
Computational Modeling of Chemical Protective Clothing

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19 November 2003

**Presented at
2003 Joint Scientific Conference on
Chemical & Biological Defense Research
Towson, Maryland**



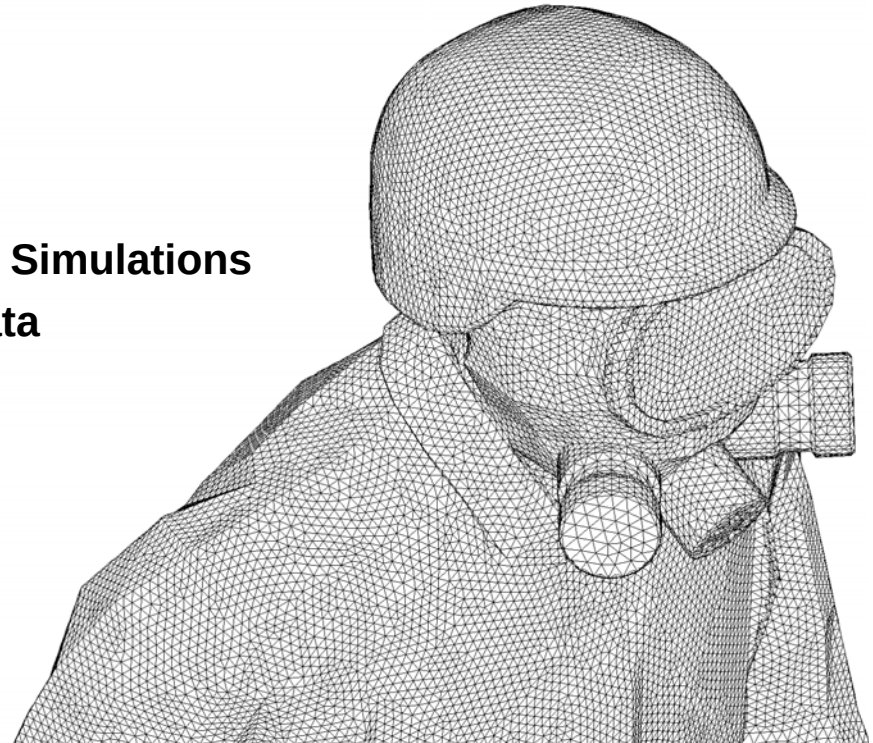
MTG-03-11-1777/4215/1

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Report Documentation Page				Form Approved OMB No. 0704-0188	
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1. REPORT DATE 01 OCT 2005		2. REPORT TYPE N/A		3. DATES COVERED -	
4. TITLE AND SUBTITLE Computational Modeling of Chemical Protective Clothing				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S)				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Creare, Inc.				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release, distribution unlimited					
13. SUPPLEMENTARY NOTES See also ADM001851, Proceedings of the 2003 Joint Service Scientific Conference on Chemical & Biological Defense Research, 17-20 November 2003. , The original document contains color images.					
14. ABSTRACT					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT UU	18. NUMBER OF PAGES 17	19a. NAME OF RESPONSIBLE PERSON
a. REPORT unclassified	b. ABSTRACT unclassified	c. THIS PAGE unclassified			

Introduction

- **Computational Modeling of Clothing Performance**
 - Utilize Computational Fluid Dynamics (CFD)
 - Initial Focus on Chemical/Biological Protective Clothing
 - Modeling Tools Developed Have Broader Application
- **Scope of Work**
 - CFD Software Enhancements
 - 2-D/3-D Clothed Human Models
 - Sensitivity Studies and Exploratory Simulations
 - Validation Against Experimental Data
- **Supported by CBD/Army SBIR
(SBCCOM-Natick)**

