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Physics Informed Neural Networks for Turbo-Jet Engine Control using SimTurbo©

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Physics-Informed Neural Networks for Turbojet Engine Control

Problem Statement: Safe, Optimal Transient Control in Extreme Flight Regimes

- **The System:** Single-spool gas turbine engines are governed by complex, non-linear Brayton cycle thermodynamics.
- **The Environment:** Operational envelope spans extreme variations in:
 - Altitude
 - Mach number
 - Atmospheric pressures
- **The Control Challenge:** Maximize transient response speed while strictly enforcing physical surge and thermal limits.
- **The Core Gap:** Classical controllers struggle with rapid atmospheric transitions, while standard black-box AI lacks structural safety guarantees.



Proposed Solution: Physics Informed Neural Networks (PINN) for Turbo-Jet Engine Control Solution

DEEP LEARNING COMPONENT Data-Driven Neural Network

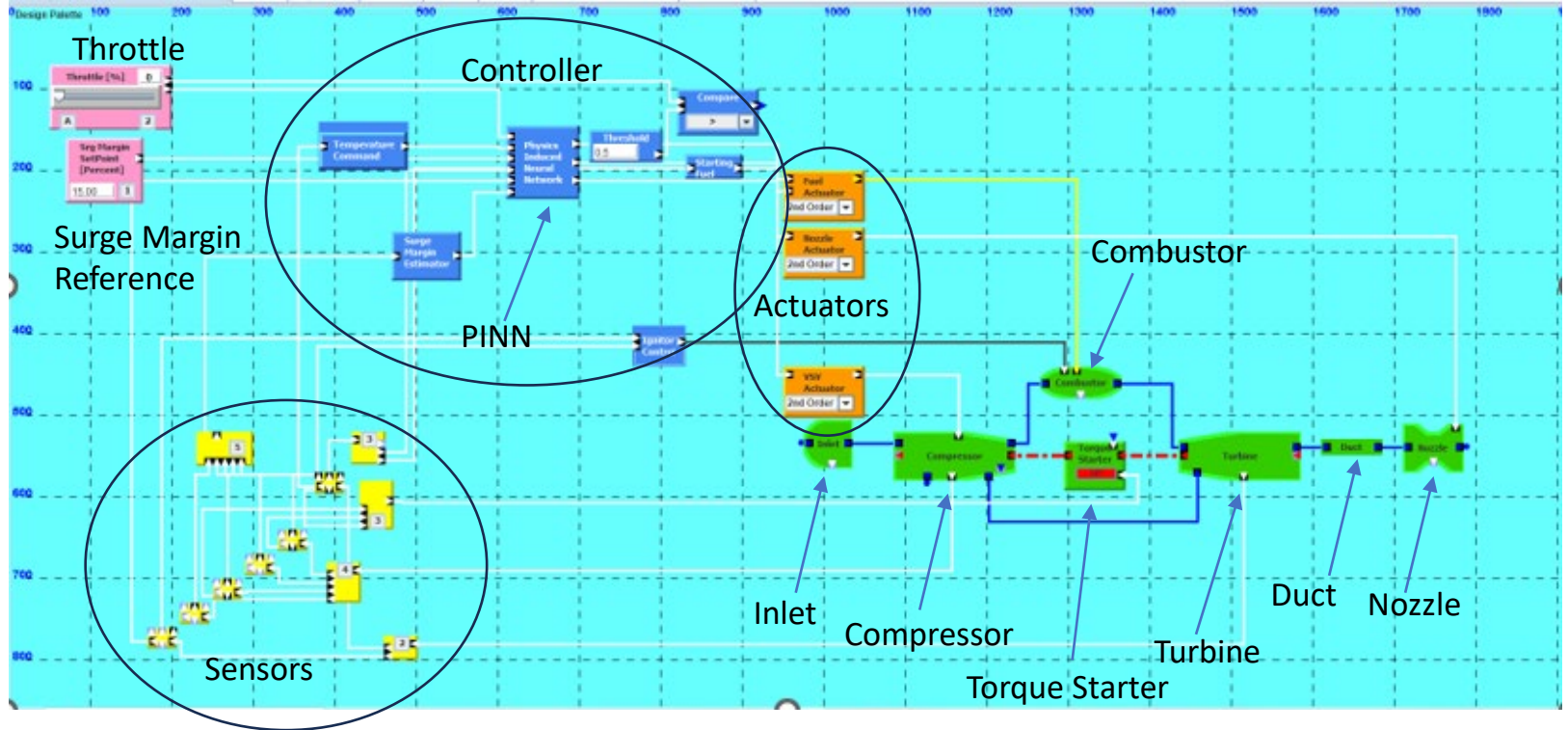
- Inputs (x): Altitude, Mach Number, Fuel Rate (W_f), Ambient Temperature
- Outputs (y): Engine Speed (RPM), Turbine Inlet Temperature (TIT), Surge Margin

