NASA Facts

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Intelligent Flight Control System

Project Summary

The Intelligent Flight Control System (IFCS) flight research project at NASA Dryden Flight Research Center was established to exploit a revolutionary technological breakthrough in aircraft flight controls that can efficiently optimize aircraft performance in both normal and failure conditions. IFCS is designed to incorporate self-learning neural network concepts into flight control software to enable a pilot to maintain control and safely land an aircraft that has suffered a major systems failure or combat damage.

Major control surface or system failures negate an aircraft flight control system's design assumptions, rendering the predefined fixed control system virtually worthless. The IFCS team has integrated innovative neural network technologies with state-of-the-art control algorithms and propulsion control concepts to correctly identify and respond to changes in aircraft stability and control characteristics, and immediately adjust to maintain the best possible flight performance during an unexpected failure. The adaptive neural network software "learns" the new flight characteristics, onboard and in real time, thereby helping the pilot to maintain or regain control and prevent a potentially catastrophic aircraft accident.

The testbed aircraft selected to validate the IFCS neural network flight control software is a highly-modified McDonnell-Douglas NF-15B Eagle that was formerly flown in the Advanced Control Technology for Integrated Vehicles project at NASA Dryden from 1996 through 1999.

The flight test results will be utilized in an overall strategy aimed at advancing neural network-based flight control technology to new aerospace systems designs, specifically targeting the U.S. Air Force C-17 T1 test aircraft. This aircraft, based at Edwards Air Force Base, Calif., is currently being modified to support IFCS experiments as part of the Intelligent Vehicle Systems (IVS) activity. Other vehicle classes will be considered as opportunities arise, including fighter and transport aircraft, reusable launch vehicles, uninhabited vehicles, and space vehicles.

The IFCS project is representative of the type of flight research conducted by NASA to explore new control technologies, blending intelligent flight controls with adaptive airframe structures to expand aircraft performance and capabilities. The project is in line with the Revolutionary Vehicles element of NASA's Aeronautics Blueprint, with a specific goal of developing adaptive and fault-tolerant flight control systems leading to unprecedented levels of safety and survivability for both civil and military aircraft.

The IFCS project is a collaborative effort among NASA Dryden Flight Research Center (DFRC), NASA Ames Research Center (ARC), Boeing Phantom Works (BPW) (St. Louis, MO), the Institute for Software Research (ISR), West Virginia University (WVU) Fairmont, West Virginia, and the Georgia Institute of Technology (GIT).

IFCS Objectives

- Implement and fly neural network software for flight controls
- Develop verification and validation procedures for flight critical checkout of non-deterministic neural net software
- Demonstrate safe in-flight simulated failure recovery using learning neural network software with adaptive flight controls

The project is scheduled for flight test beginning in 2003 (IFCS Generation I) and early 2004 (IFCS Generation II). In addition, initial parameter-identification test flights with an IFCS neural network that was pre-trained to the F-15's aerodynamic database were flown in 1999. A follow-up series of flights are being flown in the summer of 2002 to calibrate new instrumentation and air data systems and repeat several of the test points flown in the 1999 series to reduce risk for the Generation I and II flight research phases.

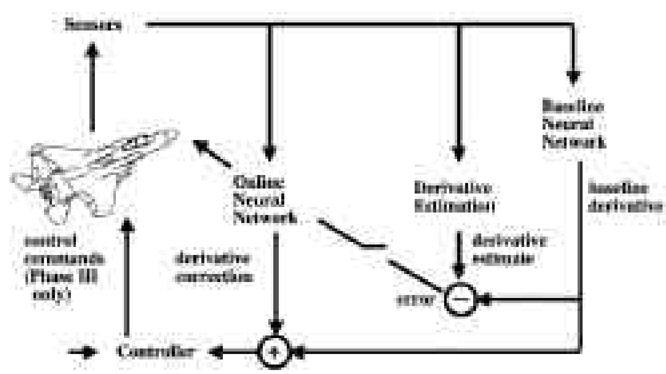
Project Overview

The ultimate goal of the IFCS project is to develop and flight demonstrate direct adaptive neural network based flight control system. The direct adaptive approach incorporates neural networks that are applied directly to the flight control system feedback errors to provide adjustments to improve aircraft performance in both normal flight and with system failures. A secondary goal is to develop the processes of verification and validation (V&V) of neural networks for use in flight critical applications. The flight project results will be utilized in an overall strategy aimed at advancing neural net flight control technology to new aerospace system designs including civil and military aircraft, reusable launch vehicles, uninhabited vehicles, and space vehicles.

The IFCS is being tested in flight on the NASA NF-15B (NASA 837.) This aircraft has been highly modified from a standard F-15 configuration to include canard control surfaces, thrust vectoring nozzles, and a digital fly-by-wire flight control system. The technical approach includes:

- Integrating the Generation I and II online learning neural networks with an advanced flight controller;
- Testing the software on the NASA 837 flight control ground test bench;
- Installation of the system in the aircraft and conducting a flight test evaluation in a limited flight envelope at NASA Dryden Flight Research Center. The testing will include simulated failures to the control system.

The results of the tests are expected to prove the performance and the test process for advanced online learning neural network technology.

