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APPLICATION OF NEURAL NETWORKS TO UNSTEADY AERODYNAMIC CONTROL

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Unsteady Fluid Dynamic Models and Control

Problem

Understand → Predict → Control

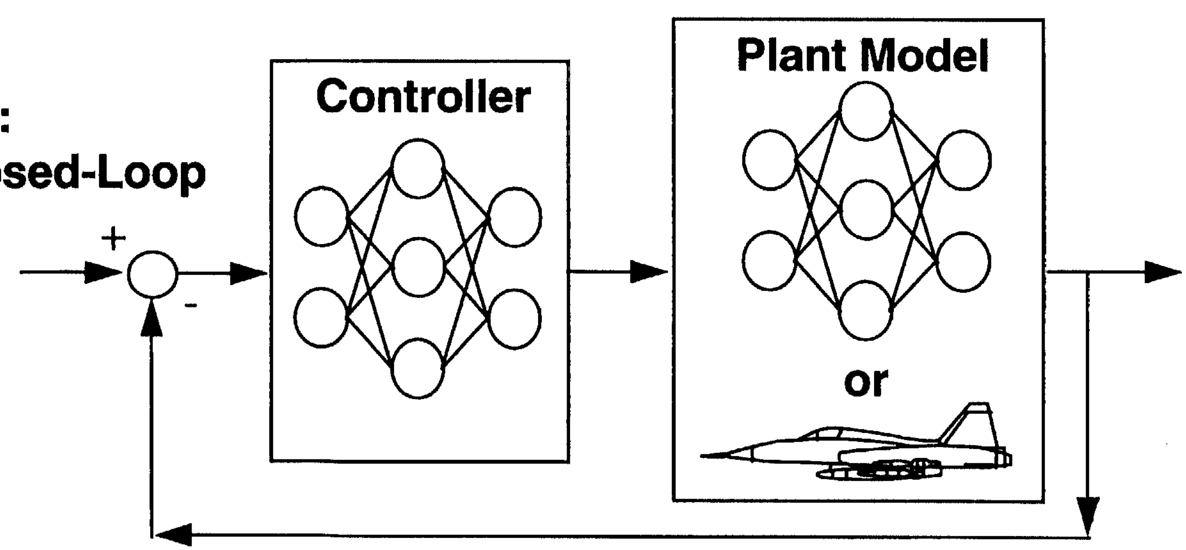
- Fluid Mechanics of Dynamic Maneuvers
- Unsteady Boundary Layers
- Vortex Dominated Flows

Potential Payoffs

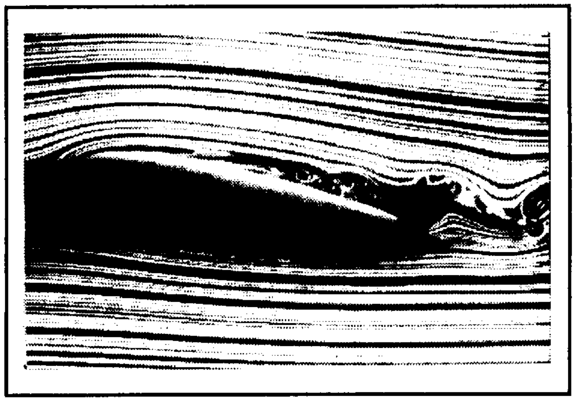
Aircraft, Helicopters, Underwater Vehicles, Wind Turbines ...

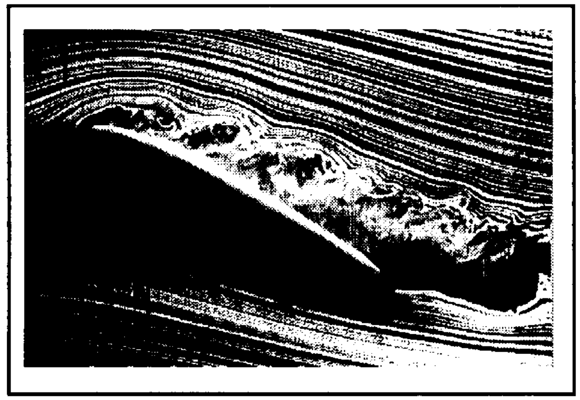
One Solution

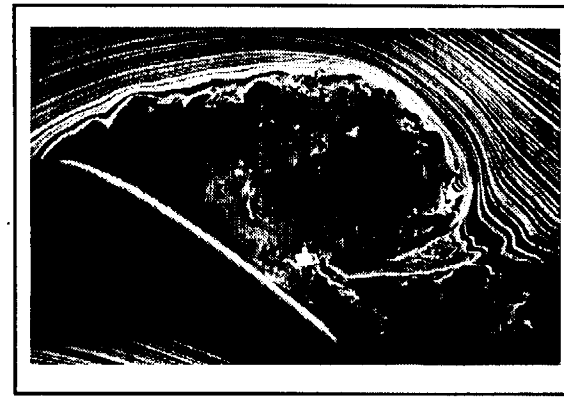
Neural Networks:
Demonstrate Closed-Loop Control



Pitching Alters Vorticity Generation and Accumulation







STEADY:

Vorticity generated and shed at equal rates

UNSTEADY:

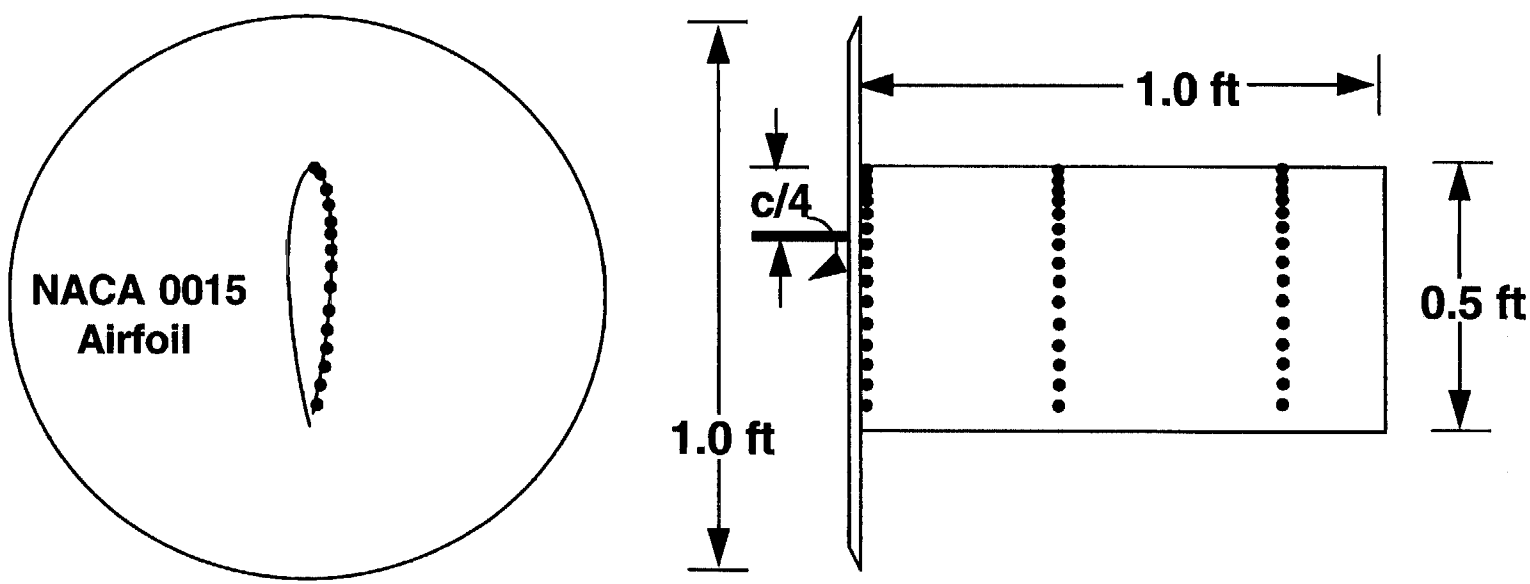
Boundary layer separates, vortex initiated near leading edge