PHYSICS-INFORMED CONSTRAINTS Loss Function Penalties (The Soft Constraints)

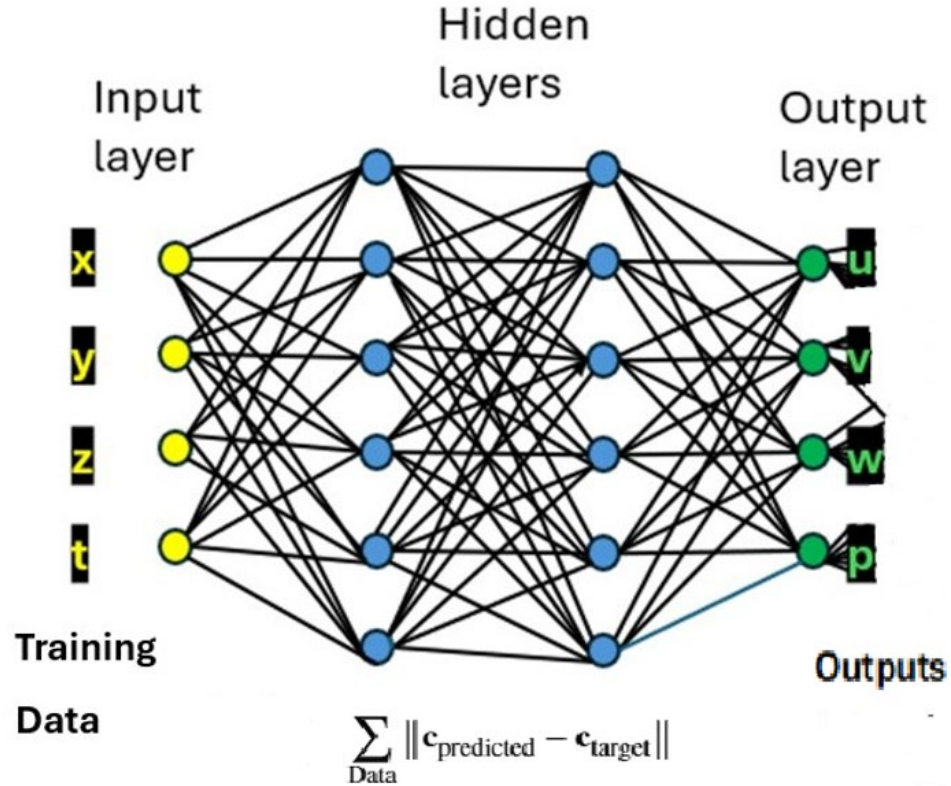
- Mass & Energy Conservation: Governed by the thermodynamic Brayton Cycle
- Hard Safety Boundaries: Penalty terms enforce $TIT < 1,800^{\circ}F$ and $Surge\ Margin > Safety\ Limit$
- Gradient Tracking: Exact partial derivatives calculated via Automatic Differentiation (AD)



