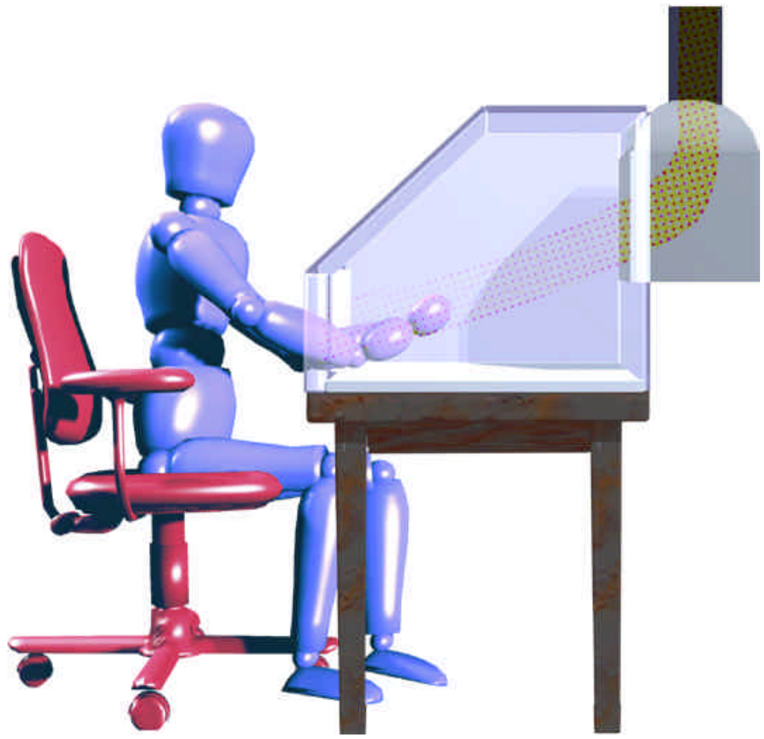
Use of Computational Fluid Dynamics to Optimize Airflow and Energy Conservation in Laboratory Hoods and Vented Enclosures



Alexy Kolesnikov, PhD
Ray Ryan, CEO
Douglas B. Walters, PhD

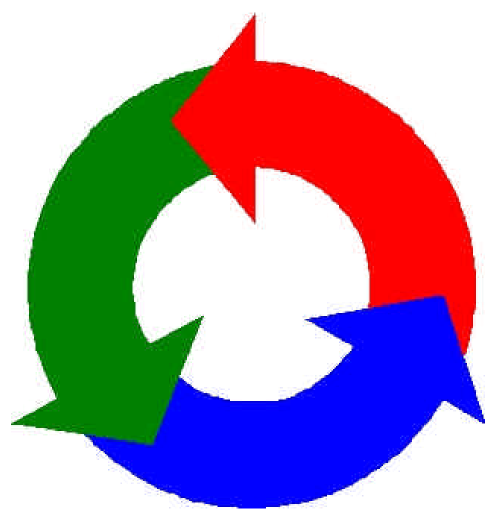
September 2001

Efficient Operation. Design Goals.

Efficiently operating enclosure must:

- Maintain high level of containment protection
- Provide a steady balance reading
- Ensure that materials inside the enclosure are undisturbed by airflow
- Provide ergonomic design and ensure ease of access
- Address energy efficiency concerns

Task specific custom design loop



End User Design Goals

Parameters

- Turbulence intensity level
- Containment protection
- 1-2’ VBSE = 100 CFM air, 1-6’ hood = 1200 CFM air
- Energy efficiency, 1200 CFM = $5K/yr.
- Balance reading stability
- Task specific flexibility
- Ergonomic design, visibility, comfort

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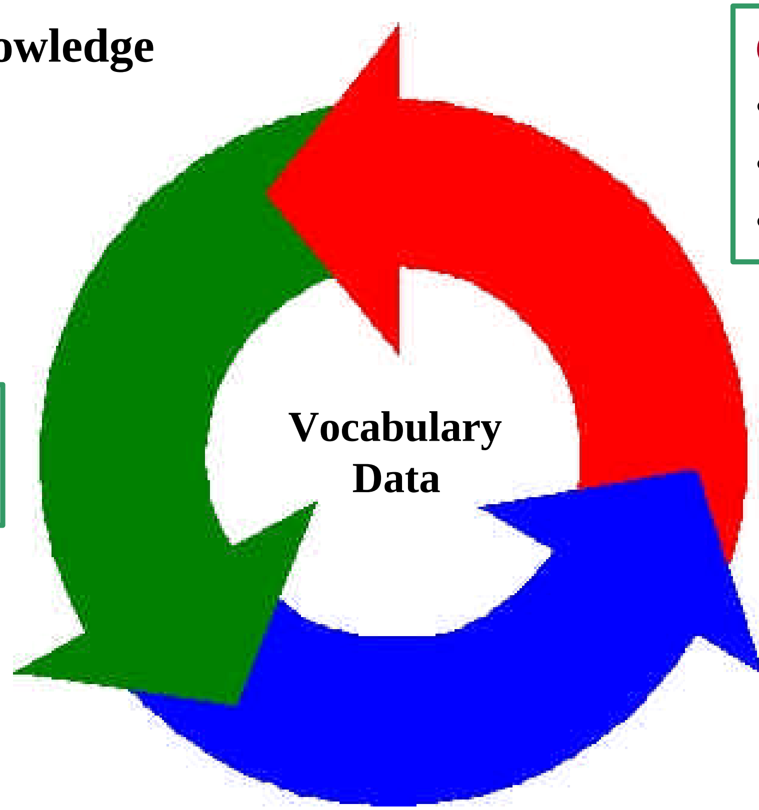
CFD Problem Solving Environment

