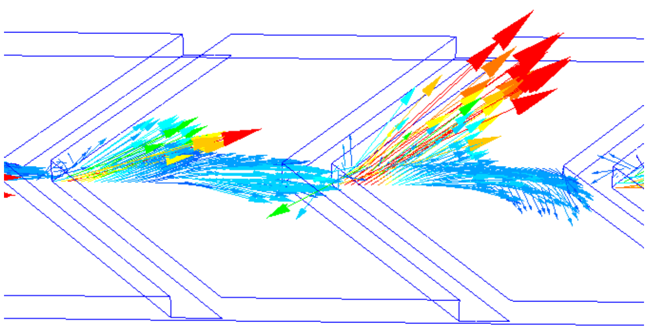
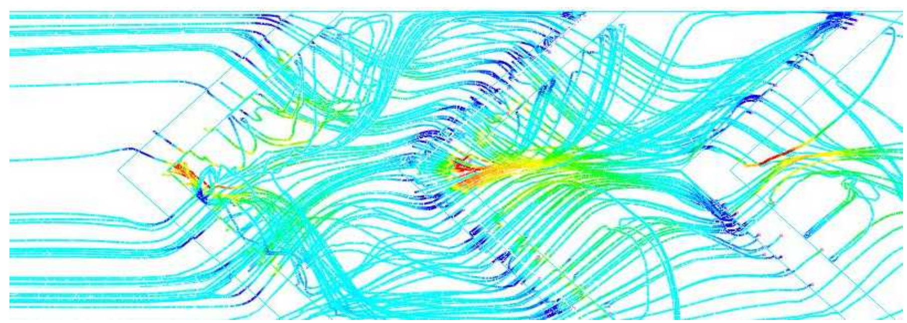
Design Optimization of Anti-Fouling Micromixers for Reverse Osmosis Membranes





Siri Sahib S. Khalsa* and Clifford K. Ho
Sandia National Laboratories
Albuquerque, NM

*Department of Physics, University of Virginia

Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company for the United States Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000

Overview

- Introduction
- Development of CFD Models
- Parameterization Results and Discussion
- Conclusions

Introduction

Problem

Biofouling: bacteria adhere to membrane surfaces and produce biofilms

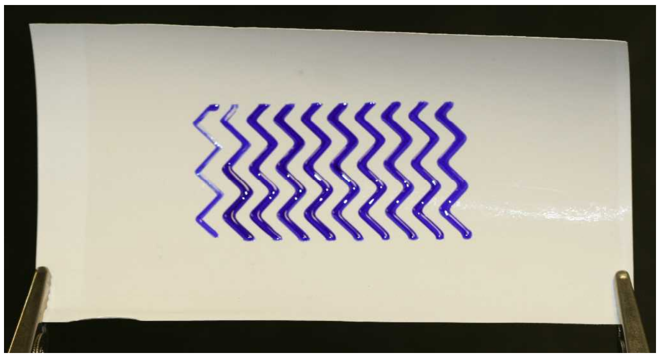
Biofouling decreases efficiency of filtration process:

- reduces membrane flux
- decreases membrane lifetime
- increases operational costs

Sandia National Laboratories

Introduction
Objective and Approach

Objective: maximize scouring and mixing along membrane



Printing courtesy Paul Clem, SNL

Micromixers

- induce chaotic mixing
- increase shear stress along membrane surface

Approach: use CFD to optimize micromixer configuration to maximize scouring and mixing along membrane

Printing courtesy Paul Clem, SNL

Sandia National Laboratories

Overview

- Introduction
- Development of CFD Models
- Parameterization Results and Discussion
- Conclusions

