The Use of Artificial Neural Networks In Experimental Data Acquisition and Aerodynamic Design

by

Andrew J. Meade, Jr.
Assistant Professor
Department of Mechanical Engineering and Materials Science
Rice University
Houston, TX 77251-1892

During the ASEE summer tenure at NASA Langley I participated in two projects that were of mutual interest to myself and the staff of the Transonic Aerodynamics Branch. The primary project was the numerical simulation, by a finite element/finite difference method, of the viscous flow about an airfoil [1]. This project is currently funded by the branch and is considered a long term project. The secondary project was a feasibility study on the use of artificial neural networks (ANN) in experimental data acquisition and the design of aerodynamic components. Preliminary results from the secondary project are presented.

An appreciable amount of work done by the Transonic Aerodynamics Branch's (TAB) Applied Aerodynamics Group is in the design of aerodynamic components in the transonic regime. The tools used for design include both physical experimentation and computational fluid dynamics (CFD). The considerable costs in money and manpower in the collection of experimental data and the construction and use of numerical models greatly hampers high-risk, innovative research. The use of an ANN data acquisition system and the resulting construction of the data base could significantly reduce those costs.

Traditionally programmed digital computers can process numbers at great speed; however, they do not easily recognize patterns, nor can they deal with imprecise or contradictory data. Artificial neural networks [2] exhibit an adaptive behavior that makes them capable of self-learning. Instead of being programmed, neural networks are trained by exposing them to repeated examples. When networks are trained with correct examples from available data, they accurately supply missing information and can even extrapolate the information. Consequently, a neural network is an attractive method for encoding and compressing empirical knowledge. ANN models have been studied for many years in the hope of achieving human-like performance in the complex problems of real-time pattern recognition (i.e. speech and vision). The proposed application to aerodynamics would be comparatively modest.

It is proposed that an artificial neural network be used to construct an intelligent data acquisition system. The benefits of the proposed "smart" acquisition system would be:

- The neural network, with proper hardware and software, could possibly in real time steer the experimentalist away from the parameter combinations that give well behaved and well known results, and towards combinations that give interesting phenomena. This may save a considerable amount of time and effort in the wind tunnel.

- The resulting neural net model could then be used as an easily accessible and easily usable data base. This data base code could find numerous uses, including CFD validation.

Currently table lookups, statistical packages, and curve fitting interpolation codes are used on data bases for aerodynamic problems. The ANN model has a potential for replacing these traditional procedures as well as use in CFD validation. Some of the potential advantages of the ANN model for aerodynamics are as follows:

1. The ANN model would not store experimental data for interpolation but would rely upon the trained neural network to store the pattern with relatively little memory requirement. This includes data generated from highly nonlinear processes.

2. ANN adaptation provides a degree of robustness by compensating for minor variabilities (noise) in the experimental data. Traditional statistical techniques are not adaptive but typically process all training data simultaneously before being used with new data. As a result, the statistical techniques can be memory intensive and slow.

3. The trained neural network can be widely distributed to other users and function within a traditional computer environment.

As proof of concept the author [3] modeled a NACA 0012 airfoil (Fig. 1), at specific conditions, using the neural network simulator "NETS" developed by James Baffes of the NASA Johnson Space Center [4]. The code does not require special hardware and runs on virtually any digital computer with an ANSI-C compiler. Fig. 2 illustrates a typical backpropagation network topology.

The experimental chordwise coefficient of pressure (C_p) distribution curves for the NACA 0012 airfoil were taken from the actual experimental data [5] and tabulated for use by the neural network. The curves used were taken at $Re = 3.0 \times 10^6$, based on chord, and at angle of attack $\alpha = -0.14°$. Turbulent transition was fixed on the airfoil at 0.05 x/c. The nominal freestream Mach numbers M_∞ were 0.30, 0.35, 0.50, 0.55, 0.60, 0.65, 0.70, 0.74, and 0.76. The backpropagation topology used for the test consisted of one input node for M_∞, thirty seven hidden nodes and thirty eight output nodes for the thirty eight components of the C_p distribution vector. The net was trained to a maximum rms error of approximately 0.008 using the data sets at $M_\infty = 0.30$, 0.50, 0.70, and 0.76. A comparison of the neural net prediction (triangles) at $M_\infty = 0.74$ with the actual data is shown in Fig. 3. The C_p plot of Fig. 4 compares the ANN results with data from a training set sample ($M_\infty = 0.76$).

