

A Machine Learning Approach for Modeling Turbulent Scalar Flux in Jet in Crossflow

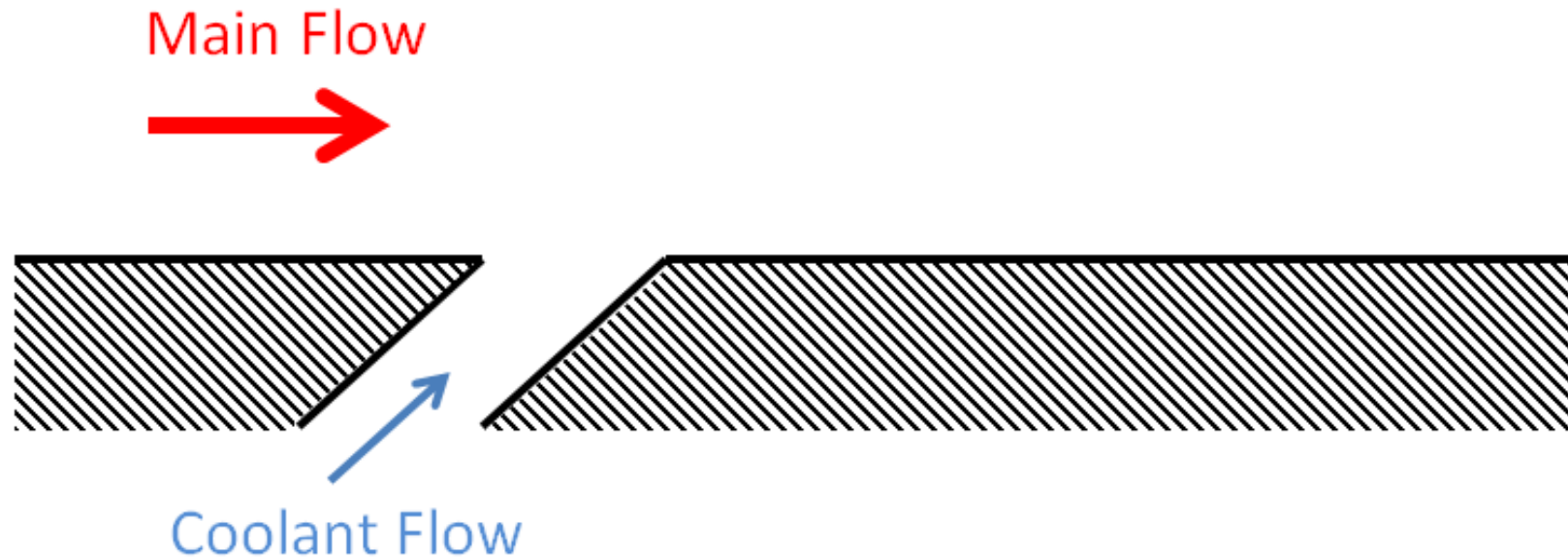
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11/07/2016

Goal



- Improve scalar field predictions in RANS simulations of film cooling configurations



Schematic of an inclined jet in crossflow.

Turbulent Scalar Flux



- Average transport of scalar due to turbulent fluctuations in mean velocity and scalar fields
- Gradient diffusion hypothesis (GDH) is simplest model:

