An Optimized Neural Network Approach for Rapid Aircraft and Spacecraft Venting Predictions

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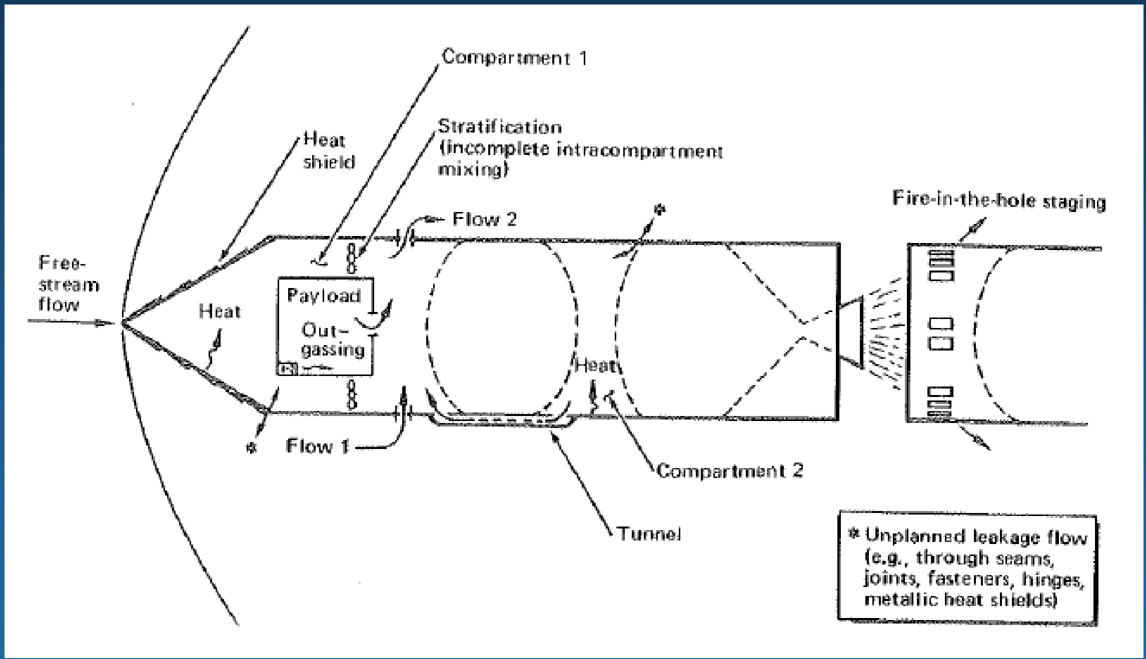

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Rapid Venting Analysis – Problem Statement

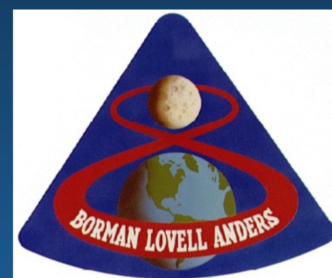
• **Background:** Venting of unpressurized vehicle compartments is important on both aircraft and spacecraft. Air moves between compartments and in/out of the vehicle via vents on the Outer Mold Line. For spacecraft, proper ascent venting (during launch) and descent venting (during re-entry) is important to reduce loads on the structure and components.