Artificial neural networks can provide an elegant and valuable class of mathematical tools for data analysis. Since the hardware, software, and expertise already exist in other fields, such as computer science and electrical engineering, it is thought then that the use of neural networks, and the accompanying hardware, would be more of an application problem than basic research. The feasibility study will continue.

References

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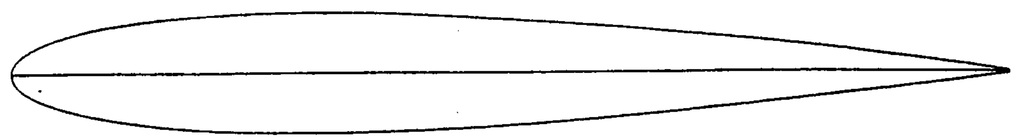

Fig. 1 Sketch of a NACA 0012 Airfoil

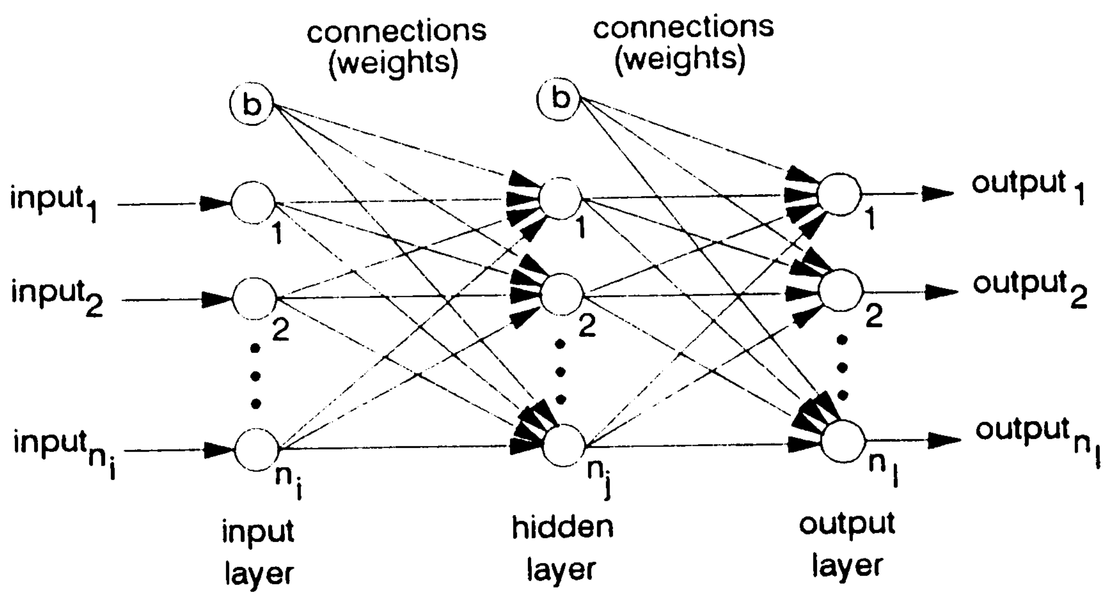

Fig. 2 Typical Backpropagation Topology

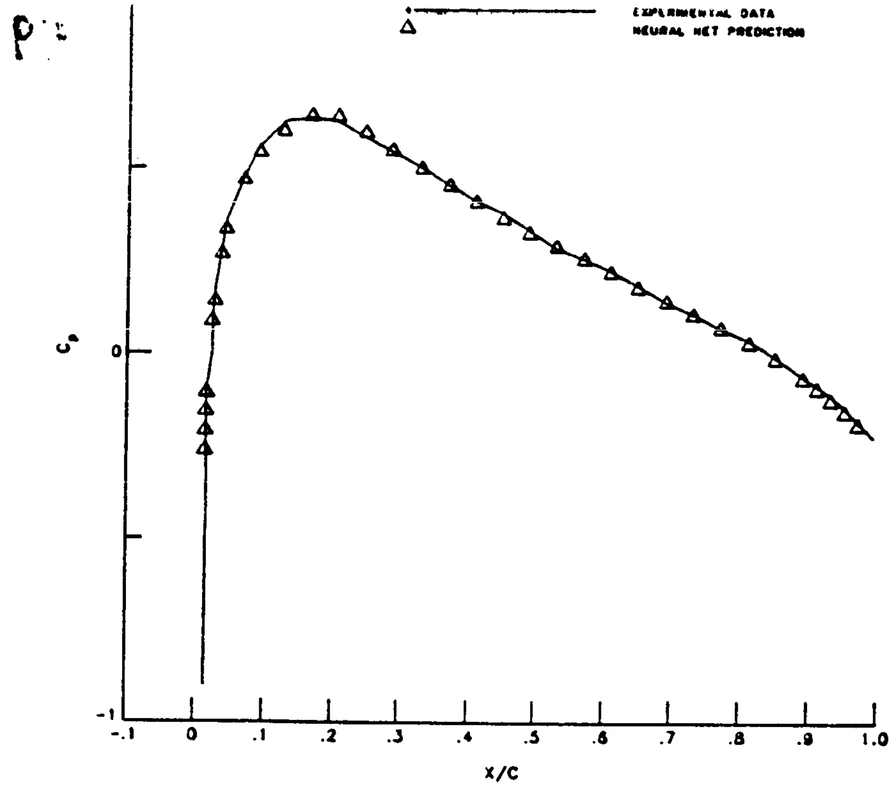

Fig. 3 NACA 0012 AIRFOIL M_∞ = 0.74

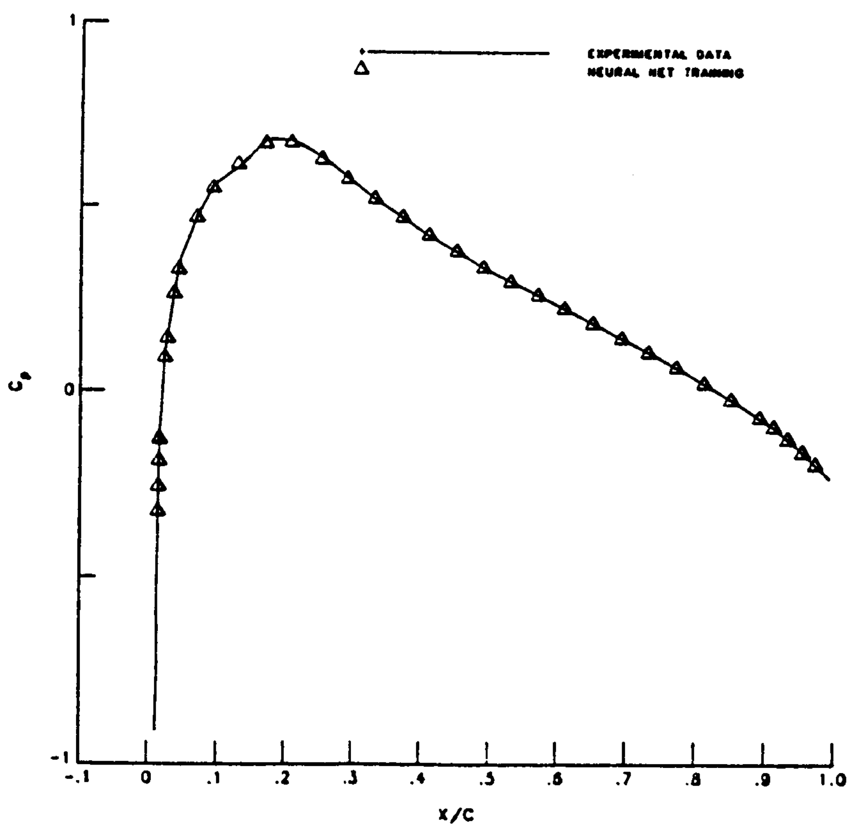

Fig. 4 NACA 0012 AIRFOIL M_∞ = 0.76