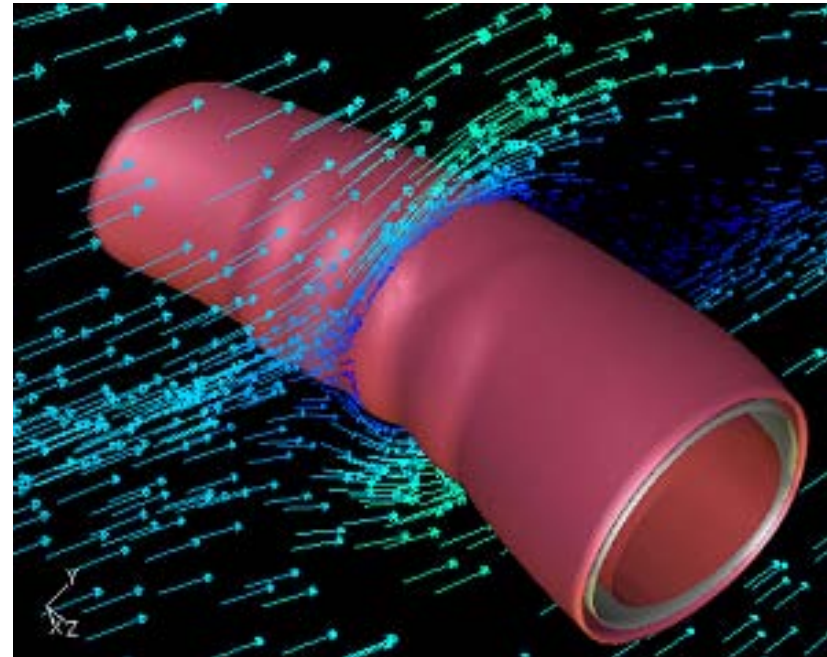


Objectives of Computational Modeling

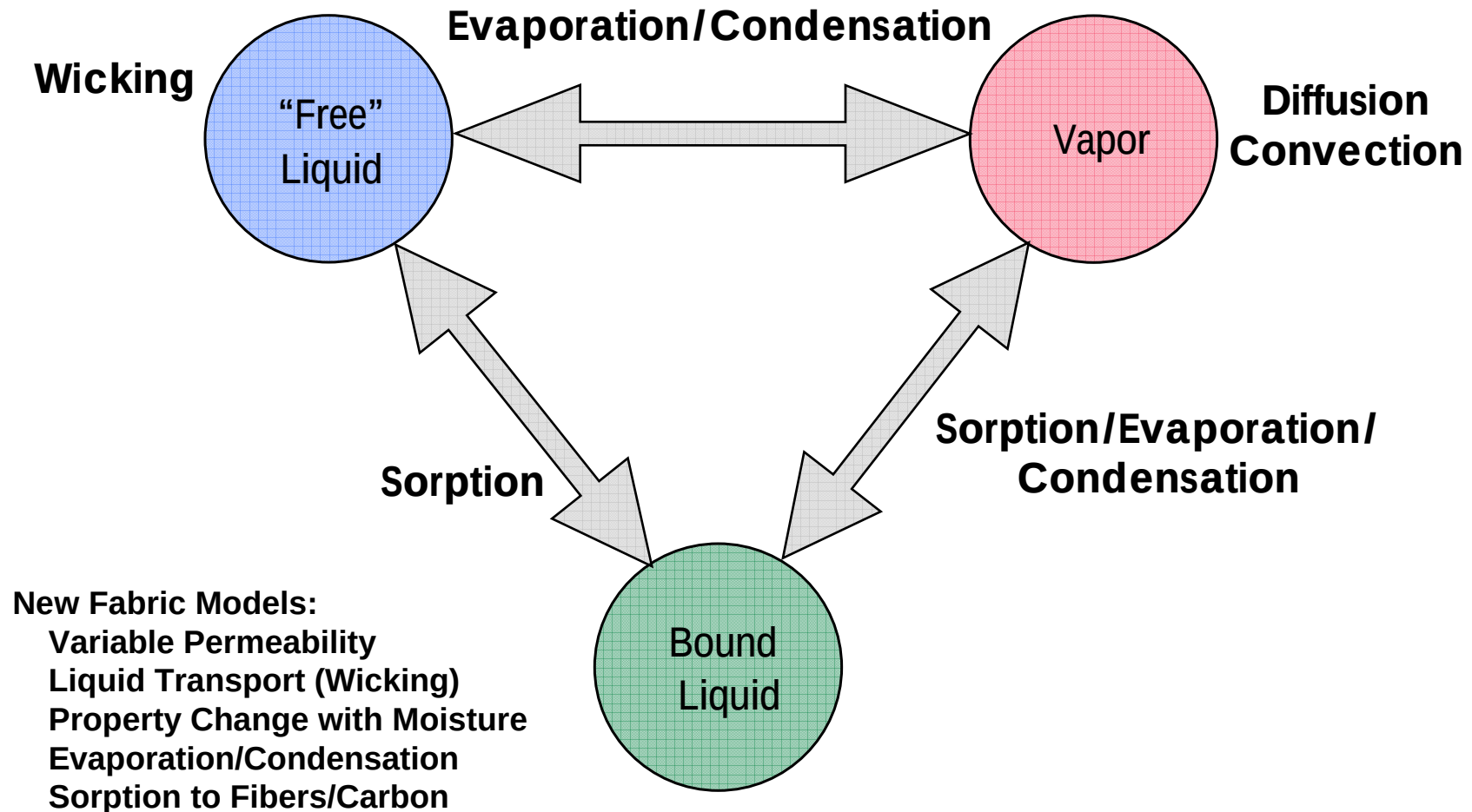
- **Address Thermal/Fluid Issues in Protective Clothing**
 - Protection from Chemical/Biological Agents
 - Thermal Impact on Clothed Soldier
- **Evaluate Clothing Designs/Protective Strategies**
 - Fabric Characteristics
 - Clothing Geometry and Layering
 - Environmental Conditions
- **Excellent Complement to Lab/Field Tests**
 - Idealized Geometry and Boundary Conditions
 - “Perfect Instrumentation”
 - Visualization of Complex Flow Fields
 - Cost Effectiveness

Technical Approach

- **CFD Simulations**
 - Solve 3-D Mass/Momentum/Energy Equations
 - Volume-Averaged Porous Media Approach
 - Extend Commercial FLUENT® Software for Vapor/Liquid Physics in Fabric
- **Mix of Geometries**
 - 2-D Body Section
 - 3-D Partial or Full Body Models
 - 3-D Model of Exterior Surface
- **Encompass Range of Physics**
 - Basic Air Flow and Heat Transfer
 - Sweating and Thermal Balance
 - » Evaporation/Condensation
 - » Sorption and Wicking
 - Agent Transport and Absorption
 - » Aerosol/Liquid/Vapor
 - » Activated Carbon