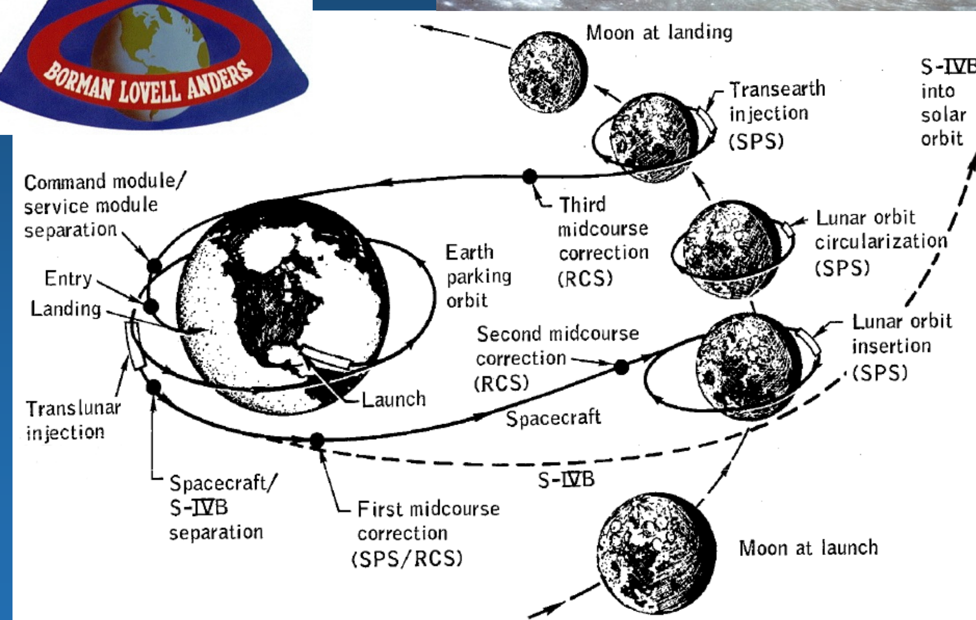
• **Problem:** In modern vehicle development programs, a large number of trajectories (100,000+) are generated to quantify the impacts from system and environmental dispersions. Aircraft/Spacecraft venting analysis tools can be time consuming to set-up and run. Therefore, only a modest number of trajectories can be evaluated with high-fidelity tools. Also, using simple semi-empirical indicators is not always effective at identifying the critical cases. Consequently, a more efficient method is required to quickly and accurately identify the critical cases for venting analysis.

• **Solution:** Develop a Matlab-based tool to "mimic" the high-fidelity venting analysis results sufficiently well for use as a filter to quickly identify the specific trajectories that are critical for venting.

Generation of Re-Entry Venting Data

- Generate Many Dispersed Trajectories From Available Apollo Data
- Apollo Command Module (CM) Aft Bay Unpressurized Volume

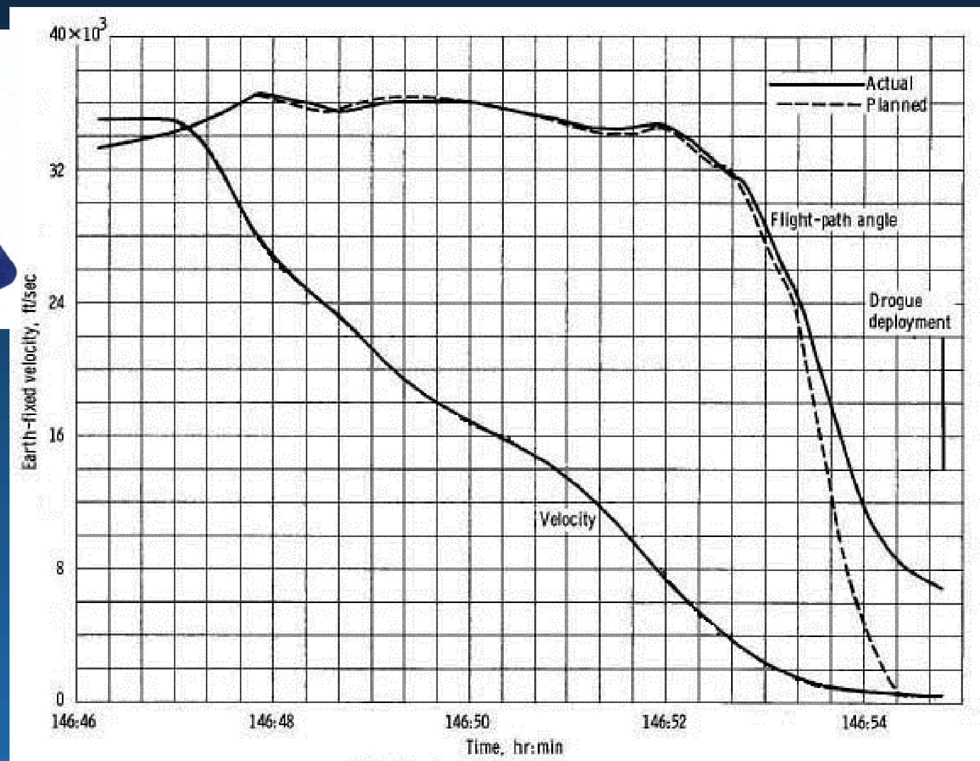




- Use Apollo 8 High Velocity Re-Entry Trajectory as the “Nominal” Case

Generation of Re-Entry Venting Data

- Apollo 8 Earth-Relative Velocity and Flight-Path Angle Time Histories



(c) Earth-fixed flight-path angle and velocity.