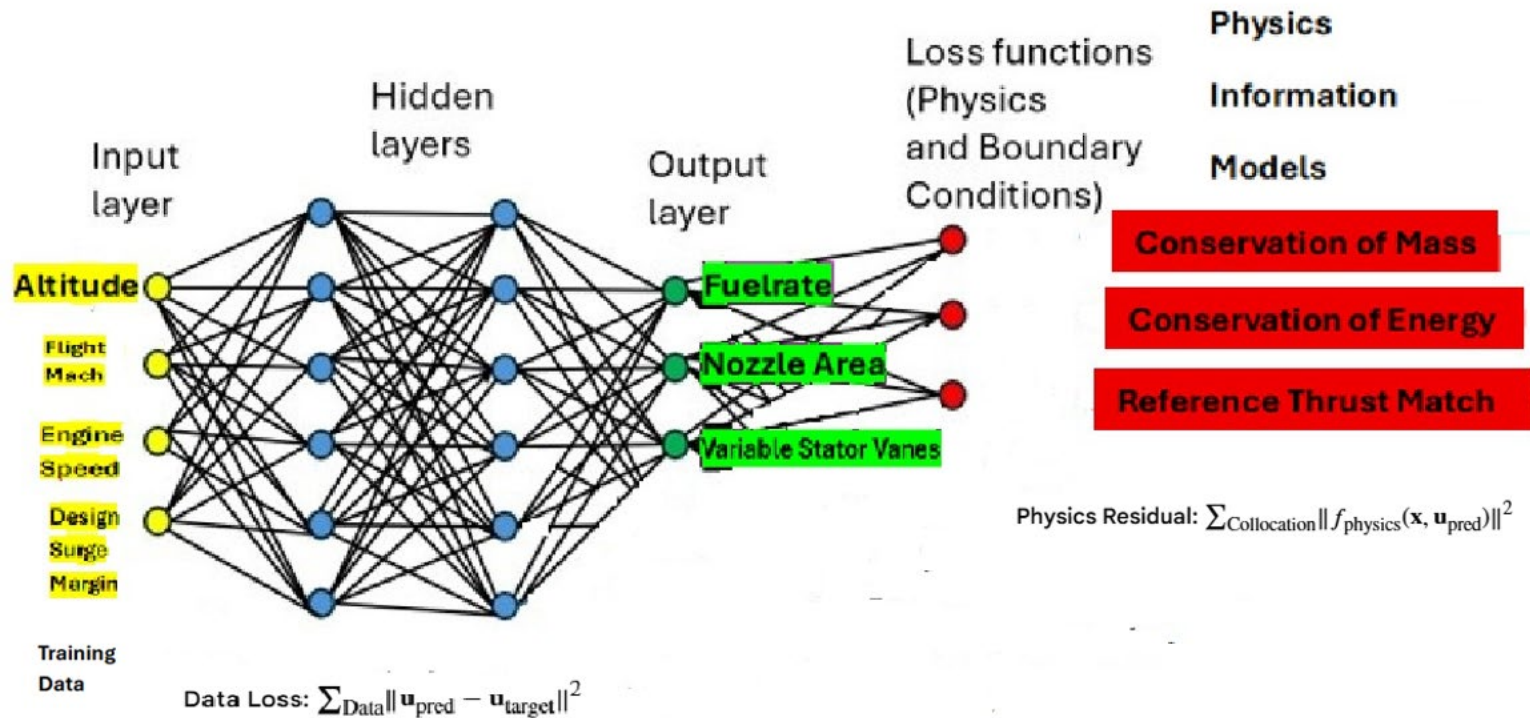
High Level Schematic of Transient Simulation of Single Spool Turbo-Jet Engine with Physics Informed Neural Network (PINN) Control