Model Domain
Cross Flow Test Cell

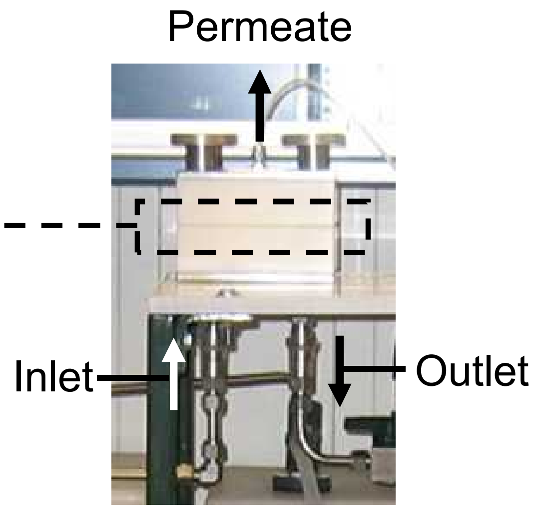
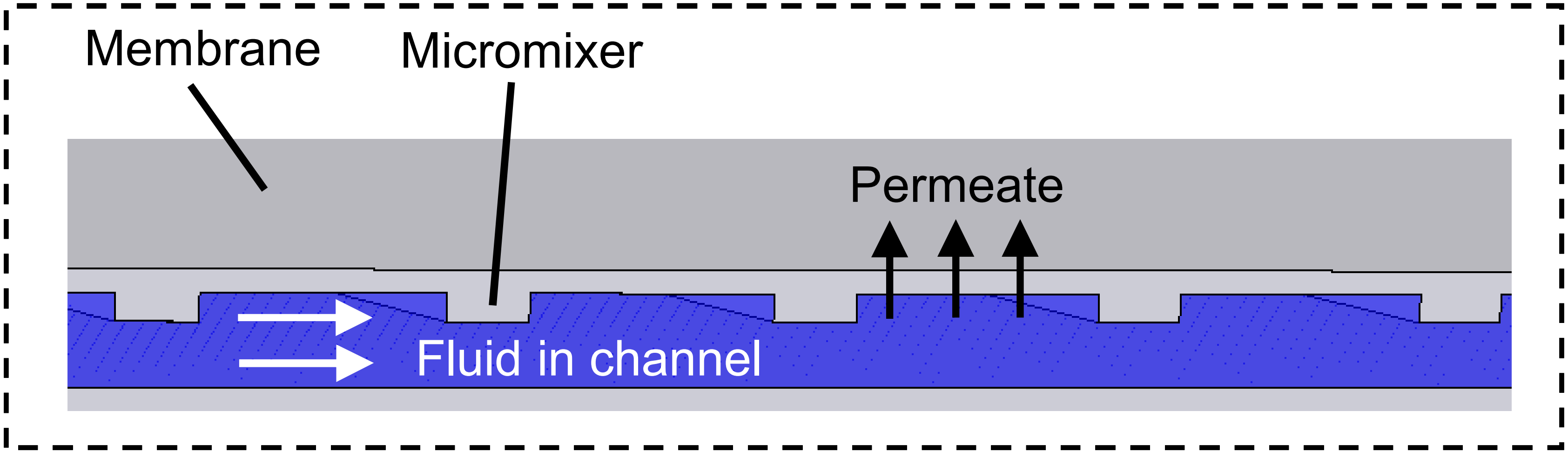
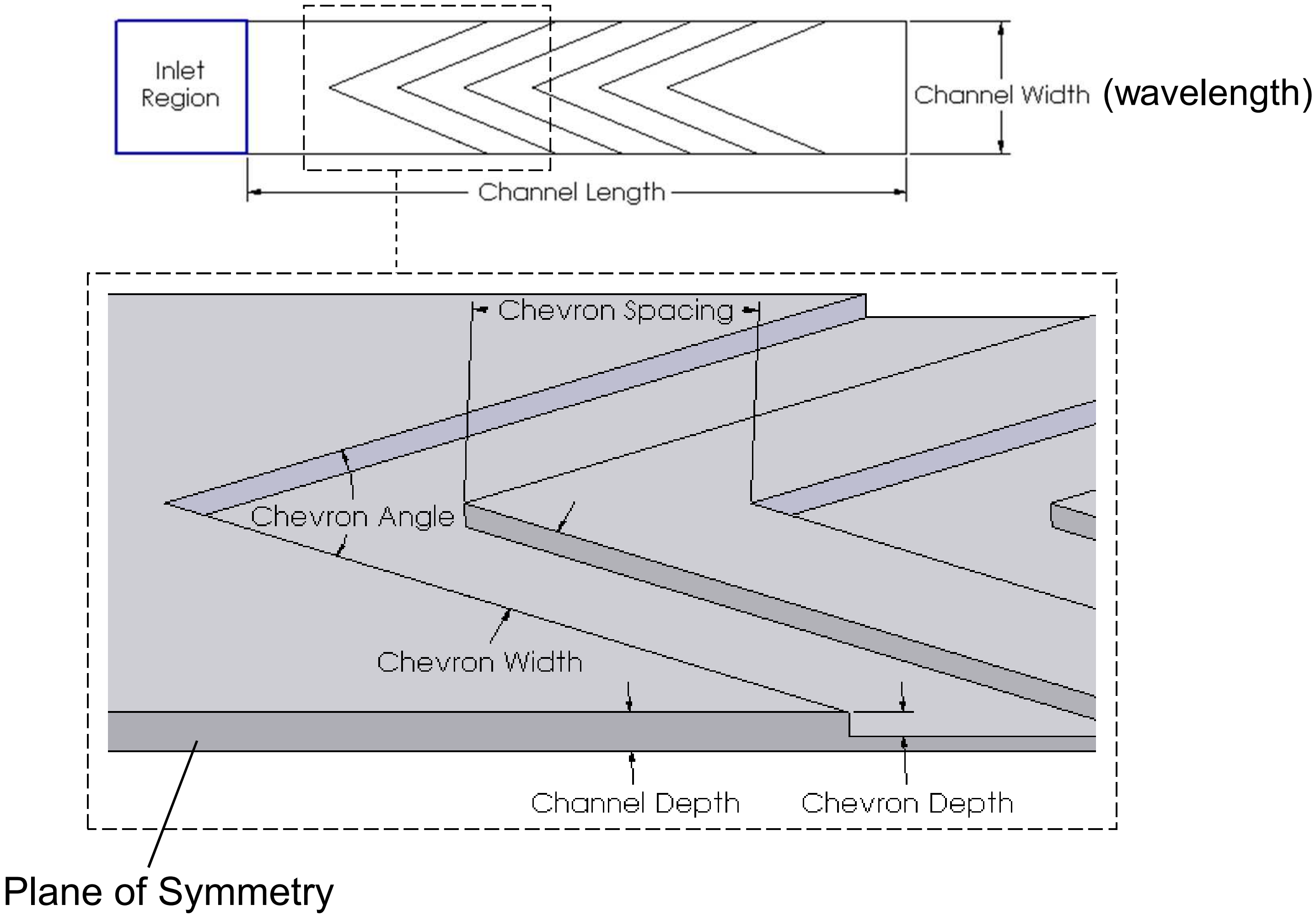