UNSTEADY:

Vorticity accumulates into large, energetic unsteady vortex

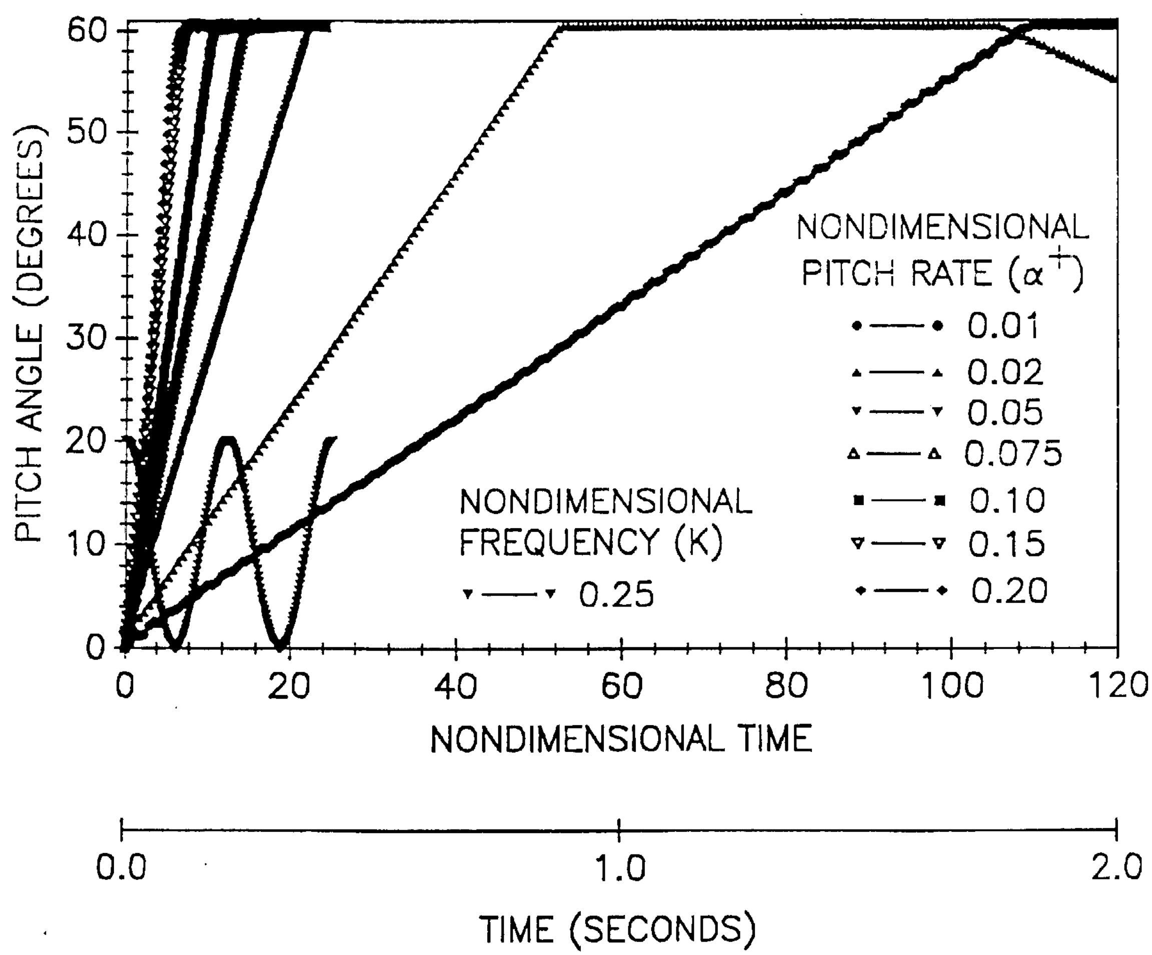
Wind Tunnel Wing Model

Side View | **Planform View**



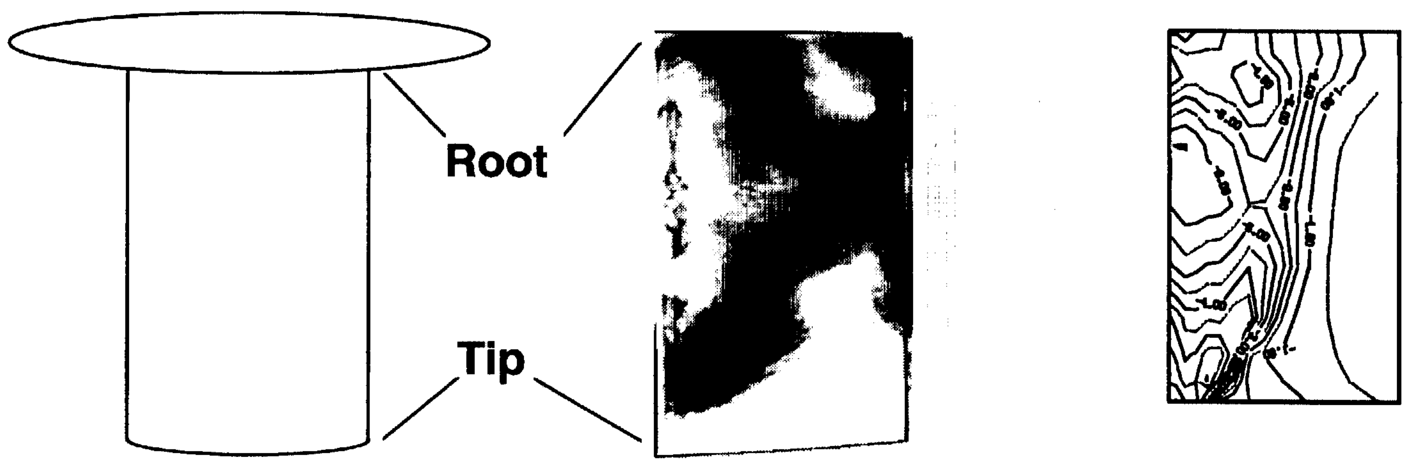
- 15 Pressure Taps (0 to 90% Chord)
- Pressure Transducers Close Coupled With Wing Surface
- 3 Span Locations (Wing Root, 37.5% Span & 80% Span)

