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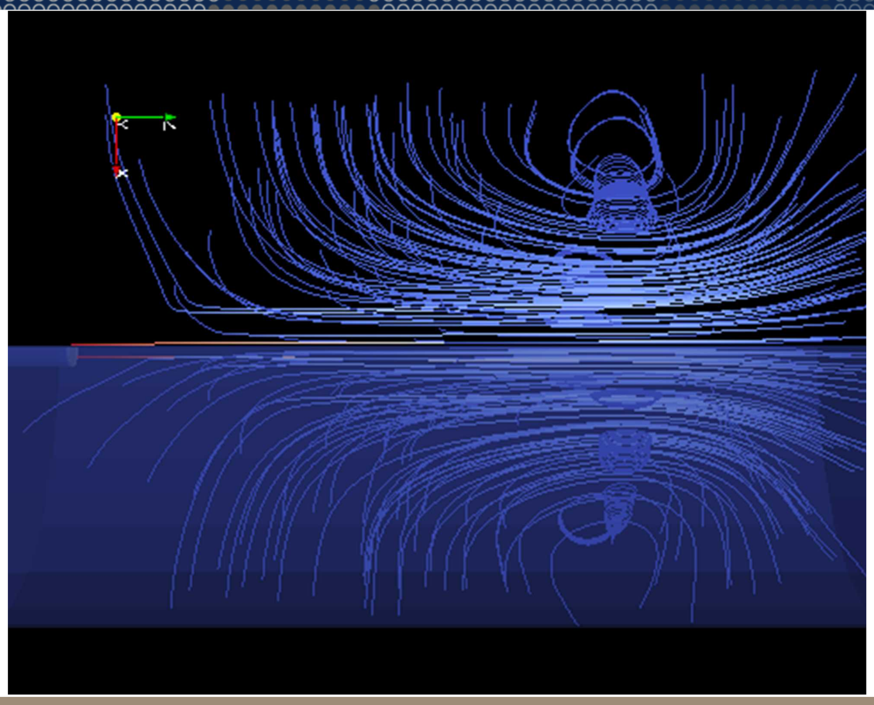