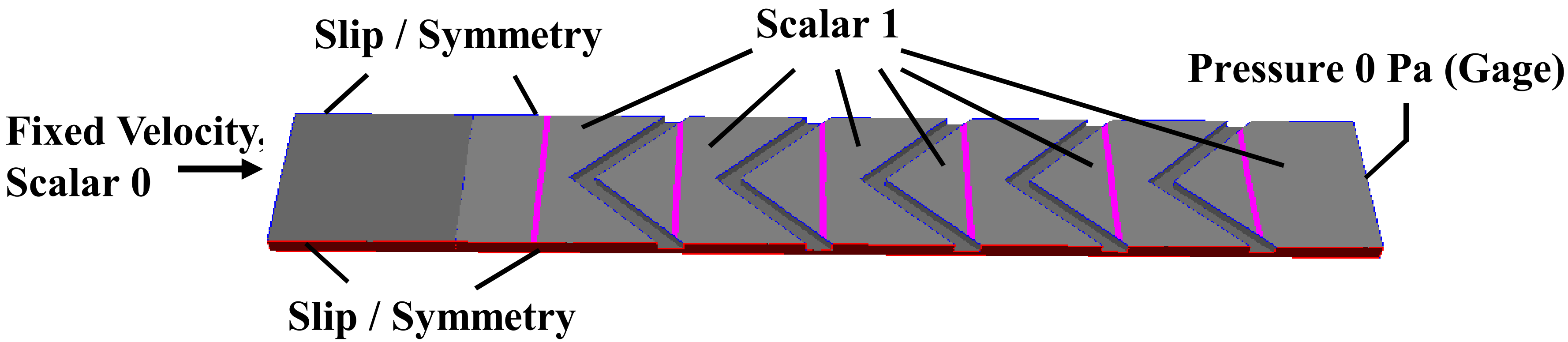
Photo courtesy Susan Altman, SNL



Parameter Definitions

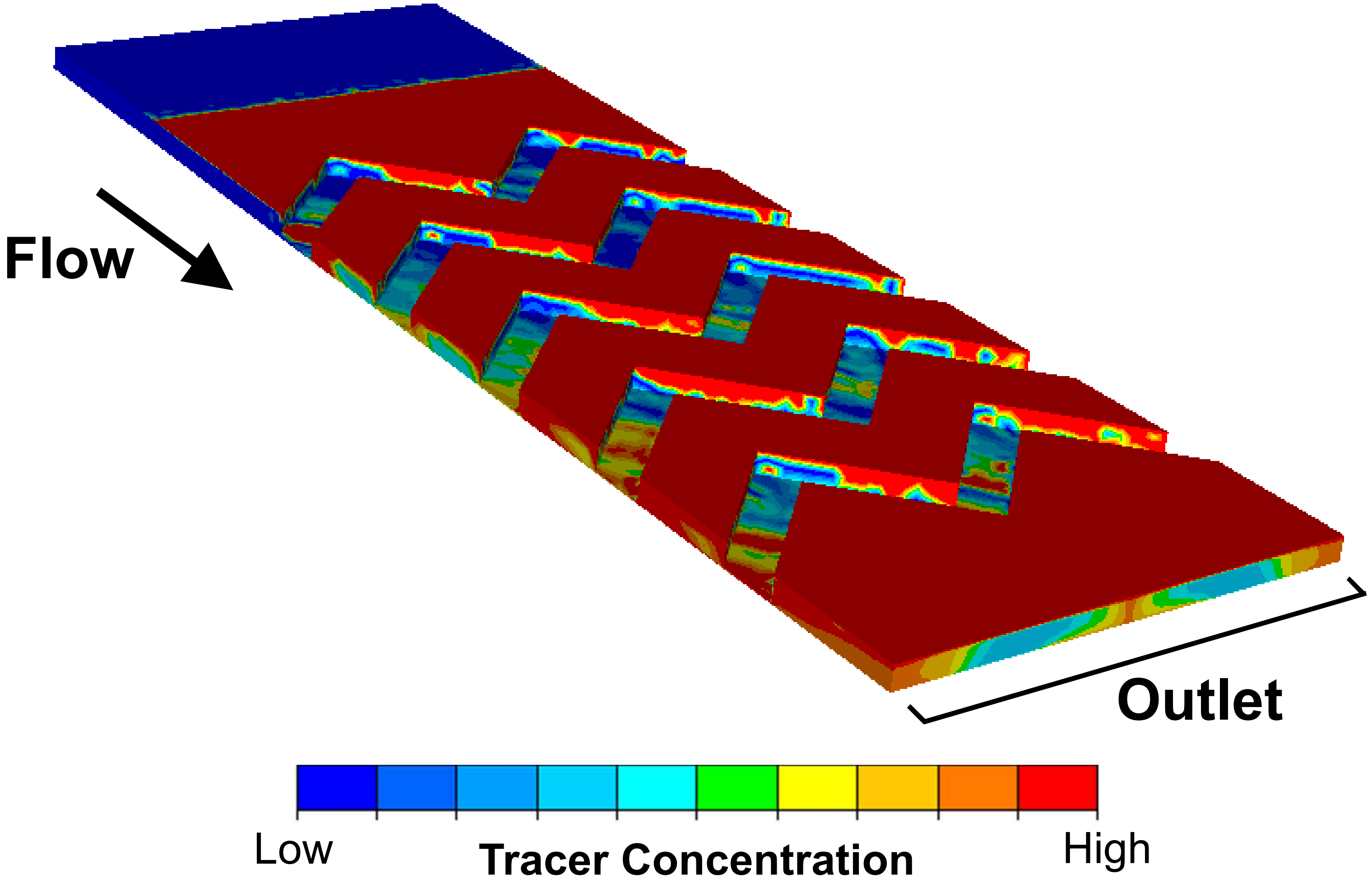


Boundary Conditions



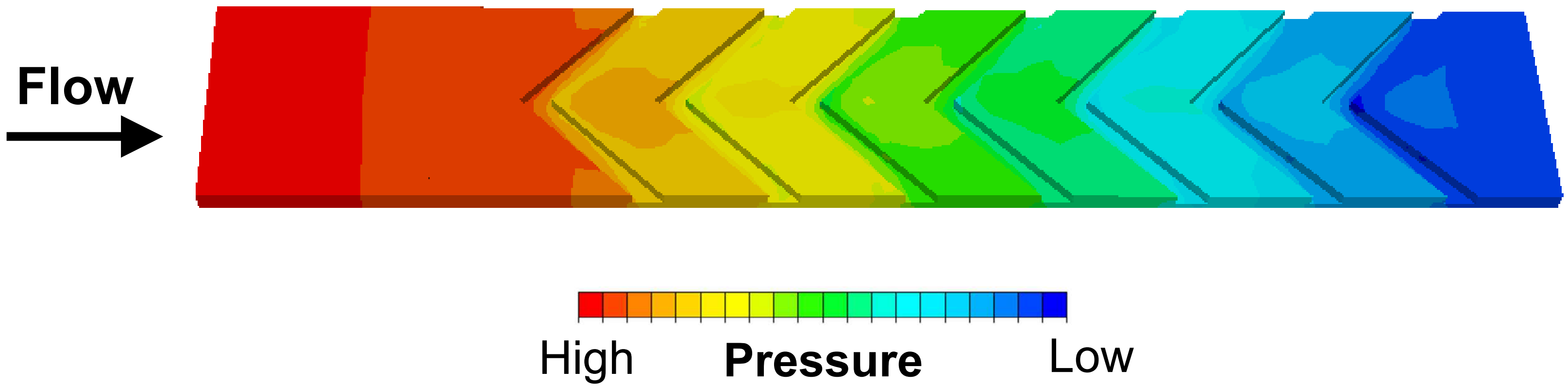
Sandia National Laboratories

Performance Metrics
1. Outlet Scalar



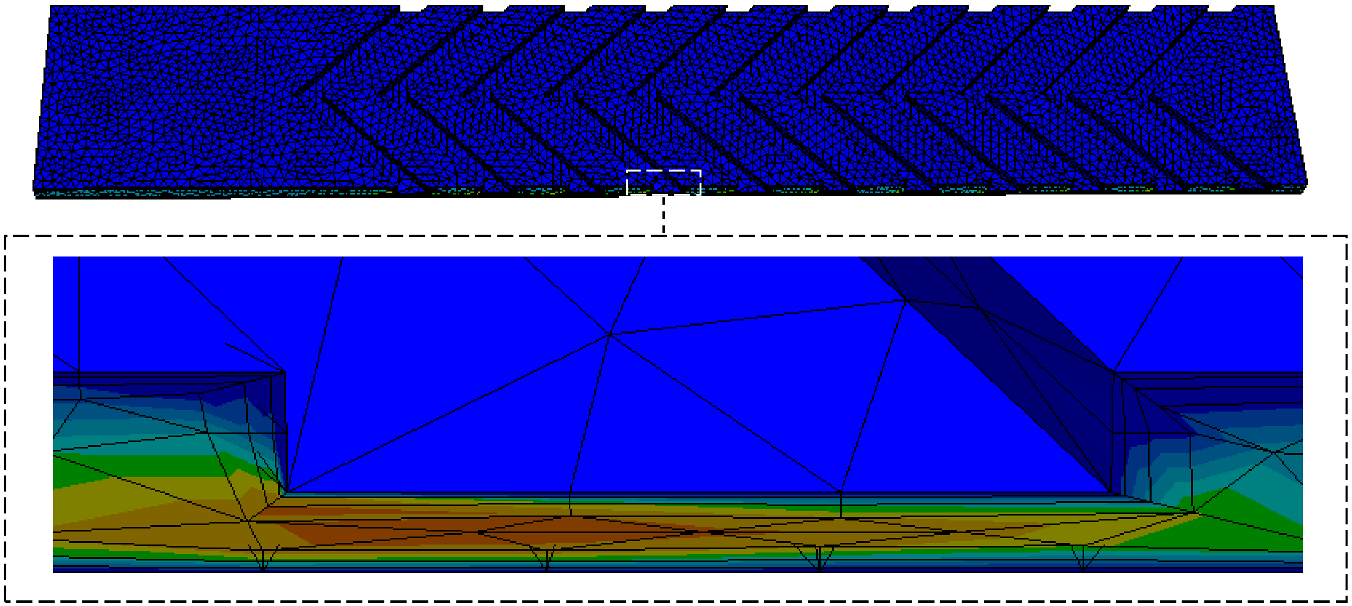
Sandia National Laboratories

Performance Metrics
2. Pressure Drop



Grid Development

~100,000 0.5mm tetrahedral elements