Wing Motion Histories



Surface Pressure Topologies and Flow Visualization

- Free wing tip and bounded wing root give 3-D unsteady flow field



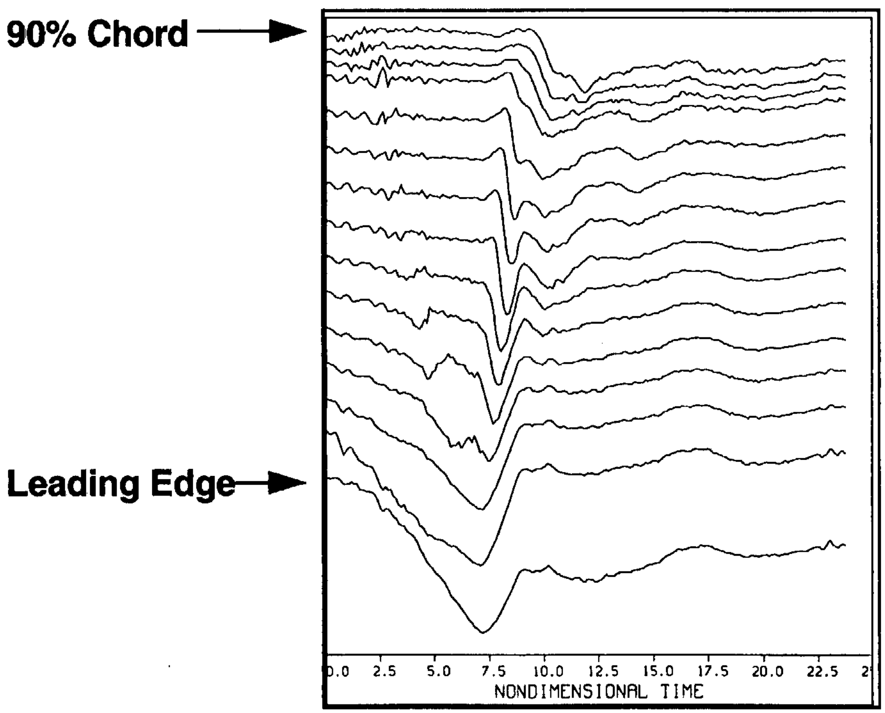
Asymmetrical Geometry

Vortex

Vortex Signature

Experimental Data Format

- Data Acquisition
  Sampling Rate 500 Hz



Samples

$c_{p15}(t1)$ $c_{p15}(t2)$ .... $c_{p15}(t200)$

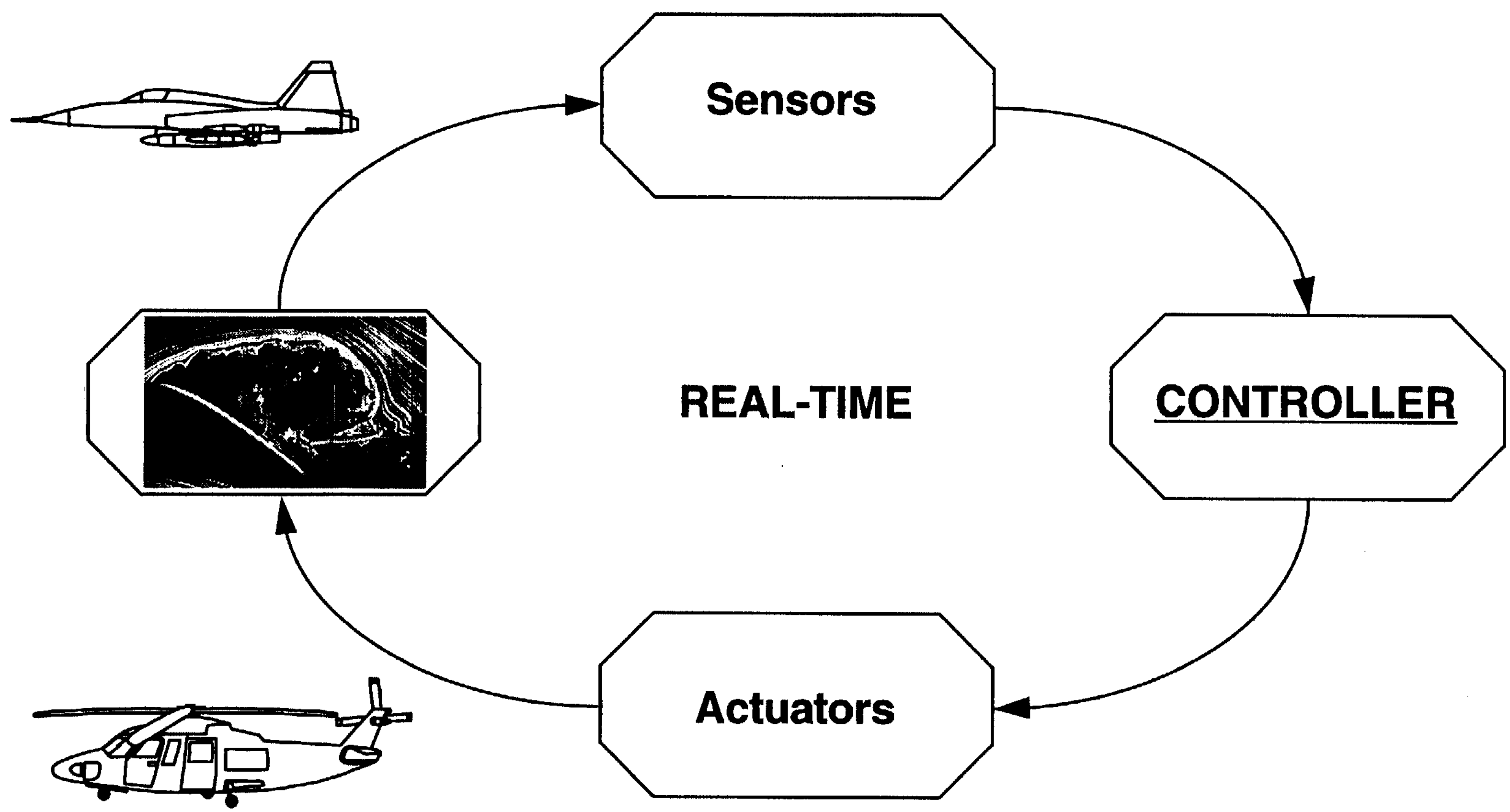
. . .

