VALIDATION AND VERIFICATION OF AIRCRAFT CONTROL SOFTWARE FOR CONTROL IMPROVEMENT

A Project Report

Presented to

The Faculty of the Department of Computer Science

San Jose State University

In Partial Fulfillment

of the Requirements for the Degree

Master of Science

by

Thien-Anh Pham

May 2007

APPROVED FOR THE DEPARTMENT OF COMPUTER SCIENCE

Dr. Chris Tseng
Professor of Computer Science Department, San Jose State University, San Jose, California

Dr. Agustin Araya
Professor of Computer Science Department, San Jose State University, San Jose, California

Dr. Johann Schumann
Member of the Robust Software Engineering Group RSE at NASA Ames, Moffett Field, California

APPROVED FOR THE UNIVERSITY

ABSTRACT

VALIDATION AND VERIFICATION OF AIRCRAFT CONTROL SOFTWARE FOR CONTROL IMPROVEMENT

by Thien-Anh Pham

Validation and Verification are important processes used to ensure software safety and reliability. The Cooper-Harper Aircraft Handling Qualities Rating is one of the techniques developed and used by NASA researchers to verify and validate control systems for aircrafts. Using the Validation and Verification result of controller software to improve controller's performance will be one of the main objectives of this work. Real user feedback will be used to tune a PI (Proportional Integral) controller in order for it to perform better. The Cooper-Harper Aircraft Handling Qualities Rating can be used to justify the performance of the improved system.

Table of contents

1. Introduction

Ever since the beginning of our existence on Earth, humans have always dreamed to fly like a bird. This dream came true in Dec 18, 1903 when the first airplane test flight was successful. The flight control system at that time was very primitive, but it has evolved a lot over time with the help of new technology. I will explain more about flight control system technologies in this section.

Most hi-tech flight control systems are controlled by software nowadays. It is important to have processes to ensure software safety and reliability. Validation and Verification are the two processes to do this work. They become even more important for safety-critical software such as aircraft control software. The Cooper-Harper Aircraft Handling Qualities Rating is one of the techniques developed and used by NASA researchers to verify and validate control systems for aircrafts. Section two will explain about Validation and Verification processes for adaptive control software. Section three will explain how the Cooper Harper Aircraft Handling Qualities Rating is used to verify and validate control software.

The main objective of this research is to use the real Validation and Verification result of controller software to improve its performance. I use standard adaptive methodologies from the literature to design and implement an adaptive tuning software to improve the performance of the Proportional Integral (PI) controller in F-14 aircrafts. This software is able to use the Cooper-Harper Aircraft Handling Qualities Rating value from the fixed controller in F-14 system to dynamically adjust the proportional gain value adaptively.

The innovation and challenge in this project is to use the Validation and Verification results as feedbacks to fine tune the controller software. The Cooper-Harper Aircraft Handling Qualities Rating results will be captured, and then passed to the adaptive tuning software to compute the correct amount of control value needed for the controller. With the new control value, the controller software will adapt more quickly and accurately to changes in the operating environment. In other words, the adaptive tuning control software uses the user feedback, to adjust its control value adaptively, whereas the fixed controller software uses system sensors. Section four will further explain how this method is implemented on the PI controller in F-14 aircrafts.

1.1. Flight Control System

In the early 1920s, designers replaced the mechanical linkage with electrical wire to reduce system weight and increase reliability. Nowadays, the aircraft control system is a collection of thousands of integrated circuits which help aircraft perform at a much better rate than it did in the early days.

Any flight control system is required to have cockpit controls, flight control surfaces, linkage between cockpit control and flight control surfaces, and the actual mechanisms to control the aircraft. We will explain about the underlying mechanisms of flight control system in this section because it is relevant to this paper.

A basic cockpit control contains the three components described below.

- “Control yoke for roll which moves the ailerons
- Control column for pitch which moves the elevators
- Rudder pedals for yaw which moves the rudder” [7]

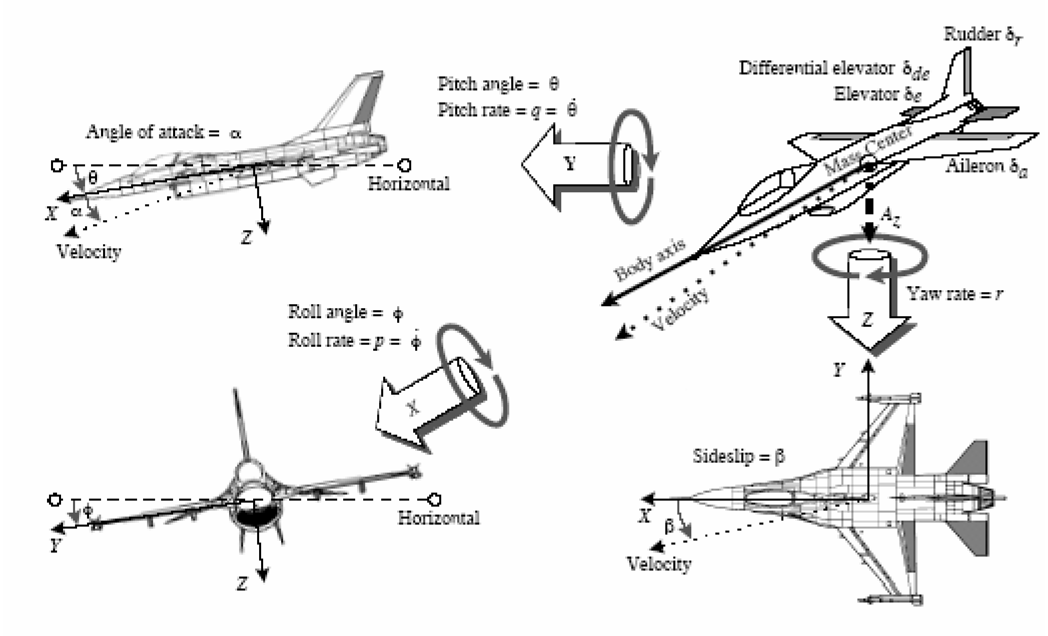


Figure 1.1: Aircraft axes of rotation [21]

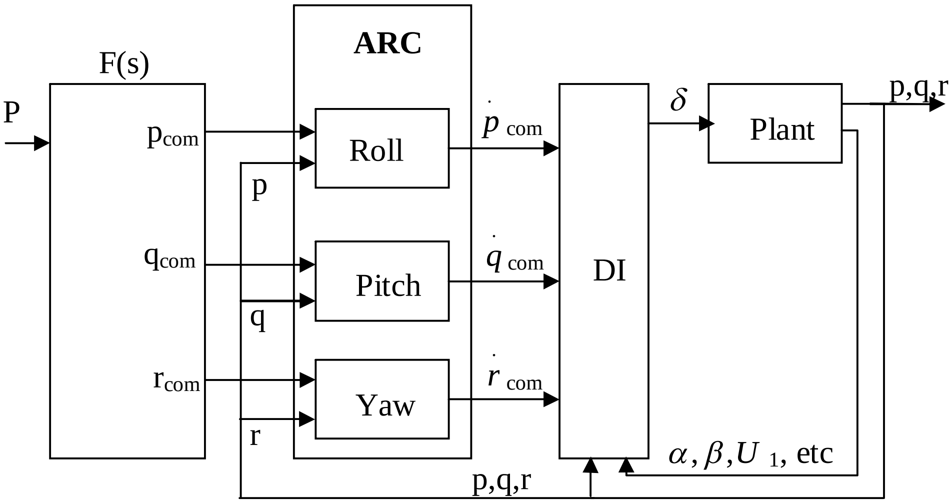


Figure 1.2: ARC implementation [13]

An example of a modern flight control system is the Adaptive Robust Control (ARC) shown in Figure 1.2. Pilot inputs will be converted to p_{com}, q_{com}, and r_{com} by the F(s). The output of F(s) together with aircraft current situation (p, q, r) will be passed to ARC to compute new values of control ($\dot{p}_{com}$, $\dot{q}_{com}$, $\dot{r}_{com}$). These new values $\dot{p}_{com}$, $\dot{q}_{com}$, $\dot{r}_{comp}$ will enter the DI (dynamic inversion) component. The DI inner loop will process these new values and compute an output vector δ (rudder, elevator, aileron). This vector will be passed to the plant. This plant will fly the aircraft and output new sensor values p, q, and r. These values will be passed back to the ARC as input for the next iteration.

1.2. Flight Controllers

1.2.1. Classical Controller

There are many classical controllers, but the Proportional-Integral-Derivative Controller (PID Controller) is the most widely used.

A PID controller has 3 components: the Proportional component, Integral component, and Derivative component. Each component has its own purpose because each one contains a different algorithm. Sometimes one or two algorithms are left out because they are not needed in the control design. It is possible to have a PI, PD or just a P controller, but it is rare to have an ID controller

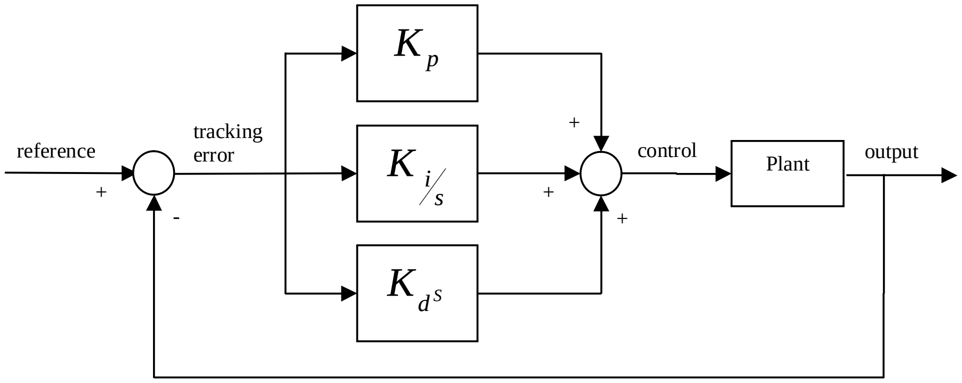


Figure 1.3: PID Controlled System [28]

Tracking error is computed by the difference of the reference and previous output value. This tracking error is passed into three different components K_p, $K_{i/s}$, and K_d^s. K_p indicates that the control in this component is proportional to the error. $K_{i/s}$ indicates that the control is an integral control. K_d^s indicates that this control is a derivative control. Each component works independently of others to produce some values. The sum of these values will be the control for the plant. This plant will perform its task, and then yield new sensor values (output) for the next iteration.

A specific application is the ARC implementation explained in Figure 1.2

1.2.2. Adaptive Flight Controller

Adaptive systems are systems "whose function evolves over time, as they improve their performance through learning." And, "If learning and adaptation are allowed to occur after the control system is deployed, the system is called online adaptive system." [3]. An Adaptive Flight Controller is a flight controller that can learn about changes in aircraft control, and adapt to those changes in order to keep the aircraft stable.

Figure 1.4 shows an adaptive controlled system with a PI controller. Kp and Ki/s are replaced by a Fuzzy Tuner for Kp and a Fuzzy Estimator for Ki, respectively. The two new components, using fuzzy logic tuning, are responsible for computing a new proportional control value up and integral control value up. The sum u of up and ui will be passed to plant, and this plant will yield new sensor output. The difference of this output and the reference is the tracking error. This tracking error will be passed back to both Fuzzy Tuner for Kp and Fuzzy Estimator for Ki to continue with the next iteration.

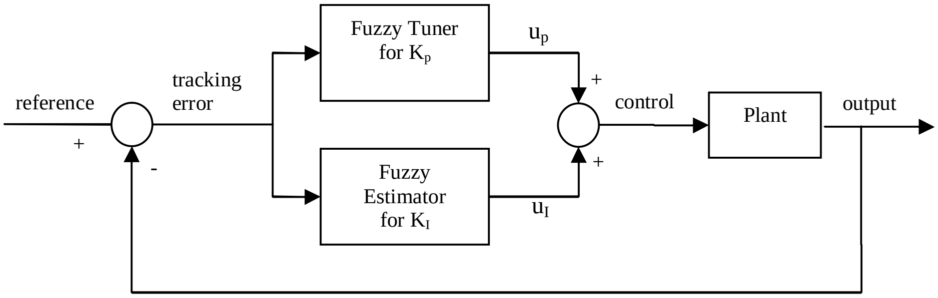


Figure 1.4: PI Controller with fuzzy tuning [9]

Another Flight Adaptive system is the Flight Control System with Neural-Network Controller. This system is also known as the Intelligent Flight Control System (IFCS) developed by the National Aeronautics and Space Administration (NASA).

