.1%	-
Modified 2	5.9%	<0.1%	2.7%

CONCLUSIONS

Results from this study suggested that adding monitors to the clean bench does not significantly impact the likelihood of particle accumulation; while providing an envelope of locations in which items can safely be placed without impacting the flow through critical areas. The modified bench layout with monitors proved to be 21% more efficient than the baseline according to a usability study.

Further work included exporting streamline data from COMSOL Multiphysics to create an immersive application in which the user can navigate the environment with a keyboard and mouse. This application is being used as a teaching tool for engineers and operators to demonstrate how items on the bench impact airflow.

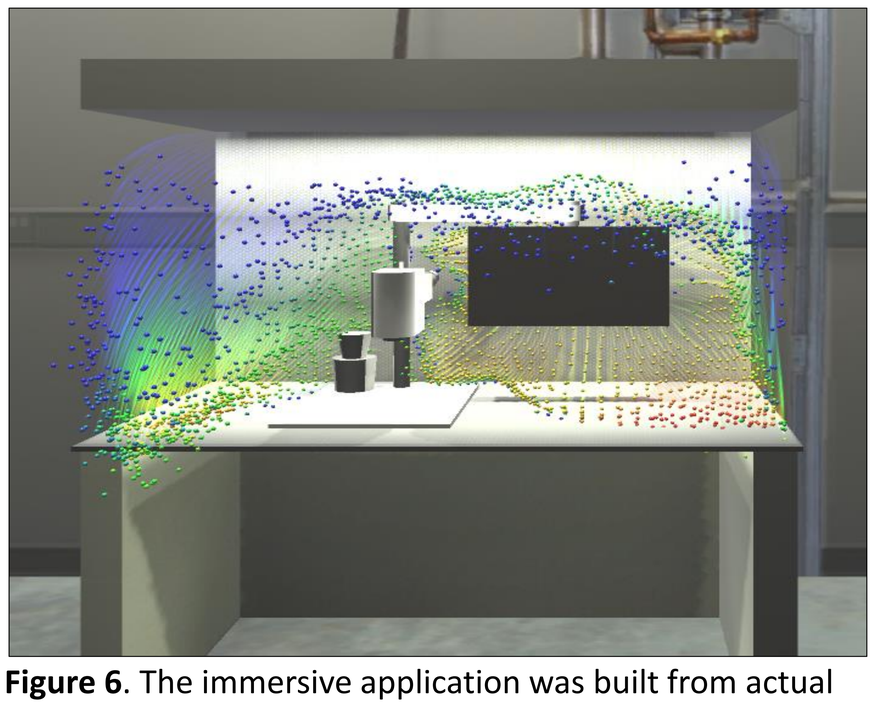

Figure 6. The immersive application was built from actual streamline data and photos of a clean room to create a familiar environment for the user

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