$c_{p2}(t1)$ $c_{p2}(t2)$ .... $c_{p2}(t200)$

$c_{p1}(t1)$ $c_{p1}(t2)$ .... $c_{p1}(t200)$

Time

Neural Network Control
Unsteady Aerodynamics



Control System Requirements

Constraints

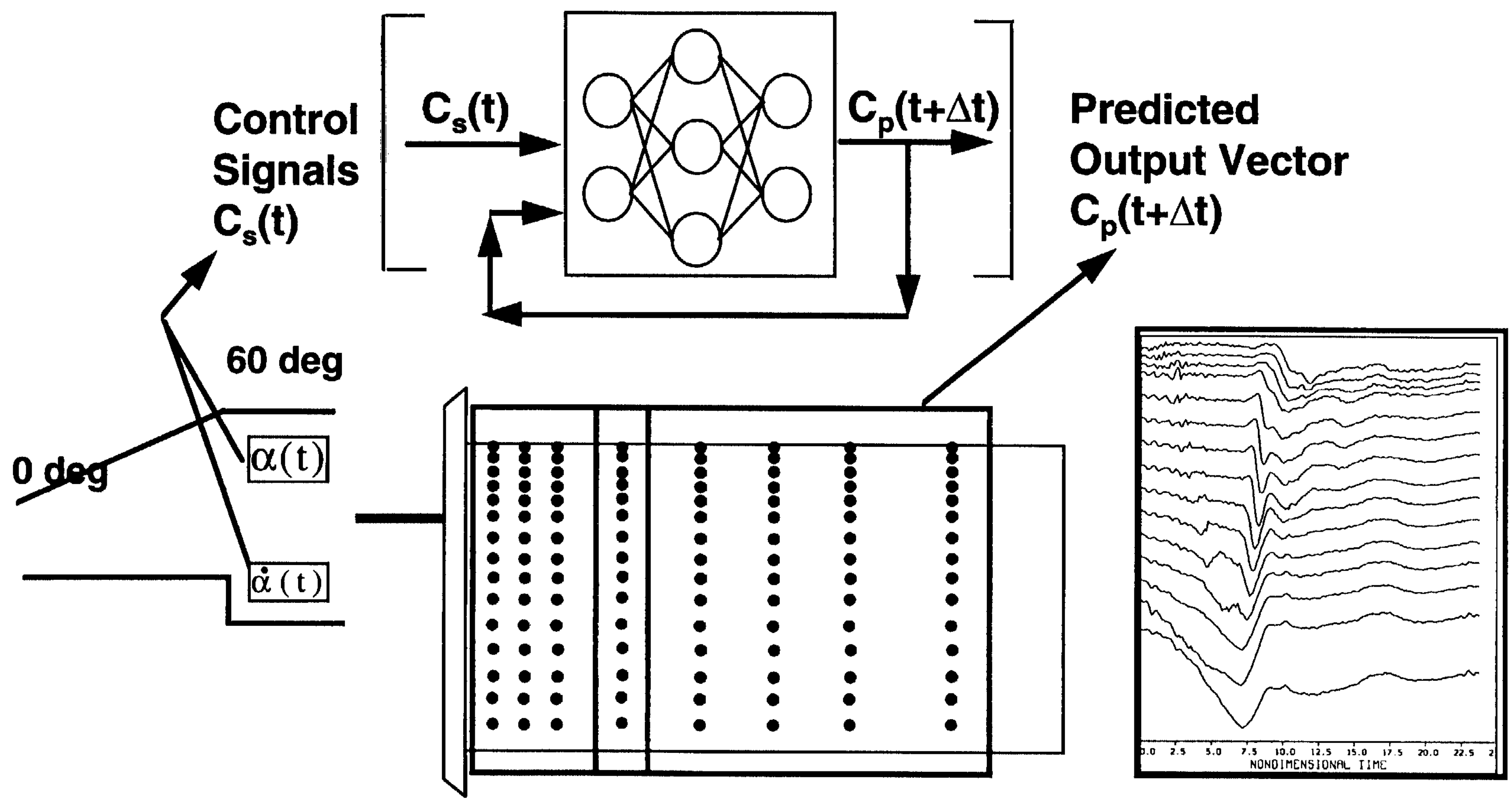
- Plant Output Can Be Highly Nonlinear
- Significant Time Lags Inherent to the System
  (Mechanical, Viscous and Convective)
- System Integration
  (Sensors, Actuators, Controllers, Flow Field Dynamics and the Time-Lags Associated with Each)

Requirements

- Controller for Both Linear and Nonlinear Responses
- Predict the Future State of the Plant / Generate Control Signals with the Required Lead Times
- Many Inputs and Many Outputs in Parallel
- Integrate Multivariate Signals (Sensors, Actuators and Controller)
- Handle Temporal Mismatches (Time-Lags) Automatically

Neural Network Control

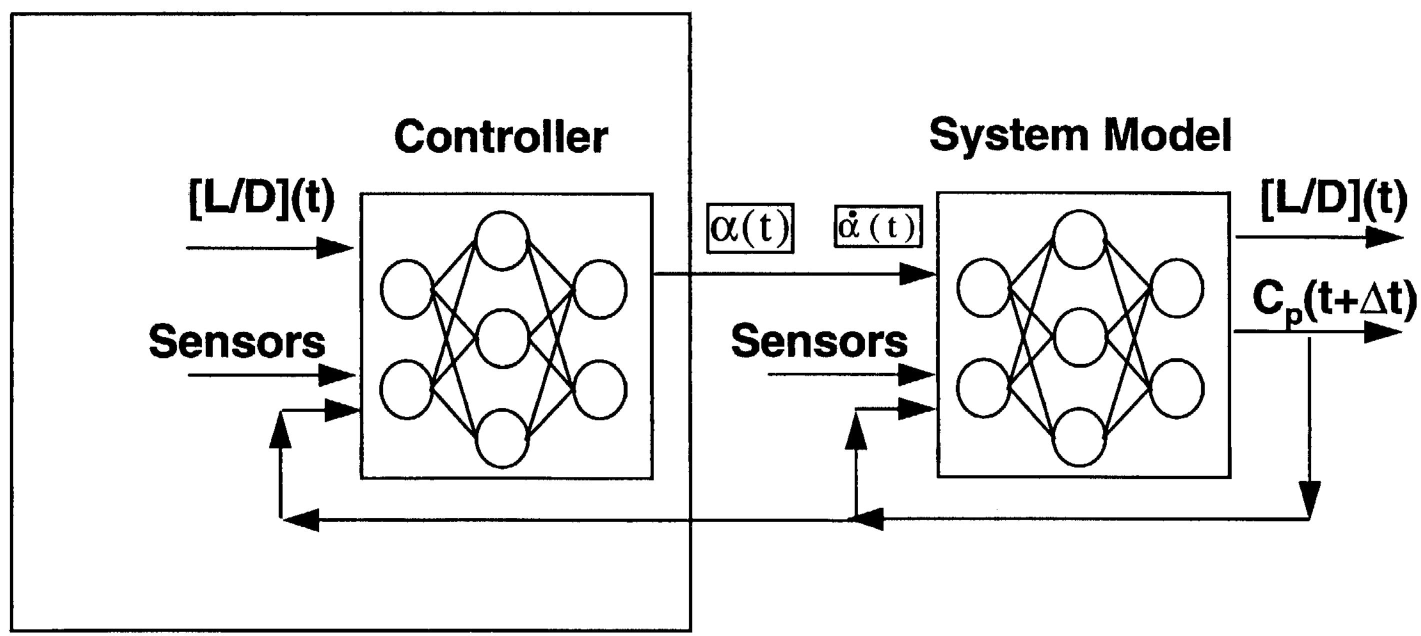
- Develop Neural Network Model of the Plant



- Inputs: Wing Motion History and Recurrent Feedback
- Outputs: Time-Dependent Unsteady Surface Pressures & Forces/Moments