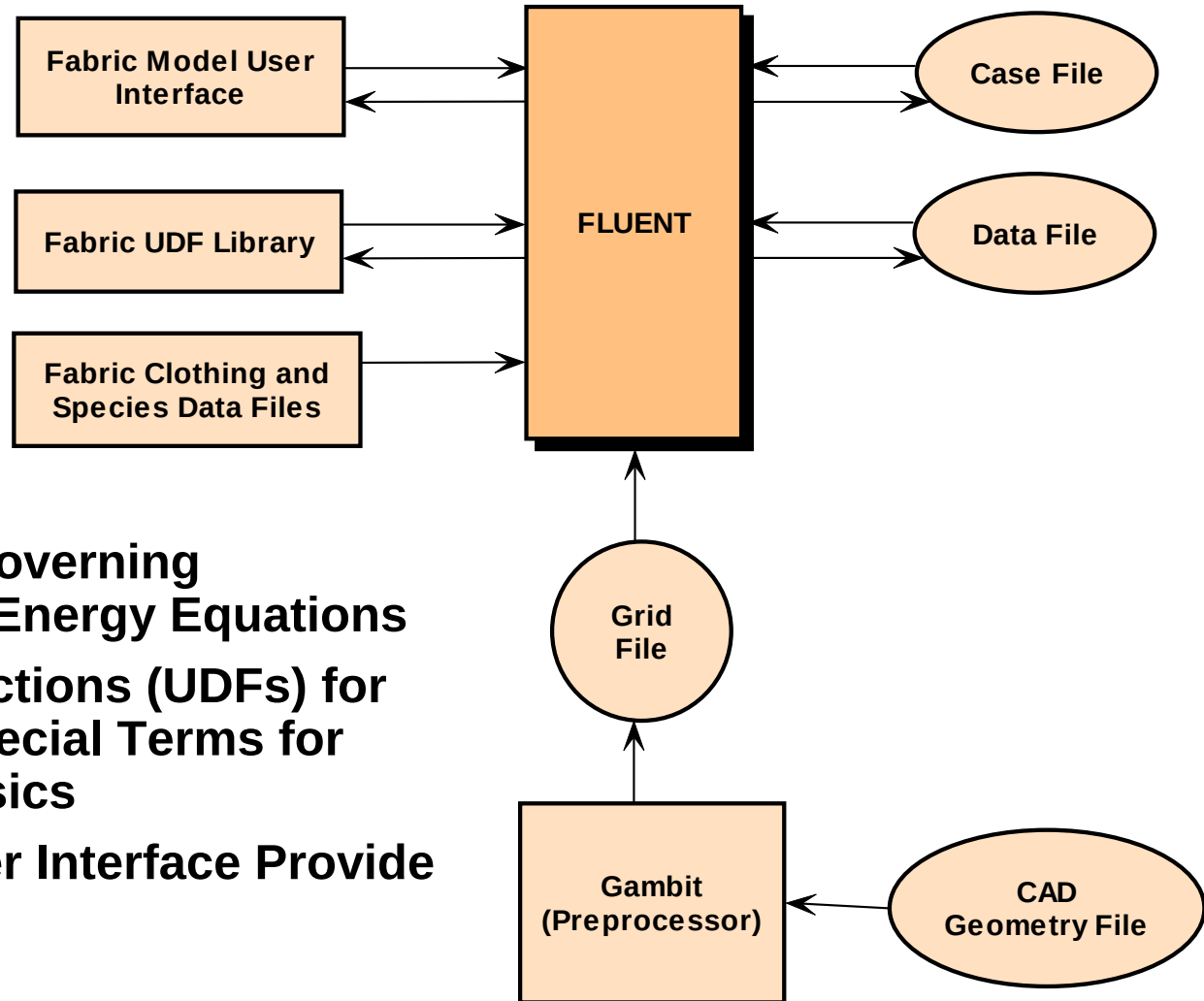


Transport and Phase Change



Approach Applicable to Water or CB Agents

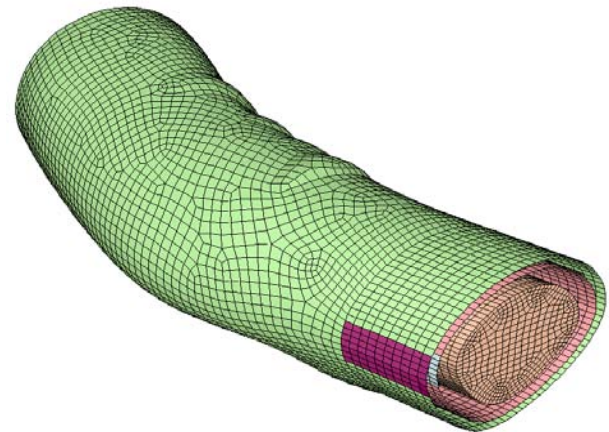
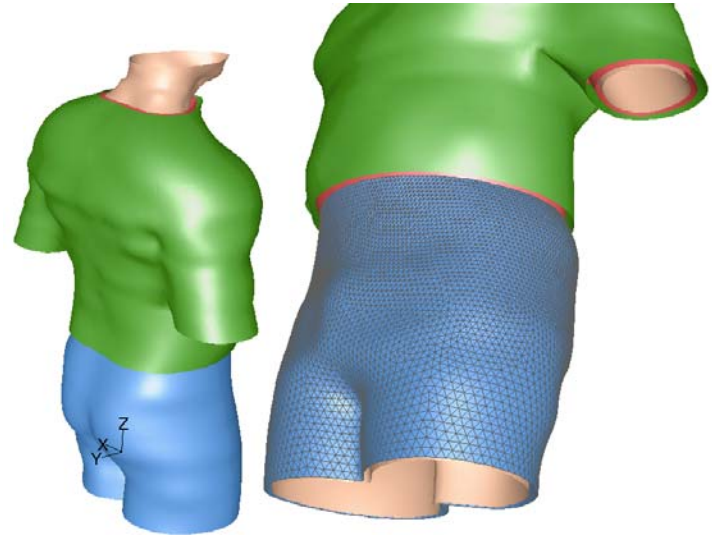
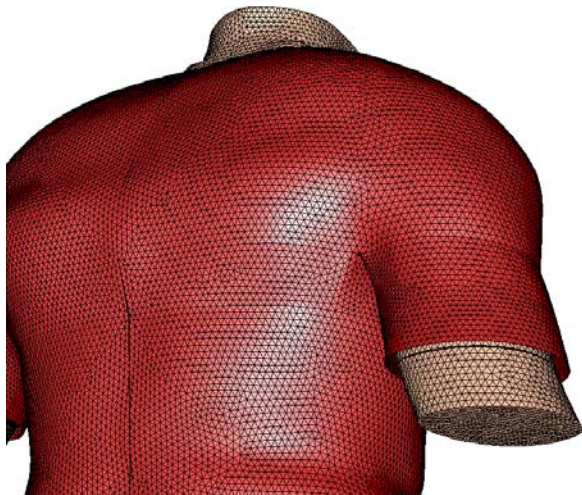
Integration With FLUENT



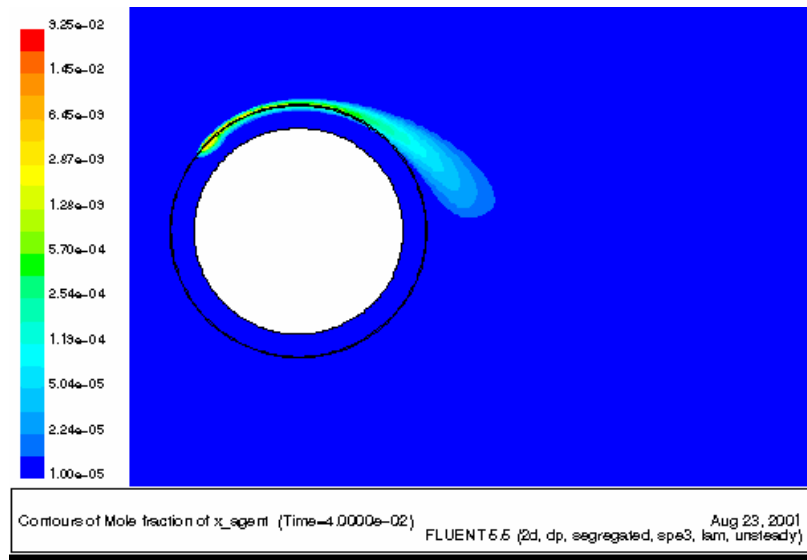
- **FLUENT Solves Governing Mass/Momentum/Energy Equations**
- **User-Defined Functions (UDFs) for Fabric Provide Special Terms for Vapor/Liquid Physics**
- **Extensions to User Interface Provide Access to Models**