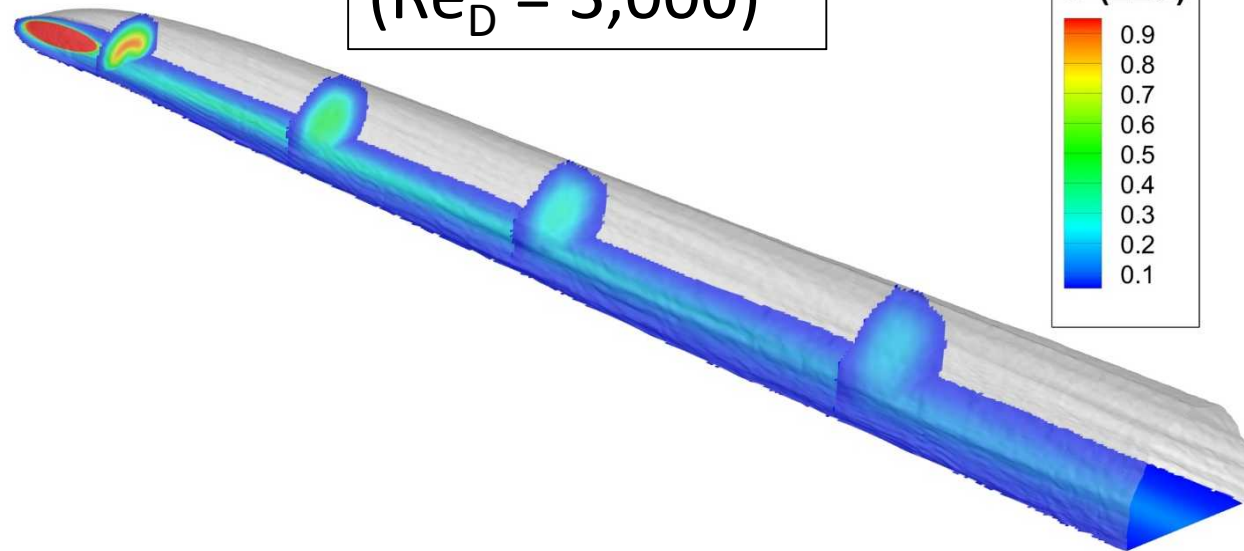
$$\overline{u'_i c'} = -\alpha_T \frac{\partial \bar{c}}{\partial x_i}$$

- Need to specify turbulent diffusivity (α_T)

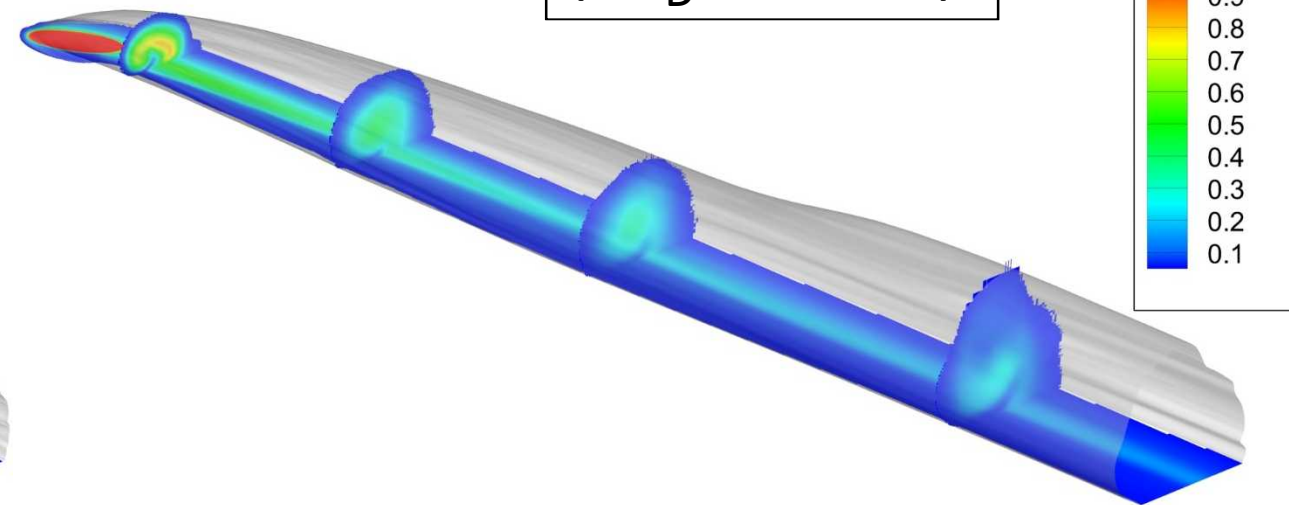
Datasets



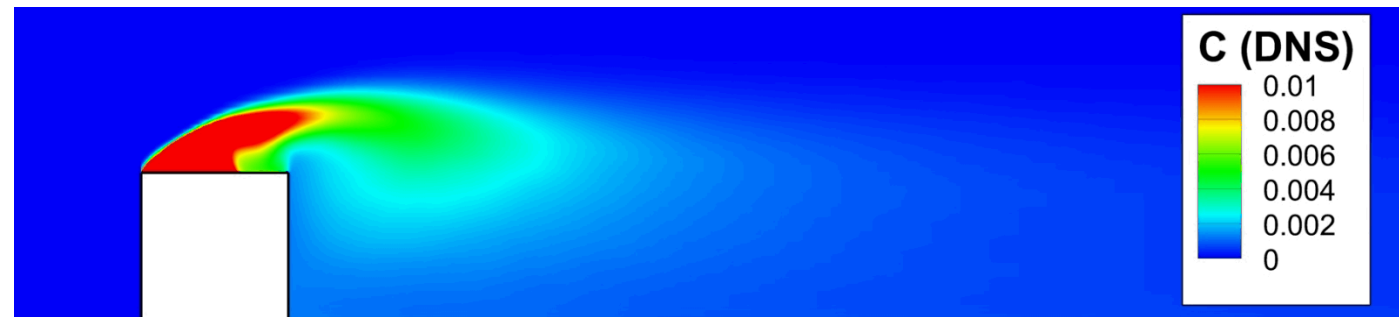
1) Baseline Jet
($Re_D = 3,000$)