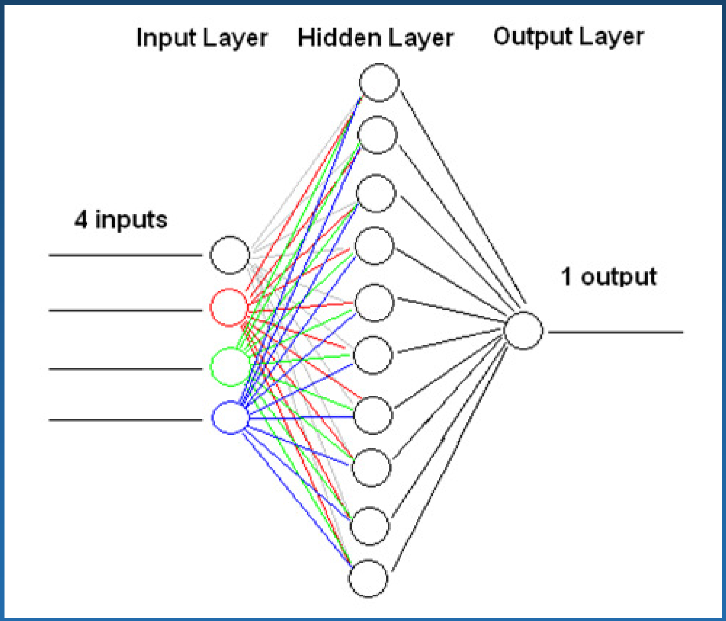
- Assumed Nominal 1976 Standard Atmosphere, Apollo Aerodynamics
- Reverse-Engineered the Flight Trajectory, absolute accuracy not critical
- "Disperse" the Atmosphere to Create 100,000 Unique Pressure Time Histories as BCs for the Aft Bay Compartment Venting
- Venting Analysis Results from *CHCHVENT* (NASA-Marshall) via Matlab

Rapid Venting Analysis – Overall Process

- Employ an Artificial Neural Network (NN) to “Mimic” the Results for the Venting Analysis for the Compartment(s) on the Vehicle
- Train the NN on High-Fidelity Venting Code Results for a Small Number of Diverse Cases
- NN Inputs are Based on the Freestream Static Pressure and Mach Number Time Histories, and Functions Thereof
- Use Genetic Algorithms (GA) to Optimize the NN’s Input Parameters
- Run the Trained NN Through the Dispersion Set to Identify Critical Trajectories for Venting (relative accuracy only)
- Run Those NN Identified Cases with the High-Fidelity Tool to Refine the Predictions and Bracket the Venting

An Artificial Neural Network

- An Artificial Neural Network is a Computer Program that Attempts to Simulate the Structure and Behavior of a Biological Brain
- The NN is Comprised of Interconnected Neurons
- Each Neurons Receives Inputs, and Employs an “Activation Function” to Produce an Output
- NNs use Multiple Layers, such as this 3-layer Feed-Forward NN (4/10/1)



- NNs Learn by Repeated Application of a Training Set to Adjust the Weights between Neurons
- Used for Pattern Recognition and as an “Universal Approximator”
- NN Inputs Optimized via a Genetic Algorithm (more on GAs later)

Rapid Venting Analysis – Process Maturation

- Selected Four Trajectory "outliers" from the 100,000 Cases
- Conducted *CHCHVENT* Venting Analysis on These Four Trajectories
- Each Trajectory Case Included Input Data and Venting Results at 10 Hz, One Trajectory has ≈4600 Training Cases (10Hzx8'x60"/'=4600)
- Initially a 9/20/1 NN was Trained Using P_∞, dP_∞/dt, and P_∞ Moving Averages (MAs) of 1", 5", 10", 15", 20", 25", and 40" as Inputs
- Output was Pressure Differential (ΔP) Between Compartment P and P_∞
- NN Work Performed in Matlab using the *Neural Network Toolbox*

- The NN's MA Intervals were Changed to 1", 3", 5", 10", 15", 25", and 40", to Eliminate an Observed ≈1/2Hz Oscillation