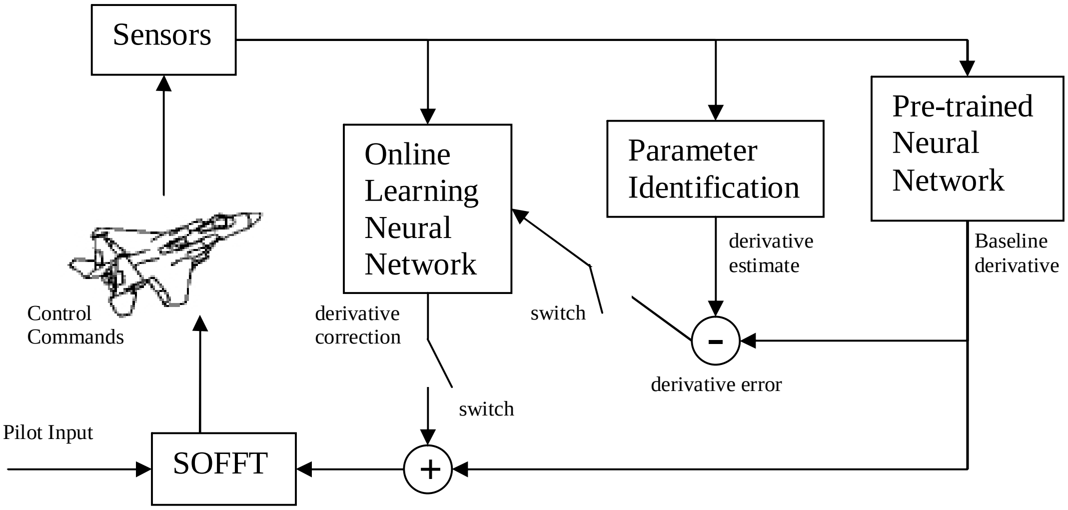


Figure 1.5: Flight Control System with Neural-Network Controller [35]

Figure 1.5 shows that sensor data from the aircraft such as altitude and airspeed are passed to three components: the Pre-Trained Neural Network (PTNN), Parameter Identification (PID) and Online Learning Neural Network (OLNN). The PTTN contains baseline derivative data is just a lookup table with data which is collected from the lab. Result output of the PTNN flows to the SOFFT (Stochastic Optimal Feed-Forward & Feedback Technology) controller. The SOFFT controller takes pilot inputs and computes a new command to feed back to the aircraft. It uses the stability and control derivatives data (PTNN output) to calculate a plant model that controls the aircraft so it can perform as desired.

For an online adaptive configuration, both switches on Figure 1.5 are closed. Data from sensor flows through both PID and OLNN components. Output from the PID and OLNN will be compared to the output from the PTNN before passing to the SOFFT controller. The derivative estimate from the PID are used to train the OLNN, and OLNN is used to correct data produced by the PTNN.

1.2.3. Neural Network Adaptive Controller

Online Learning Neural Network is also referred to as Dynamic Cell Structure (DCS) neural network. "As an online storage function approximator, the DCS network is expected to approximate the differences between the parameter estimation of the stability and control derivatives by a PID and the baseline derivatives generated by the PTNN" [35]. The OLNN will update the aircraft when there are changes in control or when there are model inaccuracies. These model updates will happen in real-time during flights. According to Liu, "this system must be capable of providing aerodynamic derivatives to the aircraft controller at least 10 times per second".

OLNN has two modes of operation: Learning and Non-Learning. During the Learning state, the difference between the derivative estimation PID and the baseline derivative from PTNN is used to train the network. During the Non-Learning state, only the baseline derivative value from PTNN is used. The Non-Learning state is activated when the derivative estimation from the PID becomes unusable or inaccurate.

According to Liu, there are two conditions of the system.

- "We are confident in PID estimates –
  There is no need to activate DCS.
  Controller uses the derivatives generated by baseline network.
- We are not confident in PID estimates –
  DCS must be activated for adaptation.
  Controller uses the derivatives generated by PTNN plus the correction generated by DCS." [35]

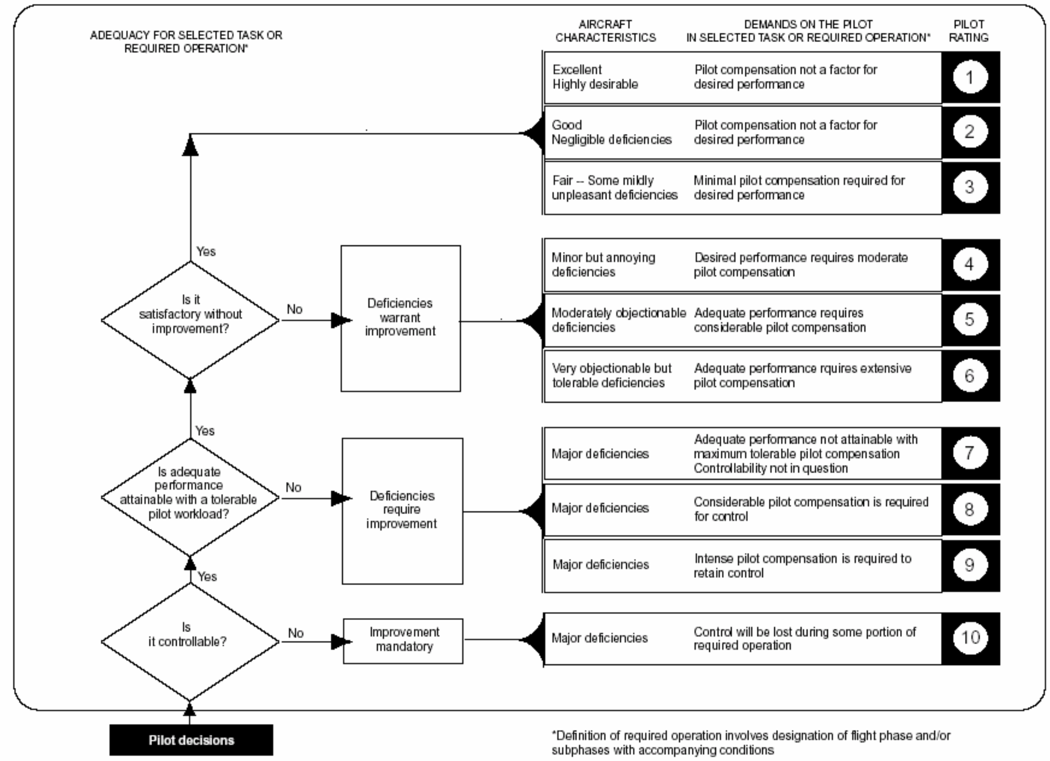
In the first condition, systems run in the safe region. Therefore we are confident about the Neural Network Controller's performance. When unusual events occur, then correct action will be taken. However we can not assure that the OLNN will have safe behavior under critical condition. There fore V&V techniques are needed to ensure safety and reliability. [35]

1.3. Handling Quality

In most flight control systems, performance assessment is carried out in terms of handling qualities. Handling qualities may be defined as those dynamic and static properties of a vehicle that permit the pilot to fully exploit its performance in a variety of missions and roles. Traditionally, handling quality is measured using the Cooper-Harper rating and done subjectively by the human pilot. In this work, we formulated the rules of the Cooper-Harper rating scheme as fuzzy rules with performance, control, and compensation as the antecedents, and pilot rating as the consequent. Appropriate direct measurements on the controller are related to the fuzzy Cooper-Harper rating system. A stability measurement like the rate of change of the cost function can be used as an indicator if the aircraft is under control. The tracking error is a good measurement for performance needed in the rating scheme. Finally, the change of the control amount or the output of a confidence tool can be used as an indication of pilot compensation. We use a number of known aircraft flight scenarios with known pilot ratings to calibrate our fuzzy membership functions. These include normal flight conditions and situations in which partial or complete failure of tail, aileron, engine, or throttle occurs.

1.3.1. Cooper-Harper Aircraft Handling Qualities Rating

The Cooper-Harper Aircraft Handling Qualities Rating is widely used since its introduction. Figure 1.6 depicts the various conditions used for the pilot to rate the aircraft handling qualities. The rating system takes on a couple of factors and deduces the aircraft handling qualities in aircraft characteristics and pilot rating columns in Figure 1.6. The ten levels from “Excellent, Good, Fair,… Major Deficiencies”, as observed by the pilot, for various cases are summarized in the column of demand on the pilot in selected task or required operation in Figure 1.6. There three input factors that lead to this output column in the rating system. Pilot compensation, performance, and aircraft control status are the inputs that lead to Cooper-Harper rating scheme.



*Definition of required operation involves designation of flight phase and/or subphases with accompanying conditions

Figure 1.6 Cooper-Harper Aircraft handling Qualities Rating [10]

2. Validation & Verification (V&V) of Adaptive Control Software

2.1. Overview

Software Validation and Verification is a process to ensure software safety and reliability. Sommerville simply explains about the terms “validation” and “verification” in his book:

- “Validation: Are we building the right product?
- Verification: Are we building the product right?” [16]

In other words, validation is a process to make sure the software was built based on the needs of users. In this process, users should have frequent updates after each phase of the project. Meeting with users frequently is a good way to ensure that the software product is consistent with users’ requirements. Another validation activity would be checking the specification with the design. Both users and developers should review the specification to make sure there is no misunderstanding between the developers' interpretation and users' interpretation.

Verification is a process to make sure the software product meets its specifications. Activities in the verification process include but is not limited to mathematical analysis, functional testing, module testing, integration testing, etc. Verification should be performed at each phase of the project to ensure the quality of the product. For example, each module should be tested individually, and when they are integrated together, the complete system should be tested as well.

Validation and Verification's goal is to processes is to create user's confidence in the software system. This software system need not to be free of defects, but it should be good enough for user's use. The level of confidence depends on the software's purpose, user's expectation and marketing environment. [16]

2.2. V&V of safety-critical Software

Traditional methods for software V&V are classified into three families:

- Fault Avoidance methods: These are the methods to make sure that systems have no error in the design stage.
- Fault Removal methods: These are the methods to make sure that errors can be removed from systems after the completion of design and implementation.
- Fault Tolerance methods: These are the methods to make sure that systems can recover and function correctly if there are errors occurs during operation. [4]

These methods works well with traditional controllers. However, they are not applicable for modern adaptive system due to the following reasons:

- Fault Avoidance methods: In traditional systems, we can determine their functional properties by analyzing the design and implementation. In adaptive systems, functional properties are defined based on systems' design and data which the systems have learn. It is not possible to use this method on adaptive systems because their functional properties are not predefined.
- Fault Removal methods: This method can be applied to traditional systems because we know their behaviors and data they produce. With these informations, we can test to find out systems' faults after they're implemented. Adaptive systems' behavior changes over time due to different environments, and their data output can not be predicted. Therefore it's not possible to use this method on adaptive system.
- Fault Tolerance methods: The practice of this method is to make duplications of a same system. This required systems' functions to be well defined. These

methods do not work on adaptive systems because their functions are not predefined until new data is learned. [4]

Many modern missions require modern control systems which can handle critical changes in a system's behavior. Intelligent adaptive controllers are the right choice for those missions. However these adaptive controllers need to be verified and validated before being used to ensure the safety of missions.

Space missions are good examples when adaptive controllers are used. Most space missions are long and autonomous. Control system should be able to find out problems and correct them by itself. Traditional controllers do not have this ability.