Models of Clothed Humans

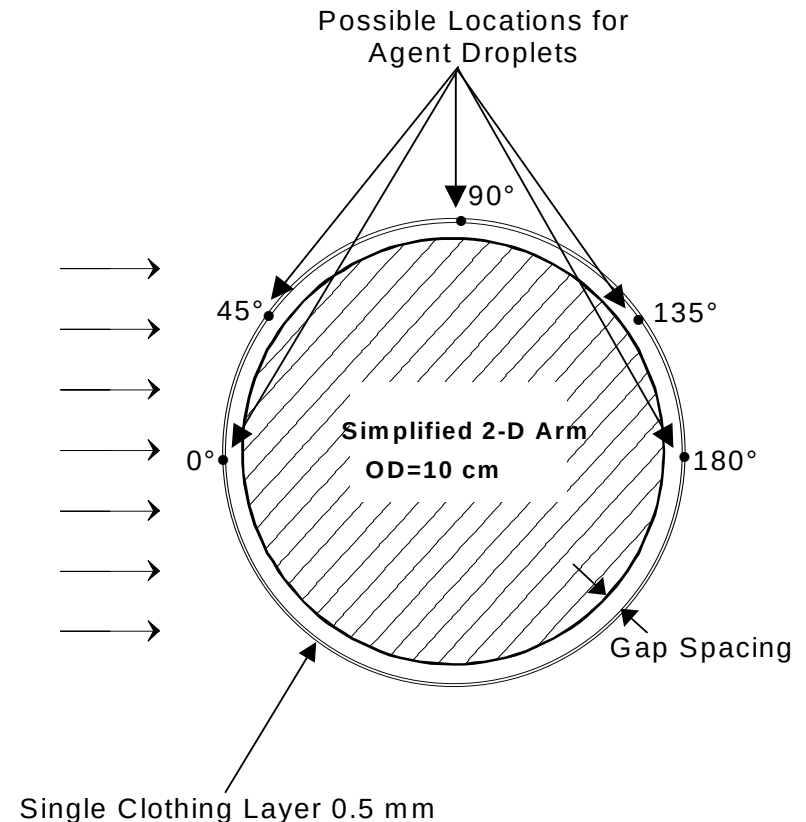
- **Geometry/Grid Models Developed**
 - Arms With One/Two Clothing Layers and Two Types of Wrist Closures
 - Torsos With One or Two Clothing Layers
 - Kneeling Soldier (No Detailed Clothing Layers)
- **Most Models Created from Laser Body Scans, Then Meshed in FLUENT**



Idealized Arm With Agent Droplet



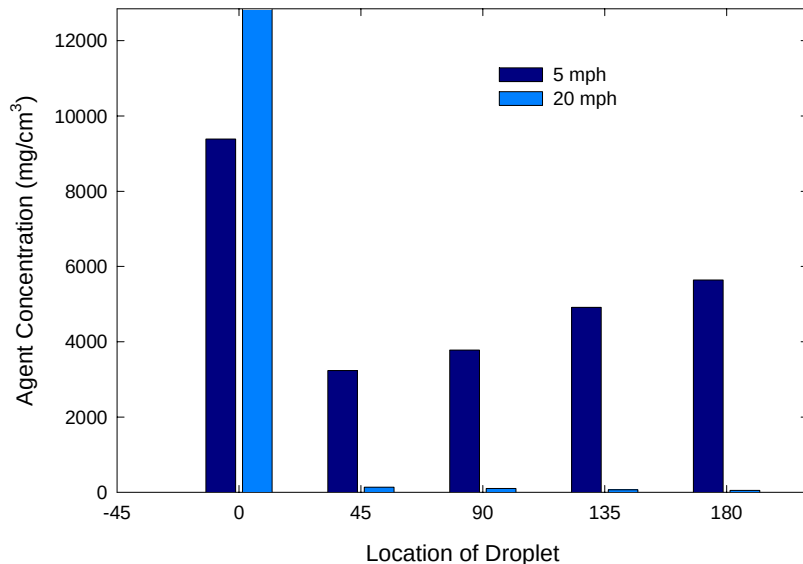
- Two Wind Speeds (5 & 20 mph)
- Sensitivity:
 - Droplet Location
 - Clothing Gap Width and Uniformity
 - Multiple Clothing Layer
- No Absorbent



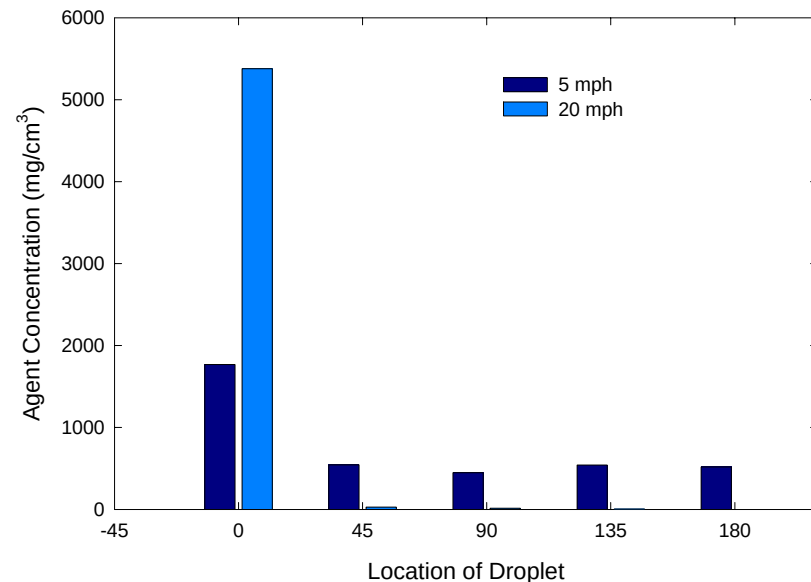
Wind Speed and Droplet Location

- Worst Case Droplet Location—Stagnation Point (0°)
- Effect of Wind Speed Depends on Droplet Location
 - Stagnation Point: Higher Speed $\Rightarrow$ Higher Penetration
 - Elsewhere: Higher Speed $\Rightarrow$ Greater Dilution
- If Absorbent Is Used, Local Overload Also Becomes Concern