2) Skewed Jet
($Re_D = 5,800$)



3) Cube
($Re_H = 5,000$)



Machine Learning

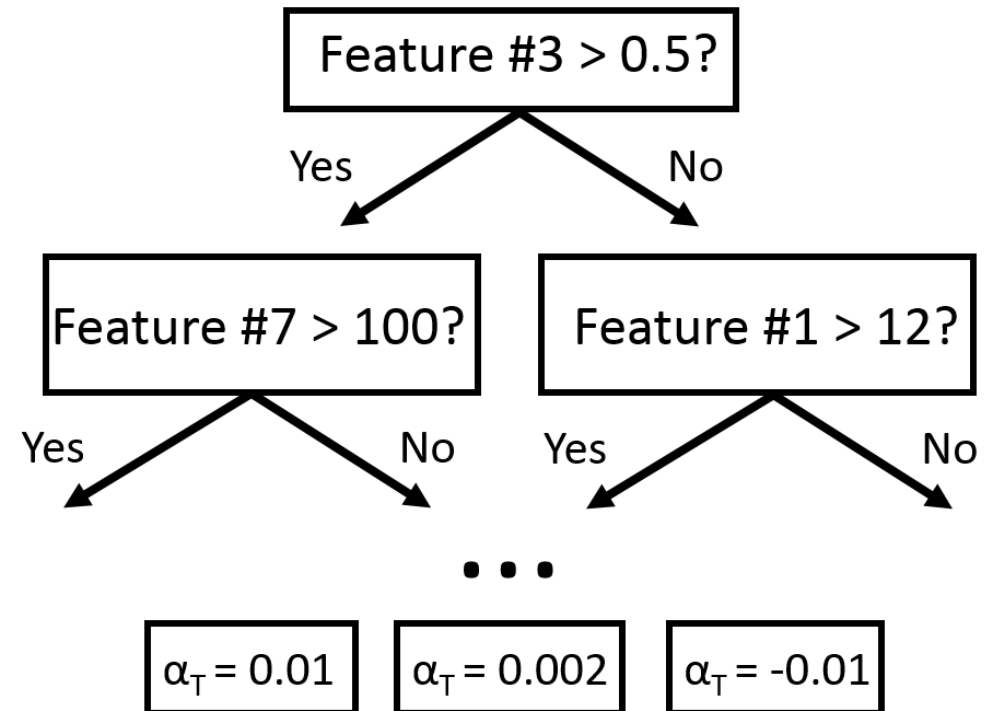


- At each cell, we predict α_T given only local RANS variables (features)
- Supervised learning problem: we have training examples where we know the “right” answer (α_T extracted from LES)
- Train on Skewed and Cube dataset, test predictions on Baseline
- Algorithm of choice: random forest

RANS local flow information



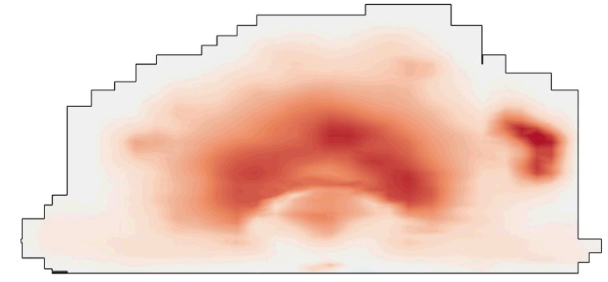
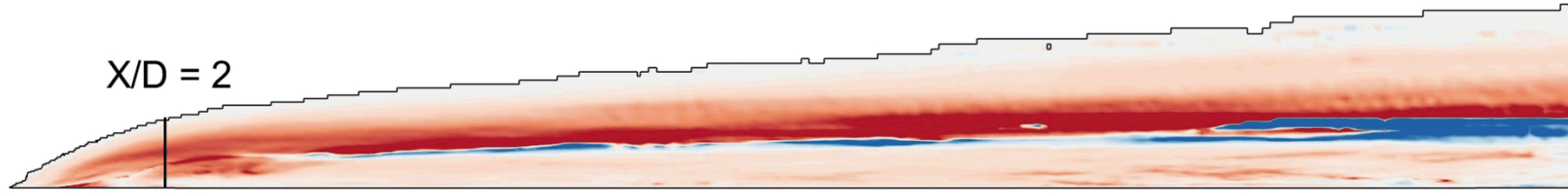
α_T at that cell