knowledge

COMPUTER SCIENCE
- Numerical Algebra
- Computer platforms
- Data management

END USER
Specific problem



knowledge

knowledge

MATH/PHYSICS
- PDE systems
- Closure “nuances”
- Discrete methods

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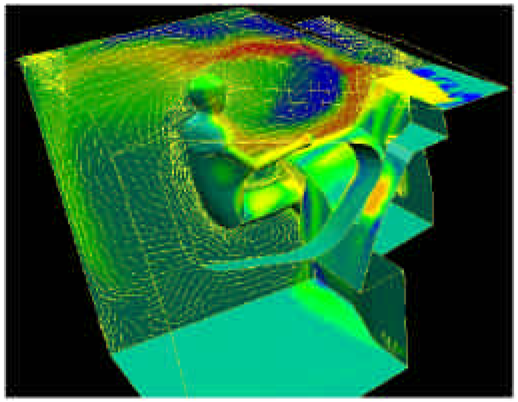
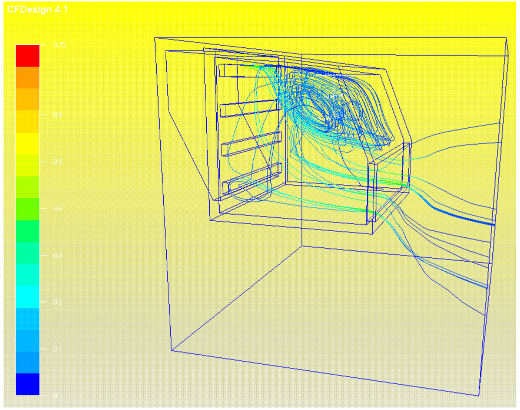
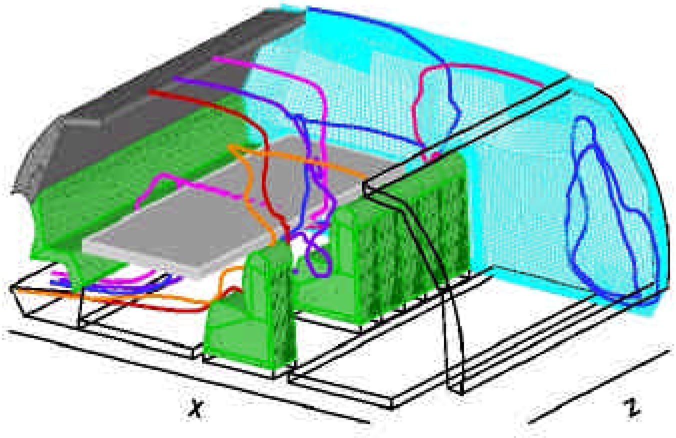
END USER. Applications.

- Aerodynamics
- HVAC
- Air quality
- Automotive
- Turbomachinery
- Combustion
- Electronics







MATH/PHYSICS. PDE Systems I.

Conservation Law System:

Conservation of mass: $$\frac{1}{r}\frac{\partial r}{\partial t}+\frac{u_j}{r}\frac{\partial r}{\partial x_j}+\frac{\partial u_j}{\partial x_j}=0$$

Conservation of momentum: $$r\frac{\partial u_i}{\partial t}+ru_j\frac{\partial u_i}{\partial x_j}-\frac{\partial s_{ij}}{\partial x_j}-rb_i=0$$

Conservation of energy: $$r\frac{\partial e}{\partial t}+ru_j\frac{\partial e}{\partial x_j}-s_{ij}e_{ij}-rs+\frac{\partial q_j}{\partial x_j}=0$$

σ – Cauchy stress tensor, e – internal energy, s – distributed heat generation,
ε - strain-rate tensor, q – heat transfer rate by diffusion.

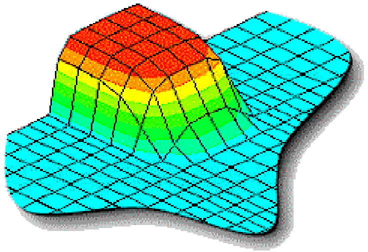
$$e_{ij}=\frac{1}{2}\left(\frac{\partial u_i}{\partial x_j}+\frac{\partial u_j}{\partial x_i}\right)$$

Math/Physics. Discrete methods.

Spatial discretization:

$$\frac{\partial q}{\partial x_j}, \frac{\partial^2 q}{\partial x_j^2} \rightarrow f(q_{i\pm n, j\pm m, k\pm l})$$

- Finite difference (Taylor series based) methods
- Finite element (weak statement based) methods
- Finite volume methods



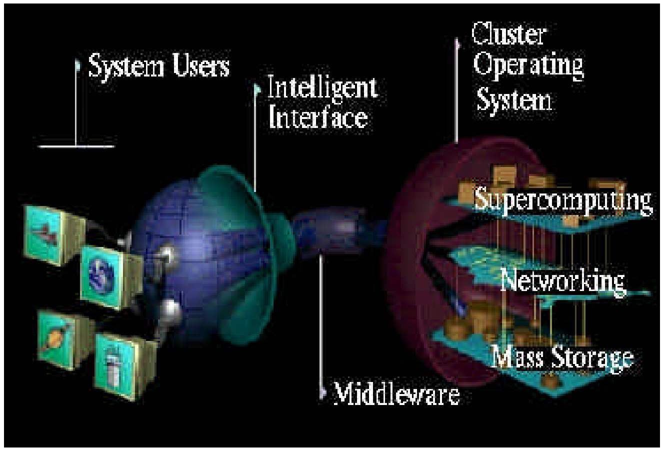
Time – dependent ODE solution methods:

$$\frac{\partial q_{i\pm n, j\pm m, k\pm l}}{\partial t} \rightarrow F(q_{i\pm n, j\pm m, k\pm l}^{p+1, p, p-1})$$