Maximum Concentration at Arm Surface

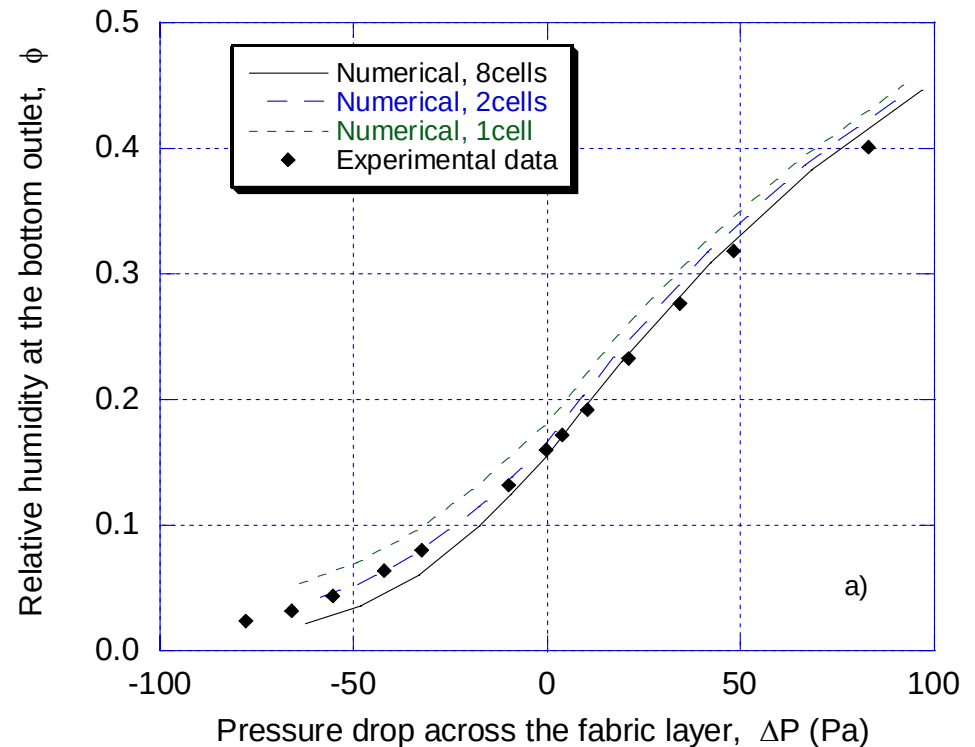


Average Concentration at Arm Surface

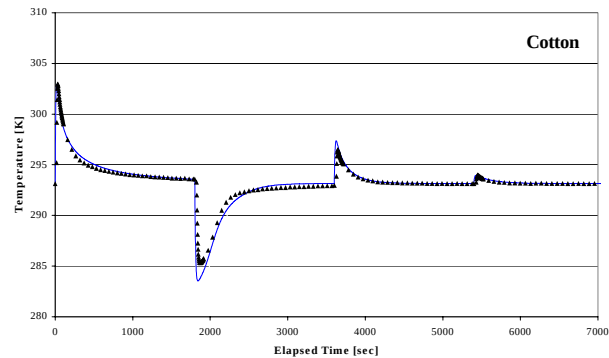


Comparisons With Natick DMPC Data

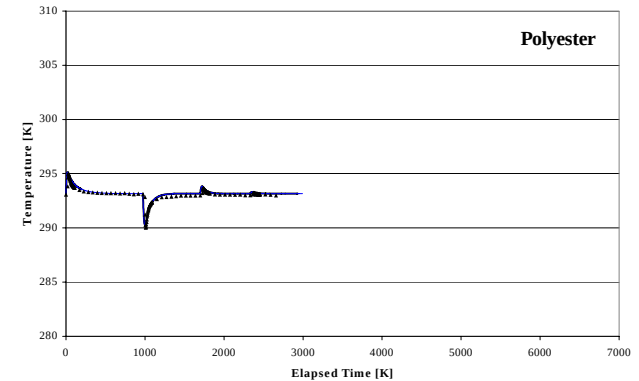
- **Steady State**
 - Cotton Fabric 0.384 mm Thick
 - 0.57 m/s N₂
100% Relative Humidity Above
 - 0.57 m/s N₂
0% Relative Humidity Below
- **Outlet Resistance Varied to Force Flow Through Fabric**
- **Test of Variable Flow Resistance With Fabric Regain**
- **Good Agreement With Experimental Data**



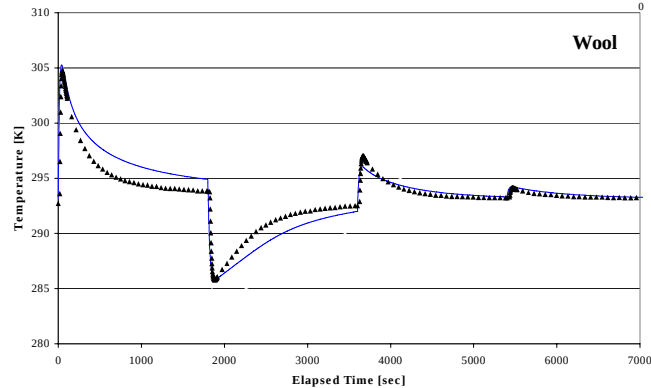
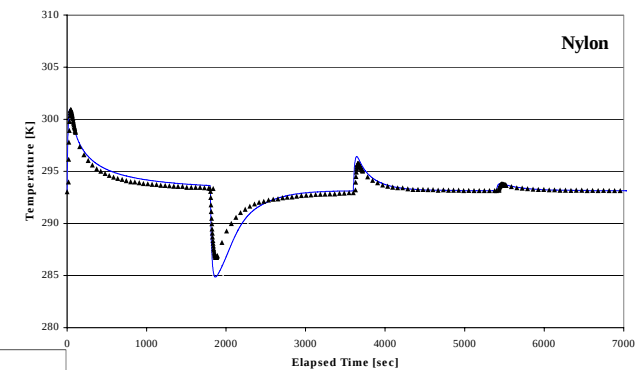
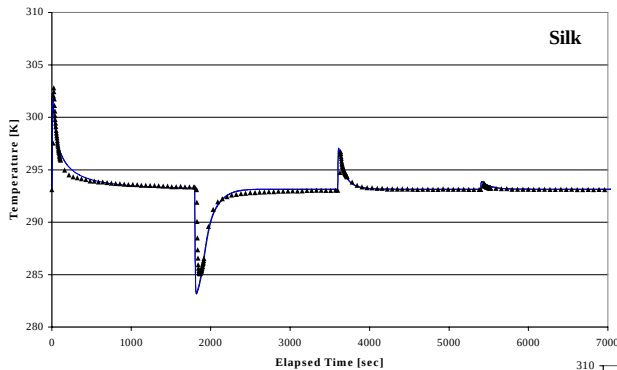
Comparisons With Natick DMPC Data