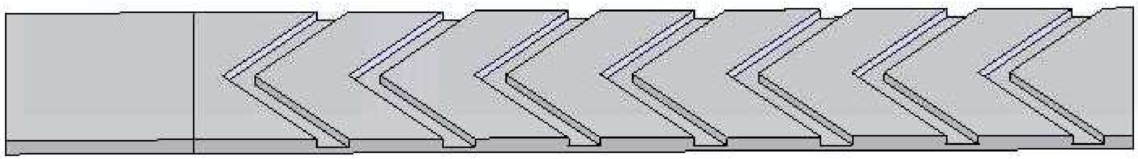
Parameterization

- Four parameters varied with low, middle, and high values.

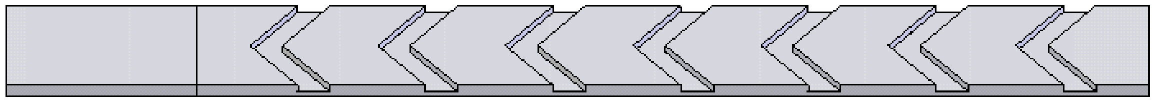
Channel Depth = 1 mm, **Channel Length** = 50 mm

Chevron Wavelengths (Channel Widths)		**Chevron Depths**		**Chevron Widths**		**Chevron Angles**		**Chevron Spacings**
5 mm	x	0.2 mm	—	0.4 mm	x	45°	x	1 mm
10 mm		0.6 mm	—	1.2 mm		90°		5 mm
20 mm		0.9 mm	—	1.8 mm		135°		20 mm