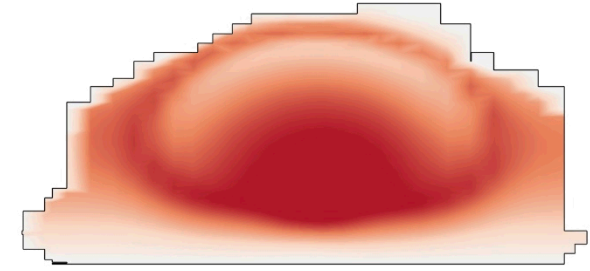
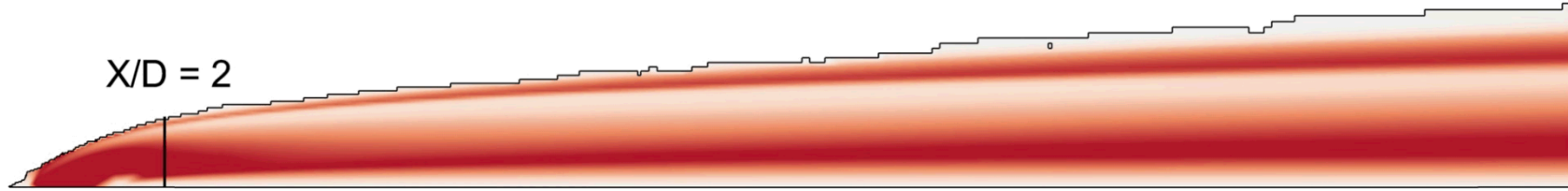
Diffusivity Results



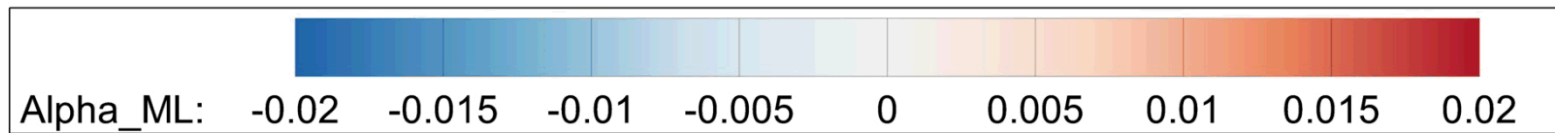
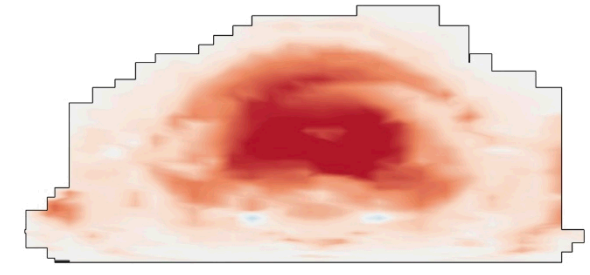
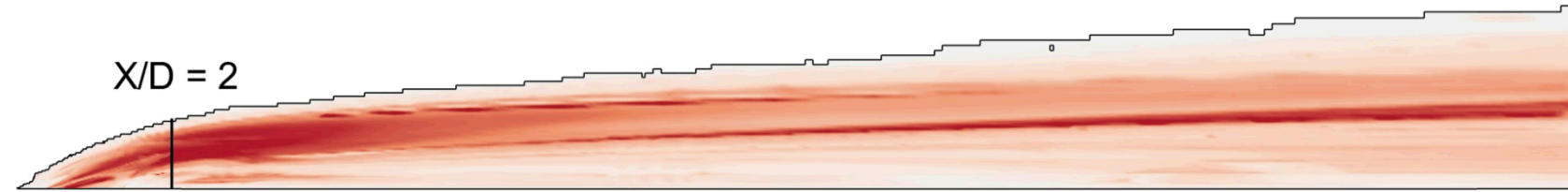
LES