- Single-step
- Multi-step
- Runge-Kutta

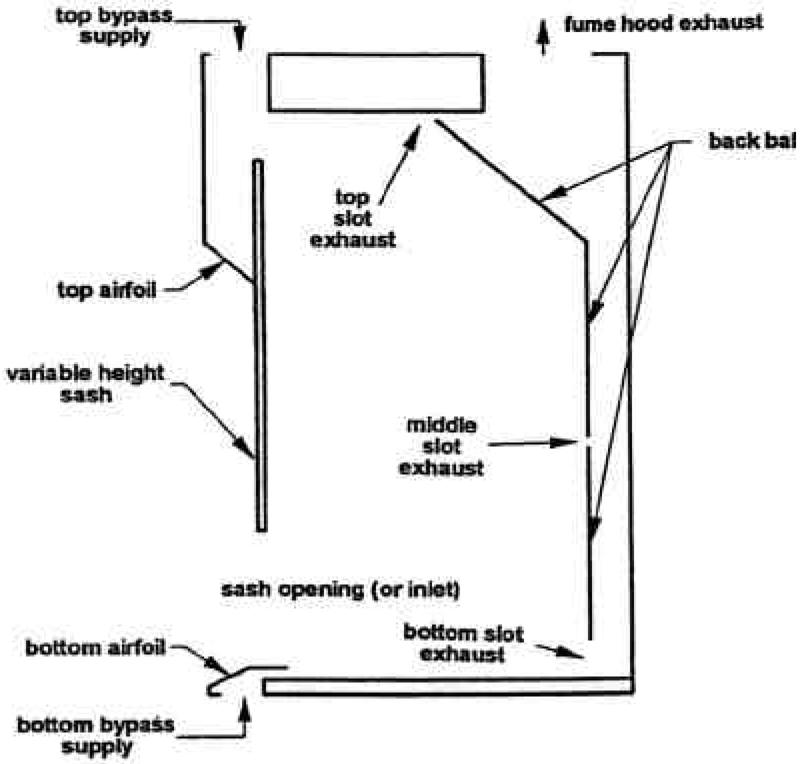
Matrix computation:

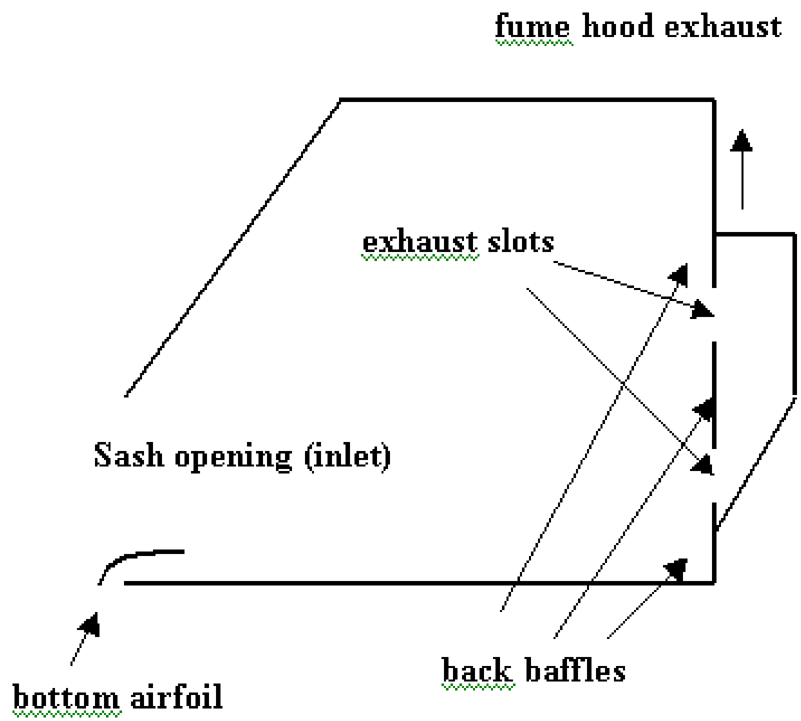
- Iterative methods
- [A]{x}={b}
- Parallel implementation



