Journal of Solid and Fluid Mechanics (JSFM), 15(4): 19-21, 2025

Shahrood University of Technology

Journal of Solid and Fluid Mechanics (JSFM)

DOI: 10.22044/jsfm.2025.15197.3904

Manufacturing Engineering of Iran

# Non-Linear Modeling and Design of Control System for an Aero Gas Turbine Engine Using NARMA L-2 Neural Network

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Received: 10/26/2024 Revised: 07/28/2025 Accepted: 08/19/2025

## Abstract

Modeling the behavior of a gas turbine system and designing its control has always been of interest to researchers in this field. Proper modeling allows the implementation of a suitable controller on a dynamic system, and using suitable control, the system can be controlled in the best and safest way possible. In the design of gas turbine control, due to the existence of irreparable risks to the system, protective constraints must be observed. These risks include surge, turbine overheating, and flame extinction. In this study, a non-linear model of the J85 engine was initially built, and its results were validated with the Gasturb software. The validation results show that the maximum error for this engine in the compressor pressure ratio and turbine inlet temperature in transient conditions is 5 and 5.8 percent, respectively. Then, using the Narma L-2 neural network and the Min-Max protection constraints, a controller was designed for this system. The designed controller is able to maintain the surge limit at the idle to maximum speed maneuver above 5% and prevent turbine over temprature and flame-out, and its constant error value at the design point is zero.

**Keywords:** Turbojet; Neural Network Controller; NARMA L-2; Min-Max

## 1. Introduction

Gas turbines have always been one of the most crucial technologies for power generation and thrust production. In fact, it can be said that the primary requirement for any airborne system has consistently been its thrust generation component. The issue of designing and simulating these systems has always attracted the attention of researchers, and various methods have been proposed for simulating and analyzing the performance of gas turbines. On the other hand, controlling these systems and designing a control system is one of the most critical challenges in this industry. A well-designed control system can prevent potential hazards from occurring.

Based on the reviewed literature, it has been identified that accurate nonlinear modeling assuming volumetric effects, along with the implementation of NARMA-L2 control for this specific system to control the model from idle to maximum speed and vice versa, has not been previously undertaken. The innovations of this research can be stated as follows:

- Implementation of a nonlinear engine model with integral equations in the Simulink environment.
- Implementation of an NARMA-L2 controller coupled with a Min-Max protective criterion for an aircraft gas turbine engine. This is significant as most references using this approach have focused solely on industrial engines.
- Implementation of idle-to-maximum and maximum-to-idle speed maneuvers. In references that have used this controller for engine control, commands were used for small maneuvers which do not threaten the engine, thus eliminating the need for protective constraints.

## 2. Methodogy

The behavior of a gas turbine is nonlinear, and all its dynamic and thermodynamic behaviors must be examined. The dynamics of a gas turbine are divided into three parts [1]:

- Shaft Dynamics
- Pressure Dynamics
- Thermal Dynamics

Transient control for a gas turbine is of paramount importance. This control system must be capable of covering the entire range of flight speeds and altitudes. The dynamics of the gas turbine system are inherently nonlinear. In this project, no linearization was performed for control purposes, and the equations were

modeled in their original nonlinear form. Consequently, during system operation, the controlled system has the potential to exceed all its operational limits.
Some of these limits include the physical limit of shaft rotational speed, the maximum temperature for turbine blades, compressor surge or stall, and combustion flameout. In gas turbine control, two main objectives are discussed [2]:

- Preventing the engine from reaching critical conditions** that could lead to engine destruction, such as compressor stall and surge, excessive temperature rise in the turbine (overtemperature), or flame extinction (flameout).
- Maintaining optimal performance** during engine transients or changes in external environmental conditions.

In this research, it has been decided to utilize an NARMA-L2 controller for the intended engine. This controller employs neural networks to predict the behavior of the nonlinear plant. The control system calculates the control inputs to enhance the system's performance over time and, among control models, requires minimal computation. Its training is performed batch and offline. The only online computations involve the forward pass of the neural network.

## 3. Results and Discussion

For transient validation, a two-step maneuver over a twenty-second duration was considered. Three distinct speed points (e.g., idle, intermediate, maximum) were selected for this maneuver. The results (Table 1) demonstrate that the model developed in Simulink possesses high validity.