RANS



ML



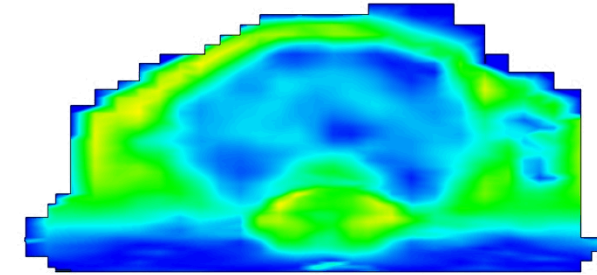
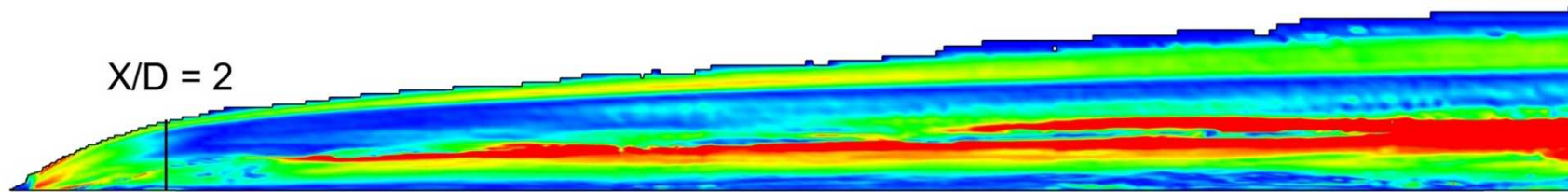
Center plane $Z/D = 0$

Plane $X/D = 2^6$

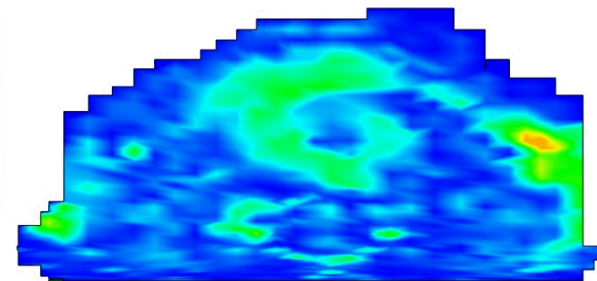
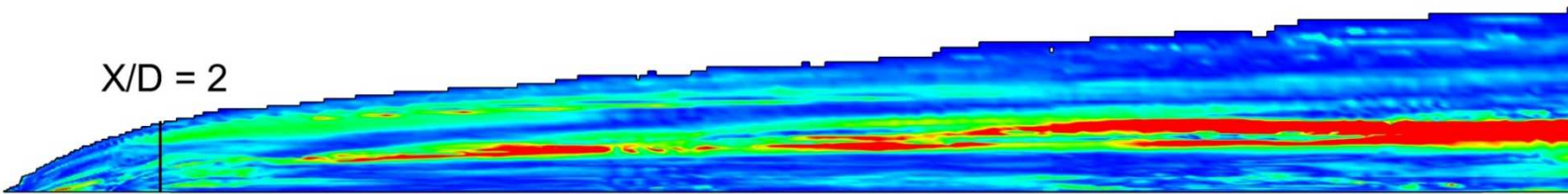
Diffusivity Results



RANS



ML



Center plane $Z/D = 0$

Plane $X/D = 2$

L1 error:

- RANS = 1.21

- ML = 0.60

Forward Propagation



- Calculate the scalar field that results from the diffusivity field

Reynolds-Averaged
Advection Diffusion
(RAAD) equation

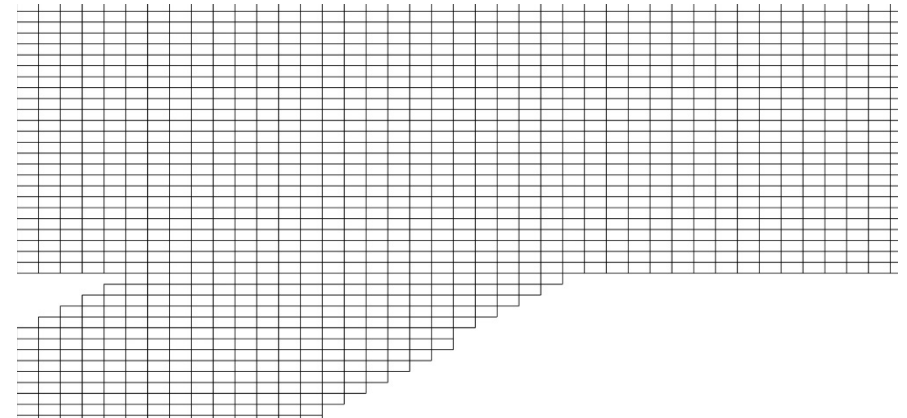
$$\frac{\partial}{\partial x_i} (\bar{u}_i \bar{c}) = \frac{\partial}{\partial x_i} \left(\alpha_T \frac{\partial \bar{c}}{\partial x_i} \right)$$

RANS
Velocity Field

Diffusivity
Field (RANS
or ML)



Scalar field (c)



Grid used in solver

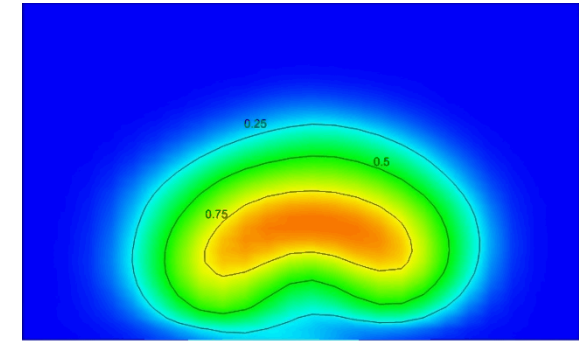
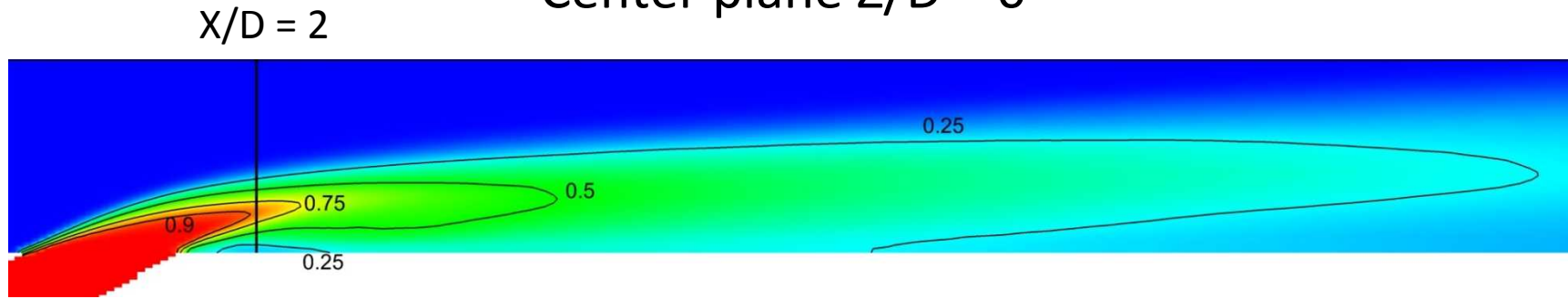
Concentration Results



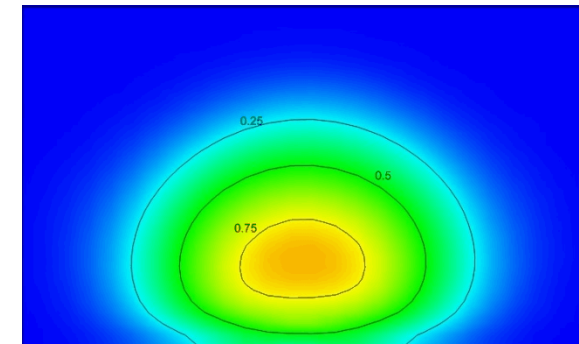
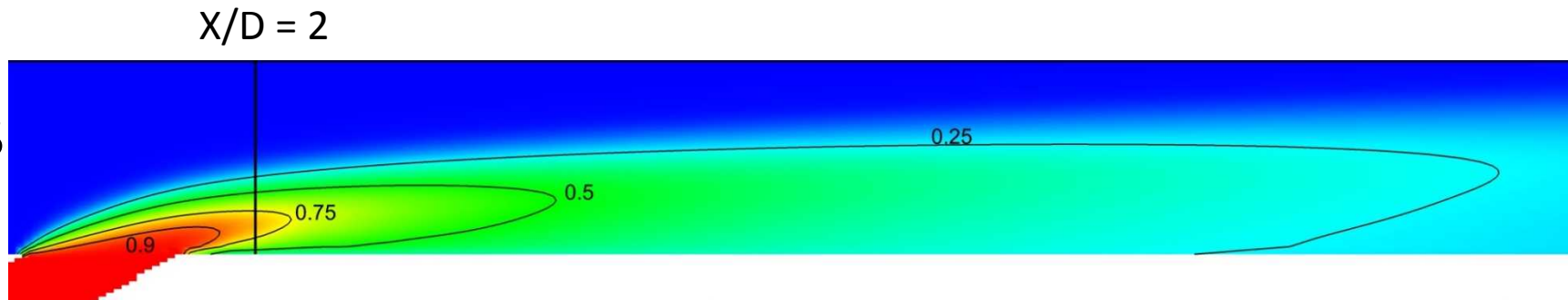
Center plane $Z/D = 0$