Airflow modeling

General configuration





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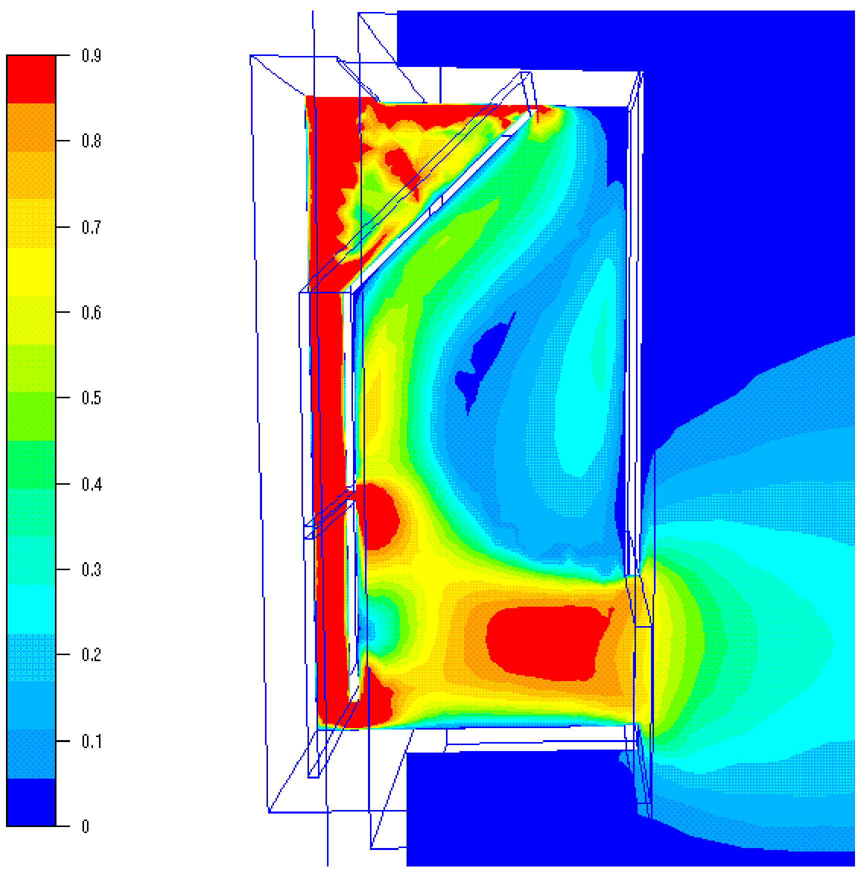
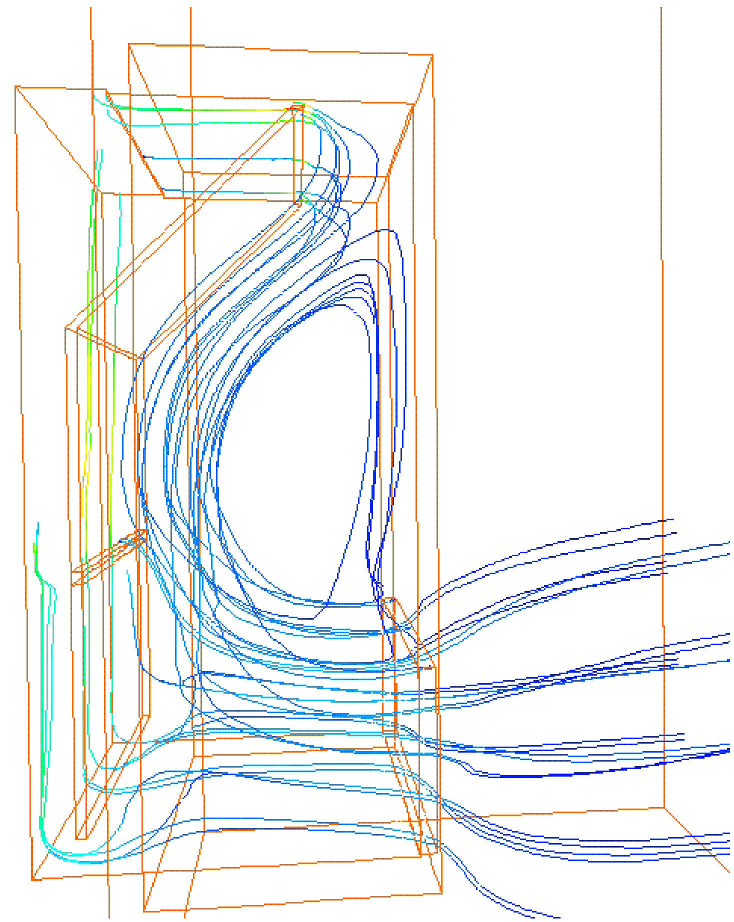
Airflow modeling

Velocity profile



Particle traces



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Airflow modeling verification

Literature data

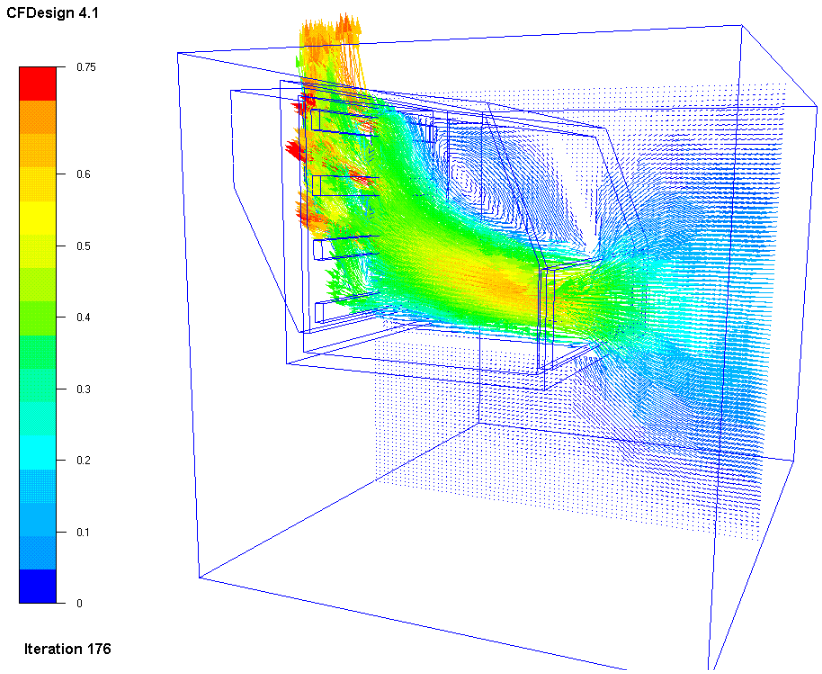
	Experimental flow %	*Computational Flow %*
Top exhaust	23	24
Middle Exhaust	29	17
Bottom exhaust	48	59