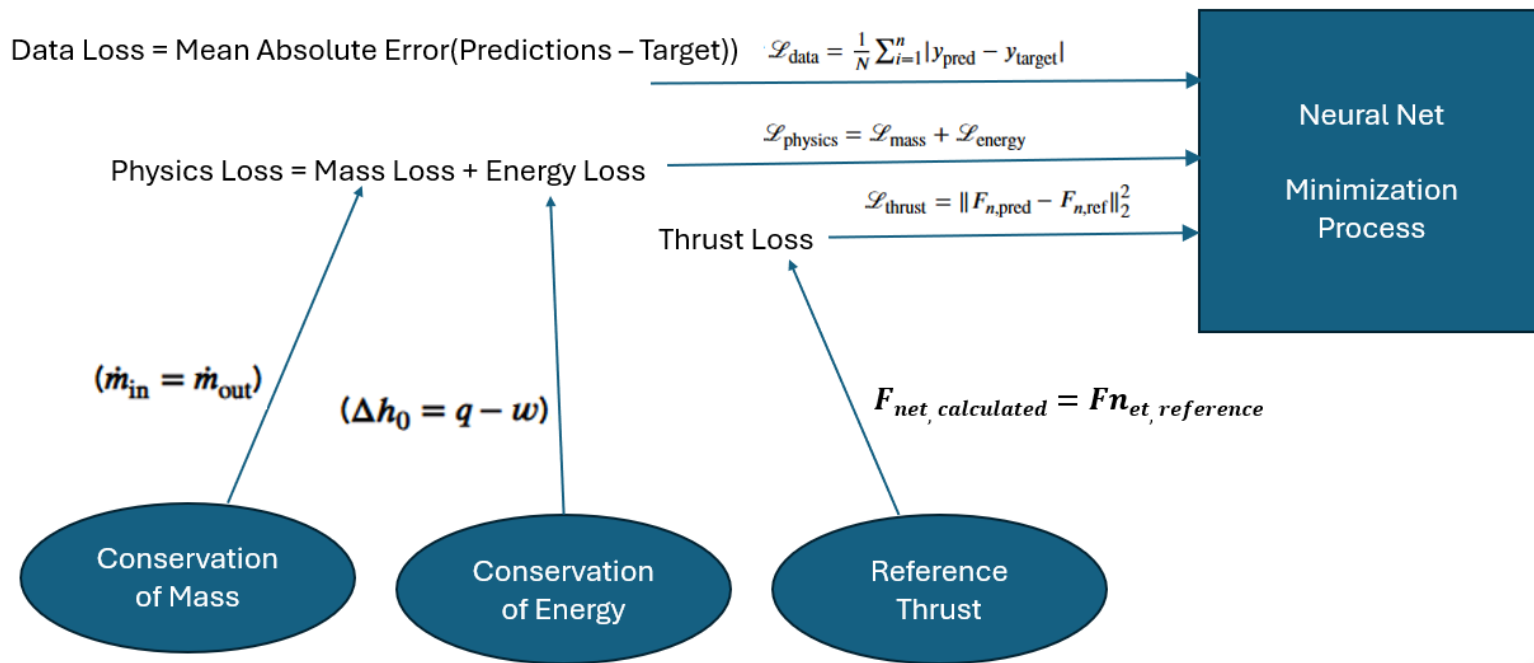
Basic Neural Network



Model Training with Physics Informed Neural Net (PINN)



Methodology: Multi-Objective Loss Formulation for a Single-Spool Turbojet PINN



Structure of Physics Informed Neural Net (PINN)

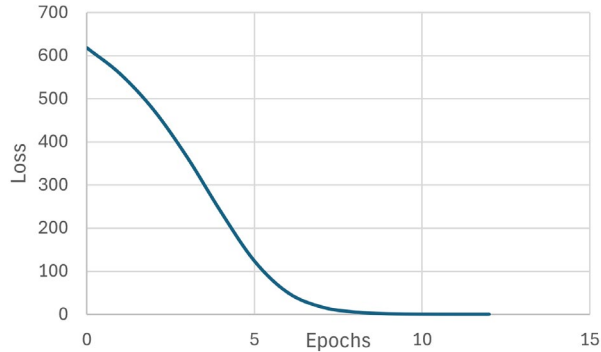
GE J85-21 Turbojet Engine Simulation

PINN Attribute	Value	Engineering Justification
Number of Input Nodes	4	Characterize Flight Domain
Number of Hidden Layers	4	Balances deep representations of the physics.
Number of Nodes for Hidden Layers 1 through 3	128	Large capacity to capture coupled, multi-variable thermodynamic states.
Number of Nodes for Hidden Layer 4	64	Tapered “funnel” to compress information into final layer.
Number of Output Nodes	3	One per Control Actuator.
Data Loss Weight	50000	INCREASED: Force matching the exact curve shape
Thrust Loss Weight	50000	INCREASED: Force matching the exact curve shape
Mass Loss Weight	0.001	Keep physics minimized as soft boundary regulations
Energy Loss Weight	0.001	Keep physics minimized as soft boundary regulations
Hidden Layer Activation	Swish	Smooth, non-zero derivatives for stable calculations.
Output Layer Activation	Static, Sigmoid	Static bounding to Control Actuator Steady State Values.
Learning Rate	2e-3 to 1e-4	Reduces for finer accuracy as Epochs increase.