- Response to Step Changes in Humidity



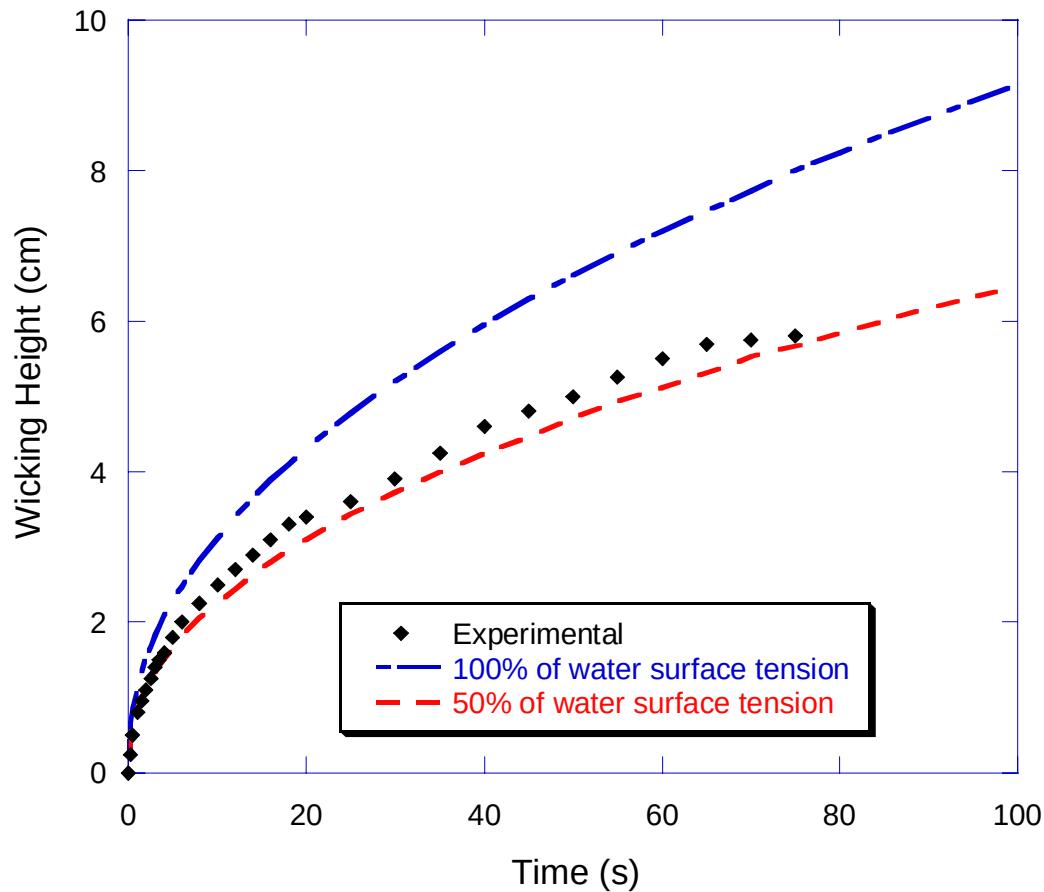
- Rise/Fall Profiles of Temperature Well-Matched by Model



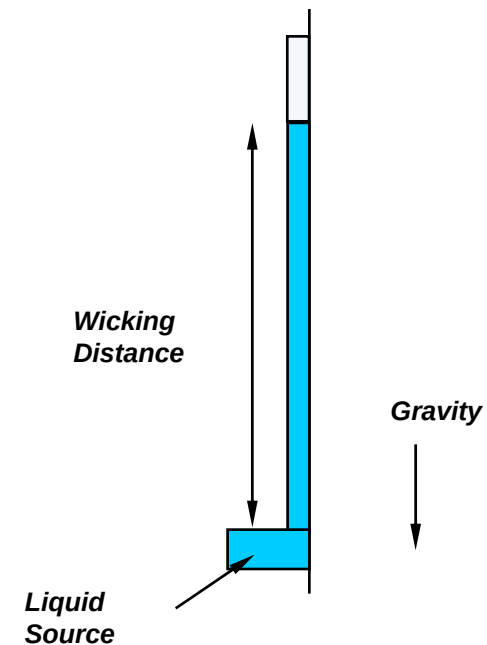
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Comparison to Wicking Data