Present research

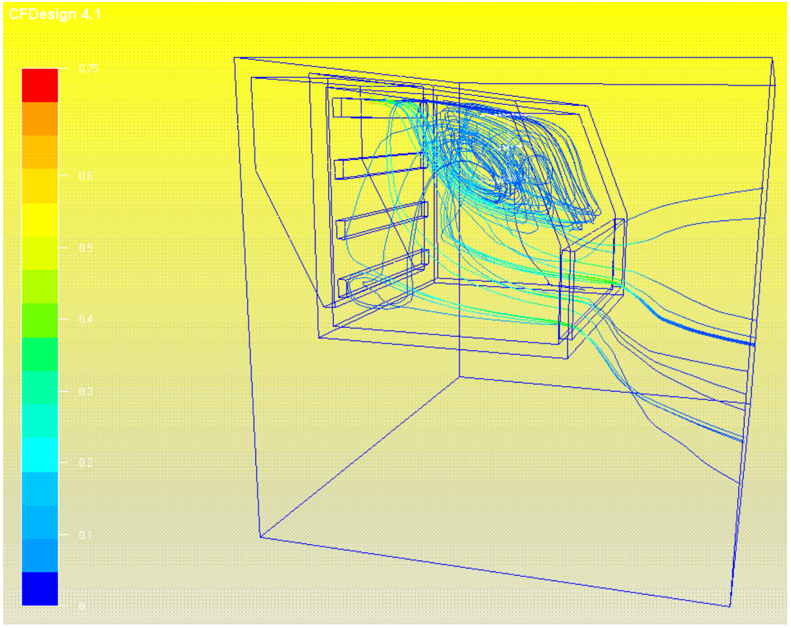
	Experimental flow %	*Computational Flow %*
Top exhaust	23	21
Middle Exhaust	29	29
Bottom exhaust	48	50

Airflow modeling

Velocity profile



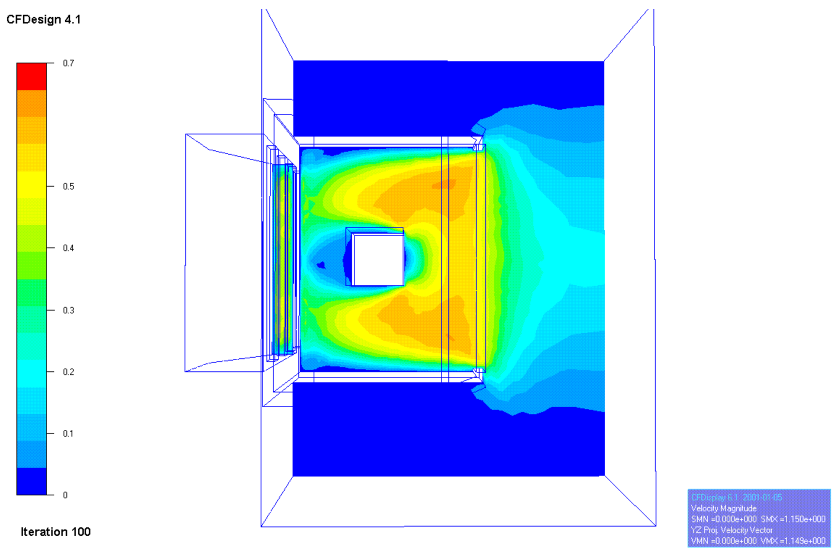
Particle traces

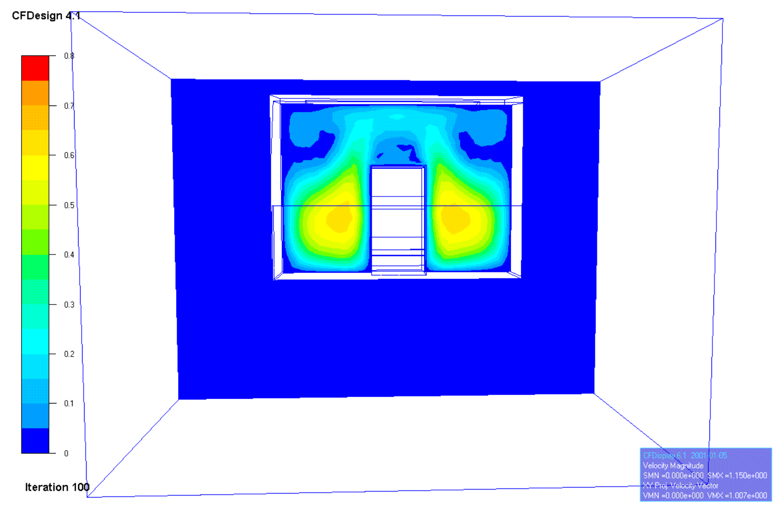


Airflow distribution control

Airflow pattern inside of the enclosure work area is controlled by:

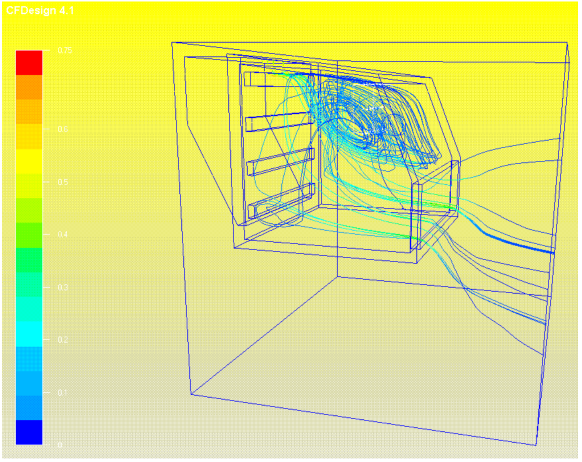
- Geometric configuration
- Sash opening height
- Face velocity
- Operator presence
- Room air currents
- Lab equipment arrangement inside of the work area





Task Specific Design. Laboratory Enclosure

General work area arrangement



Optimization requirements

- Maximized containment protection
- Potent powder protection
- Ergonomic design
- Work place flexibility
- Energy efficiency

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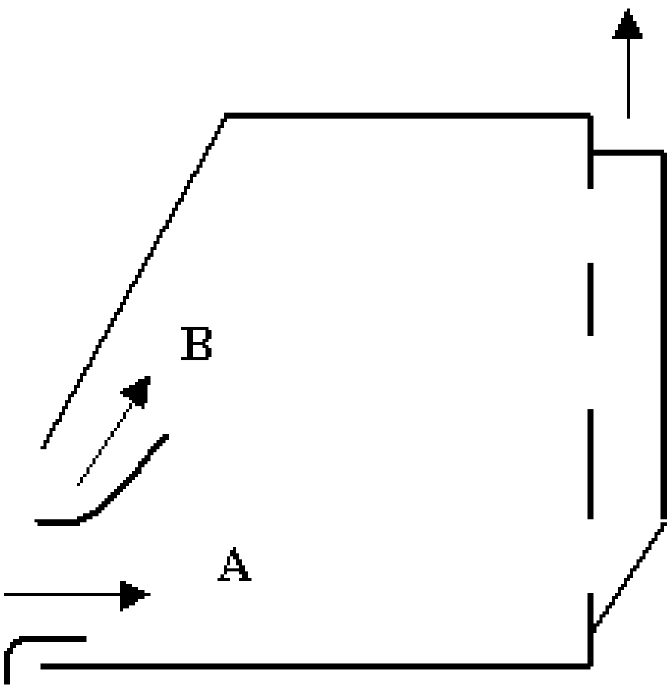
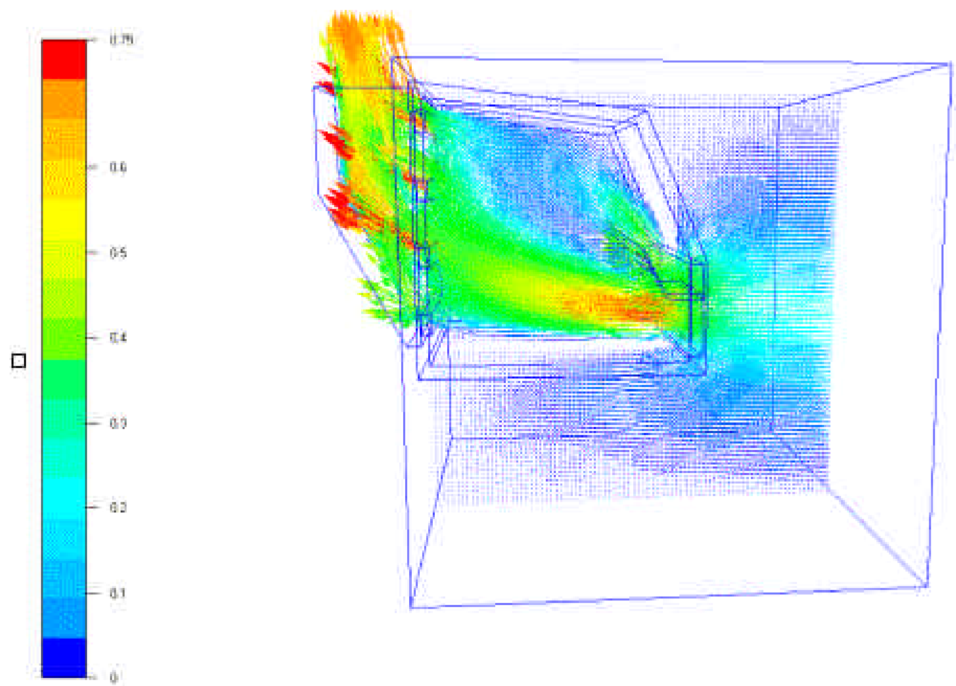
Task Specific Design. Laboratory Enclosure

Proposed solution

- Incoming air is redirected to eliminate the counter-clockwise roll
- Inlet/outlet design is computer controlled and optimized
- Face velocity, work area turbulence minimization
- Smoke/tracer gas testing for prototype optimization



