

Artificial neural network ensembles applied to missile aerodynamic coefficient prediction and wind tunnel data storage

These slides were presented at the Arnold Engineering Development Complex (AEDC), the US Air Force's largest wind tunnel facility. On the right are some sample slides and a summary of the topics represented.

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Cover illustration courtesy of AEDC.

Using Surrogate Models for Data Compression

The presentation starts with an overview of the goal. Surrogate models have been used to model the properties of aerodynamic surfaces. The models yield excellent interpolation results (calculating intermediate results between known data points) and extrapolation results (calculating results outside of, but close to, the trained data space).

As a result, the performance of the aerodynamic surface is encapsulated in a very compact model. The same result can be accomplished when used for data compression—a large quantity of data is summarized by a very accurate, trained model.

Overview

- Aerodynamic coefficients required for Aero-Vehicle Design Optimization
- Need Fast, Flexible, Iterative Aerodynamic Design Tool
 - Large Wind Tunnel Database
 - Difficult to Access
 - Database methods retrieve only original data points – models interpolate and smooth
 - CFD is reasonably accurate, but Slow
- Artificial Neural Networks (ANN) offer a **Fast and Accurate** Solution
- AEROModeler™: Aerodynamic data → Compact ANN Models
 - Fast and accurate estimates
 - ~10,000 full aero models per second (laptop)
 - $Q^2 = 0.998+$
 - Compact models
 - 500+ MB data condensed to 277 KB

Slide 4. Sets the stage, to show how 500+ MB of wind tunnel data can be compressed to 277 KB with high fidelity and minimal loss of precision.

Problem

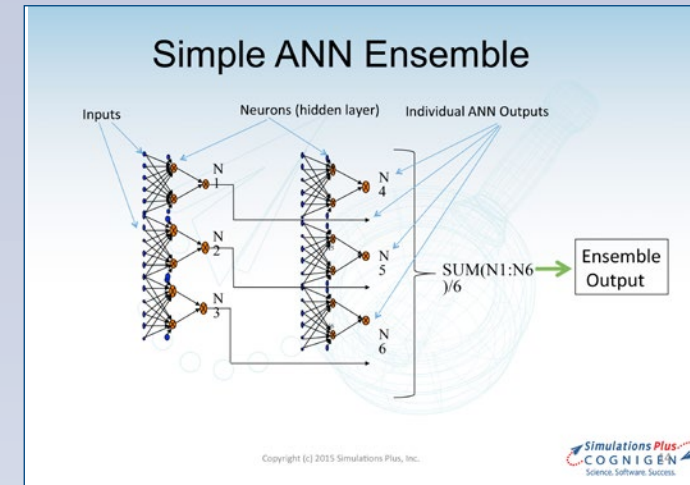
- Calculate force and moment coefficients for arbitrarily shaped missiles at arbitrary subsonic, transonic, and supersonic Mach and arbitrary angle of attack
 - Accurately and quickly
- Simple missile used for proof-of-concept, but method expected to apply to any aircraft

CN – Normal force coefficient
CA – Axial force coefficient
CMcg – Moment coefficient about the nose

Slide 5. A brief summary of the problem. The goal was to use simulated wind tunnel test data to train an ANNE to calculate force coefficients for any arbitrarily-shaped missile. The missiles in the data set represented a wide variety of configurations and Mach number.

Detailed Introduction to Surrogate Modeling with Neural Network

The presentation includes a strong introduction to modeling with neural nets—how data is prepared, how neural networks and ensembles of neural networks function, and how to avoid overtraining.



Slide 14. This diagram shows the architecture of our ANN Ensembles. In this example, the best six networks trained are used in the calculation of the ensemble output.

Demonstrating the Solution

The surrogate model solution is demonstrated and results are shown for the subsonic, transonic and supersonic regimes, showing that the neural network-based surrogate model encodes aerodynamic data with high fidelity and minimal loss.

Proof-of-concept Demonstration

- Training data set generated using the AERODSN software package developed at Redstone Arsenal
- Simple missile used for convenience – method expected to apply to any aircraft
- Approximately 200,000-300,000 lines (individual missile geometries at specific Mach numbers and angles of attack) for each Mach regime

Figure 1: Missile geometry design parameters.

Training/Prediction Inputs	Configurations Explored
Mach number	0.20, 0.50, 0.70, 0.90, 0.98, 1.05, 1.10, 1.15, 1.20, 1.30, 1.40, 1.60, 2.00, 2.50, 3.00, 3.50, 4.00, 5.00
Finesse ratio	2, 2.5, 3, 4, 5, 6, 7, 8, 9, 10
alpha (angle of attack, degrees)	0.01, 0.5, 1, 2, 3.5
tc (tail root chord)	0.01, 0.5, 1, 2, 3.5
st (tail taper ratio, cubic)	0.00001, 0.2, 0.5, 0.7, 0.9
Lam_1c (tail trailing edge sweep angle)	0, 5, 10
tc_wing (wing taper ratio)	0.01, 0.5, 1, 2.5
stc (wing root chord)	0.01, 0.5, 1, 2.5
twc (wing taper ratio, cubic)	0.00001, 0.2, 0.5, 0.7
Lam_1c_w (wing trailing edge sweep angle)	-10, 0, 10
twc_w (wing location)	1.5, 2, 3.5

Slide 21. Using generated data, we were able to produce a proof-of-concept experiment to demonstrate the abilities of our ANNE package, namely the success in predictions.

Demonstrating the Solution continued

Subsonic Results

$Q^2 = 1.000$ (to 3 decimal places)

Predicted vs. Observed CN at Mach 0.2, 0.5, 0.7 and 0.9 from ANNE consisting of 50 neurons and 11 inputs. Training time was 26 minutes with 211,800 data points (10% held out for external test set)

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Slide 24. A sample of the results from the subsonic data set. Subsonic, transonic, and supersonic regimes are modeled.

Concluding slides

The presentation concludes with a summary of the benefits of using surrogate modeling as a method of compressing wind tunnel data with high compression, high fidelity, minimal loss of precision, and extremely fast access.

Surrogate Model Advantages

- SPEED:** Facilitates rapid design evolution
- ACCURACY:** With accurate training data, results are very accurate
- COMPACT:** Store large amounts of data in compact model
- INTERPOLATION:** Automatically smooths and interpolates
- INSIGHT:** Descriptor Sensitivity Analysis provides tremendous insight into local effects of design and flight conditions on aerodynamic performance

Slide 32. Summarizes the advantages of surrogate modeling and AEROModeler. Large quantities of wind tunnel data have been generated over the years – models can provide compact storage and rapid/accurate retrieval.