$X/D = 2$

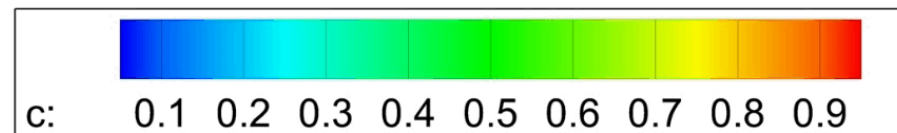
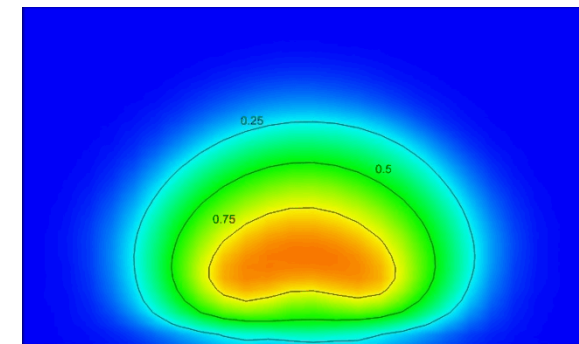
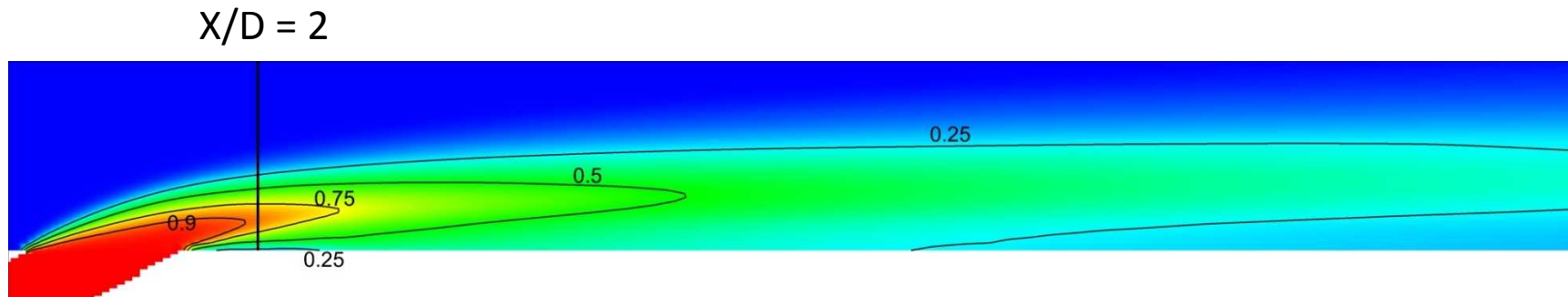
LES
field