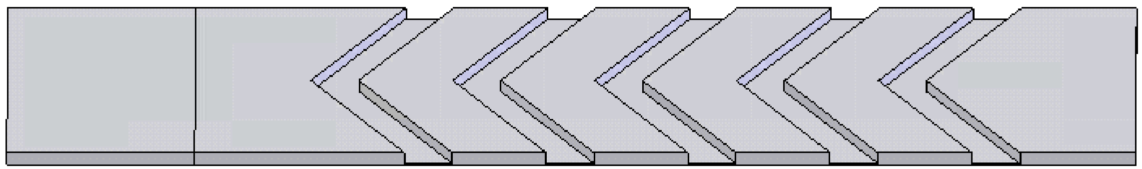
3D Model Examples



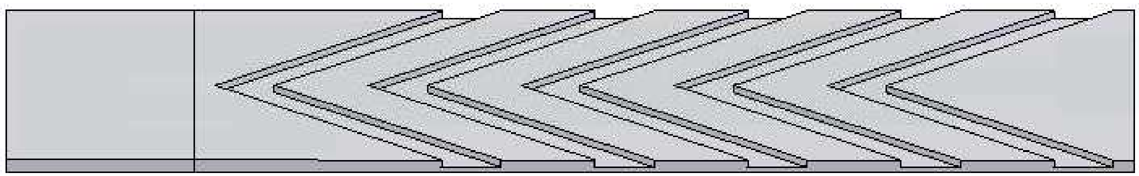
(a) All parameters at middle values



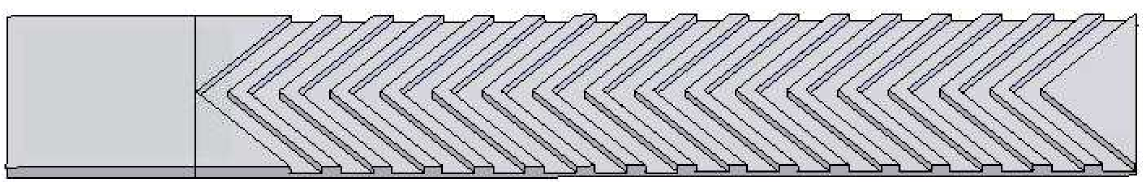
(b) Channel Width low



(c) Chevron Depth and Width high



(d) Chevron Angle low

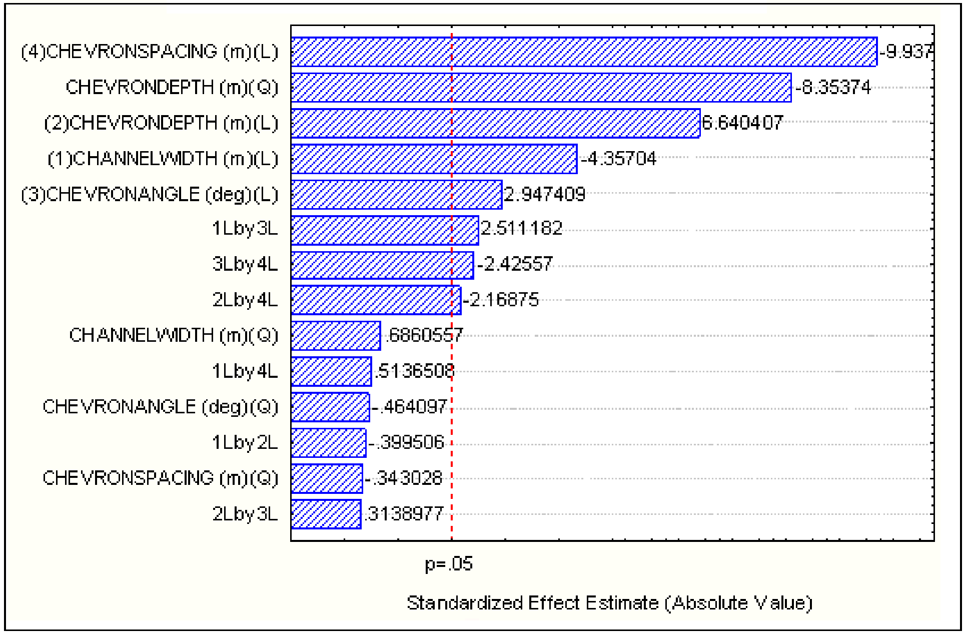


(e) Chevron Spacing low

Overview

- Introduction
- Development of CFD Models
- Parameterization Results and Discussion
- Conclusions

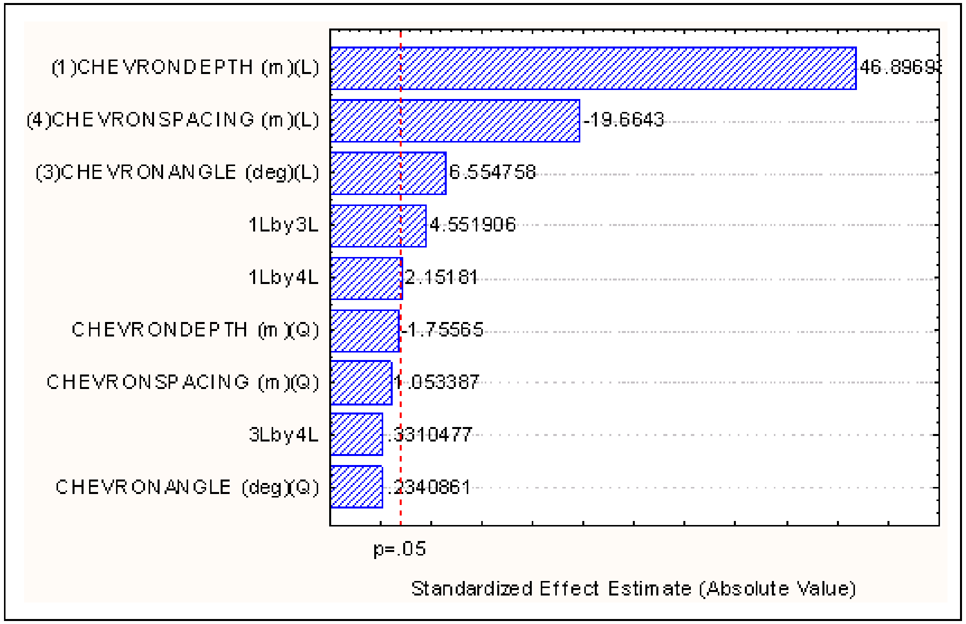
Statistical Analysis
1. Outlet Scalar



Significant Effects:

1. Low Chevron Spacing ⟹ High Outlet Scalar
2. High Chevron Depth ⟹ High Outlet Scalar
3. Low Channel Width ⟹ High Outlet Scalar

Statistical Analysis
2. Pressure Drop



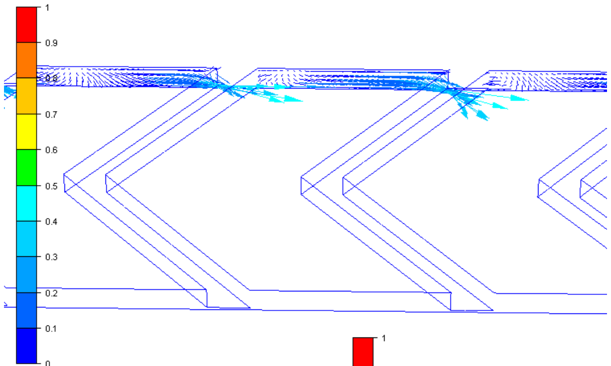
Significant Effects:

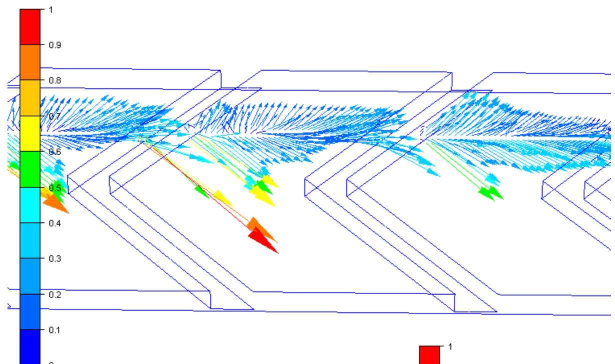
1. High Chevron Depth → High Pressure Drop
2. Low Chevron Spacing → High Pressure Drop