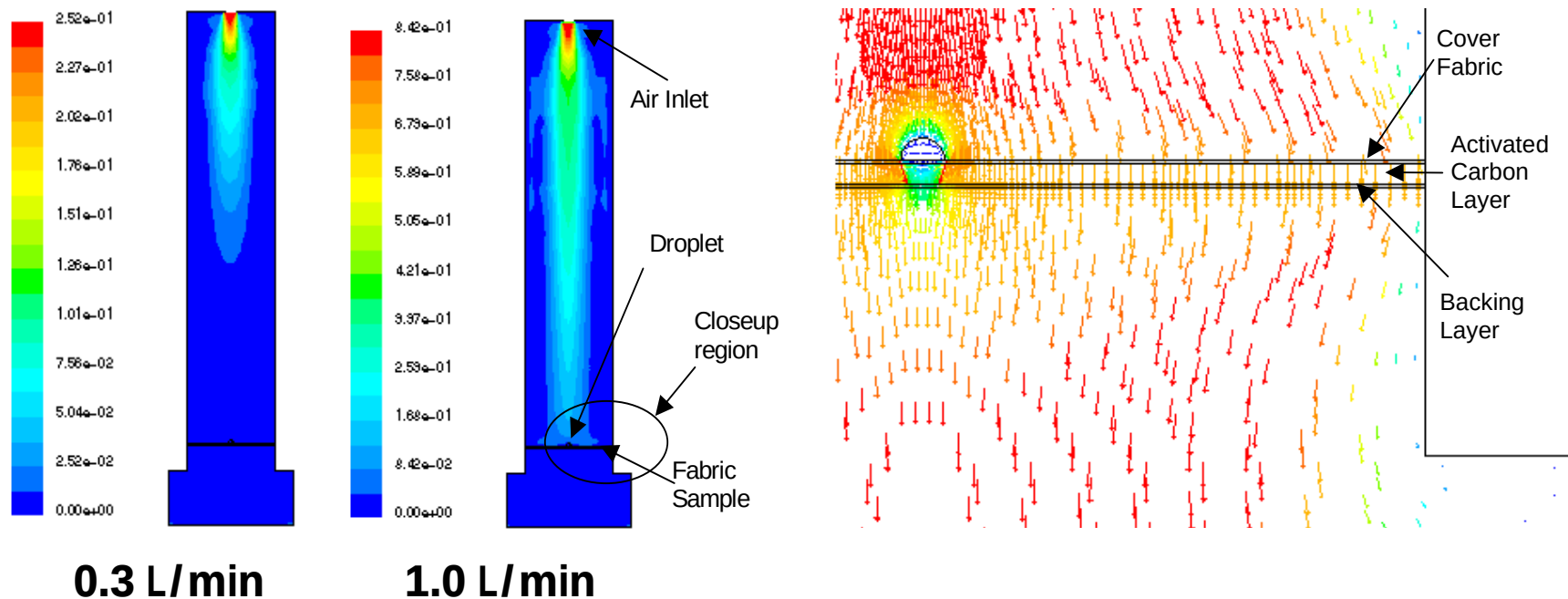


- **Commercial Wipe:**
 - 70% Polypropylene
 - 30% Cellulose Wipe
- **Agreement Within Property Uncertainty**



Activated Carbon

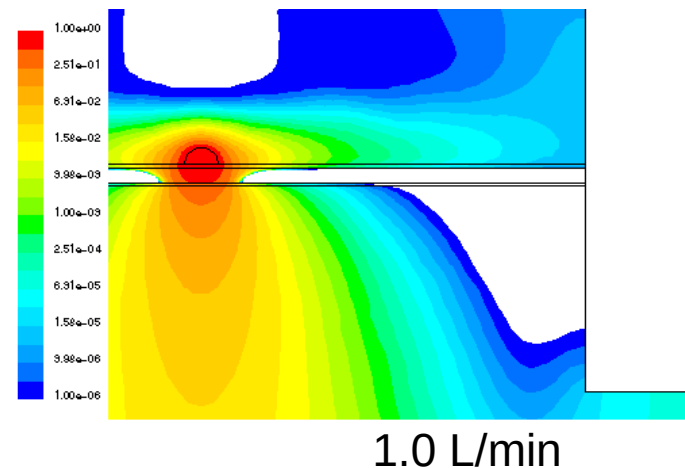
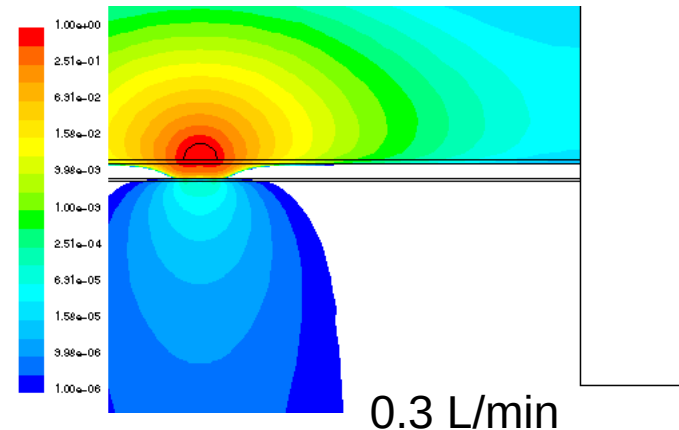
- AVLAG Swatch Test Cell Geometry
- Single MeS Droplet (1 μ L, 30°C) Enables 2-D



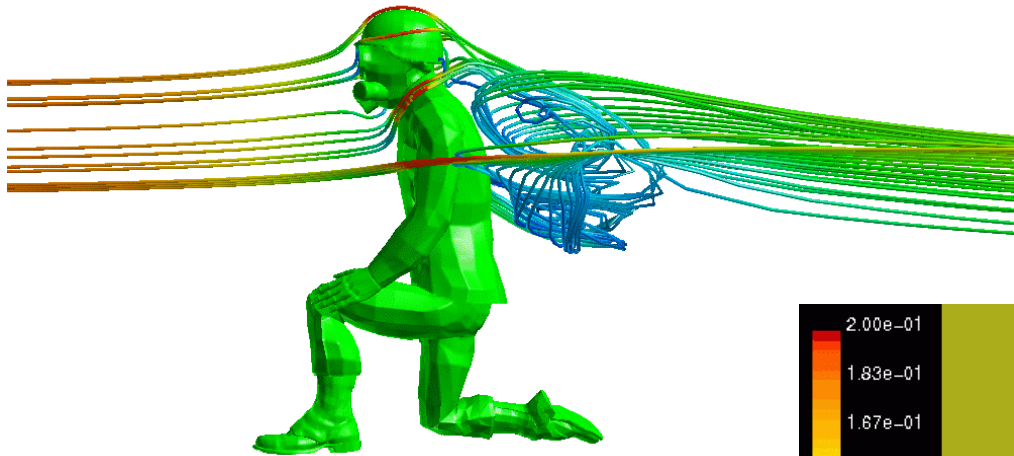
Effect of Flow Rate on Penetration

- Local Overload of Activated Carbon Allows Penetration
- Higher Flow Velocity
 - Inhibits Vapor Spread Above Fabric
 - Faster Breakthrough
 - Larger Integrated Penetration
- Consistent with Data