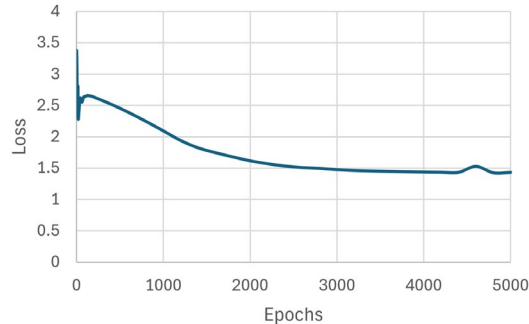
Physics Induced Neural Network Normalized Loss Values

Data Loss

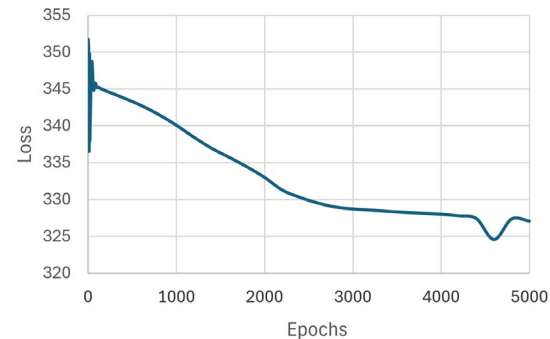


- **Gradual Convergence**
- **Prioritized Goal Tracking**
 - **Larger Weighting on**
 - **Data**
 - **Thrust**
- **Asymptotic Stability**
 - **Smooth, flat behavior**
 - **Small Oscillation**
 - **No Over-fitting**