Spacecraft such as CEV or JIMO operate in different environment than Earth. Their control systems must be reliable and safe even when they face situations which are impossible to predict ahead of time on Earth. Automatic component repair is required because manual repair is not an option. The entire system must cope with these changes as fast as possible to maintain stability. Traditional fixed-gain controllers do not have the required capabilities. However, These adaptive systems must be certified to use on these missions. NASA has developed the Intelligent Flight Controller System and have several standards to perform V&V:

- NASA Procedures and Guidelines (NPG) 8730.DRAFT 2, Software Independent Verification and Validation
- NASA Guidebook for Safety Critical Software, NASAGB- 1740.13-96
- IEEE Standard for Software Test Documentation, IEEE Std 829-1998 (Revision of IEEE Std 829-1983)
- NASA Procedures and Guidelines (NPG) 2820.DRAFT and NASA Software Guidelines and Requirements. References IEEE/EIA Standards 12207.0, 12207.1, and 12207.2 which reference standards published in 1995 as ISO/IEC 12207.
- Trial-Use Standard for Information Technology Software Life Cycle Processes - Software Development, JSTD-016-1995
- (IV&V) Management. Any mission which costs more than $100 million will required IV&V1 [19]

There is also a guidance which has V&V process integrate to Software Life Cycle. At every phrase of the Software Life Cycle, V&V are performed to ensure the correctness of product. These V&V phrases are used to enhance but not to replace traditional testing. Figure 2.1 shows the Software Life Cycle with integrated V&V process

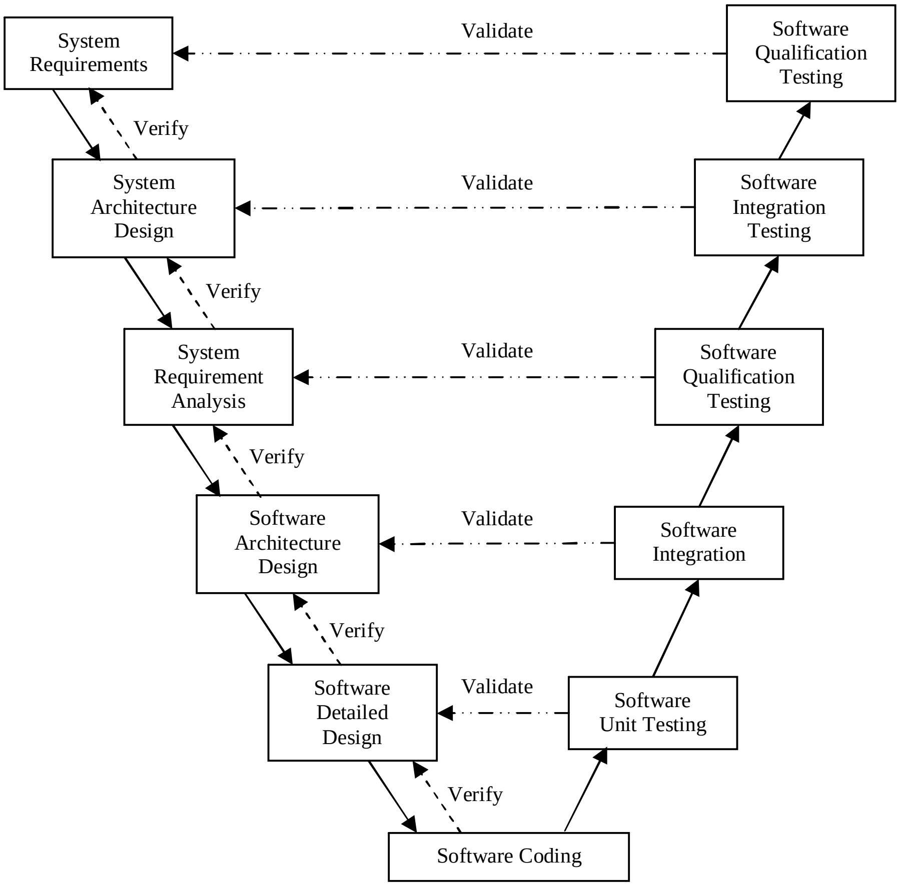


Figure 2.1: Software Life Cycle with integrated V&V process [19]

2.3. Issues and Methods in V&V of adaptive systems

2.3.1. Issues

It is clear that we can not use traditional V&V methods on adaptive systems. New V&V methods must be developed to ensure safety and reliability of adaptive systems. According to Mili, V&V of on-line learning systems can be summarized in the following premises:

- Analyzing the design process cannot be used to prove the correctness of the system. However, by analyzing the functional properties of the final products, and how they evolve through learning, we can then verify the correctness of the system.
- Exact function that the system defines at any stage in the learning process will not be capture for analyzing. We have to use the range of all possible functions which was defined in the system's learning history.

- We have to make sure that the system evolves, but it can still preserve or enhance the behavior. Online system should perform better over time because new data is learned. By “perform better”, we mean that the possible functional properties will grow and be more refined.
- System’s possible learning data must be taken in for consideration. These data will affect the functional properties.

2.3.2. Design and analysis

Lyapunov’s functions are well-known in the control studies and implementations to prove systems’ stability or instability of fixed points in dynamical systems and autonomous differential equations [22]. I will briefly explain the idea of Lyapunov’s functions in this section.

Stability properties of a system should be the first concern for designer because if a system becomes unstable, then there is no chance that any performance specification will hold. [21]

An undisturbed motion is consider being stable if there is a small disturbance to it, and this motion remains close to the unperturbed one for all time. More specifically, Lyapunov’s ideas about stability are as below:

- If for small disturbances, the effect on the motion is small, then the undisturbed motion is “stable”
- If for small disturbances, the effect is considerable, then the undisturbed motion is ”unstable”
- If for small disturbances, the effect tends to disappear, then the undisturbed motion is “asymptotically stable”
- If ignore the magnitude of the disturbances, and the effect seems to disappear, then the undisturbed motion is “asymptotically stable in the large”[23]

Definition

Let f be a vector field in Rn defined as

$$f : D \subset R^n \to R^n \tag{2.1}$$

which is two times continuously differentiable with

$$f(p) = 0; p \in D \tag{2.2}$$

and an open neighborhood U of p contained in D a scalar function

$$V : U \to R \tag{2.3}$$

is called Lyapunov function for f and p if

- V is continuous on U and continuously differentiable on $U \setminus \{p\}$
- $V(p) = 0$ and $V(x) > 0; \forall x \in U \setminus \{p\}$ V(x) > 0 (V is a positive-definite function)
- $\nabla V(x) \circ f(x) \le 0; \forall x \in U \setminus \{p\}$ (Derivative of V in direction f(x) is decreasing).

If additionally the stronger condition $\nabla V(x) \circ f(x) < 0$ is satisfied, we say V a strict Lyapunov function.[22]

3. Validation with Fuzzy Cooper-Harper Rules

3.1. Cooper-Harper Rating Rules

We will use the magnitude of control as an indication of pilot compensation effort. When high/low compensation is needed to maintain the aircraft desired performance, corresponding extent of high/low control effort is applied accordingly. The status of the aircraft being under control or not can be observed by examining the stability of the flight system. The rate of change of an appropriate Lyapunov function will be a good indication of how the flight system in under control. In accordance with the Lyapunov function theory, a negative rate of change of Lyapunov function is an indication of the given system being stable whereas a positive rate change would indicate instability. [8]

Lyapunov function

$$J = \frac{1}{2}(e^2 + \dot{e}^2) \tag{3.1}$$

Negative rate of change of Lyapunov

$$-\Delta J(k) = -(J(k) - J(k-1)); k \in \mathrm{N}, k \ge 1 \tag{3.2}$$

In the case of aircraft performance, we shall use the magnitude of tracking error as an indicator. Obviously, when the tracking error is small the flight system exhibits a good performance and vice versa.

With these indicators, and based on the Figure 1.6. We can come up with typical rating rules in the following:

Group 1: Rating 1, 2 and 3. According to the flowchart on Figure 1.6, the aircraft is controllable, adequate performance is attainable with a tolerant pilot workload, and it is satisfactory without improvement. This means aircraft control in this group is **stable**. Pilot needs only a **little** effort to control the aircraft.

Pilot Rating is 1
Cooper-Harper Statement: "Aircraft characteristics are excellent (highly desirable). Pilot compensation is not a factor for desired performance."

Interpretation: Rating 1 indicates that aircraft performance is at its excellent condition. The control is stable. None or a small amount of the control-effort is needed to have the desired performance.

Rule 1: If **Control-Effort** is *small* and **Control** is *stable* and **Performance** is *excellent*, then Rating is 1

Pilot Rating is 2
Cooper-Harper Statement: "Aircraft characteristics are good (negligible deficiencies). Pilot compensation is not a factor for desired performance."

Interpretation: Rating 2 indicates that aircraft performance is in good condition. The control is stable. It has some deficiencies, but they are negligible. None or a small pilot control-effort is needed to have the desired performance.

Rule 2: If **Control-Effort** is *small* and **Control** is *stable* and **Performance** is *good*, then Rating is 2

Pilot Rating is 3
Cooper-Harper Statement: "Aircraft characteristics are fair (some mildly unpleasant deficiencies). Minimal pilot compensation required for desired performance."

Interpretation: Rating 3 indicates that aircraft performance is in good condition. There are some mildly unpleasant deficiencies, but desired performance is still attainable with minimal pilot control-effort. "Desired performance" is the key phrase to decide that the performance is good in this rating. Control is stable

Rule 3: If **Control-Effort** is *minimal* and **Control** is *stable* and **Performance** is *good*, then Rating is 3

Group 2: Rating 4, 5 and 6. According to the flowchart on Figure 1.6, the aircraft is controllable, adequate performance is attainable with a tolerant pilot workload, but it is not satisfactory without improvement. This means control of aircraft in this group is **stable**. Pilot has to put in some trivial efforts to control the aircraft.

Pilot Rating is 4
Cooper-Harper Statement: "Aircraft characteristics have minor (but annoying) deficiencies. Desired performance requires moderate pilot compensation."

Interpretation: Rating 4 indicates that aircraft performance is in good condition. There are some minor deficiencies, but desired performance is still attainable with moderate pilot control-effort. “Desired performance” is the key phrase to decide that the performance is good in this rating. Control is stable

Rule 4: If **Control-Effort** is *moderate* and **Control** is *stable* and **Performance** is *good*, then Rating is 4

Pilot Rating is 5
Cooper-Harper Statement: “Aircraft characteristics have moderately objectionable deficiencies. Adequate performance requires considerable pilot compensation.”

Interpretation: Aircraft performance in this rating is adequate. Control is stable, but it has some moderately objectionable deficiencies. Pilot has to put in considerable control-effort to maintain the aircraft in good condition.

Rule 5: If **Control-Effort** is *considerable* and **Control** is *stable* and **Performance** is *adequate*, then Rating is 5

Pilot Rating is 6
Cooper-Harper Statement: “Aircraft characteristics are very objectionable (but tolerant deficiencies). Adequate performance requires extensive pilot compensation.”

Interpretation: Rating 6 indicates that the aircraft performance is adequate. Control is stable, but it is very objectionable. Extensive pilot compensation is needed to maintain the aircraft.

Rule 6: If **Control-Effort** is *extensive* and **Control** is *stable* and **Performance** is *adequate*, then Rating is 6

Group 3: Rating 7, 8 and 9. In this group, the aircraft is controllable, but adequate performance is not attainable with a tolerant pilot workload. Pilot has to put in a lot of efforts to control the aircraft.

Pilot Rating is 7
Cooper-Harper Statement: “Aircraft characteristics have major deficiencies. Adequate performance is not attainable with maximum tolerable pilot compensation, but controllability is not in question.”

Interpretation: Rating 7 indicates aircraft performance is not adequate. Control is stable, but it has major deficiencies. Pilot has to put in maximum effort to control the aircraft. “Controllability not in question” is the key phrase to decide the stability of the aircraft.

Rule 7: If **Control-Effort** is *maximum* and **Control** is *stable* and **Performance** is *not adequate,* then Rating is 7

Pilot Rating is 8

Cooper-Harper Statement: "Aircraft characteristics have major deficiencies. Considerable pilot compensation is required for control."

Interpretation: Aircraft performance is not adequate because aircraft characteristics have major deficiencies in this rating.

"Considerable pilot compensation is required for control" means when pilot compensation is lower than "considerable", the aircraft will be unstable. Therefore control in this rating is unstable.

Due to the poor stabilities of the aircraft control in this rating, pilot will have to apply different levels of effort to control the aircraft. Pilot control-effort can range from small, minimal, to moderate effort. This will give three more rules for rating 8

Rule 8: If **Control-Effort** is *small* and **Control** is *unstable* and **Performance** is *not adequate*, then Rating is 8

Rule 9: If **Control-Effort** is *minimal* and **Control** is *unstable* and **Performance** is *not adequate*, then Rating is 8

Rule 10: If **Control-Effort** is *moderate* and **Control** is *unstable* and **Performance** is *not adequate*, then Rating is 8

Pilot Rating is 9

Cooper-Harper Statement: "Aircraft characteristics have major deficiencies. Intense pilot compensation is required to retain control."

Interpretation: Aircraft performance is not adequate because aircraft characteristics have major deficiencies in this rating. "Intense pilot compensation is required to retain control" means when pilot compensation is lower than "intense", the aircraft will be unstable. This means control is unstable in this rating

Aircraft requires higher level of pilot effort to keep control it. Pilot effort can range from small to extensive, but we already cover the case of pilot compensation from small to moderate in rating 8. Therefore we will have just two more rules for rating 9 to cover the case when control-effort is considerable and extensive.

Rule 11: If **Control-Effort** is *considerable* and **Control** is *unstable* and **Performance** is *not adequate*, then Rating is 9

Rule 12: If **Control-Effort** is *extensive* and **Control** is *unstable* and **Performance** is *not adequate*, then Rating is 9

Group 4: Rating 10. In this group, the aircraft is not controllable. Highest level of pilot's effort is needed to control the aircraft.

Pilot Rating is 10
Cooper-Harper Statement: "Aircraft characteristics have major deficiencies - improvement is mandatory, Control will be lost during some portion of required operation."