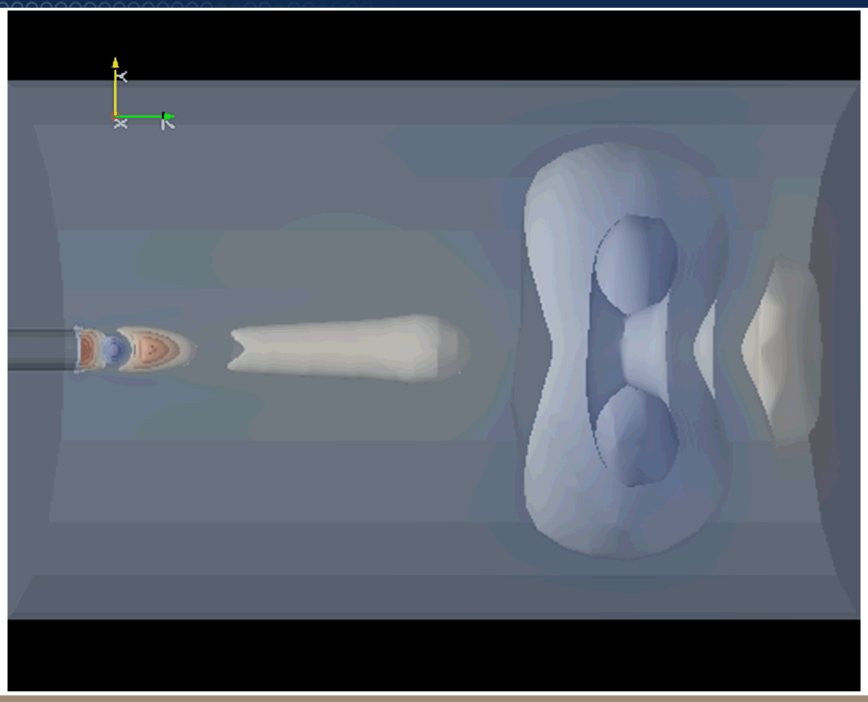
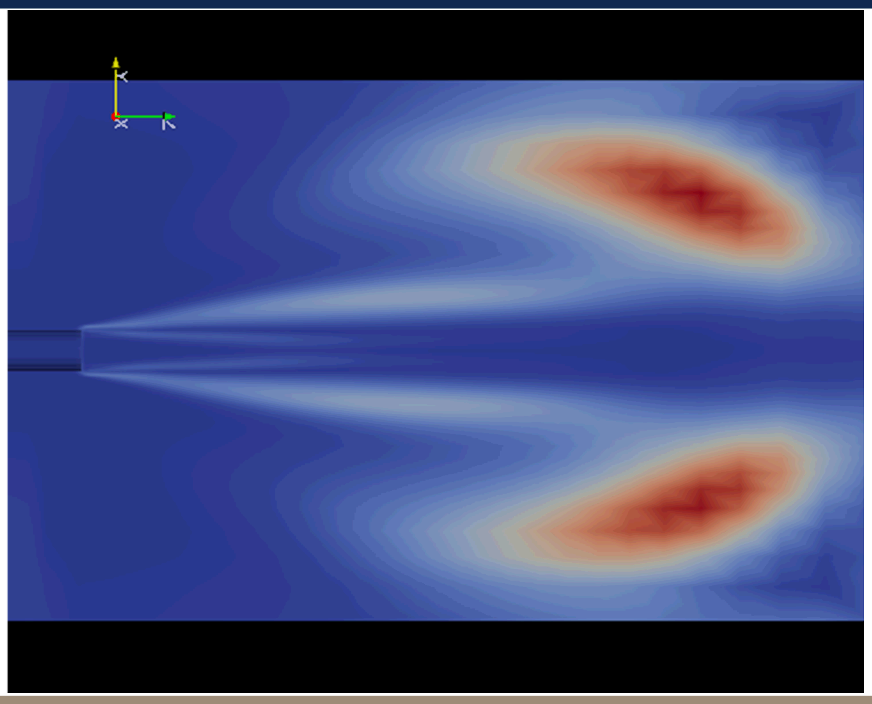
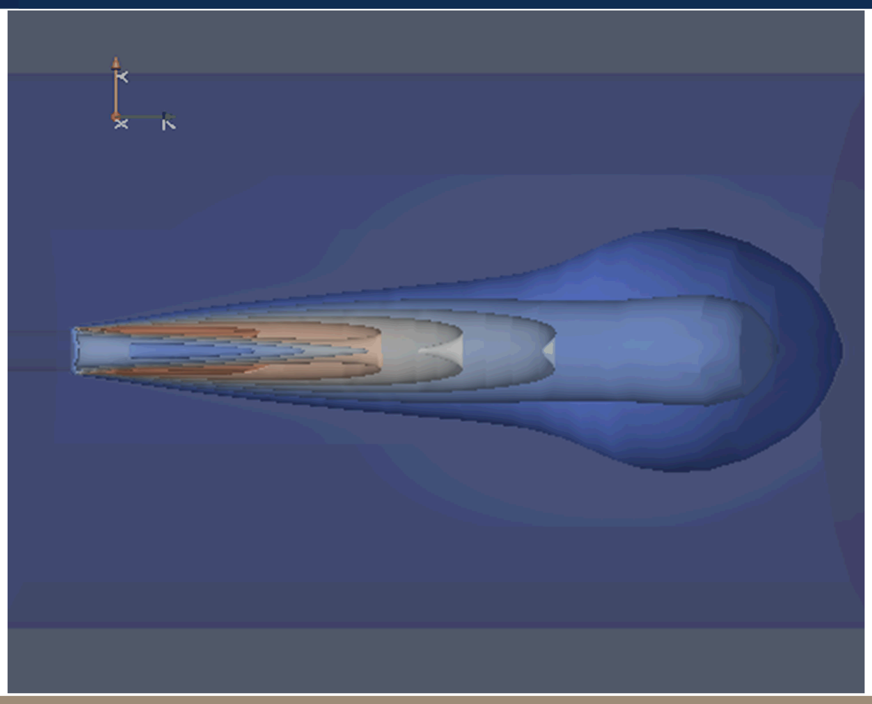