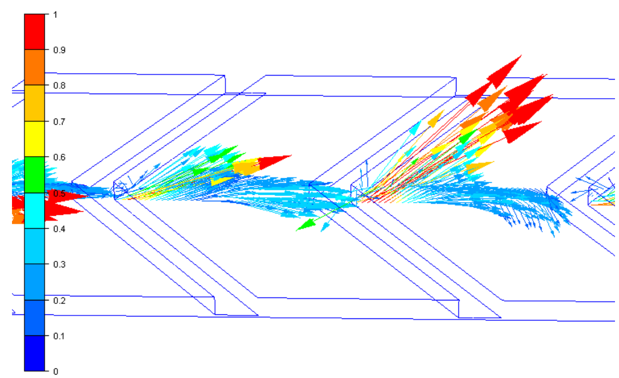
Sandia National Laboratories

Flow Analysis – Deep Chevrons

Velocity Vectors

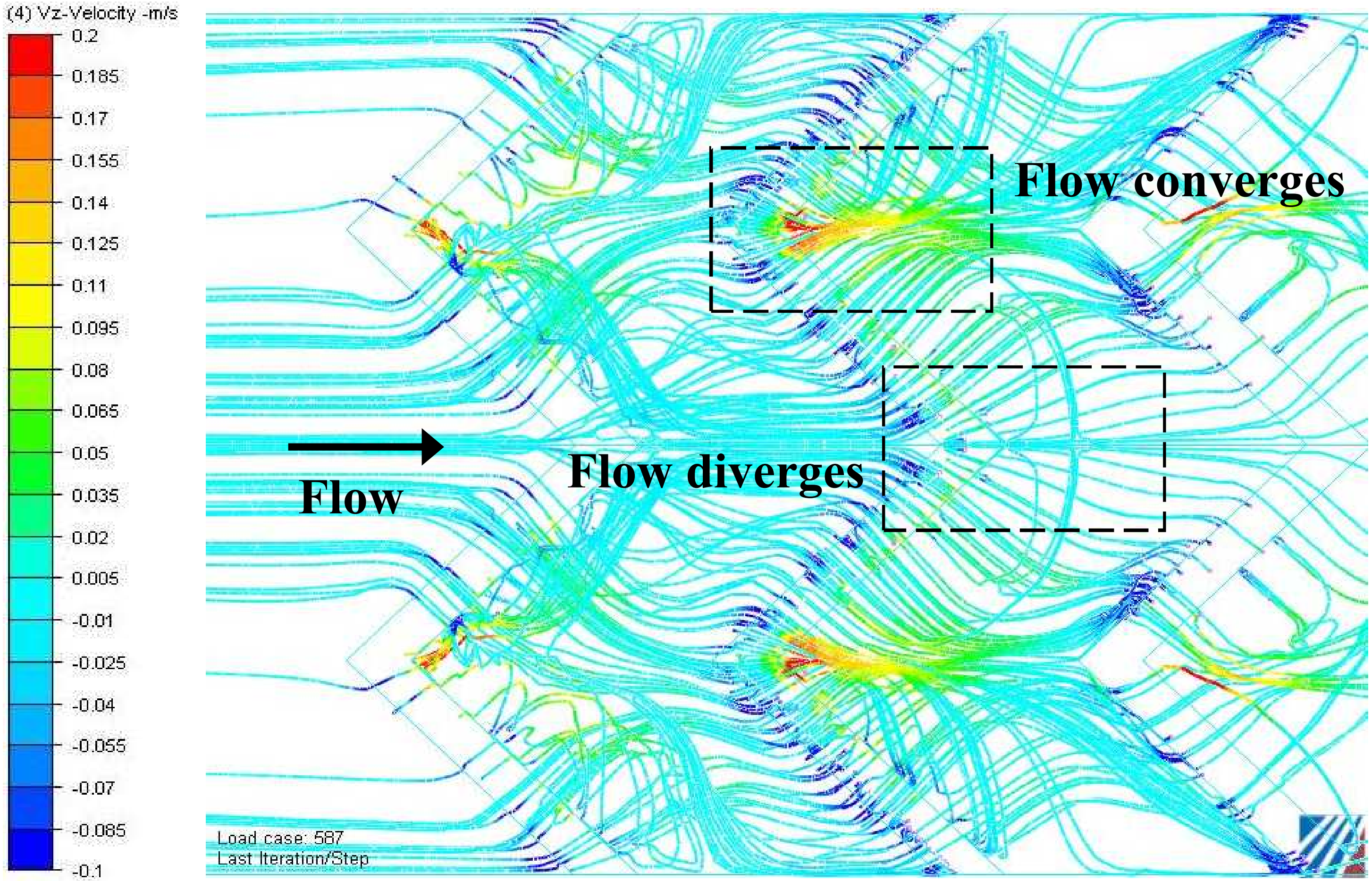






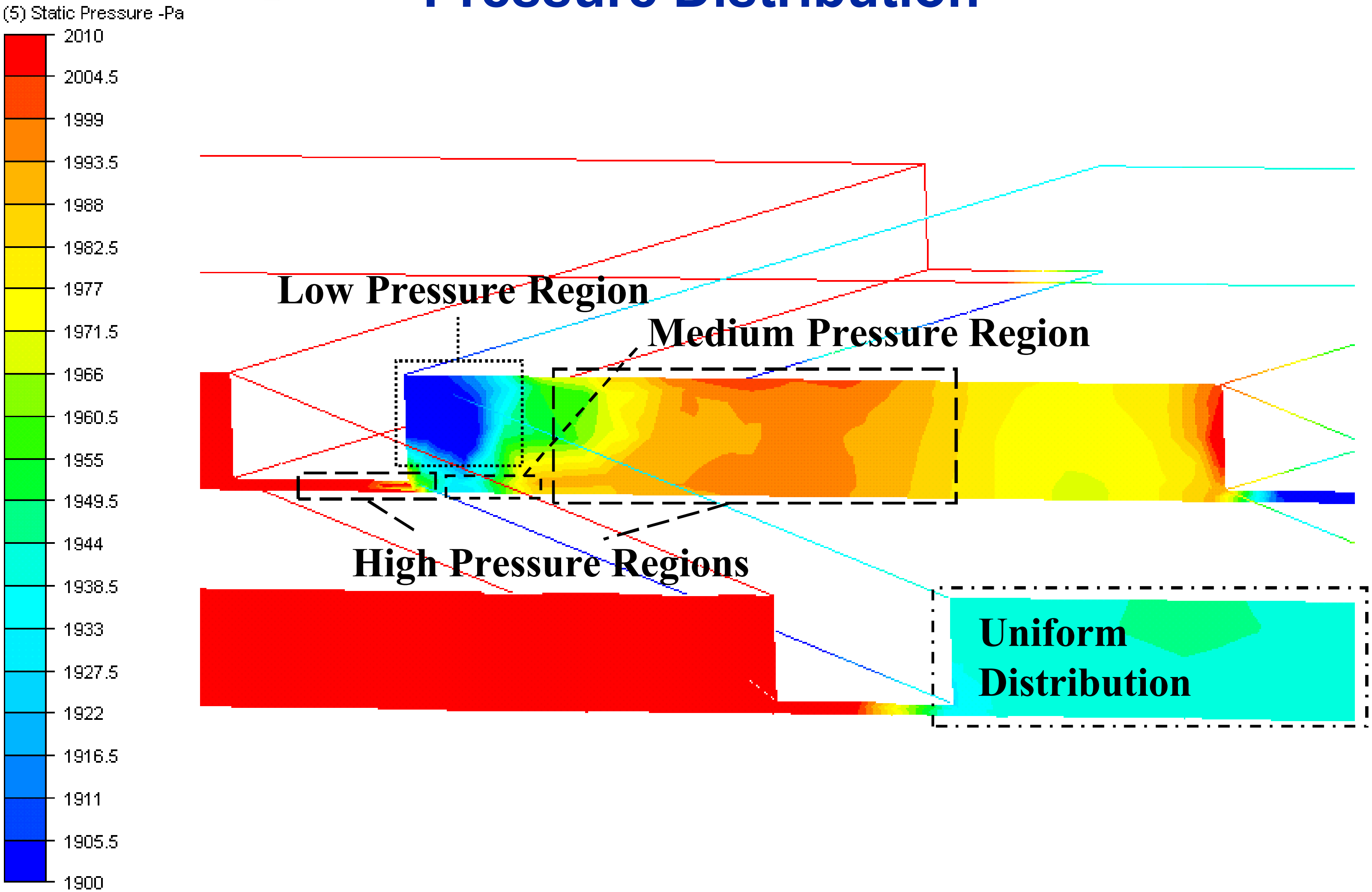
Flow downstream of left-pointing chevrons is accelerated toward membrane