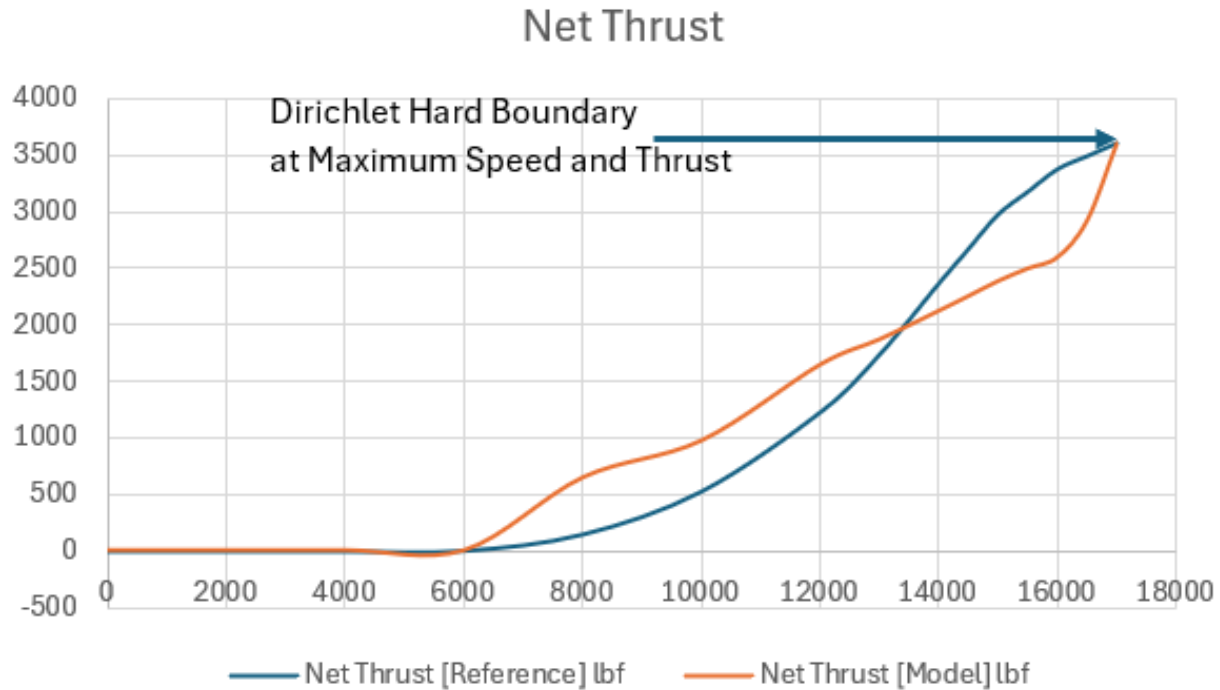
Physics Loss







Thrust Loss



Thrust Modeling

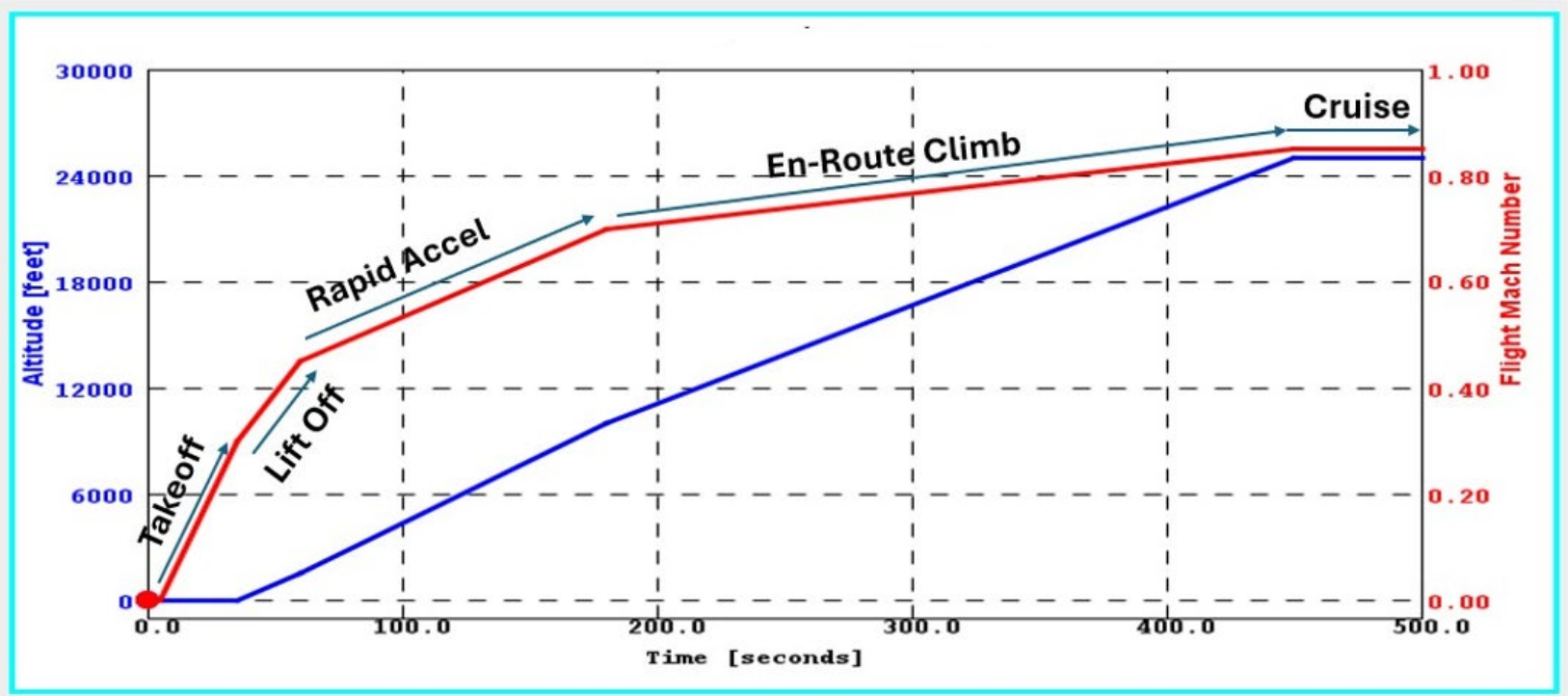


Intelligent Multi-Variable Controller for GE J85-21 Turbojet Engine

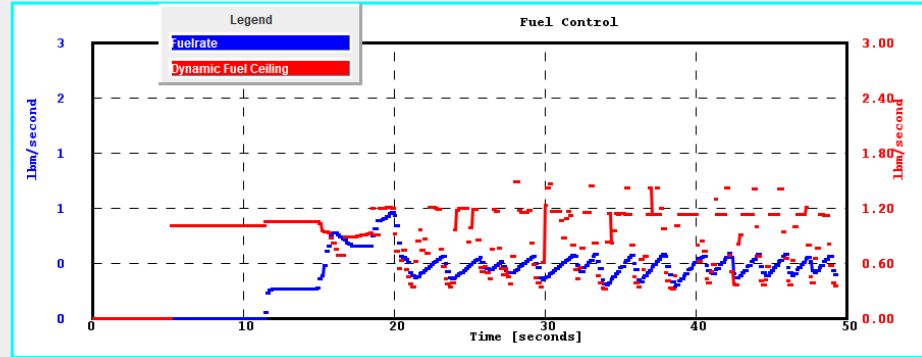
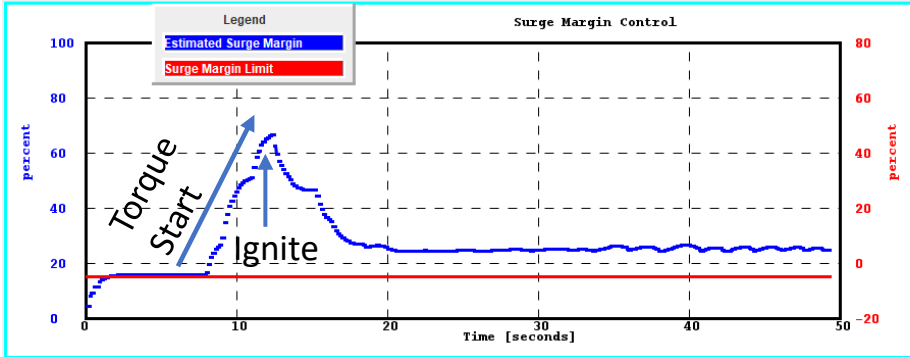
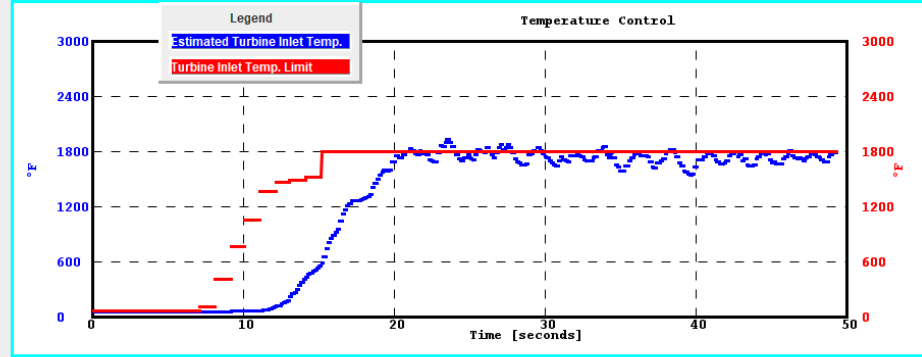
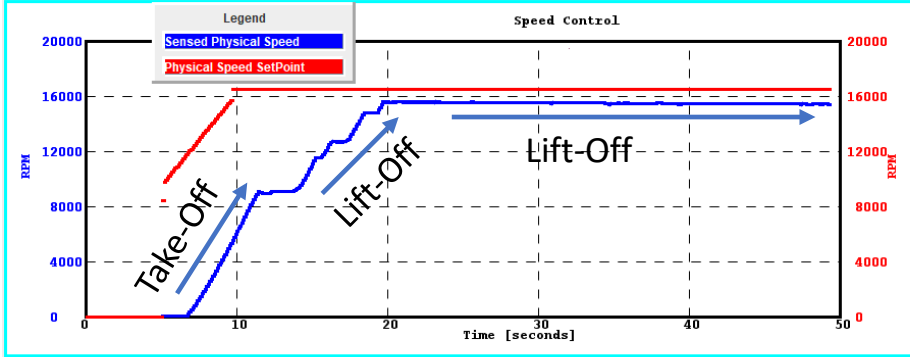
-  **Guaranteed Boundary Enforcement:** Eliminates critical turbine over-temperature violations (T_4) by riding exactly on the 1,800°F life-extension limit while maintaining a safe compressor surge margin floor above 15%.
-  **Asymmetric Transient Agility:** Deploys an asymmetric rate limiter providing an instant fast-attack safety override (1.75 lbm/s^2) to clip thermal spikes, while locking down steady-state cruise adjustments (0.20 lbm/s^2) [3.1].
-  **Complete Actuator Stabilization:** Successfully resolves high-frequency numerical chattering and two-frame algebraic loop toggle noise, condensing wide scatter clouds into a clean, smooth, unified tracking trace.
-  **Real-Time Deterministic Readiness:** Eliminates complex classical PID gain-scheduling networks by natively coordinating multi-variable fuel flow and variable geometry within a single, continuous physics-informed model.