Machine Learning Extension for Fuego

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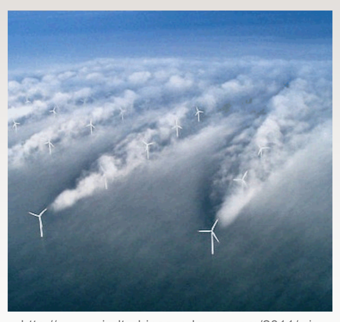
Objective

- Extend the SIERRA software collection to allow access to machine learning classifiers by implementing the OpenCV machine learning library. Machine learning classifiers will help the performance of Reynolds Averaged Navier-Stokes (RANS) simulations by identifying flow regions which require more extensive computation.

Motivation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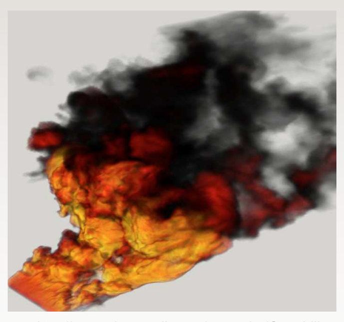
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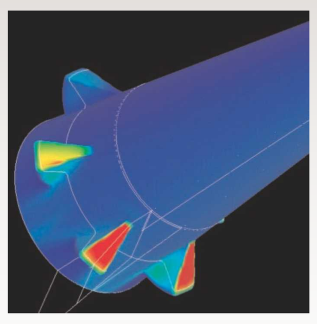
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- Accurate Fluid Modeling is a important aspect of many projects of interest to SNL.
  - Combustion Modeling, Wind Energy Modeling, Flight Modeling
- Turbulence arises in fluid modeling from the convective term in the Navier-Stokes Equation.
- Turbulence makes direct fluid computations expensive because of the range of length scales involved.
- RANS uses filtering to reduce the computational demands of turbulent fluid simulations but introduces new uncertainties.

RANS

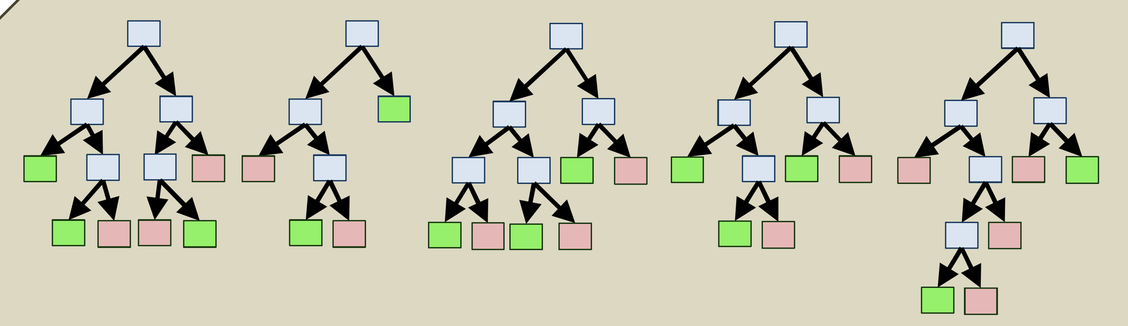
Separate the average and fluctuating parts of flow and solve for the average values

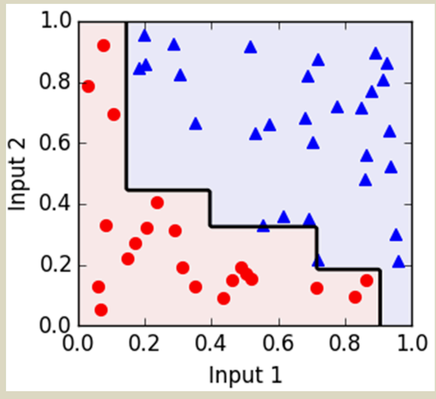
Mass Conservation: $$\frac{\partial \bar{u}_i}{\partial x_i} = 0$$

Momentum Conservation: $$\rho \frac{\partial \bar{u}_i}{\partial x_j}\bar{u}_j = \bar{f}_i - \frac{\partial \bar{p}}{\partial x_i} + \frac{\partial}{\partial x_j}\left(\mu\left(\frac{\partial \bar{u}_i}{\partial x_j} + \frac{\partial \bar{u}_j}{\partial x_i}\right) - \rho\overline{u'_i u'_j}\right)$$

Equations are left with a closure issue because of remaining fluctuating terms:
$$\rho\overline{u'_i u'_j}$$
Term is modeled as a stress like term with constitutive equations.

Machine Learning





- Machine learning is a computational technique that allows for the processing of data into abstract computational boxes that can be used to predict or classify future data.
- Random Forests (RF) are decision tree based methods that are built on random samples of data to classify new data.
- The RFs trained for the RANS simulations were trained off of large direct numerical simulations to identify regions of high Reynolds stress anisotropy.
- OpenCV is a C++ library built for image processing that contains a variety of machine learning methods.