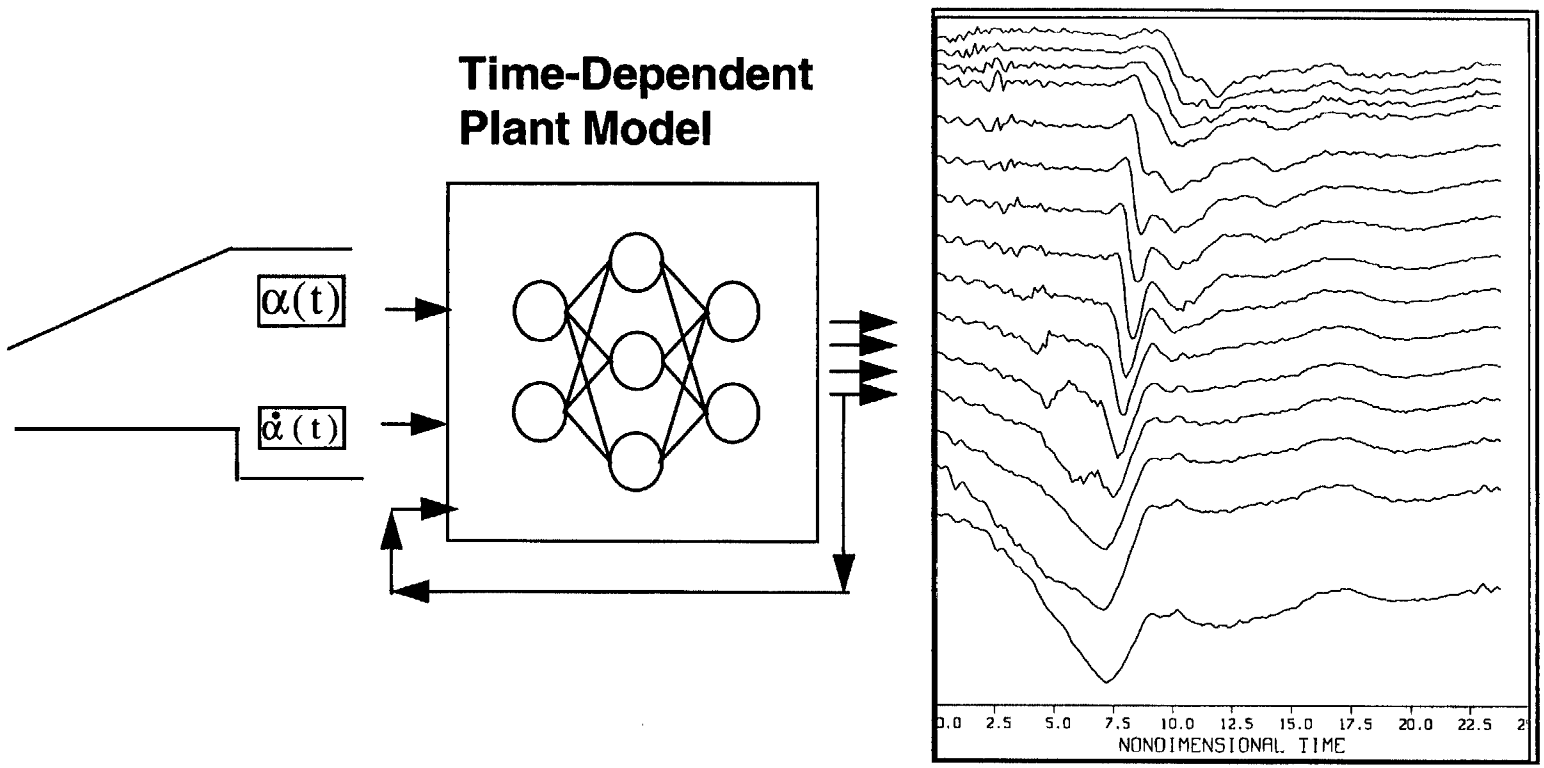
Neural Network Control

- Closed-Loop Control



- Actual system would include sensor inputs to both the plant & controller

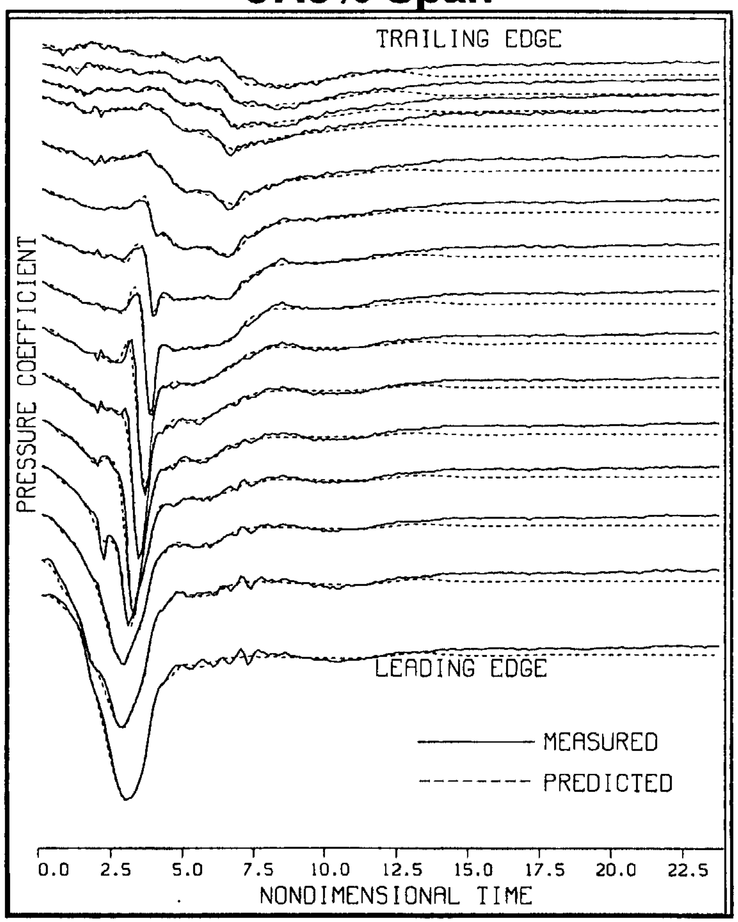
Neural Network Model of Unsteady Flow Field Wing Interactions