- Freestream Mach # was Added as a New NN Input to Improve Results

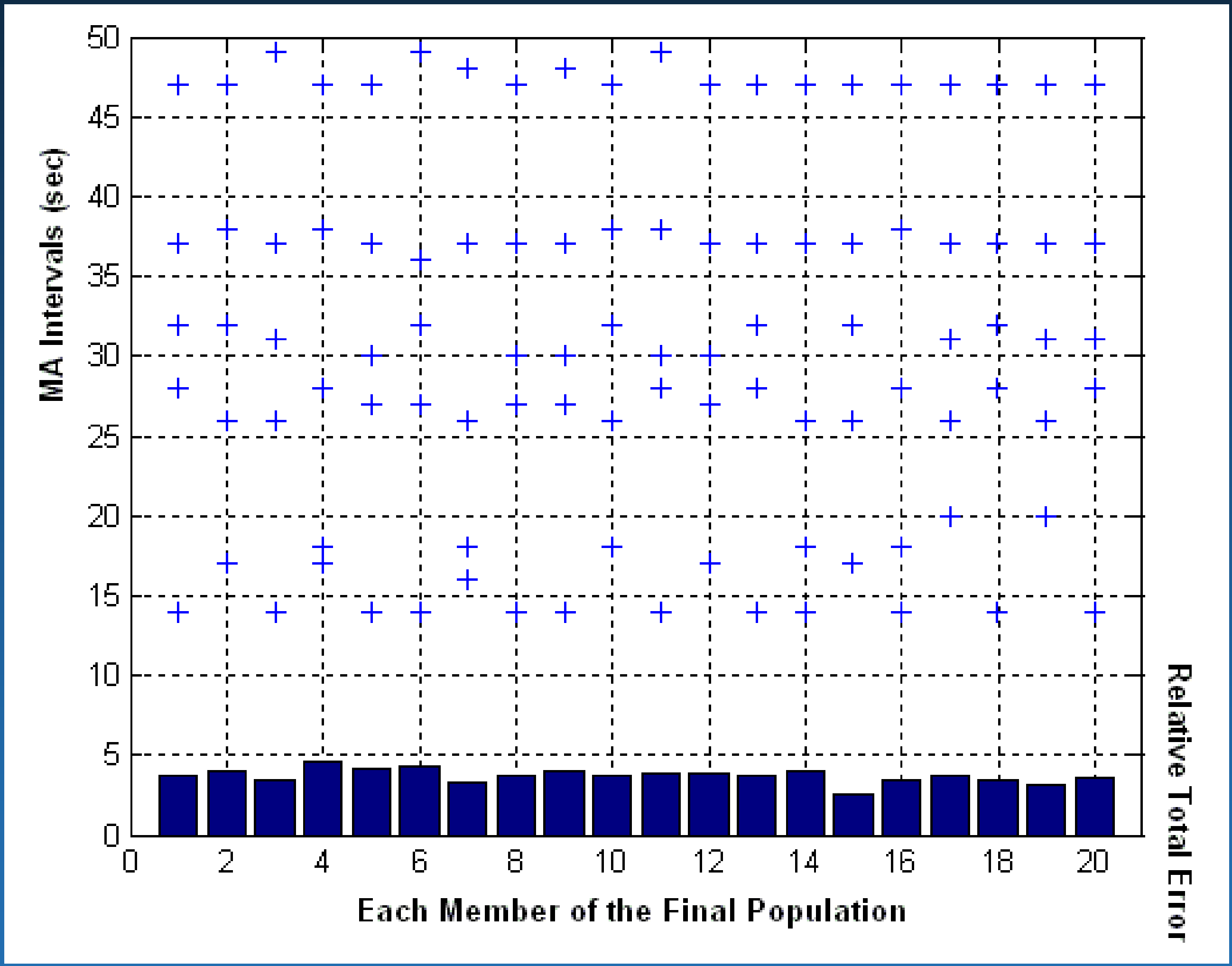
- NN's MAs were then Optimized via a Genetic Algorithm
    - 1"MA and 3"MA were retained to stop low-frequency oscillations
    - Five other MA time periods were constrained to the range 5"<MA_i<50" (MAs limited by available data) and optimized
    - GA Optimization found 10", 17", 27", 37", 50" as the best MA set
    - GA Work Performed in Matlab via *Genetic Algorithm and Direct Search Toolbox*

