DSDS24, Cranfield Defence and Security Doctoral Symposia 2024, 13-14 November 2024, STEAM Museum, Swindon, UK

Supersonic Flow Field Reconstruction using CNNs

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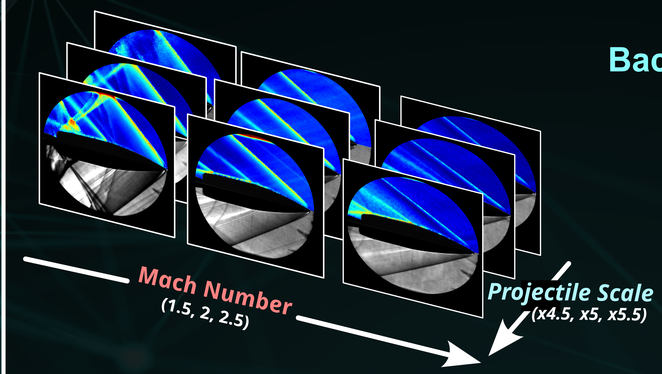
Motivation

- Understanding the effects of scale in supersonic wind tunnel experiments is a key step in the accurate aerodynamic coefficient determination of projectiles [1].
- The Background-Oriented-Schlieren (BOS) technique is a valuable technique that can provide non-intrusive, numerical, density measurements [2].
- Coupling BOS with machine learning algorithms, the complete experimental flow fields may be reconstructed, providing a full description of the dynamics at play [3].



Background-Oriented-Schlieren

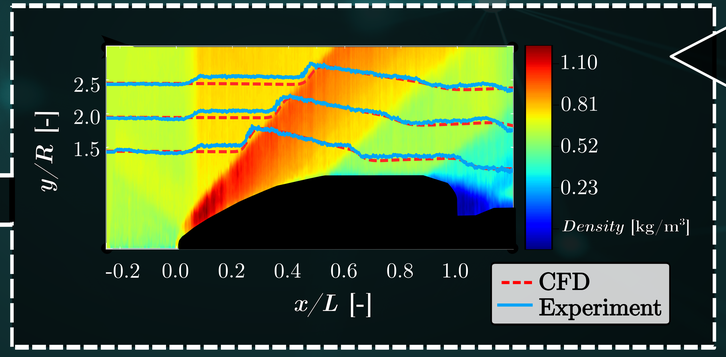
We conducted BOS measurements on scaled versions of the NATO 5.56 mm M855 proejctile at varying Mach numbers. Using cross-correlation, we obtain details of the flow fields which we can compare with traditional Schlieren images.

Experimental Density Calculations

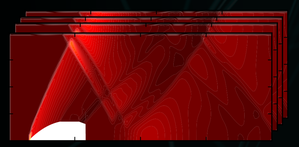
Our code converts measured pixel displacements to angular deflections from which the density field can be reconstructed, using modified inverse Abel transforms [2].

$$\epsilon_y(x,y) = \frac{2y}{n_0}\int_{r=y}^{R}\frac{\partial n}{\partial r}\frac{dr}{\sqrt{r^2-y^2}}$$

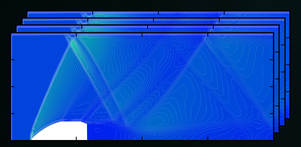
$$\epsilon_x(x,y) = \frac{2}{n_0}\int_{r=y}^{R}\frac{\partial n}{\partial x}\frac{rdr}{\sqrt{r^2-y^2}}$$



Model trained with ~450 Simulations



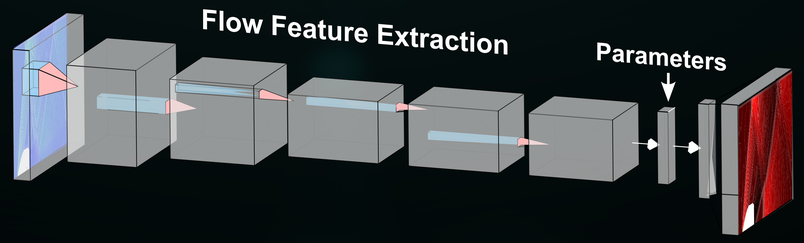
Pressure



Density

The neural network was trained with the results from 450 2D-CFD simulations. The Mach number and upstream pressure (and hence Reynolds number) where varied between simulations to train the network to identify the relationship between pressure and density in the flow field.

The Convolutional Neural Network

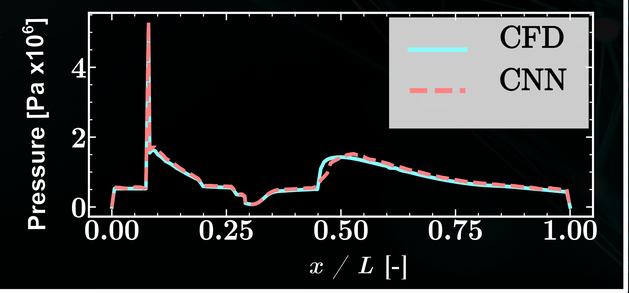


The CNN uses four convolution layers to perform the flow feature extraction. The output of the fourth layer is flattened to a 1D linear layer where the upstream Mach nuber and operating pressure is introduced into the model. This is then followed by a fuly connected layer and a final convolutional layer to recover the 2D flow field.

Flow Field Reconstruction

The trained model was used to reconstruct a pressure field for a given input density field from CFD. The pressure distribution along the projectile surface and bottom surfaces is shown below.

The model will be next tested with the experimental density fields in an attempt to predict drag forces on the projectile, to be validated with force balance measurements.



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[3] Molnar, J. P. et al, "Estimating density, velocity, and pressure fields in supersonic flows using physics-informed BOS", Experiments in Fluids, Vol 64, No. 14, 2023, https://doi.org/10.1007/s00348-022-03554-y

[4] Background image from https://www.freepik.com/free-photo/3d-abstract-cyber-network-visualization-design_34940972.htm#fromView=search&page=1&position=8&uuid=1418b888-88a4-4955-bd5d-76f585b5e3b7

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