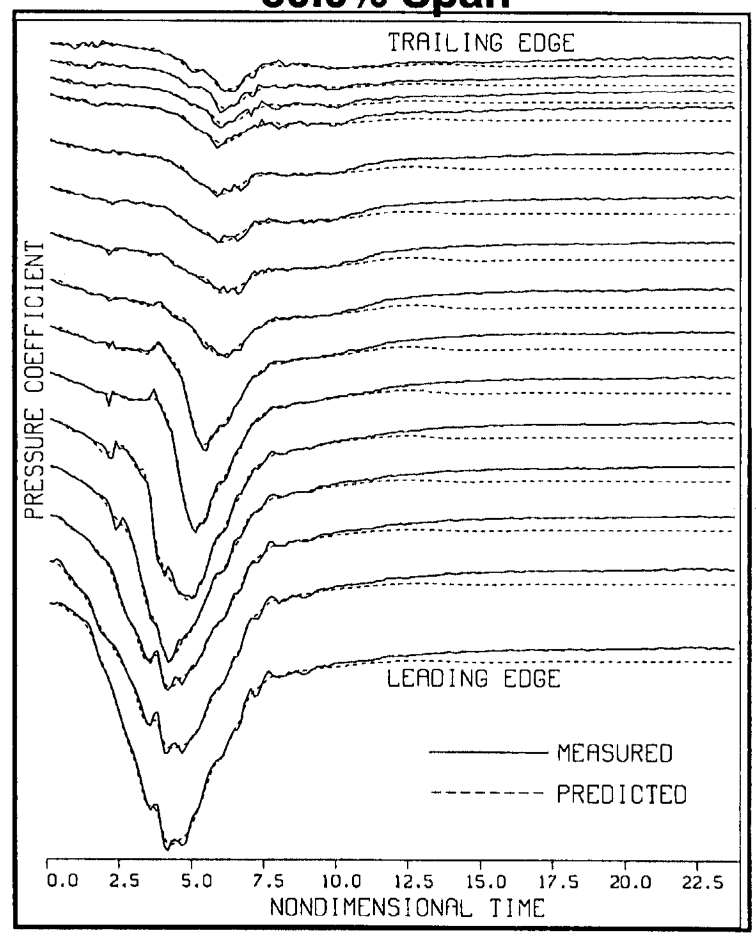
Model Replicates 3-Dimensionality

- **Constant rate pitch motion, $\alpha^+ = 0.20$**

37.5% Span

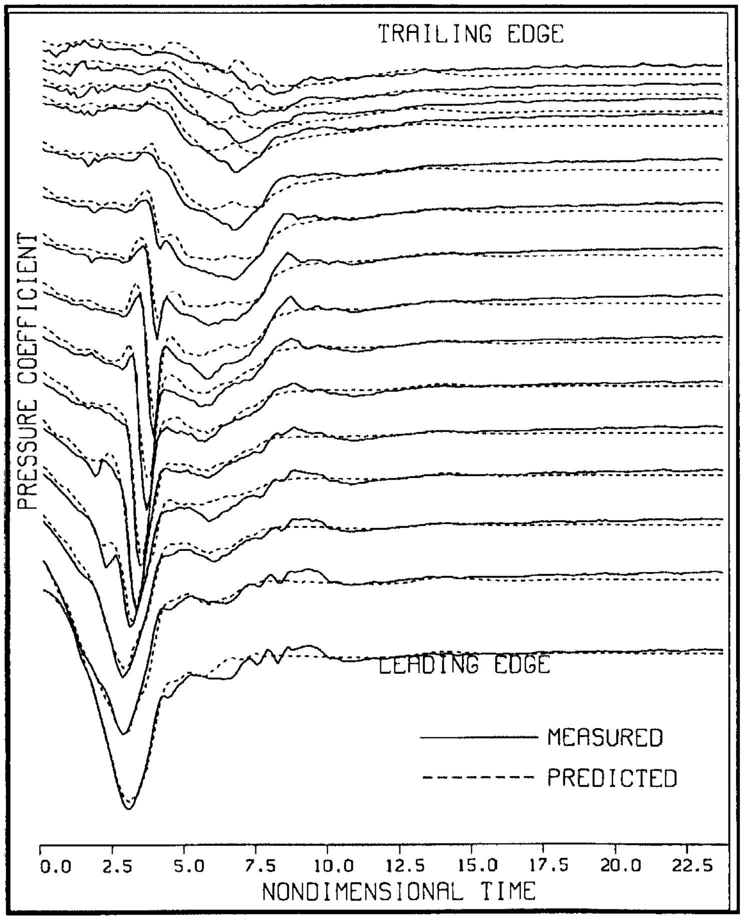


80.0% Span

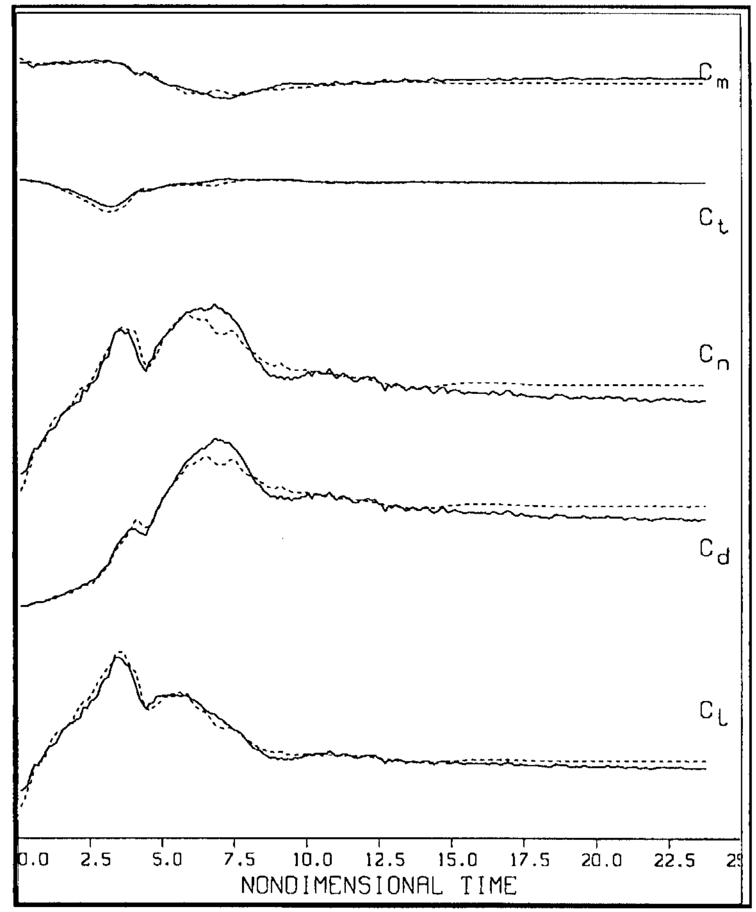


Model Interpolates to Novel Cases

- **Constant rate pitch motion, $\alpha^+ = 0.15$**



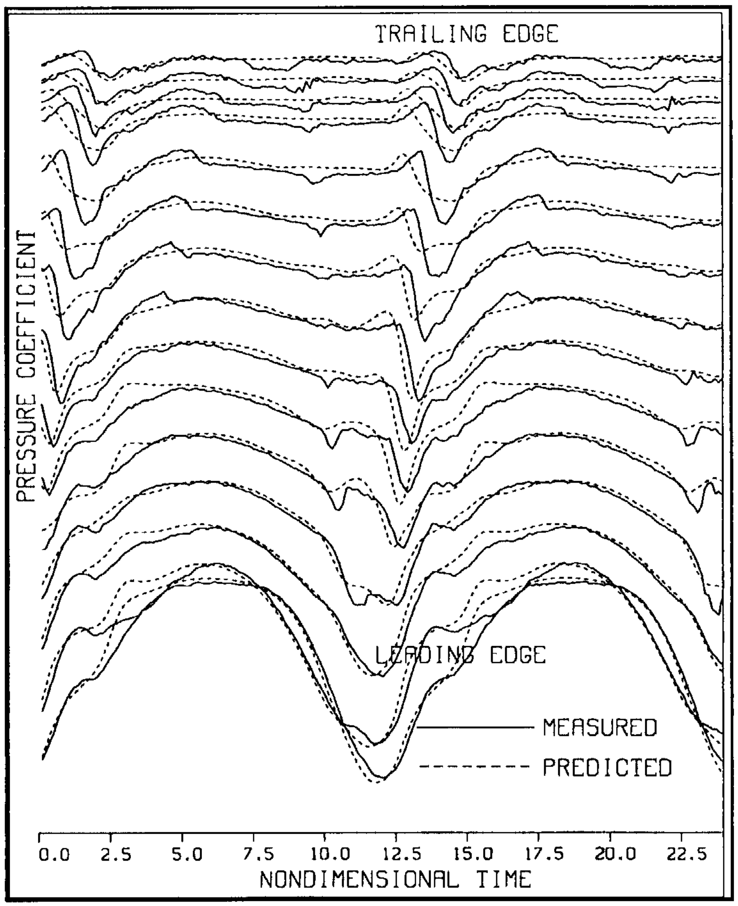
Surface Pressures



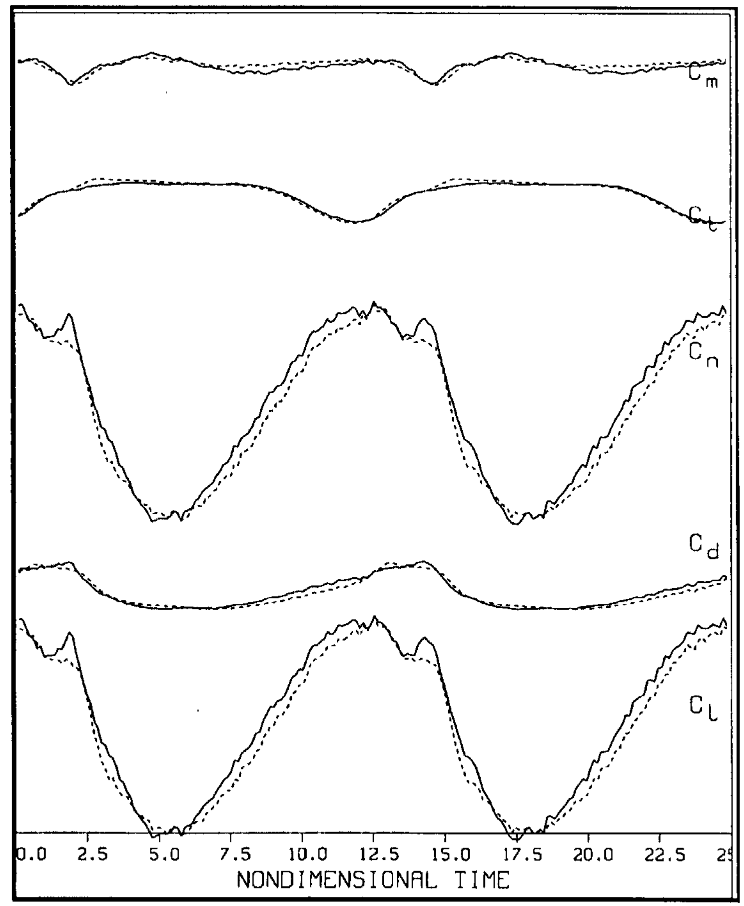
Aerodynamic Coefficients

Model Extrapolates to Novel Cases

- **Harmonic motion history, K = 0.25**

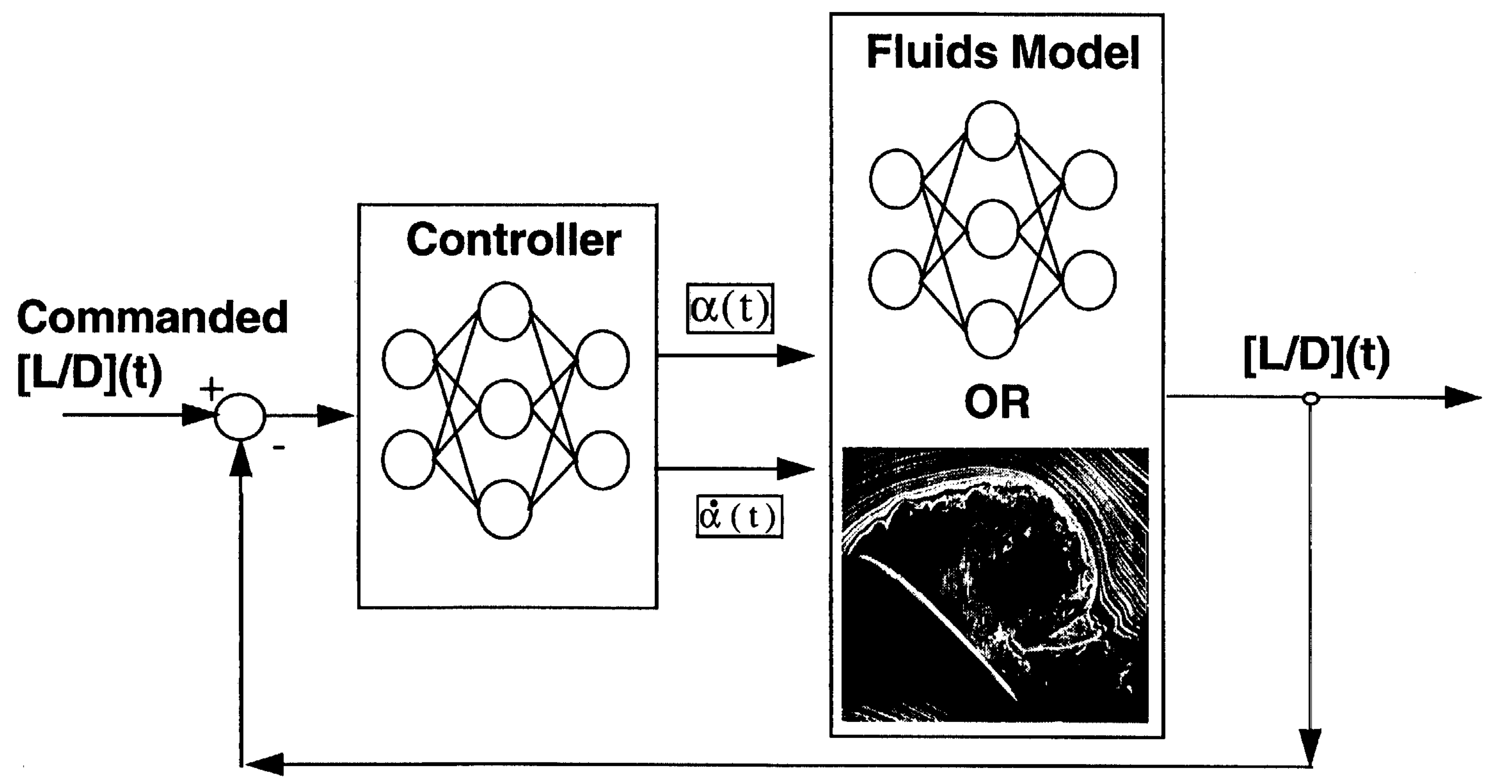


Surface Pressures