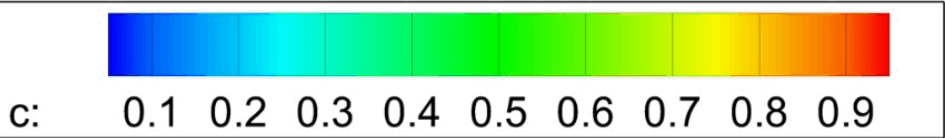
RANS
diff



ML
diff

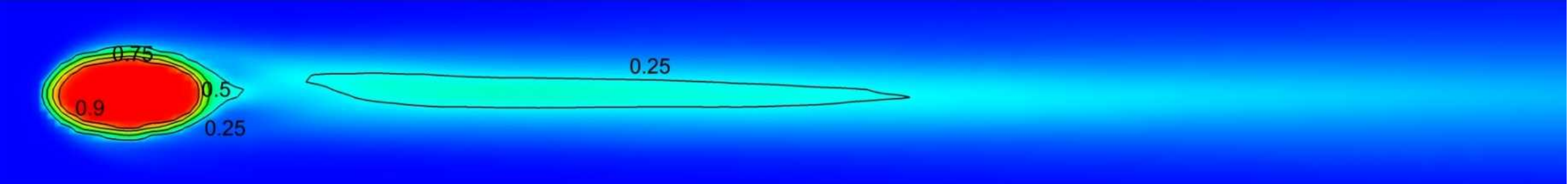


Concentration Results

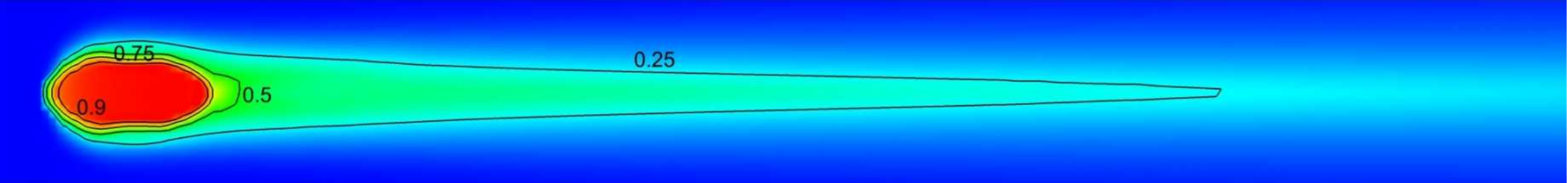


Wall plane $Y/D = 0$

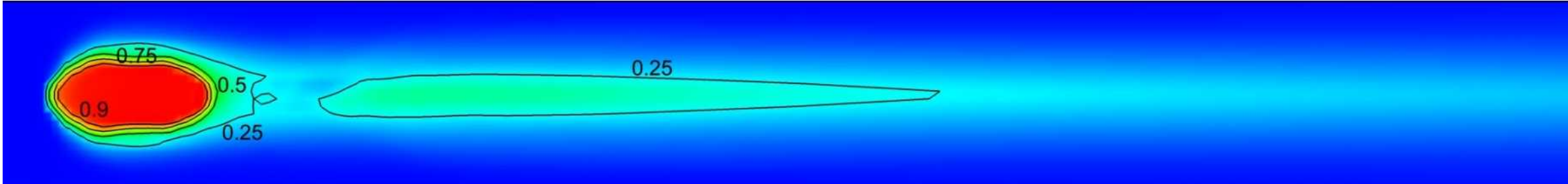
LES
field



RANS
diff



ML
diff



Concentration Results



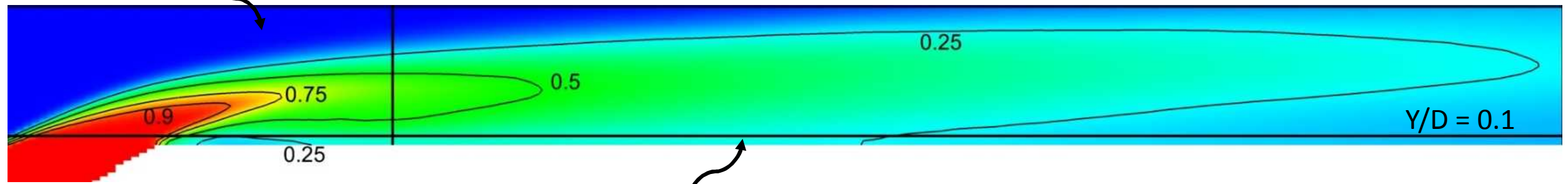
| | Total | Injection | Wall |
|-------------|--------------|------------------|-------------|
| RANS | 2.77 | 4.70 | 5.66 |
| ML | 2.31 | 3.39 | 2.23 |

Average L1 error for each diffusivity model in 3 different regions of interest (% of maximum concentration)

Injection

$X/D = 4$

Total



Wall

Conclusions and Future Work



- Machine learning approaches have great potential
- We have the framework to make informed predictions in any jet in crossflow configuration
- Generalize to different classes of turbulent flows
- Use data driven models to learn about the underlying physics