Damage Tests on an Adaptive Flight Control System

J.E. Steck[1], F. Sayeed[2]

[1] Professor, Department of Aerospace Engineering, Wichita State University, Wichita, Kansas 67260, U.S.A.
[2] Masters Student, Department of Aerospace Engineering, Wichita State University, Wichita, Kansas 67260, U.S.A.

Introduction

An EZ-Fly System on a Bonanza Raytheon NASA Test-bed has been used by WSU to develop a Neural Network based Adaptive Flight Control System. This paper describes a series of simulations done on the control system to evaluate its ability to adapt to damage that may occur to the aircraft in flight. These tests were done to verify that it would be possible for an un-experienced or un-trained pilot to continue flying a damaged aircraft with ease.

When an aircraft is damaged, its parameters change. This causes normal autopilots and other control systems, which are fine-tuned to the parameters of the aircraft, to be unable to compensate for the damage. This prevents them from operating effectively. The Neural based Adaptive Flight Controller uses an Artificial Neural Network (ANN) to compensate for these modeling errors and control-surface failures. . The most important characteristic of an ANN, similar to that of a biological neural network, is fault tolerance[1]. An ANN is able to look at an input signal that may seem different from what it has seen before and make a decision on what that signal may mean. This simply means that a neural network is easily able to handle modeling error in a system and possibly compensate for it. The simulations were carried out in X-Plane, using its features for simulating damage on the aircraft.

Flight Test on Simulator

The EZ-Fly flight control system simplifies the flying of an aircraft for an un-experienced pilot. The longitudinal stick commands the flight path angle of the aircraft instead of the pitch angle, while centering it commands level flight. Similarly the lateral stick commands a bank angle instead of a bank rate and centering it commands a constant heading [2]. The throttle is replaced with a speed lever, hence letting the pilot set a speed and letting the controller control the throttle to maintain that speed.

The Adaptive Flight Control system was initialized in MATLAB® SIMULINK®. This system consists of the longitudinal and the lateral neural networks, and an inverse model of the aircraft which is defined through the equations of motion to serve as a reference for the neural network as to what the aircraft should be doing. The tests were designed so as that both the lateral and longitudinal portions of the controller could be tested by setting up a strict flight profile for the aircraft to follow. A model of the Beech Bonanza F33C single engined aircraft was setup to fly in X-Plane.

The aircraft was then flown in the designated pattern to establish the base case for the performance of the controller. With the base case established, the aircraft was then flown in the same pattern during which various control surfaces were failed. These failures included physical losses of one or both elevators, physical damage to the wings and loss of ailerons and flaps, and loss of the rudder, all which occurred at various times during the flight, both before and during the maneuvers.

The results of these tests were then observed and compared to see how the neural network reacted to these sudden changes in the parameters of the aircraft, and if it was possible for it to continue flying the aircraft with the damage. The following is a result of the tests conducted;

Elevator Damage Flight Profile

- Speed: 120kts
- Test done: Right Elevator Fail DURING Climb

- Step 1:- Initialize Matlab and place aircraft at 3000ft heading 0
- Step 2:- Wait for settle
- Step 3:- Apply 5 degrees up gamma angle @30secs
- Step 4:- Loss of right elevator 90secs into flight
- Step 5:- Level out at 5000 ft
- Step 6:- Apply 5 degrees down gamma angle @200secs
- Step 7:- Level out at 3000 ft

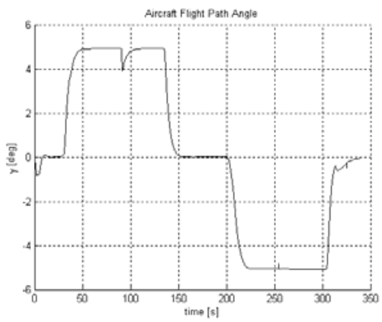


Figure 1: Flight Path Angle

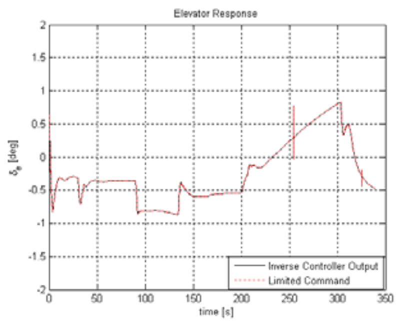
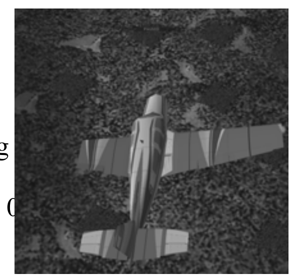


Figure 2: Elevator Response

Aileron Damage Flight Profile

- **Speed: 120kts**
- **Test done: Left Outboard wing Fail DURING RIGHT bank**
- Step 1:- Initialize Matlab and place aircraft at 5000ft heading 0
- Step 2:- Wait for settle (100secs into flight)
- Step 3:- Apply -30 degrees bank angle @200secs into flight to turn to heading
- Step 4:- Level out at 180
- Step 5:- Apply 30 degrees bank angle @350secs into flight to turn to heading 0
- Step 6:- Loss of left outboard wing 380secs into flight
- Step 7:- Level out at heading 00



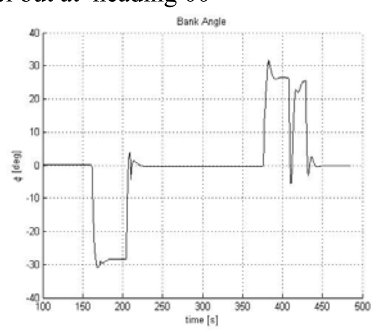


Figure 3: Bank Angle

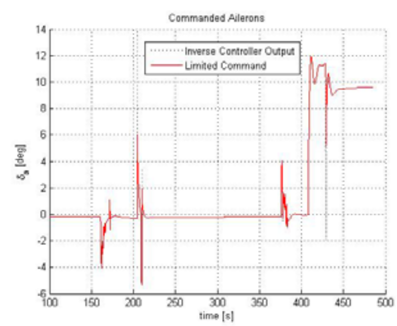


Figure 4: Aileron Response

Conclusion and Further Research

The results show that the controller was able to fly the damaged aircraft within the prescribed flight profile as long as the damage inflicted on the aircraft was not extreme. It was also noticed that with loss of a portion of ailerons, the remaining ailerons did not require to deflect any more than they would have deflected than if there was no damage. It was found that the controller's limitation was in handling the aircraft when a sudden and extremely large bank angle of 60 degrees was commanded. This sort of a bank command sent the aircraft into an irrecoverable spin with the neural network unable to compensate fast enough to bring the aircraft back into control.

The next step for this project is to begin to implement this controller for multi-engine aircraft, whereby applying differential power to the engines gives the controller another means of controlling the heading of the aircraft if the rudder were damaged.

References:

[1] Fausett, L, Fundamentals of Neural Networks, L.P.Edition, Pearson Education

[2] Pesonen, U.J., Steck, J.E., Rokhsaz, K., Bruener, H.S., Duerksen, N., "Adaptive Neural Network Inverse Controller for General Aviation Safety", Journal of Guidance, Control, and Dynamics, Vol. 27 – 2004