Interpretation: This rating is the highest rating in Cooper-Harper rating. Aircraft performance is not adequate due to the Cooper-Harper statement "aircraft characteristics have major deficiencies. Control is highly unstable because 'control will be lost during some portion of required operation'.

It needs all of control-effort levels from the pilot. Pilot compensation can range from small to maximum, but we already cover the cases of pilot compensation from small to extensive in rating 8 and 9. Therefore we will have just two more rules for rating 10 to cover the case when control-effort is intense and maximum.

Rule 13: If **Control-Effort** is *intense* and **Control** is *unstable* and **Performance** is *not adequate*, then Rating is 10

Rule 14: If **Control-Effort** is *maximum* and **Control** is *unstable* and **Performance** is *not adequate*, then Rating is 10

Based on these rules, we summarize the Cooper-Harper aircraft handling qualities rating system as shown in Table 3.1 below.

Rule	Compensation (|Control|)	Control (Stability)	Performance (Tracking)	Rating
1	Small	Stable	Excellent	1
2	Small	Stable	Good	2
3	Minimal	Stable	Good	3
4	Moderate	Stable	Good	4
5	Considerable	Stable	Adequate	5
6	Extensive	Stable	Adequate	6
7	Maximum	Stable	Not Adequate	7
8	Small	Unstable	Not Adequate	8
9	Minimal	Unstable	Not Adequate	8
10	Moderate	Unstable	Not Adequate	8
11	Considerable	Unstable	Not Adequate	9
12	Extensive	Unstable	Not Adequate	9
13	Intense	Unstable	Not Adequate	10
14	Maximum	Unstable	Not Adequate	10

Table 3.1 Cooper-Harper Rating Rules

3.2. Fuzzy rule-based system

I will briefly explain how Fuzzy rule-based system works in this section for a better understanding. According to Tseng, Gupta, and Schumann on paper [23], fuzzy system has four major components as shown in Figure 3.1

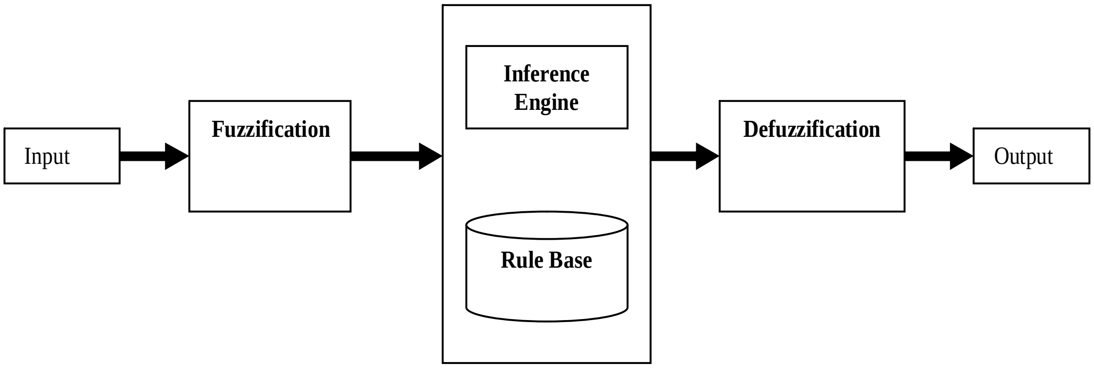


Figure 3.1 - Fuzzy Inference System Component.

Fuzzification:

Each linguistic variable (performance, compensation, control) is associated with membership functions that are defined for the affiliated Fuzzy sets such as “excellent”, “good”, etc. This component will acquire an input value for each linguistic variable and then base on the affiliated Fuzzy set to evaluate the degree of membership of this variable

- **Fuzzy Rule Base**

  Fuzzy systems use Fuzzy IF-THEN rules. A Fuzzy IF-THEN rule has the form of:

  IF $X_1 = A_1$ and $X_2 = A_2$ ... and $X_n = A_n$ THEN $Y = B$

  Where X_i and Y are linguistic variables and A_i and B are linguistic values. A Fuzzy Rule Base will be used to store the collection of the Fuzzy IF-THEN rules. This Fuzzy Rule Base will be accessed by the Fuzzy Inference Engine when it receives inputs and processes them. In this research, we have 14 rules from the Cooper-Harper Rules Table 3.1 above.

- **Fuzzy Inference Engine**

  This component receives all the crisp input values that have been fuzzified with respect to their respective linguistic membership functions and process them based on the Fuzzy Rule Base to deduce the conclusive output. Aggregation and composition are the two main steps in the inference process.

  - Aggregation is the process of computing for the membership values of the IF part of the rules
  - Composition is the process of computing for the membership values of the THEN part of the rules.

  Each condition in the IF part of a rule is assigned a degree of truth based on the degree of membership of the corresponding linguistic membership functions during aggregation.

  The minimum or the product of the degrees of truth of all the conditions is computed as the overall degree of truth of the IF part. For the case of crisp output design, this aggregated truth value is also the truth value of the associated rule subject to the inputs

- **Defuzzification**

  This is the process of generalizing the fuzzified values with respect to the fuzzy rule base back to crisp output values. There are different ways to defuzzify. Some common defuzzification methods include centroid and maximum height [8]

3.3. Fuzzy Cooper-Harper rating system

Cooper-Harper rating system takes on three indexes from the system under control and deduces a rating based on the fuzzy engine as shown in Figure 3.2. The three indexes (performance, control, and compensation) are in accordance with the original Cooper-Harper aircraft handling system. A real-time human readable rating between values of 1 to 10 will be produced based on the actual inputs at application stage.

Measurement data can never be precise because of sensor or other possible design errors. In this case, fuzzy logic proves to be an effective scheme to correct these issues. Furthermore, fuzzy logic has the well-known generalization capability that will enable us to deal with various cases that may or may not match our 14 rules exactly in the application stage.

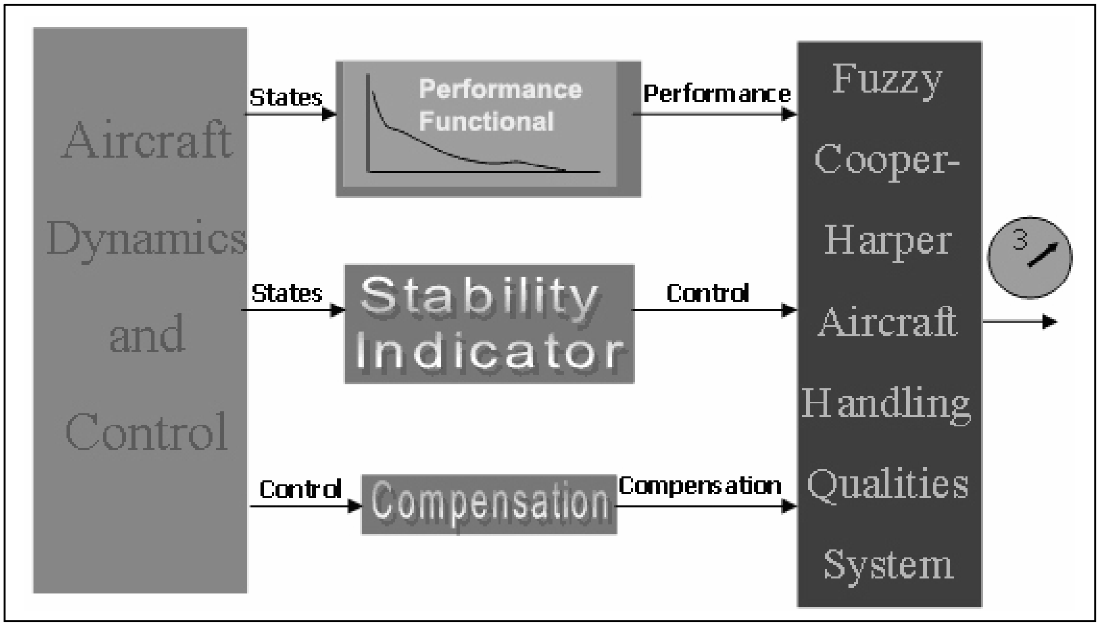


Figure 3.2: Fuzzy Cooper-Harper rating system

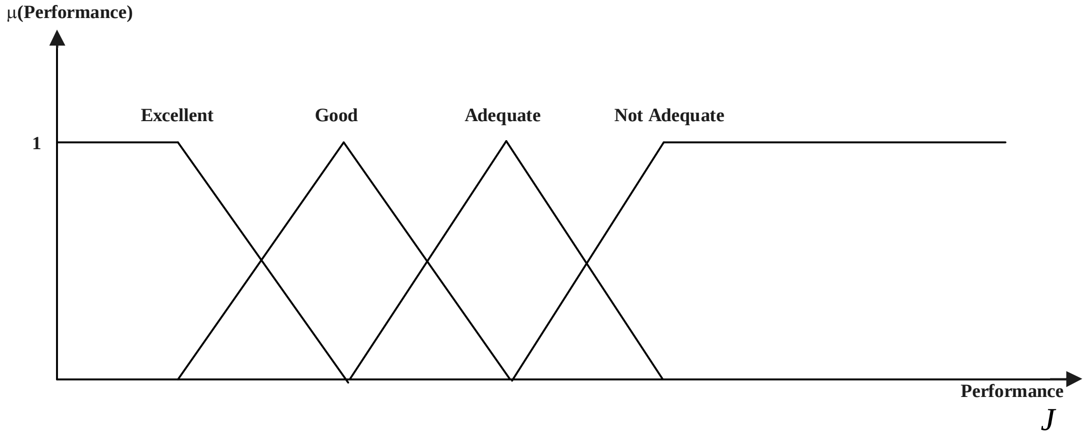


Figure 3.3: Membership function for linguistic variable performance

In application stage, associated membership function values for each linguistic value can be computed based on the given input as illustrated in Figure 3.3.

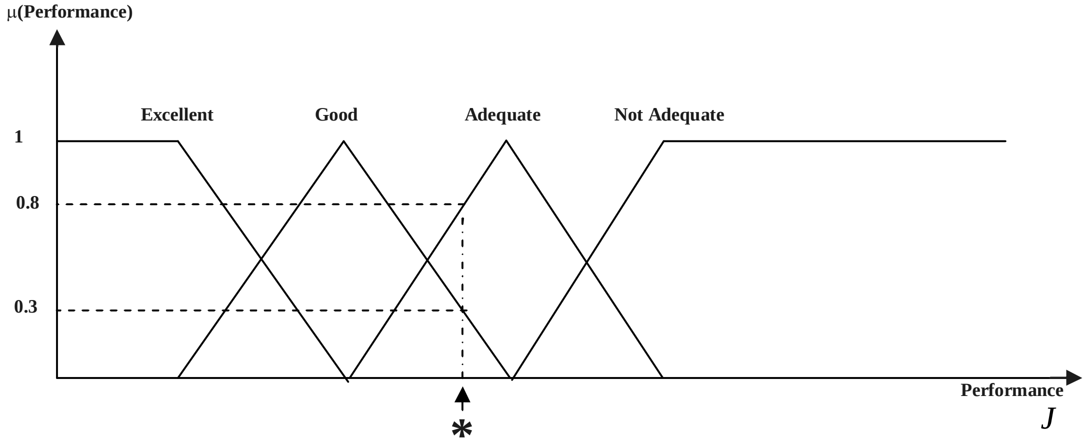


Figure 3.4: Computing membership values

Figure 3.4 above shows how we have the computed membership values as
μ_{Adequate}(Performance) = 0.8 and
μ_{Good}(Performance) = 0.3

Similarly, Figures 3.5 and 3.6 show the membership functions for the compensation and the control linguistic variables, respectively.