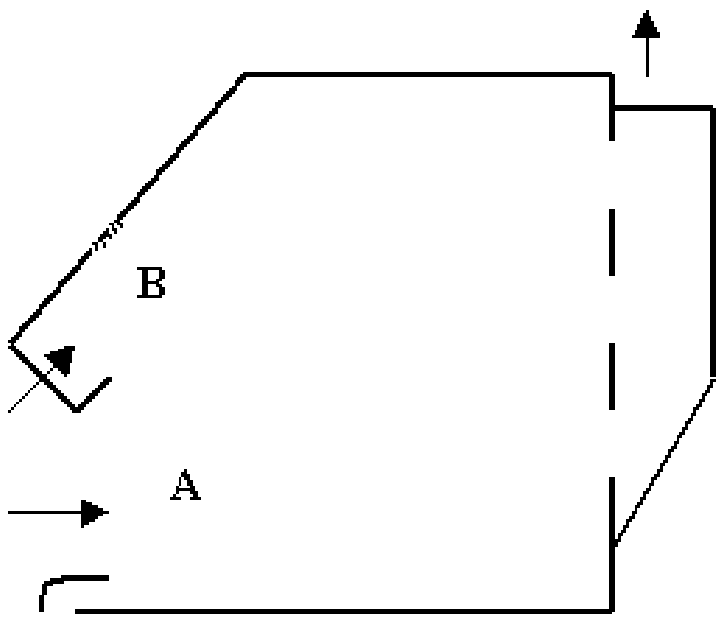
Patent pending

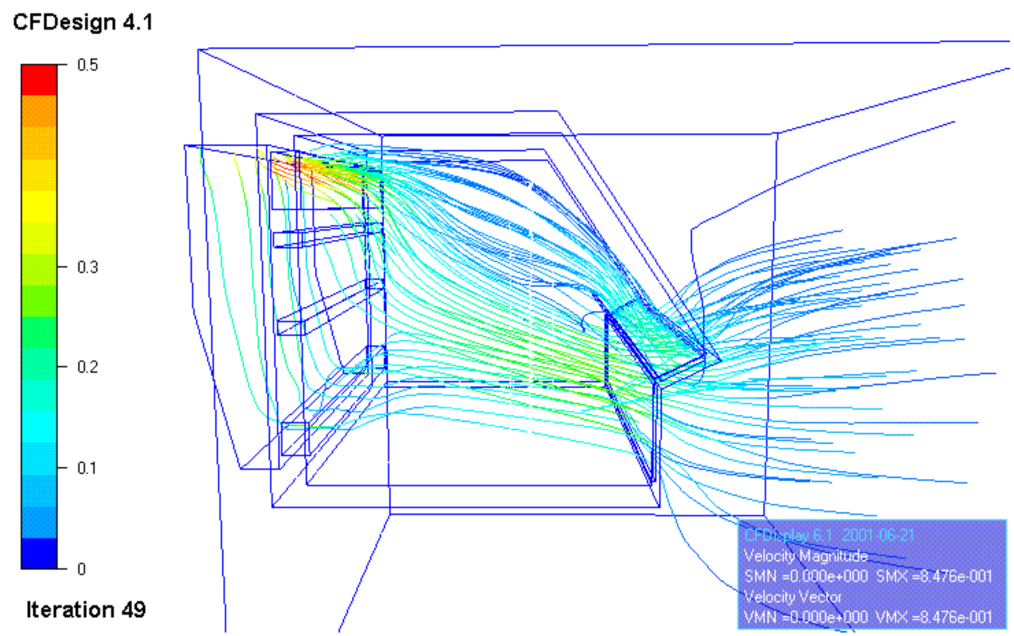


Task specific design. Laboratory enclosure

Proposed solution

- Maintain high level of containment protection
- Provide a stable balance reading
- Ensure that materials inside the enclosure are undisturbed by airflow
- Provide ergonomic design and ensure ease of access
- Address energy efficiency concerns





Patent pending

Task specific design. Robotic enclosure

General work area arrangement

Optimization requirements

- Maintain high level of containment protection, two-mode operation
- Provide a stable balance reading
- Ensure that materials inside the enclosure are undisturbed by airflow
- Provide ergonomic design and ensure ease of access
- Address energy efficiency concerns

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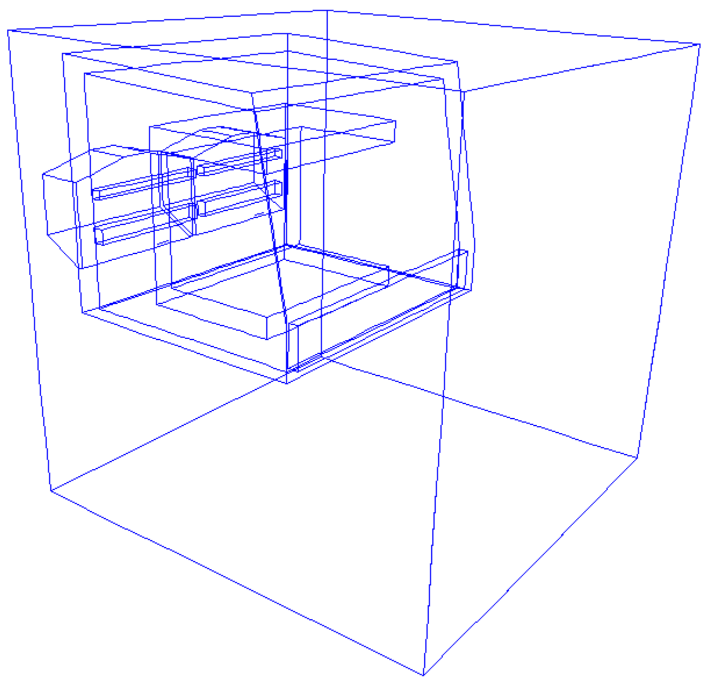
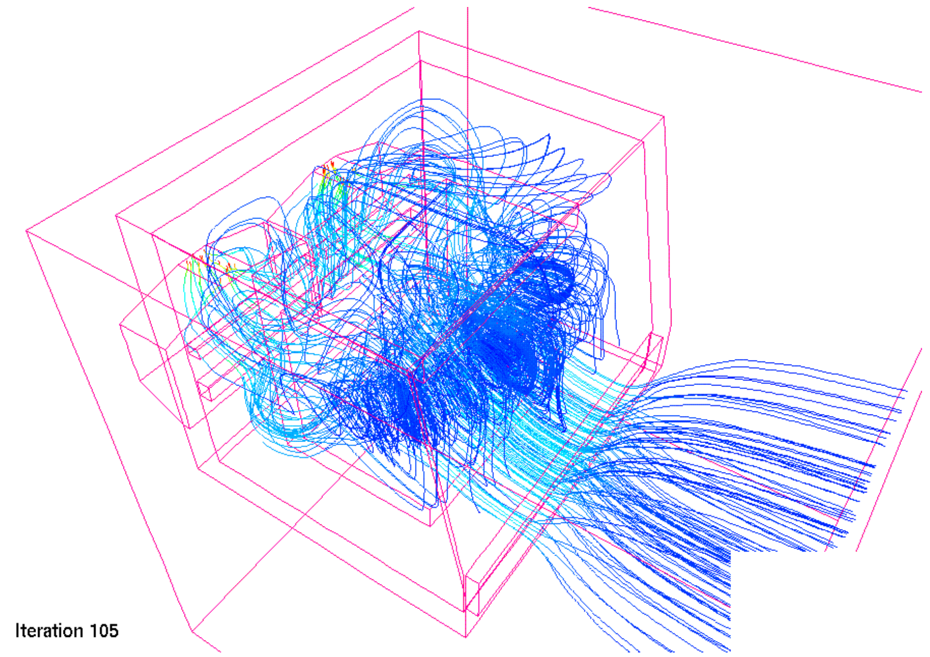
Task specific design. Robotic enclosure