**Table 1. Simulink model Validation**

| Parameters | Experimental [3] | Current research | Error (Percent) |
|---|---|---|---|
| Thrust (N) | 14.4 | 14.57 | 1.2 |
| Comperessor Exit Pressure (kPa) | 1011.3 | 1033.85 | 2.2 |
| Comperessor Exit Temprature (K) | 531.7 | 547.33 | 2.9 |
| Turbine Exit Pressure (kPa) | 261.7 | 271.72 | 3.8 |

One of the maneuvers the engine must be able to perform is the transition from maximum speed to idle speed and vice versa. Figure 1 illustrates the controller's response for this maneuver. The engine controller's performance indicates that the designed NARMA-L2 controller is free from any steady-state error. It executes the deceleration maneuver in 12 seconds and the acceleration maneuver in 13 seconds.

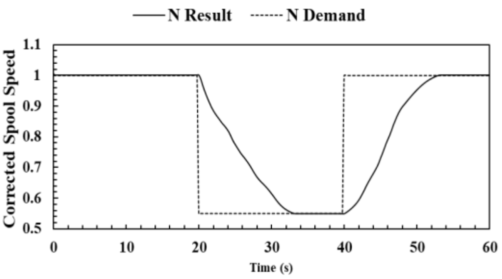


**Figure 1. Controller Response to input demand**

The surge margin and turbine inlet/outlet temperature profiles are also provided in Figures 2 and 3, respectively. These figures show that the surge margin never dropped below five percent, and no severe thermal oscillations occurred that would lead to excessive turbine temperature or flame extinction. During the deceleration maneuver, the maximum temperature overshoot did not exceed 10 percent.

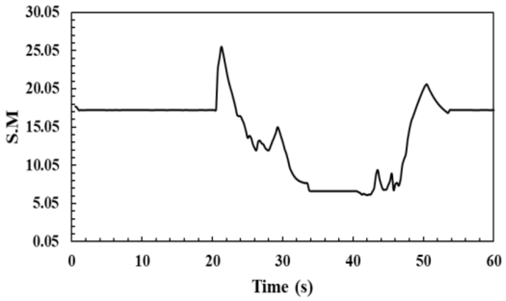


**Figure 2. Surge margin in maneuveor**

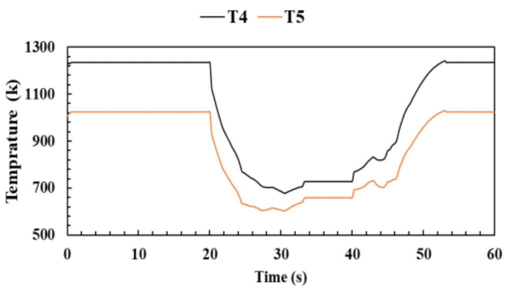


**Figure 3. Turbine inlet & outlet tempratue in maneuver**

## 4. Conclusions

In this research, a nonlinear model of the J85 turbojet engine was first developed in the Simulink environment, assuming volumetric effects, and was subsequently validated. The validation results indicate that the modeling is highly accurate. The maximum error for the compressor pressure ratio and thrust force parameters is 5% and 8.76%, respectively, demonstrating the high accuracy of the modeling performed in Simulink.
Subsequently, using an NARMA-L2 neural network, a controller was designed, on which Min-Max protective constraints were also implemented. The results of the controller's response during two maneuvers (from idle to maximum speed and vice versa) show that the engine

can perform the maximum-to-idle and idle-to-maximum speed maneuvers within a safe margin in 12 to 13 seconds. Throughout this maneuver, the surge margin does not drop below 7% to prevent any risk to engine health. Furthermore, any spikes in turbine temperature during the acceleration maneuver were prevented. Consequently, the engine has been able to undergo these two maneuvers safely and within an appropriate timeframe.

Finally, suggestions for future work can be offered. Some of these suggestions pertain to a more detailed analysis of the controller's behavior, including stability and disturbance analysis, while others relate to improving the model's performance. These are outlined below:

- Implementation of a black-box engine model for greater modeling accuracy.
- Optimization of the neural network controller's training process for higher accuracy and the use of less data.
- Implementation of other protective constraints to expedite the engine's safe operation.
- Comparison of the controller with other neural network-based control methods.
- Stability analysis of the controller's behavior.

## 5. References

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