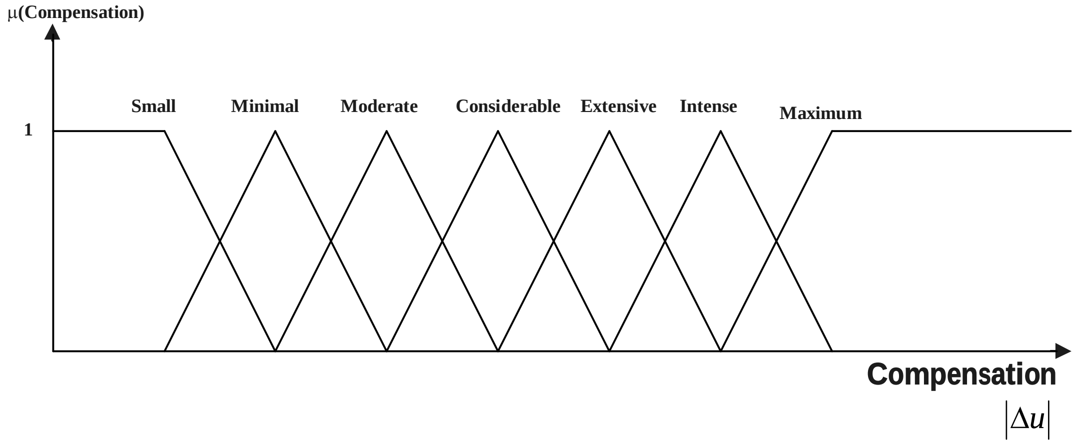


Figure 3.5: Membership function for linguistic variable compensation

Compensation:

$$\Delta u(k) = u(k) - u(k-1); k \geq 1 \tag{3.3}$$

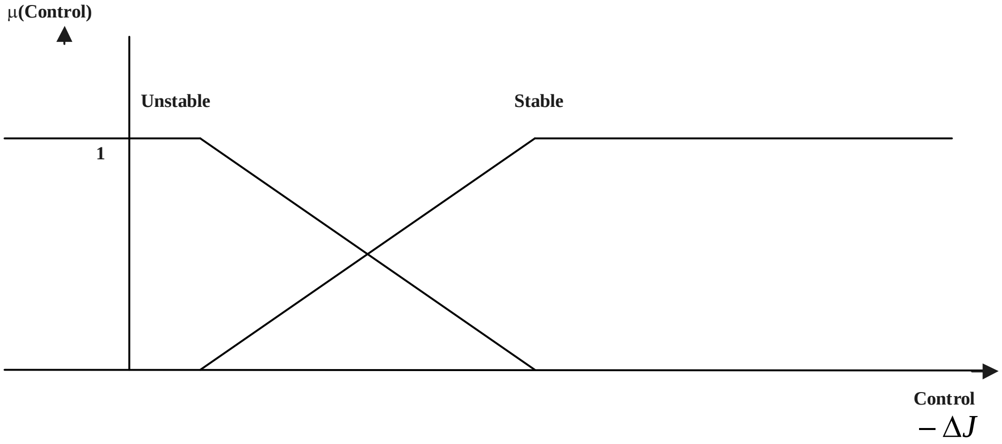


Figure 3.6: Membership function for linguistic variable control

J is the square of tracking error in the given problem.

We can also use other membership function types, e.g., Gaussian type as well [8].

3.4. Validation of an F-14 Longitudinal Control System

We apply our proposed fuzzy Cooper Harper rating system to a simplified F-14 Longitudinal control system. This system is modified from a Matlab demo example as shown in Figure 3.7. The generalized control objective is to ensure the alpha angle track the pilot input.

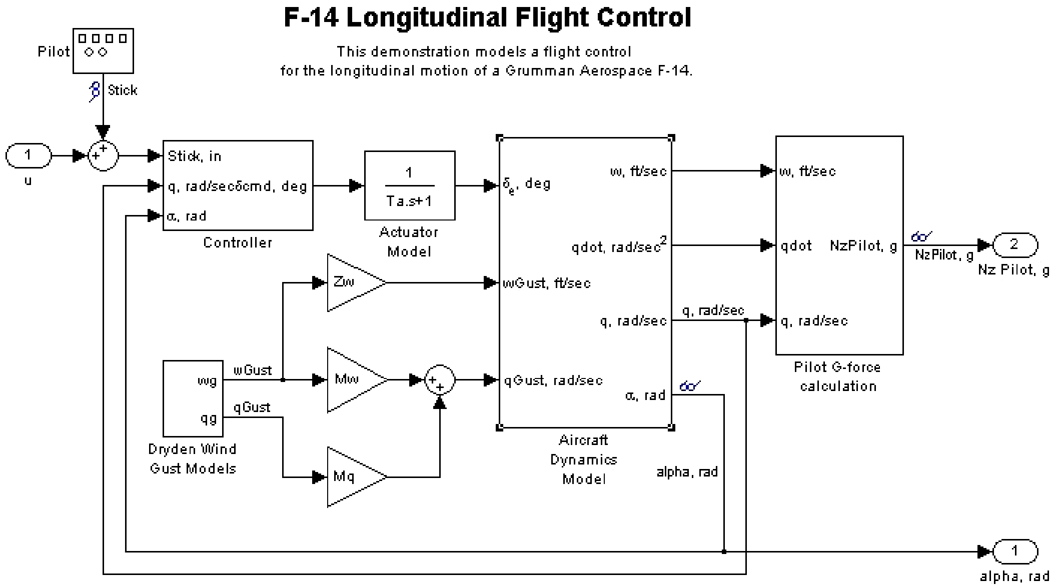


Figure 3.7: F-14 longitudinal control system

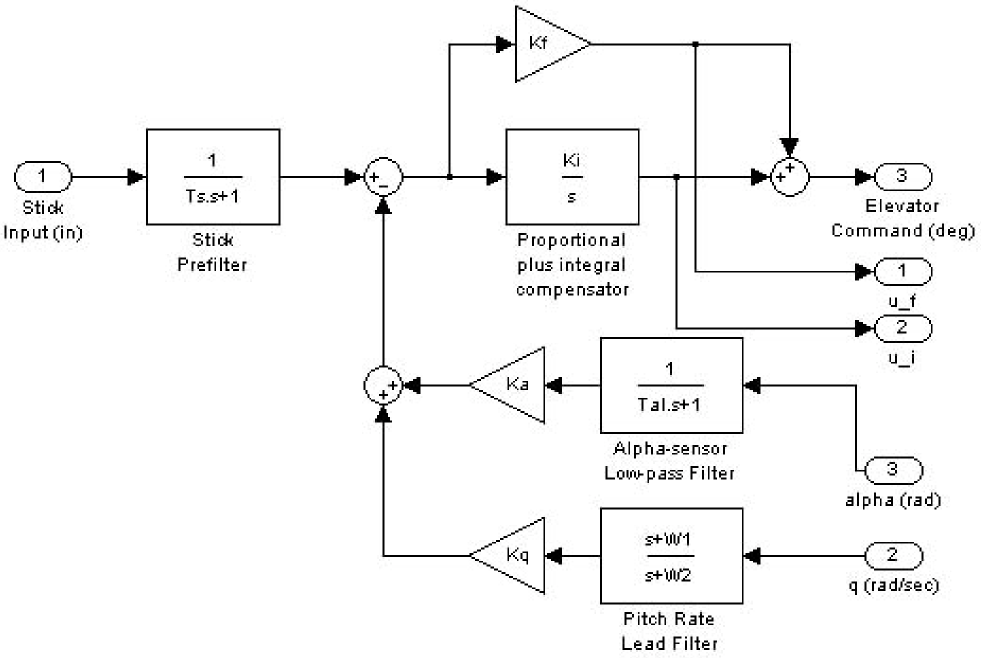


Figure 3.8: F-14 PI Controller

A fuzzy Harper-Cooper rating system is augmented to the given F-14 control to validate aircraft handling qualities. Matlab F-14 control model use PI controller where Kf is the Proportional Controller Gain and Ki is the Integral Proportional Controller Gain as shown in Figure 3.8.

The fuzzy Cooper-Harper rating system is firstly calibrated against several standard cases and its fuzzy membership functions tuned

The values we used for all fuzzy membership functions in our simulations are shown in table 3.3, 3.5, 3.6.

Small	**Minimal**	**Moderate**	**Considerable**	**Extensive**	**Intense**	**Maximum**
0.015 (Trapezoidal)	0.0925 (Triangular)	0.2 (Triangular)	0.2475 (Triangular)	0.325 (Triangular)	0.4025 (Triangular)	0.48 (Trapezoidal)

Table 3.2: Numerical values for various means Compensation linguistic variables

Unstable	**Stable**
-0.2 (Trapezoidal)	0 (Trapezoidal)

Table 3.3: Numerical values for various means Control linguistic variables

Excellent	**Good**	**Adequate**	**Not Adequate**
0.0001 (Trapezoidal)	0.08 (Triangular)	0.17 (Triangular)	0.35 (Trapezoidal)

Table 3.4: Numerical values for various means Performance linguistic variables

In the application stage, we use a square wave with alternating magnitude of +/- 0.5 as pilot input. The resultant tracking profile of alpha is as shown in Figure 3.9

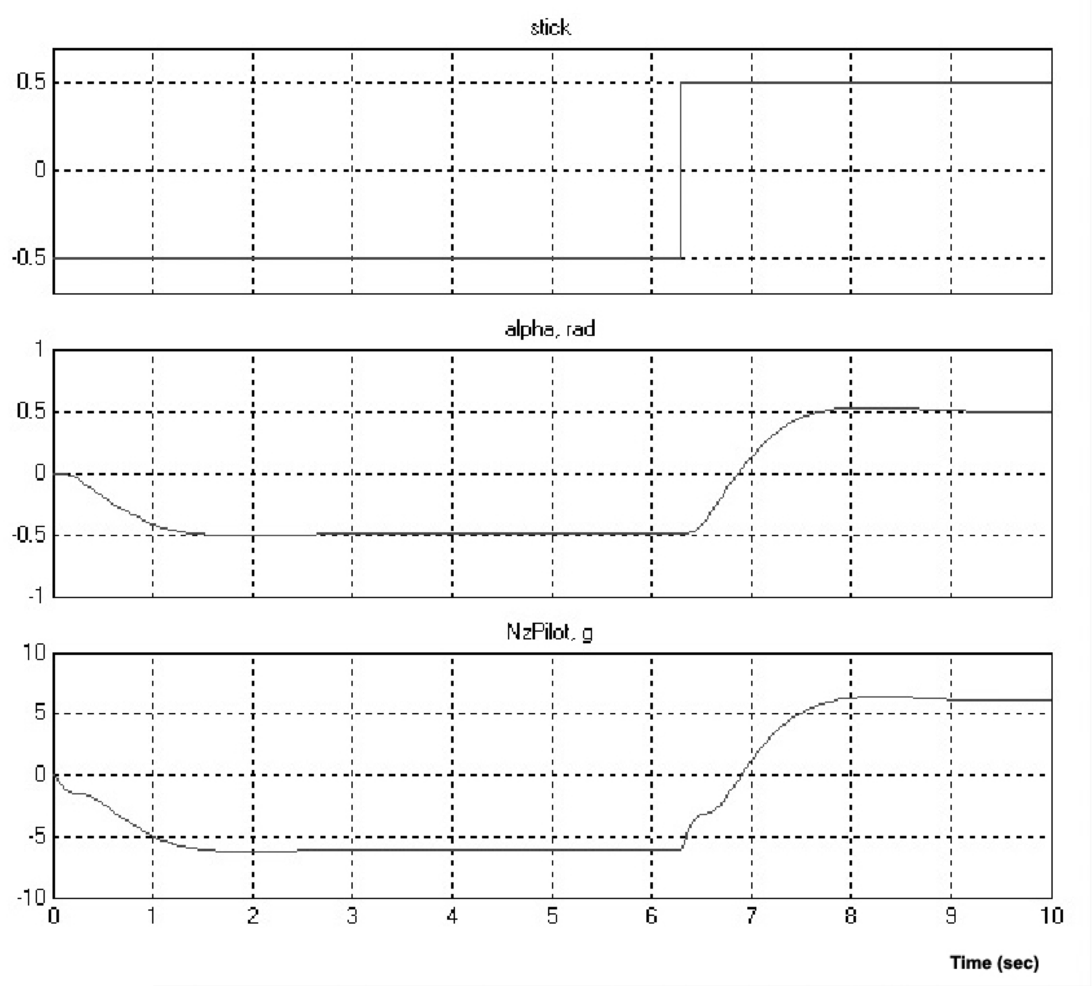


Figure 3.9 input and output profiles

After simulation is complete, we will have the profiles of three indicators which will help to determine Cooper-Harper rating.