$P_{\text{vap}}/P_{\text{sat}}$ at 180 Minutes

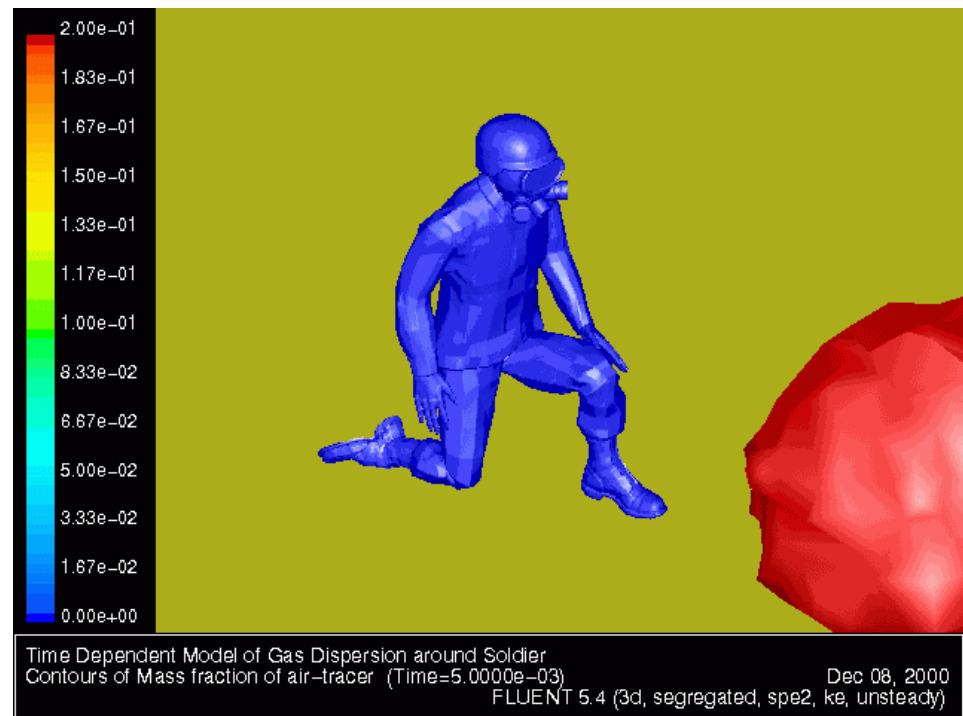


Example Calculations with Kneeling Soldier



streamlines for Steady
10 mph Headwind

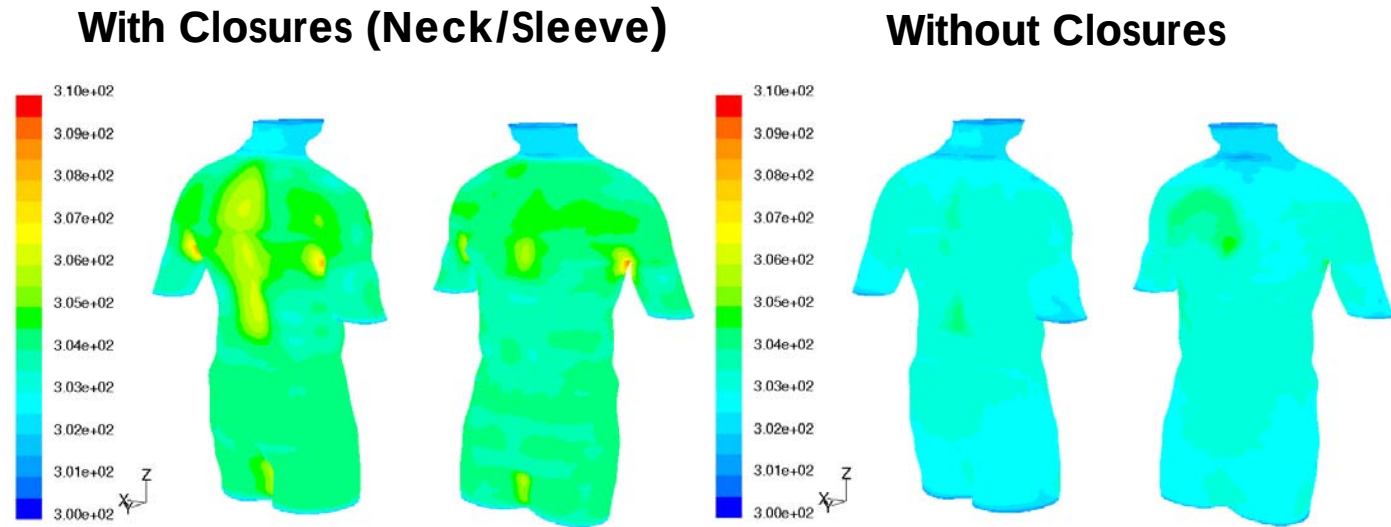
1 m Spherical Gas Cloud
Passing Over Soldier



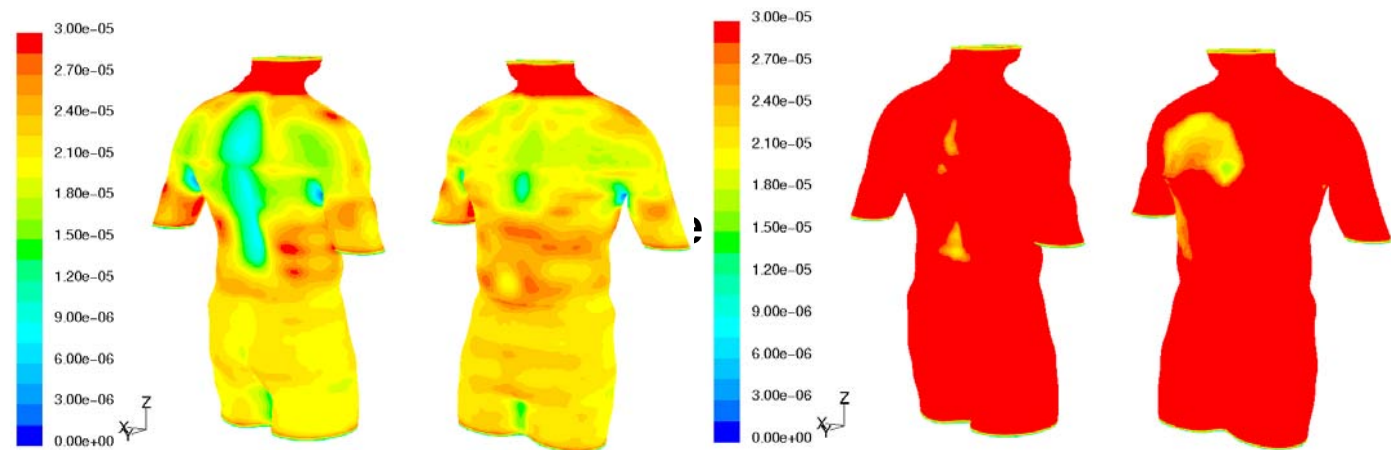
Thermal Balance Simulations

5 mph Wind
27 °C
70% RH

Temperature



Sweat
Evaporation
Rate



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Future Applications

- **Applications to CB Protective Clothing Design/Evaluation**
 - Possible Topics:
 - Comparisons of Fabric
 - Layering Strategy
 - Closure Design
 - Aerosol Contamination
 - Radiative Heat Loads
- **Related Work Proposed or Underway**
 - Support CBART Swatch Test Development
 - Steam/Heat Fabric Test Apparatus
- **Commercial/Industrial Applications**
- **Looking for Opportunities for Design/Test Support and Data Comparisons**