Flow Analysis – Deep Chevrons
Velocity Towards Membrane

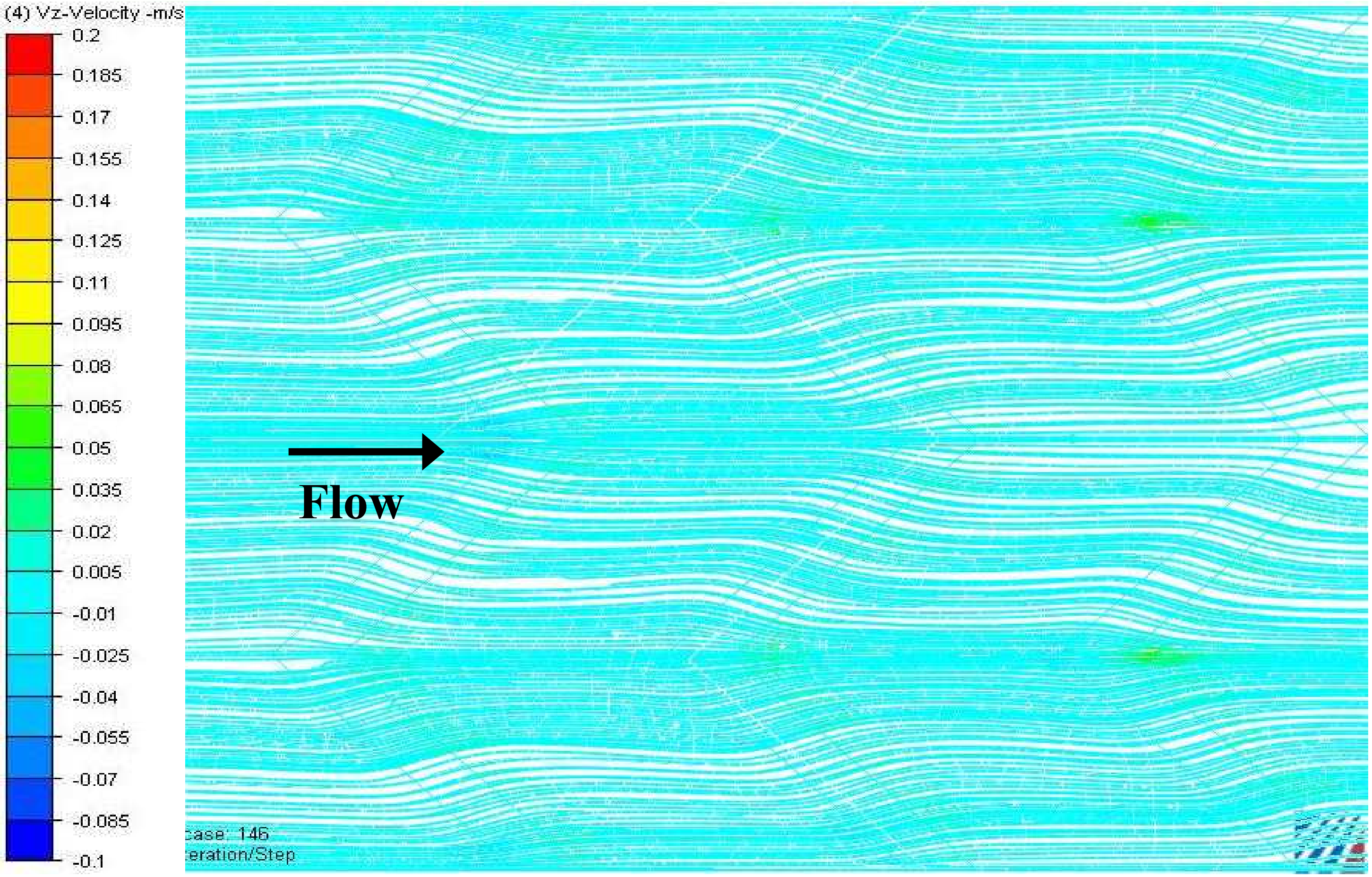


Flow Analysis – Deep Chevrons

Pressure Distribution



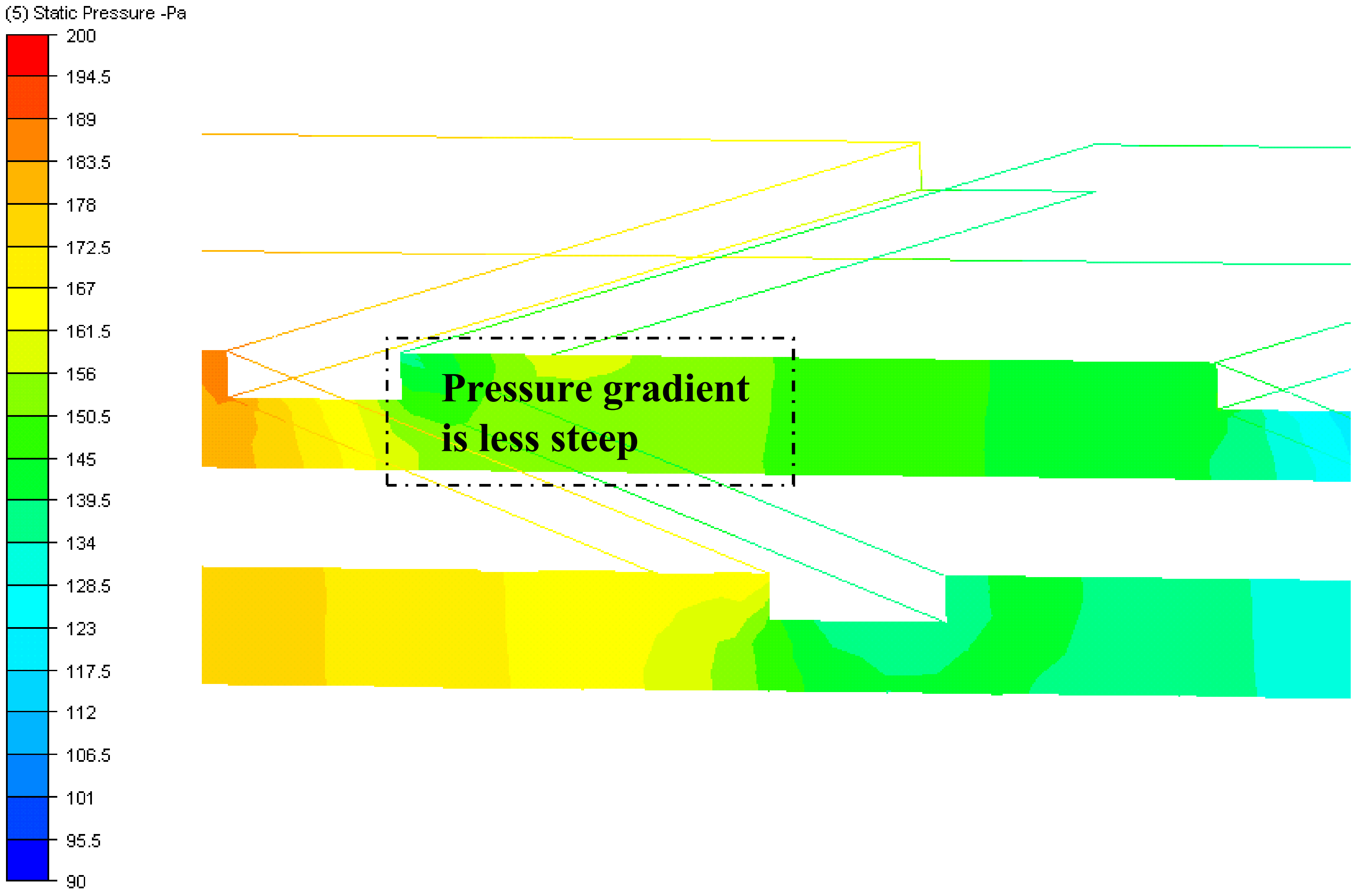
Flow Analysis – Shallow Chevrons
Velocity Towards Membrane



Sandia National Laboratories

Flow Analysis – Shallow Chevrons

Pressure Distribution



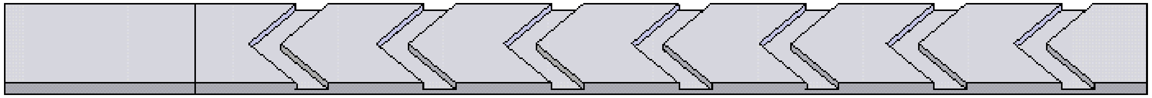
Sandia National Laboratories

Flow Analysis
Corollary

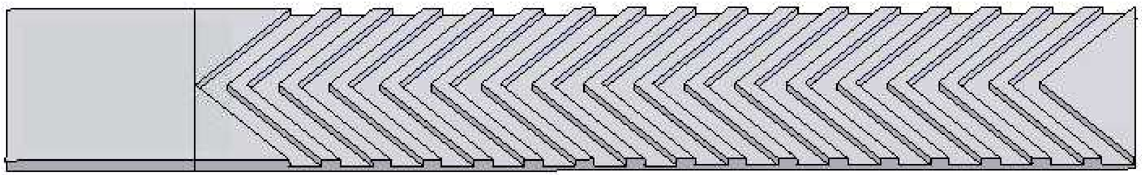
More chevron peaks per unit area of membrane

↓

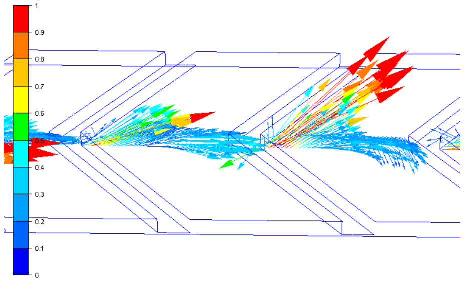
More regions of high-velocity flow toward membrane.



Channel Width low



Chevron Spacing low



Overview

- Introduction
- Development of CFD Models
- Parameterization Results and Discussion
- Conclusions

Conclusions

- Chevrons can accelerate flow toward membrane surface and increase scouring
- Parameterization conclusions:

Increased Pressure Drop ⟸ [Low Chevron Spacing, High Chevron Depth]

[Low Chevron Spacing, High Chevron Depth, Low Channel Width] ⟹ Improved Scouring

- Possible to obtain optimum balance of scouring and pressure drop