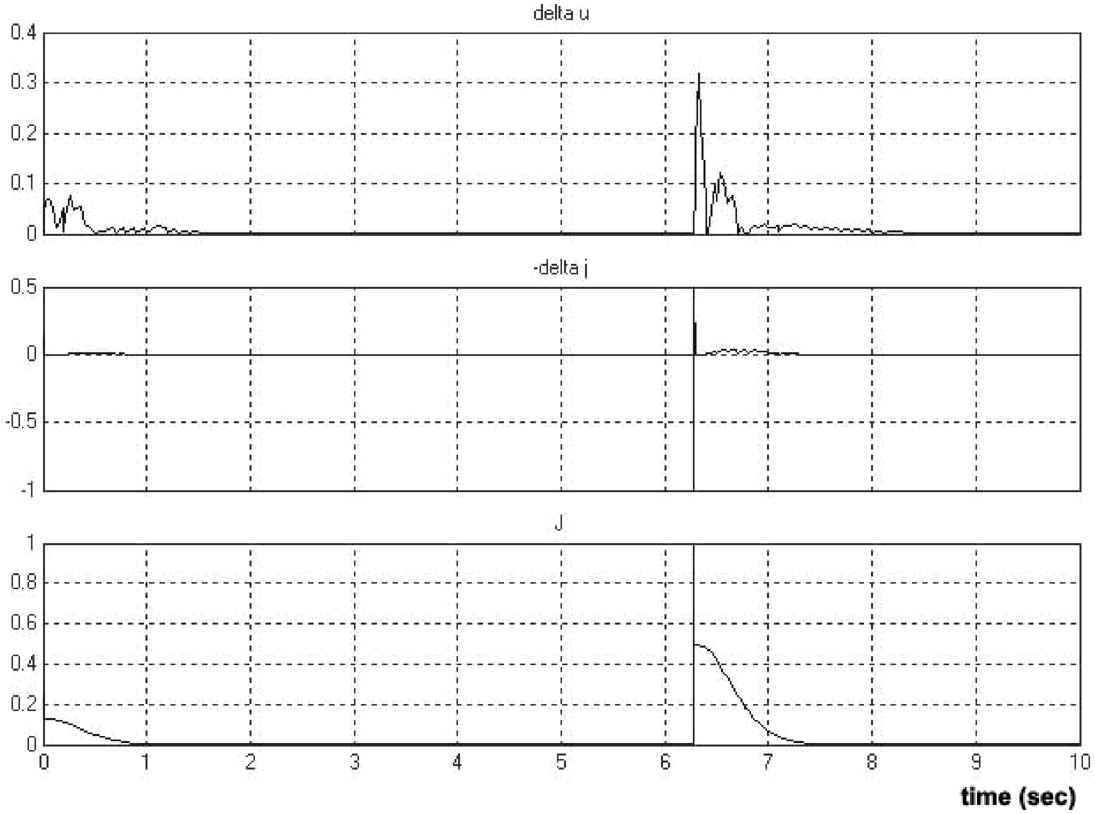


Figure 3.10: Indicator profiles for aircraft when Kf = -1.7. J, $-\Delta J$, and Δu are defined in (3.1), (3.2), (3.3).

Our fuzzy Cooper-Harper rating system yields the rating profile as shown in Figure 3.11. The y-axis represents the Cooper-Harper rating generated from our fuzzy Cooper-Harper rating system during the 10-second simulation interval.

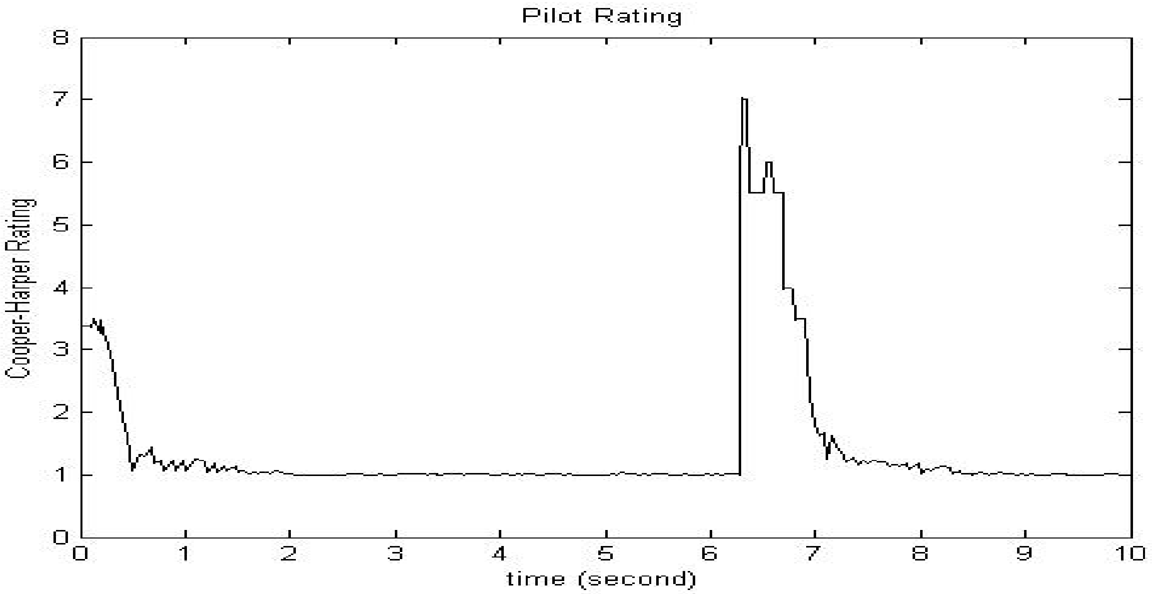


Figure 3.11 aircraft handling qualities rating profile with Kf= -1.7

At the beginning of the simulation t=0, we can see the three numerical values for compensation, control and performance variables are 0.08, 0, and 0.15 accordingly. This means compensation is minimal, control is stable and performance is good. According to Table 3.1, Cooper-Harper rating system will generate a rating 3. Figure 3.11 showed that at the beginning of the simulation, Cooper-Harper rating is 3.3, which is very close to 3.

In another simulation, we change the value Kf of the control to be 0.1. This will make the control unstable. We can see this in the tracking profile of alpha in the figure below

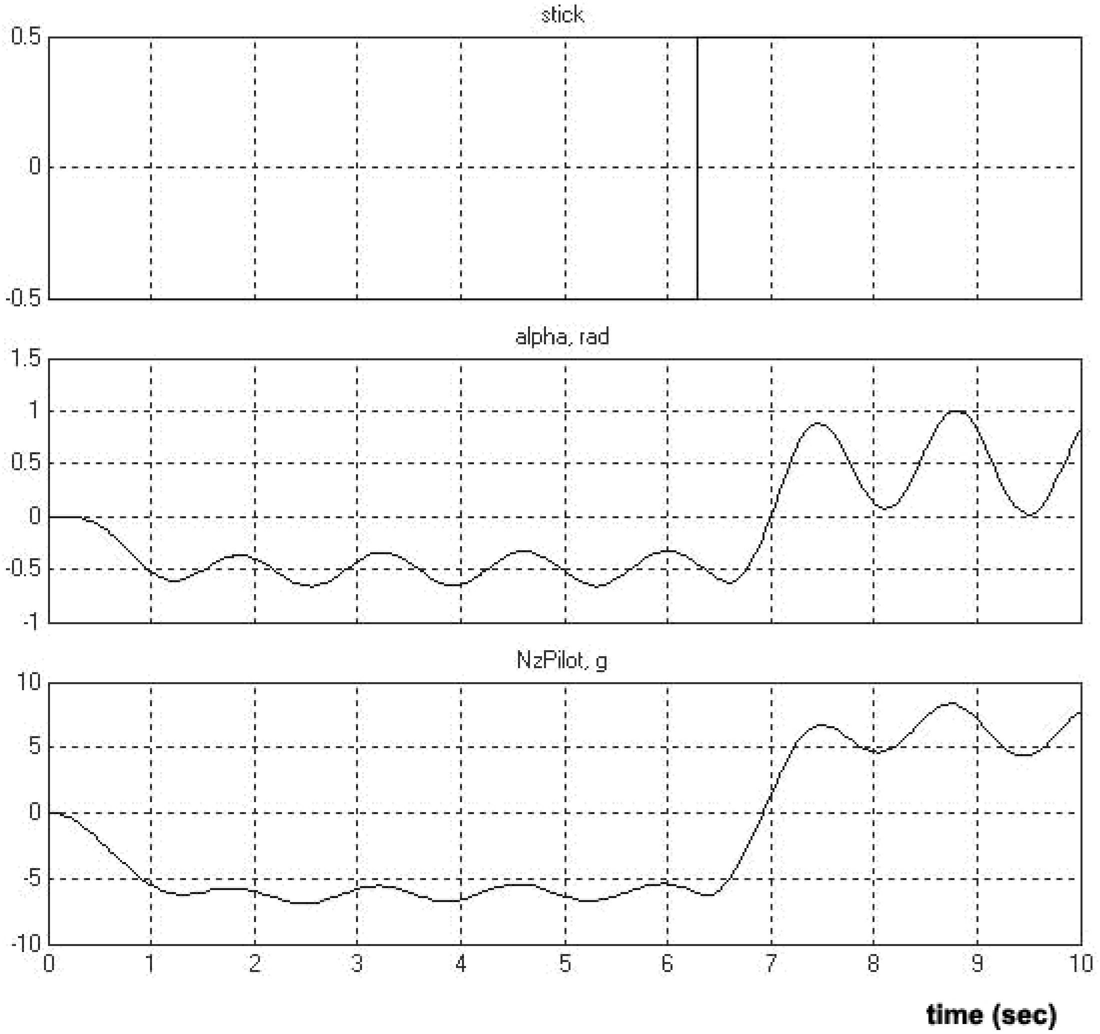


Figure 3.12 input and output profiles with Kf = 0.1

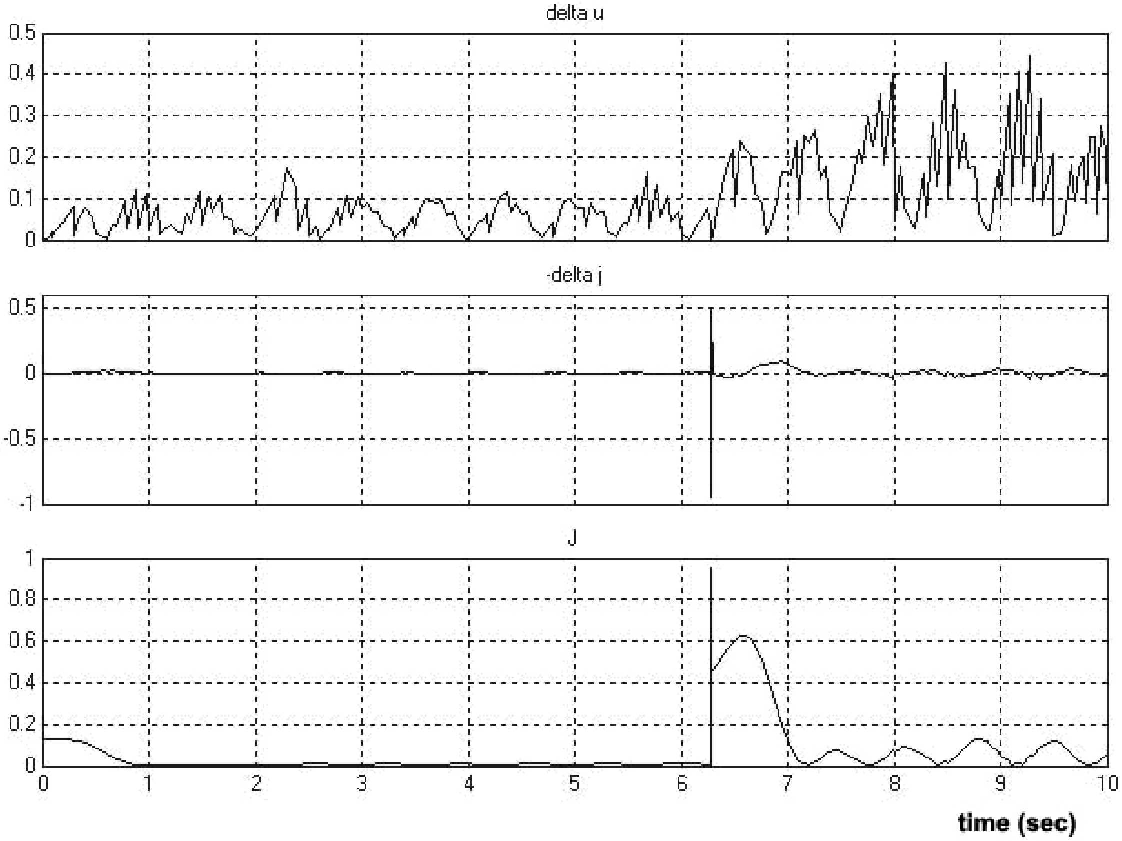


Figure 3.13: Indicator profiles for aircraft when Kf = 0.1. J, $-\Delta J$, and Δu are defined in (3.1), (3.2), (3.3).