Genetic Algorithm Primer

- **What:** Genetic Algorithms are a class of highly-adaptable optimization approaches used in a wide range of applications.
- **How:** A GA is a computer program that finds a near optimal solution by mimicking the evolutionary concepts of Charles Darwin. A given problem solution is characterized by a series of chromosomes and each is compared against rival solutions in a solution population.
- **Why:** GAs are very adaptable and can quickly find a near optimal solution. A variety of constraints and cost functions can be used.
- **Implementation Details:**
  - **The Chromosome:** The answer to the optimization problem is decoded from a chromosome. Each chromosome represents one solution.
  - **The Population:** A GA finds optimal solutions by interbreeding the chromosomes within a given solution population. Additionally, the best members of each population are carried over to the next generation.
  - **The Constraints:** Do not permit certain chromosomes from existing.
  - **The Cost Function:** Each solution is evaluated via a cost function, which can include a wide variety of economic and non-economic factors.
  - **Convergence History:** Experience has shown that GAs are very adaptable and can quickly find a near optimal solution.

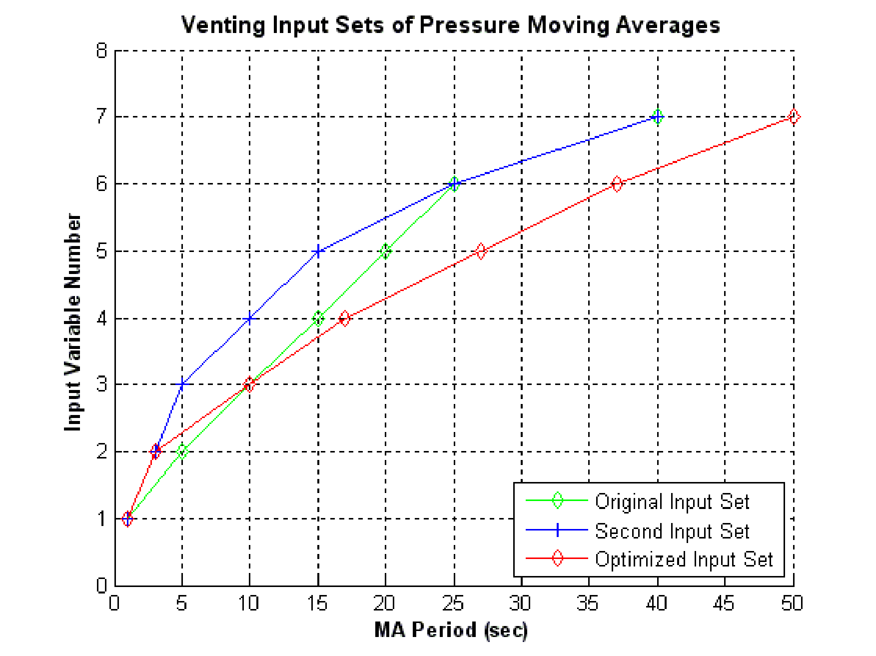
Rapid Venting Analysis – GA Optimization

- **Partial GA Results Showing Typical Trends**



- **After Many Generations, GA Results Clearly Show Preferred MAs**

Rapid Venting Analysis – Results



- All 100,000 Trajectories Evaluated with GA/NN Tool (3" per trajectory)
- Peak |ΔP| Value Predicted within ±1.3% and within ±0.25 seconds
- Worst Three Dispersed Trajectories were Correctly Identified, In Order
- 18 of the Worst 20 Identified
- Innovative Approach to Evaluate Many Trajectories for Screening
- Useful in Trajectory Design as an Indicator, Constraint, or as part of the Optimization Cost Function
- Higher-Accuracy Versions have the Potential to Provide Absolute Venting Analyses of Known Configurations

Summary

- Aircraft and Spacecraft Unpressurized Compartment Venting Problem
- Apollo Crew Module Design and A-8 Re-Entry Trajectory Re-Construction
- Overall Process of Using Neural Networks to “mimic” Venting Results
- One-Page Primer on Neural Networks
- Maturing Neural Network Configurations and Input Variables
- One-Page Primer on Genetic Algorithms
- Results From GA-Optimization of the NN Input Variables
- GA/NN Comparisons to the High-Fidelity Results
  - Peak $|\Delta P|$ Value Predicted within ±1.3% and within ±0.25 seconds
  - Worst Three Trajectories Identified in Order
  - 18 of the Worst 20 Identified
- An Innovative and Efficient Approach to Conduct Venting Analysis