Standard design solution



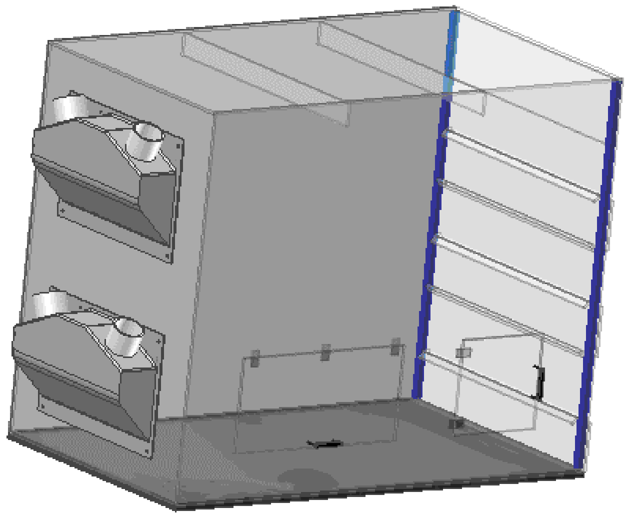


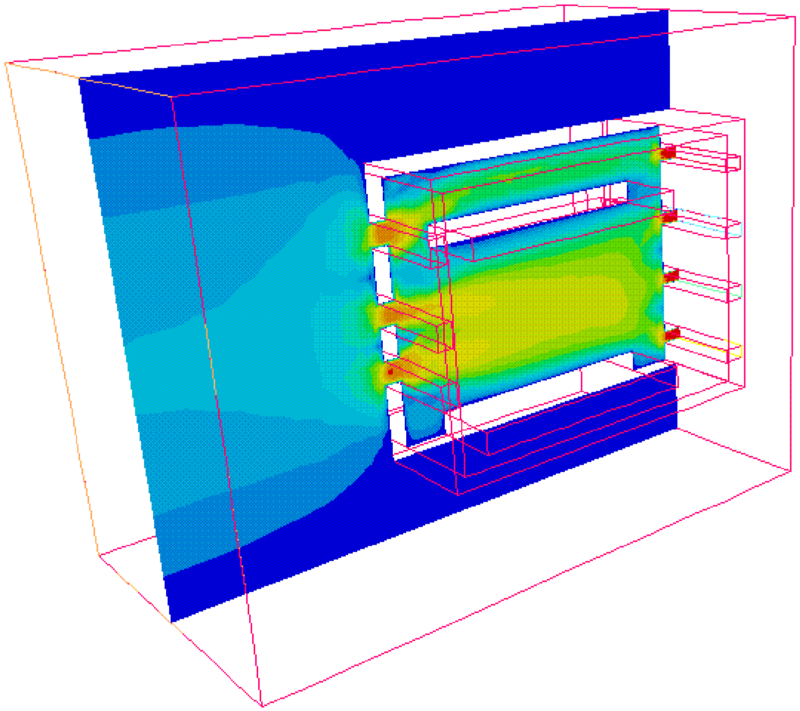
Clearly, there is room for improvement

- High level of work area turbulence
- Ergonomics concerns
- Questionable energy efficiency

Task specific design. Robotic enclosure

Proposed solution





Design improvements

- Low level of work area turbulence
- Ease of access
- Maximized energy efficiency

CFD Simulation.

Navier – Stokes PDE system is not classically solvable!!

CFD simulation protocols are very detailed.

- Mathematics
- Physics
- Discretization
- Computer science

CFD can provide data otherwise absolutely unavailable.

- Repeatability
- Parametric variation
- Density of data

CFD is a two – edged sword.

- Expertise required
- Fundamental knowledge base
- Incredible output detail