The Cooper-Harper rating in figure 3.14 is different from figure 3.11 because the aircraft control is now unstable

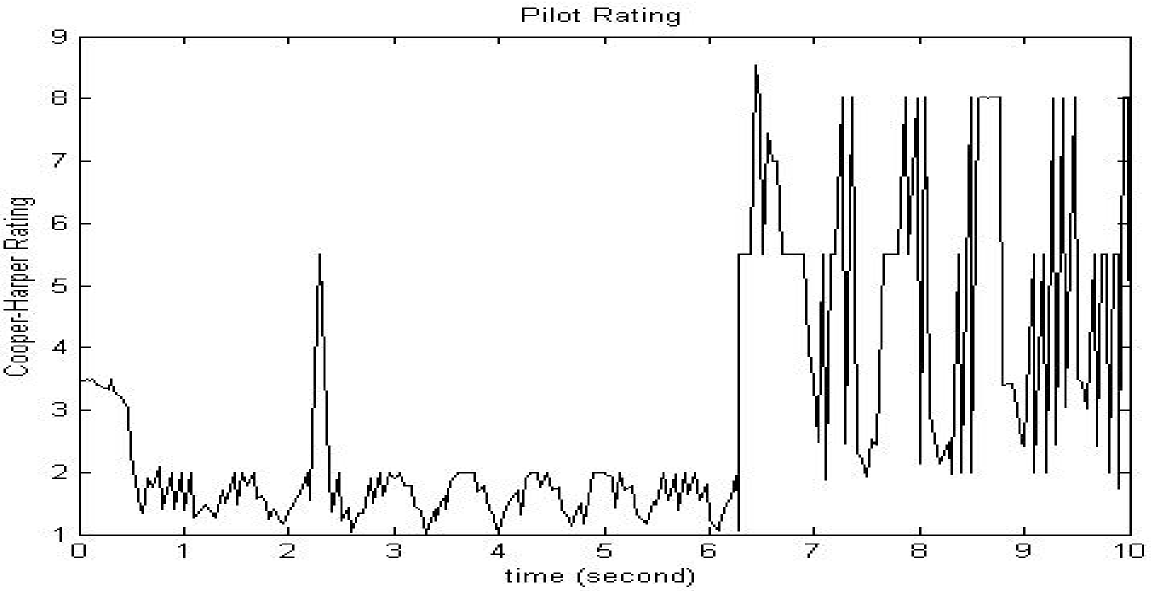


Figure 3.14 aircraft handling qualities rating profile with Kf= 0.1

At the end of the simulation t=10, we can see the three numerical values for compensation, control and performance variables are 0.24, 0, and .095 accordingly. This means compensation is considerable, control is stable and performance is adequate. According to Table 3.1, Cooper-Harper rating system will generate a rating 5. Figure 3.14 showed that Cooper-Harper rating is also 5 at the end of the simulation.

This shows that our proposed fuzzy Cooper-Harper rating system can be used to effectively validate the aircraft handling qualities.

4. Adaptive PI controller with Cooper-Harper Feedback

4.1. Fixed value F14 PI controller

A fixed value controller is a controller which use a fixed gain value Kf in its control. Figure 3.8 shows the fixed value F-14 PI Controller. It uses a fixed value Kf = 1.746 to adjust its controller. Tracking error will always multiply with a fixed value of 1.746 to compute a new control value. In order for this controller to perform better, the fixed gain value Kf should be adjustable based on some sensors values. This is the main drive the work in the next sections.

To distinguish the two gain values in this paper, we will use the notation Kf for fixed gain value and Kp for adjustable gain value.

4.2. Adaptive PI controller with Cooper-Harper Feedback VS. Adaptive PI Controller

Adaptive feedback loop controller is well-known and widely implemented. Tracking error, which is the difference between reference and plant sensors' output data, is passed to an adaptive controller to generate new controlled data values to control the plant. Figure 4.1 illustrates this idea.

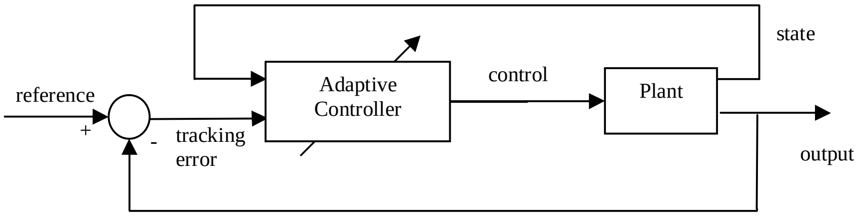


Figure 4.1: Adaptive control system without human feedback

The adaptive control system in Figure 4.1 uses plant sensors' data to adjust its controller. However, these data are very difficult to understand by human user. In this section, we propose a system which uses the same idea, but with another additional input to the adaptive controller. This additional input is a human readable rating value. This human readable rating value is important because user can understand the value which will adjust the controller directly.

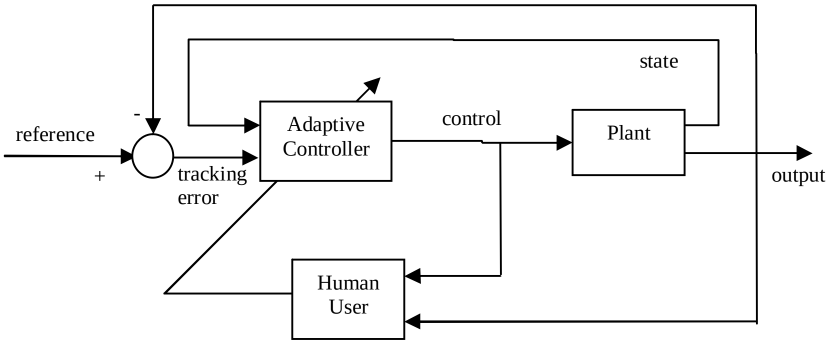


Figure 4.2: Adaptive control system with human feedback

Figure 4.2 illustrates the proposed system we mentioned above. Sensors' output data values, together with control data are passed to a human user component. This component will generate the human readable rating value. The adaptive controller will acquire both the tracking error and the human readable rating value to compute and generate new control for the next iteration.

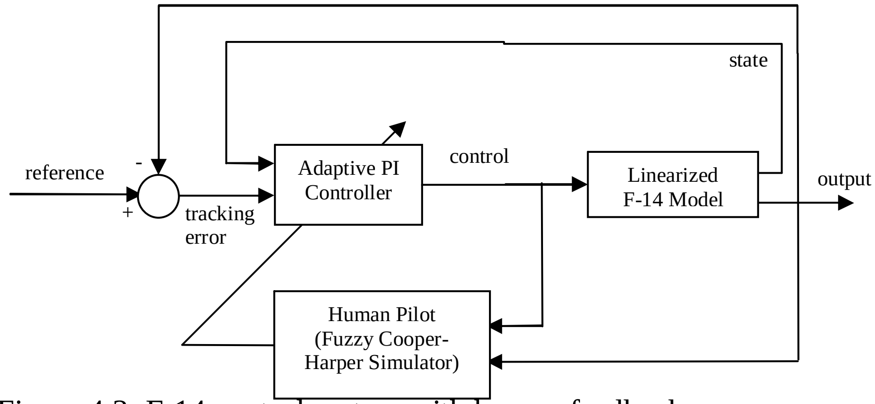


Figure 4.3: F-14 control system with human feedback

Fuzzy Cooper-Harper Rating can be used to implement the idea we propose above. The Fuzzy Cooper-Harper Rating will take both sensors' output data from the plant and controlled data to generate a human reading rating value.

Figure 4.3 shows how we implement this system using Matlab Linearized F14 Model. Matlab Fuzzy tool box is used to implement the Fuzzy Cooper-Harper Simulator. This simulator will generate a rating from 1 to 10 and pass it to the PI controller. The PI controller takes this rating, and adjusts the proportional gain value adaptively. When this gain value is adjusted adaptively, new control data are generated to control the F-14 model.

Implementation

At every simulation step, the Cooper-Harper Aircraft Handling Qualities Rating and the Kp value are passed to the adaptive controller. This controller will adjust the gain value Kp based on the following:

Change in Cooper-Harper Aircraft Handling Qualities Rating:

$$\Delta R(k) = R(k) - R(k-1); k \in N, k \geq 1 \tag{4.1}$$

and

$$\frac{\partial R}{\partial Kp}(t) \approx \frac{\Delta R(k)}{\Delta Kp(k)}; k \in \mathrm{N}, k \geq 1 \tag{4.2}$$

$$\frac{\Delta R(k)}{\Delta Kp(k)} = \frac{R(k) - R(k-1)}{Kp(k) - Kp(k-1)}; k \in \mathrm{N}, k \geq 1 \tag{4.3}$$

Then we will use the decision tree in Figure 4.4 below to determine the value of ΔKp

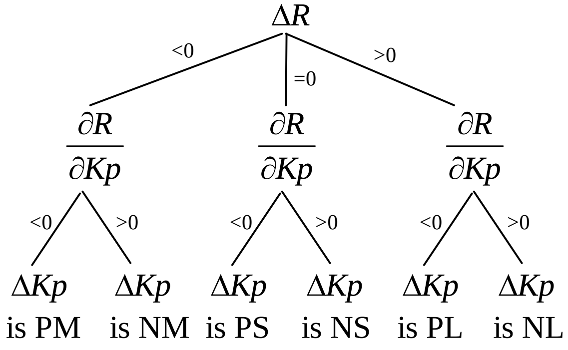


Figure 4.4: Decision Tree for ΔKp; PM: Positive Medium; NM: Negative Medium; PS: Positive Small; NS: Negative Small; PL: Positive Large; NL: Negative Large

Where the value of PM, NM, PS, NS, PL, NL are shown in the table 2.1 below

NL	**NM**	**NS**	**PS**	**PM**	**PL**
-0.15	-0.08	-0.018	0.018	0.02	0.025

Table 2.1: PM, NM, PS, NS, PL, NL values

When ΔKp is determined, it will be used to calculate the value of Kp for next iteration:

$$\mathrm{Kp(k+1)} = \Delta Kp(k) + \mathrm{Kp(k)}; \mathrm{k} \in \mathrm{N}, k \geq 1 \tag{4.4}$$

We also have a control Adaptive Update Interval. This Adaptive Update Interval will control the controller when to update the Kp value based on simulation steps. For example, an Adaptive Update Interval = 1:2 means Kp will be updated every 2 simulation steps.

Time Performance Index

Time Performance Index (TPI) from both the fixed value PI controller and the adaptive PI controller is used to evaluate the improvement of the adaptive system.

$$TPI = TotalAreaUnderTheCurve \tag{4.5}$$

In order to determine which system performs better, we introduce an improvement value. An improvement value is the difference between the TPI of both fixed value PI controller and adaptive PI controller. It will be use to determine how well the adaptive PI controller perform.

$$\text{Improvement value} = \text{TPI}_{\text{Fixed Value PI Controller}} - \text{TPI}_{\text{Adaptive PI Controller}} \tag{4.6}$$

A large positive improvement value means the adaptive controller performs better. A large negative improvement value means the fixed value PI controller performs better.

For viewing purpose, we also define a formula to calculate the improvement percentage of the adaptive control system over the fixed control system.

$$\text{Improvement percentage} = \frac{\text{Improvement value}}{\text{TPI}_{\text{Fixed Value PI Controller}}} * 100\% \tag{4.7}$$

4.3. Results

We simulate the F14 Adaptive Controller with many different pilot input frequencies, pilot input signals (Sine, Sawtooth, Square) and Adaptive Update Intervals.

Adaptive Update Interval	**Sine**	**Sawtooth**	**Square**
1:2	2.6398	0.2964	0.5276
1:5	2.3576	0.1569	0.8596
1:10	1.4199	0.0163	0.1790

Table 4.1: Improvement value results with different control variables. Frequency = 1 Hz for Sine, Sawtooth and Square input

Adaptive Update Interval	**Sine**	**Sawtooth**	**Square**
1:2	2.2205	0.5586	-0.4993
1:5	1.6545	0.8241	-0.4032
1:10	1.2274	0.6416	-0.7103

Table 4.2: Improvement value results with different control variables. Frequency = 2 Hz for Sine, Sawtooth and Square input

Observation from the result on tables 4.1 and 4.2 shows:

- Improvement value will drop when Adaptive Update Interval is high. When this system takes too long to update the Kp value, it will not perform as well. We also experience with an Adaptive Update Interval =1, which means updating Kp value every simulation step, but Matlab became unstable and crashed. This is a known problem with adaptive system. When it updates too quickly, it will become unstable.

- Sine input signal has the highest improvement overall, follow by Sawtooth, then Square. Sine input signal means input value keep changing, and the adaptive controller shows its power when input value change more frequently

Based on the values on table 4.1, 4.2, and (4.7), we generate the improvement percentage tables 4.3 and 4.4 below.