Work:

SIERRA Fuego Code Additions

Region::solve_equations()

SubMechManager::solve_and_update()

preTstepWork_->execute()

Auxiliary calculations needed in the more demanding calculations

MLClassifier::predict()

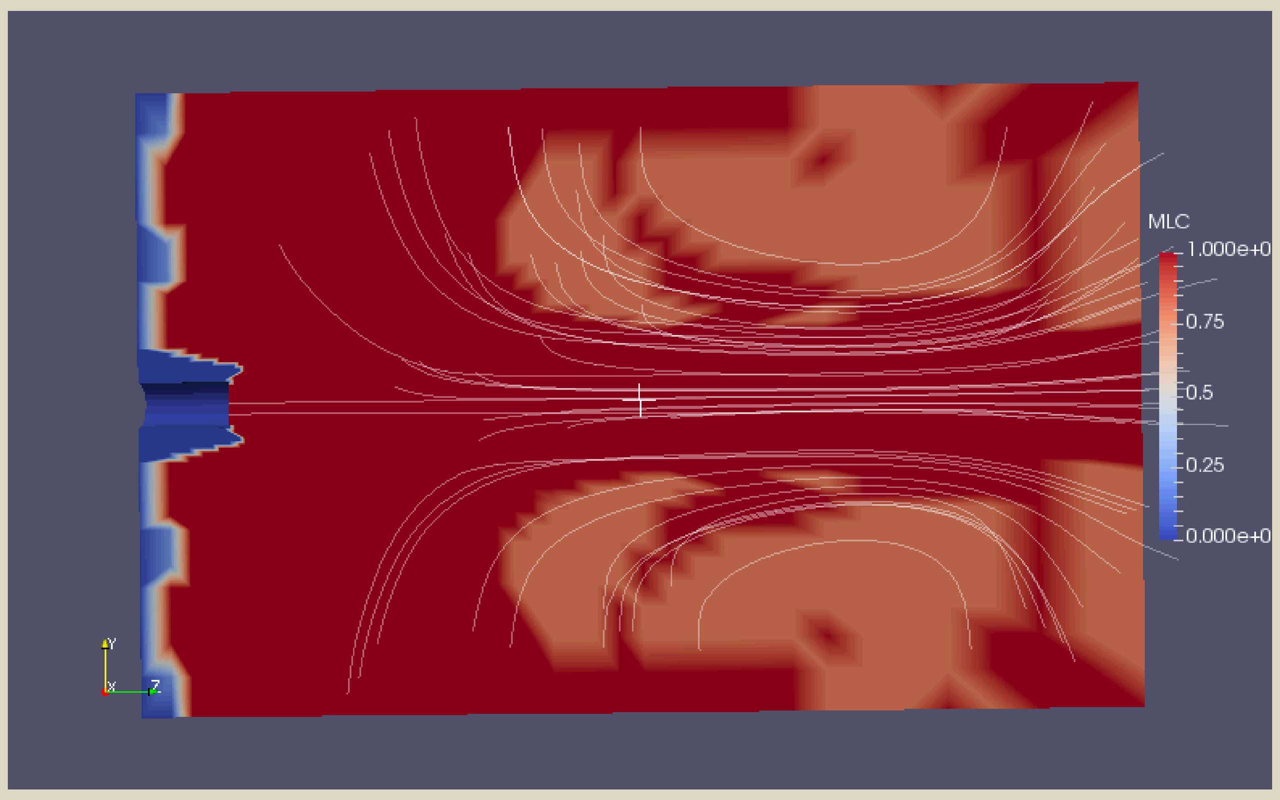
Assemble and Calculate necessary parameters and pass them to the OpenCV RF predictor, to classify the level of anisotropy at all nodal points.

myUnitMechs_-> solve_and_update()

The heavy physical calculations, iterating until convergence.

postTstepWork_->execute()

Auxiliary calculations on converged results.



Plot of the degree of turbulent anisotropy in an open jet simulation as calculated from the RF's. Red regions are regions are high anisotropy blue low regions. Stream Lines are overlaid to show flow. Results currently do not appear correct.

Future Work

- Implement parser and modular variable inputs to allow for switching of learning models without the need for recompiling.
- Correct inputs to the RFs to get correct predictions.
- Introduce the classifier in to the physical calculations to switch between the linear Boussinesq model to the Cubic Eddy Viscosity model for the Reynolds stress.
- Implement a flag in the Sierra Fuego parser to turn machine learning features on and off without recompiling.

Special thanks to Victor Brunini, Myra Blaylock, and Adrian Kopacz for their help with learning the SIERRA Fuego code base.

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