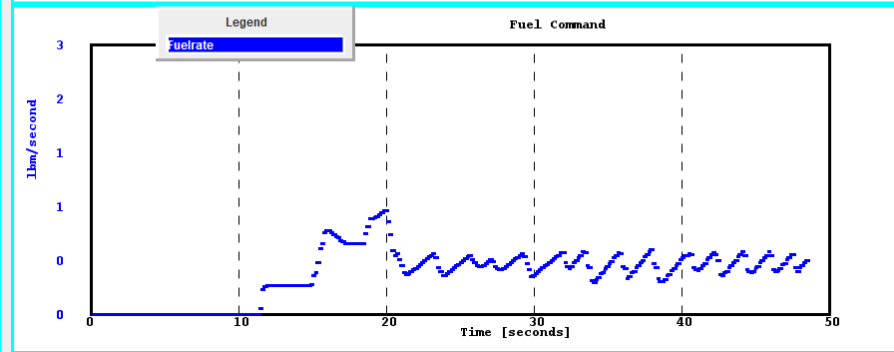
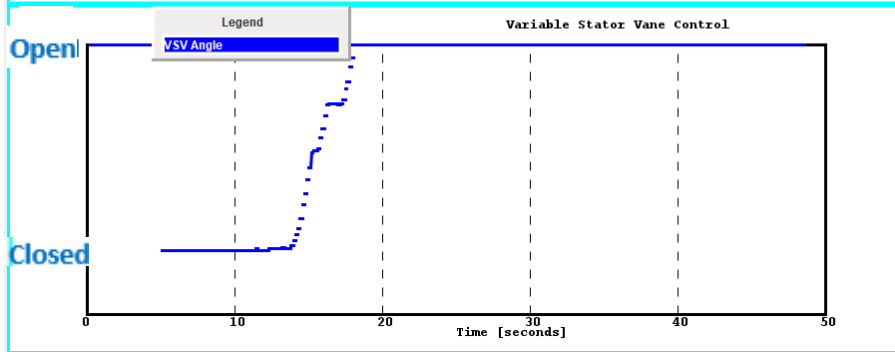
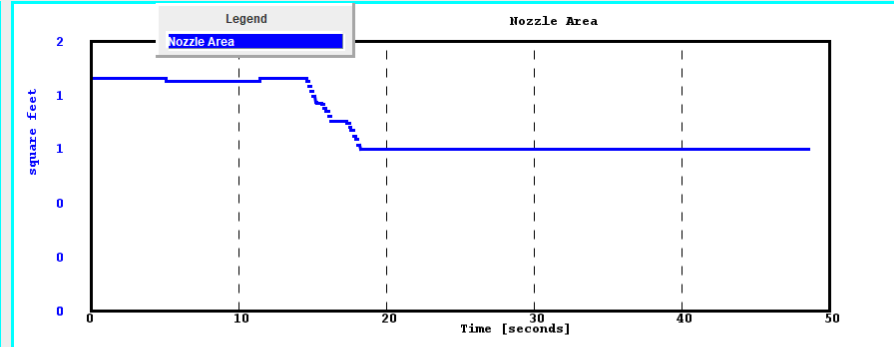
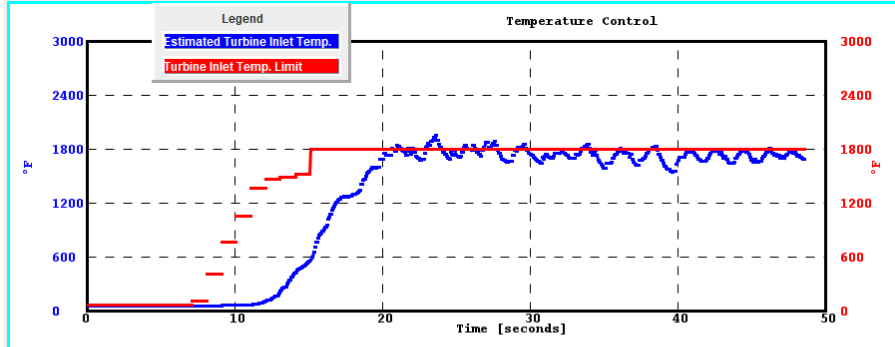
Typical Flight Profile for GE J85-21 Single Spool TurboJet Engine



Simulation Results for "Intelligent FeedForward with Multi-Variable Fuzzy Selector" for GE J85-21 Turbojet Engine (Initial Ascent)



Simulation Results for “Intelligent FeedForward with Multi-Variable Fuzzy Selector” for GE J85-21 Turbojet Engine (Initial Ascent) – Nozzle and VSV Control



Simulation Results for “Intelligent FeedForward with Multi-Variable Fuzzy Selector” for GE J85-21 Turbojet Engine (Complete Flight Profile)