Adaptive Update Interval	**Sine**	**Sawtooth**	**Square**
1:2	34.02%	6.19%	6.16%
1:5	30.38%	3.27%	16.19%
1:10	18.30%	3.40%	2.09%

Table 4.3: Improvement percentage results with different control variables. Frequency = 1 Hz for Sine, Sawtooth and Square input

Adaptive Update Interval	**Sine**	**Sawtooth**	**Square**
1:2	19.82%	7.72%	-5.17%
1:5	14.77%	11.39%	-4.17%
1:10	10.96%	8.87%	-7.35%

Table 4.4: Improvement percentage results with different control variables. Frequency = 2 Hz for Sine, Sawtooth and Square input

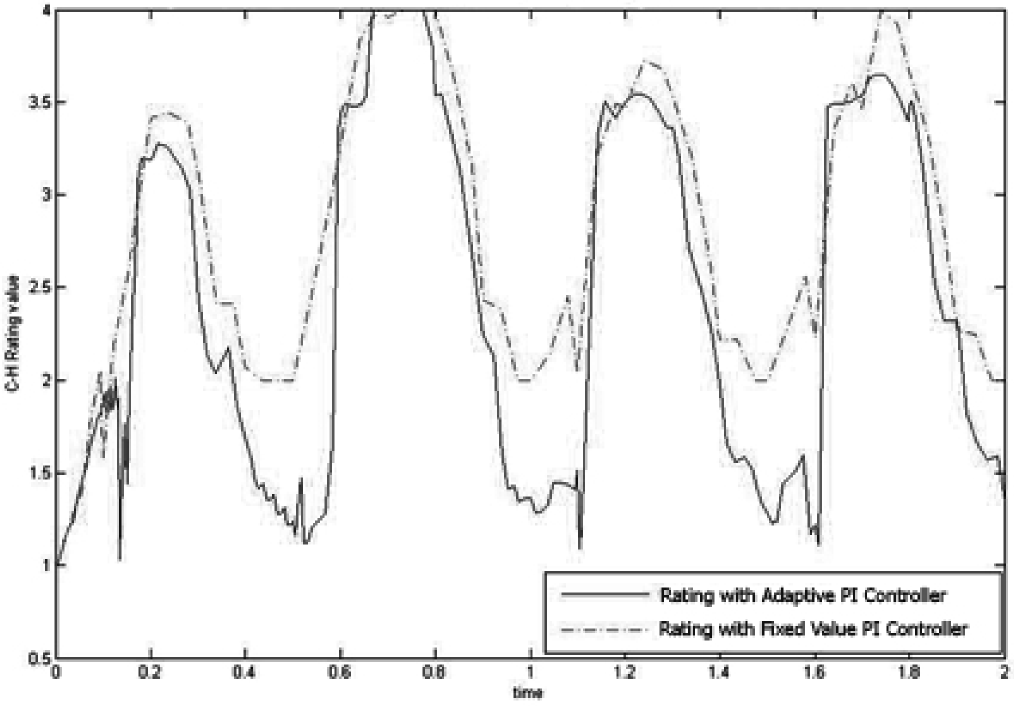


Figure 4.4: Cooper-Harper Rating values plot of Fixed value PI controller VS. Adaptive PI controllers; Pilot input frequency = 1Hz, Sine curve, Adaptive Update Interval = 1:2. Improvement Percentage = 34.02%

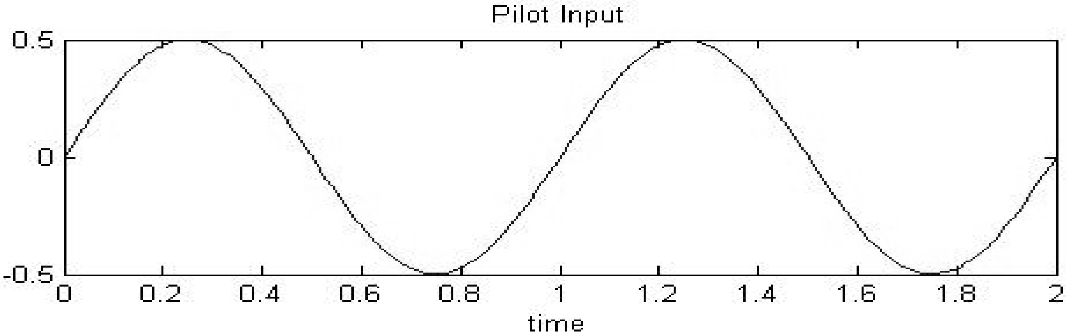


Figure 4.5: Pilot input: frequency = 1Hz, Sine curve, Adaptive Update Interval = 1:2.

Figure 4.4 is a graph of the Cooper-Harper Rating values between the fixed value PI controller and the adaptive PI controller. At t = 1.6 second, the adaptive controller yields a Cooper-Harper Rating of 1 while the fixed value PI controller yields a rating of 2.25. The change from rating = 1 to rating 3.5 at t = 1.6 second is because pilot input change. Figure 4.5 is a plot of pilot's input during the simulation. We can see that pilot's input at t = 1.6 second change faster.

Figure 4.4 shows that the adaptive controller performs much better than the fixed value controller. The goal of this research is to design an adaptive controller which will help the controller perform better by bringing the Cooper-Harper rating closer to the value of 1. Figure 4.4 is one of many good examples to show that our goal is reached.

5. Conclusion

Most control systems are software nowadays. Therefore it is very important to have processes to ensure these systems' safety and reliability. Validation and Verification are the two processes to do this work.

In critical mission, control systems need to be able to adapt in case there are changes in environment or errors occur. These control systems must be able to adjust themselves to ensure system's safe behavior. However, the traditional well-defined V&V processes can not be used on adaptive systems because adaptive systems' functional properties changed over time when new data is learn.

There are many enhanced V&V processes to help with validating and verifying adaptive system, but we choose to use Cooper-Harper Aircraft Handling Qualities Rating to perform V&V on adaptive system in this research. This work is implemented using

Matlab Simulink and fuzzy technology. Cooper-Harper Aircraft Handling Qualities Rating is shown to be affective when we need to validate control systems.

Cooper-Harper Rating output a human readable rating value in order to help pilots to analyze aircrafts' behavior without using their own judgments. This rating can also be used to feed back to adaptively adjust control systems in order to help it perform better. The innovative idea of this research is to use human-readable data to implement an adaptive system. Our simulation results show that this idea can be used to implement more user-friendly systems. Nowadays, software systems become more mature. The idea of using real human-readable data should be considered in further software design and implementing.

References

[1] A. Allen, P. Phattanarsi, K. A. Loparo, F. Soares. *ANCT User's Guide*. EECS Department, Case Western Reserve University, Contek Research, Inc, CA, 2005

[2] A. J. Calise and R. T. Rysdyk. Nonlinear Adaptive Flight Control using Neural Networks. page14-25, issue 6, Volume 18, *IEEE Control Systems Magazine*, 1998

[3] A. Mili, B, Cukic, Y. Liu and R.B. Ayed. Towards the verification and validation of online adaptive systems. *accepted for Special Volume of CI in SE*, October, 2002.

[4] A. Mili, G. Jiang, B. Cukic, Y. Liu, and R. B. Ayed. Towards the Verification and Validation of Online Learning Systems: General Framework and Applications. *in Proc. of the 37th Annual Hawaii International Conference on System Sciences* (HICSS'04), track 9, vol. 9, 2004

[5] A. Nürnberger, D. Nauck, R Kruse. Neuro-Fuzzy Control Based on the NEFCON-Model Under MATLAB/SIMULINK. University of Magdeburg Institute for Information and Communication Systems, *Neural Networks and Fuzzy Systems*, Jun 1997

[6] C. Papageorgiou and Keith Glover. Robustness Analysis of Nonlinear Flight Controllers. Vol. 28, No. 4, *Journal Of Guidance, Control, and Dynamics*, Jul-Aug 2005

[7] C. Spitzer. *The Avionics Handbook*. CRC Press, December, 2000

[8] C. Tseng, P. Gupta, J. Schumann. Analysis of Aircraft Control Performance using a Fuzzy Rule Base Representation of the Cooper-Harper Aircraft Handling Quality Rating. *IEEE Aerospace Conference,* 4-11 2006

[9] C. Tseng, V. H. Hwang. Servocontroller Tuning with Fuzzy Logic. Vol. I, No. 4, *IEEE Transactions on Control Systems Technology*, Dec 1993

[10] Cooper-Harper Handling Qualities Rating Scale, URL: http://history.nasa.gov/SP-3300/fig66.htm, 2007.

[11] D. Bedford, G Morgan, and J Austin. Requirements for a Standard Certifying the use of Artificial Neural Networks in Safety Critical Applications. *International Conference on Artificial Neural Networks*, 1996.

[12] D. M. Rodvold. A Software Development Process Model for Artificial Neural Networks in Critical Applications. *Proceedings of the 1999 International Joint Conference on Neural Networks*. Washington D.C., July 1999

[13] Fisher, SC Smith, and J Burken. Adaptive Robust Control of an F- 15 Aircraft. *American Control Conference*, 2004.

[14] F. T.Sheldon, A. Mili. Characterization of Software Quality Assurance Methods: Five Methods for Verification of Learning Systems. *Int'l Neural Networks Joint Conference: V&V Workshop Montreal*, August 5, 2005

[15] H. G. Zimmermann. *Advanced Neural Networks in System Identification & Forecasting Safe Modeling by Design*. Siemens Corporate technology, 2005

[16] I. Sommerville. *Software Engineering*. 6th edition, Addison Wesley Publishing Company, Aug 2000

[17] J. J. Burken, F. Soares. Reconfigurable Flight Control Design using a Robust Servo LQR and Radial Basis Function Neural Network. Conjunction with IJCNN, 2005, *International Joint Conference on Neural Networks*, Montreal, Canada, August 5th, 2005

[18] J. Schumann and Pramod Gupta. Monitoring the Performance of a neuro-adaptive Controller. pp. 289-296, Volume 735, Issue 1, November 16, *American Institute of Physics conference*, 2004.

[19] J. Schumann, S. Nelson. Toward V&V of Neural Network Based Controllers. *WOSS*, Charleston, SC, November 2002

[20] K. Gundy-Burlet. Augmentation of an Intelligent Flight Control System for a Simulated C-17 Aircraft. *Journal of Aerospace Computing, Information, and Communication*, vol. 1, no. 12, pp. 526-542, 2004.

[21] K. M. Passino, S. Yurkovich. *Fuzzy Control*. Addison Wesley Longman, Inc., 1998

[22] Lyapunov function, URL: http://en.wikipedia.org/wiki/Lyapunov_function, 2007

[23] M. A. Pai. *Power System Stability By Lyapunov's method*. N.Holland Publishing, 1981

[24] M. G. Perhinschi, J. Burken, M. R. Napolitano, G. Campa, and M. L. Fravolini. Performance comparison of different neural augmentation for the NASA Gen-2 IFCS F-15 control laws. *Proc. of American Control Conference*, vol. 4, pp. 3180- 3184, Jul 2004.

[25] P. Phattanasri, K. A. Loparo, F. Soares. *Verification and Validation of Complex Adaptive Systems*. EECS Department, Case Western Reserve University, Contek Research, Inc., April 2005

[26] R. D. Fresnedo. *Statistics and the Verification Validation & Testing of Adaptive Systems*. M&CT, Phantom Works, The Boeing Company, Aug 2005

[27] R. M. Murray, Z. Li, S. S. Sastry. *A Mathematical Introduction to Robotic Manipulation*. CRC Press, 1993

[28] R. Paz. *The Design of the PID Controller*. Klipsch School of Electrical and Computer Engineering, June 2001

[29] S. Piche. *Verification and Validation of Neuro-Adaptive Controllers in the Power Industry*. Pegasus Technologies, 2005

[30] S. Yerramalla, B. Cukic, M. Mladenovski, and E. Fuller. Stability Monitoring and Analysis of Learning in an Adaptive System. *Proc. of International Conference on Dependable Systems and Networks*, 2005

[31] S. Yerramalla, B. Cukic, M. Mladenovski. Stability Monitoring and Analysis of Learning in an Adaptive System. *Proc. of the International Conference on Dependable Systems and Networks*, 2005

[32] V. Crum, D. Homan, and R. Bortner. Certification Challenges for Autonomous Flight Control System. *AIAA Guidance, Navigation, and Control Conference and Exhibit*, Providence, Rhode Island, Aug 2004

[33] V. Gazi, K. M. Passino. Direct Adaptive Control Using Dynamic Structure Fuzzy System. *Proc. of the American Control Conference*, 2000

[34] P. A. Ioannou, P. V. Kokotovic. Robust Redesign of Adaptive Control. Vol. AC-29, No. 3, *IEEE Transaction on Automatic Control*, Mar, 1984

[35] Y. Liu. *Verification and Validation of Online Adaptive Systems.* Ph. D Thesis, Dept. of Computer Science and Electrical Engineering, West Virginia University, 2002

[36] Y. Liu, S. Yerramalla, B. Cukic, and S. Gururajan. Adaptive control software: can we guarantee safety?. *Proc of 28th Annual International on Computer Software and Applications Conference*, COMPSAC 2004, vol. 2, pp. 100-103, Sep 2004.