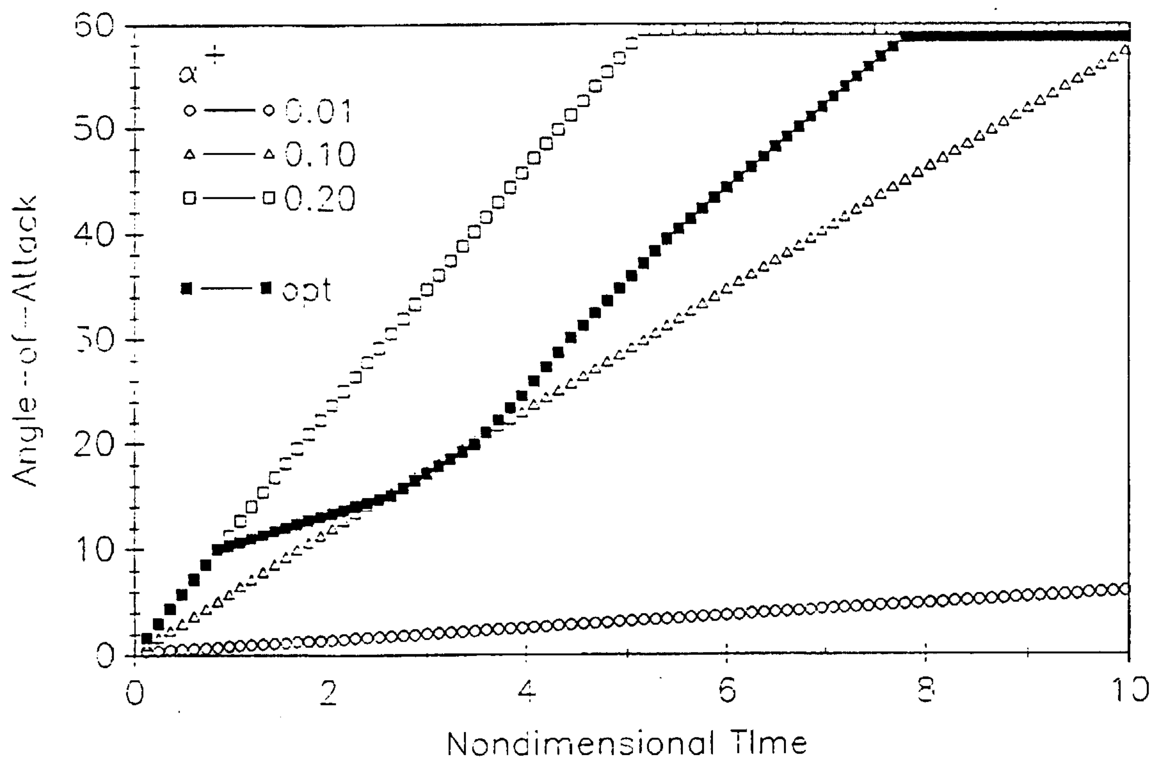
Aerodynamic Coefficients

Closed-Loop Neural Network Control of Unsteady Separated Flows

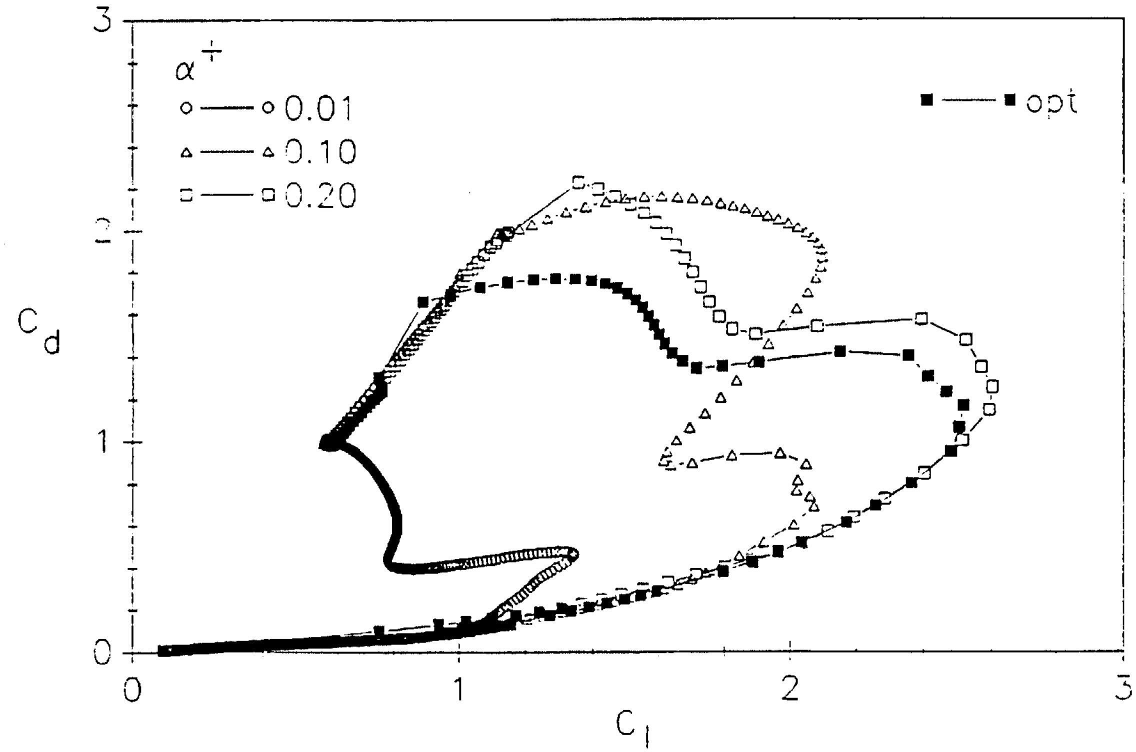


- Demonstrate Optimization and Control of Time-Dependent [L/D]

Neural Network Optimized Wing Motion History for [L/D](t)

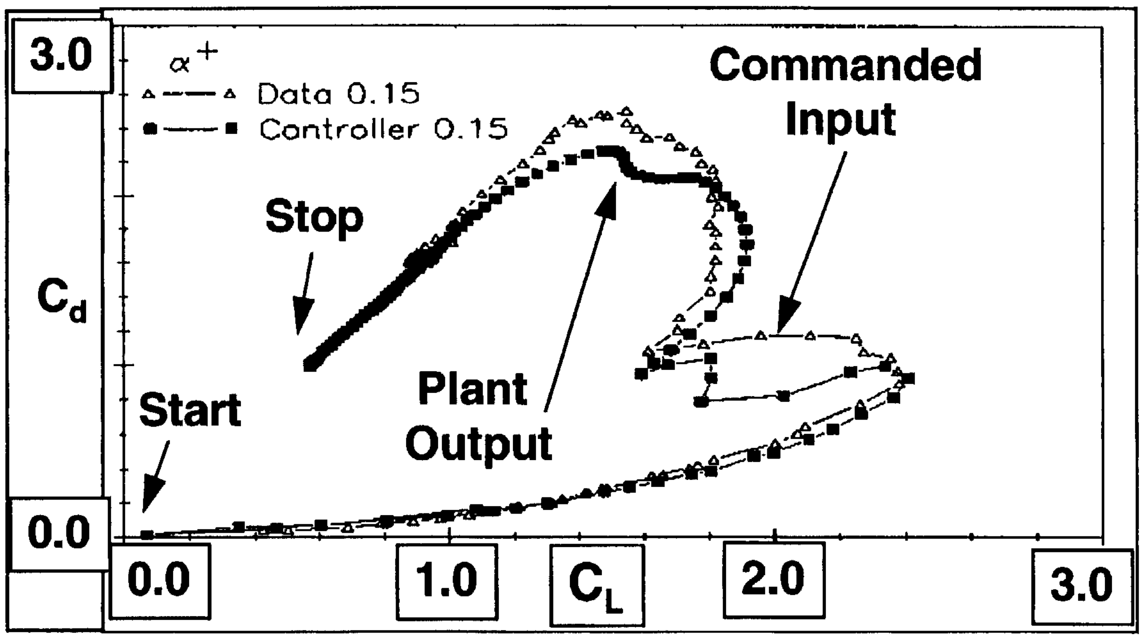


Neural Network Optimized Drag Polar



- Less Than 10% Loss in Lift
- 20% to 40% Decrease in Drag

Neural Network Controller Yields Commanded [L/D](t) for Novel Cases



- Neural Network Controller Trained on Limited Experimental Data
- Neural Network Controller Accurately Interpolates to Novel Cases

CONCLUSION

- Alternative (State-of-the-Art) Solutions

Computational Fluid Dynamics
  Two-Dimensional Solutions (No 3-Dimensionality)
  Computationally Intensive (10's of Hours of Cray Time)

To Date Control Of Unsteady Aerodynamics Has Not Been Demonstrated

- Neural Networks Offer Unique Opportunities:

Simplify Modeling of Three-Dimensional, Vortex Dominated, Unsteady Separated Flow Fields (Practical Geometries & Applications 3-D)

Effective Means for Controlling Unsteady Aerodynamics

Address Integration of Sensors, Actuators, Controllers and Time Lags Into Adaptive Control Systems