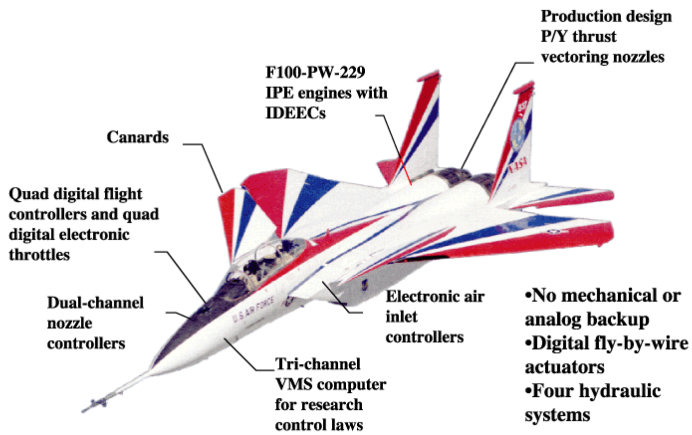


IFCS Generation I Concept

The Intelligent Flight Control System (IFCS) Generation I (GEN I) concept is a direct adaptive neural network approach. It is designed to organize and map the aerodynamic changes caused by simulated failure modes, and provide the flight control system with that information. The system identifies dynamic characteristics of the vehicle (stability and control derivatives) and uses that information to stabilize the vehicle and provide specific flying characteristics. There are four main components of the GEN I system:

1. A pre-trained neural network (PTNN)
2. A parameter identification/estimation (PID) algorithm
3. An online learning neural network, in our case Dy-

namic Cell Structure (DCS)
4. A control algorithm, in our case a Stochastic Optimal Feedforward Feedback Technique (SOFFT)



The PTNN is an algorithm that is trained to produce stability and control derivatives depending on a specific flight condition. It learns the stability and control derivatives from wind tunnel data before flight and is fixed throughout the flight. The PTNN provides the first best estimate of the vehicle dynamic characteristics.

The PID algorithm is an online function that determines the actual stability and control characteristics of the vehicle as it flies. When results from the PID algorithm differ from the PTNN an update to the system is required.

The DCS provides the online learning of the system. It tracks the differences between the PTNN and PID and provides an organized map of updates to the stability and control derivatives of the vehicle.

The SOFFT control algorithm uses stability and control derivatives information to fine-tune the system to provide optimal stability and specific flying characteristics.

IFCS Generation II Concept

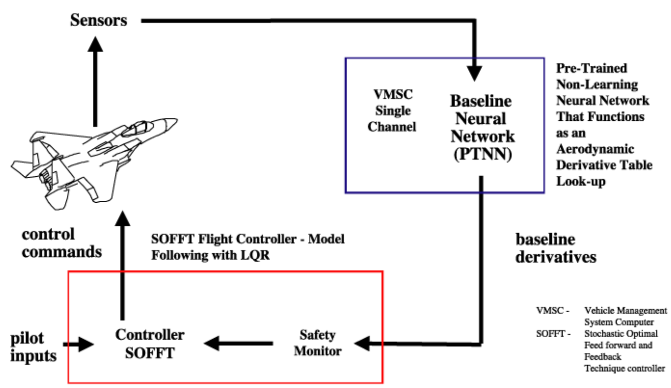
The Intelligent Flight Control System (IFCS) Generation II (GEN II) neural networks will take over more direct control of the vehicle, working alongside the flight controller to adjust for any short-comings. The neural network will be more like an equal partner with the flight control system.

Instead of explicitly identifying how the system has changed and then adjusting to compensate, the GEN II system is an indirect adaptive system that applies corrections continuously and learns by observing the overall effect on performance. Because the GEN II system is more closely integrated into the flight controller, it requires advances in techniques to flight-qualify learning systems.

The Generation II concept is based on a dynamic inversion controller with a model-following command path. The feedback errors are regulated with a proportional plus integral (PI) controller. This basic system is augmented with an adaptive neural network that operates directly on the feedback errors. The adaptive neural network adjusts the system for miss-predicted behavior, or changes in behavior resulting from damage. Demonstration of this direct adaptive neural network is the primary objective of the IFCS Generation II flight project.

The dynamic inversion portion of the control system generates acceleration commands. These commands are translated into control surface commands by a control allocation scheme. The dynamic inversion, control allocation, and model-following algorithm all require information on the dynamic behavior of the system to be controlled. This information is provided in the form of aerodynamic stability and control (S & C) derivatives. The S & C derivative calculation algorithm is based on the F-15 IFCS Generation I system.

Flight Control Architecture for Risk Reduction Flights



Flight Phases

1999 Flight Tests:

Preliminary flight tests of an IFCS neural network that was pre-trained to the NF-15B's aerodynamic database were flown in Spring 1999. These tests, conducted during 15 flights, validated the non-learning portions of the IFCS Generation I concept. As the aircraft flew, the pre-trained neural network (PTNN) provided a best estimate of stability and control characteristics based on wind-tunnel information. The SOFFT control algorithm used this information to adjust the control settings to stabilize the system and provide specific flying characteristics. These series of flight tests demonstrated that:

- Pre-trained neural networks provided correct online stability data for flight control;
- A flight control aircraft model can be defined from online neural networks;
- Full-time optimal feedback control using neural network modeled stability data;

- Demonstrated a control system that can provide selected handling qualities for any mission mode

The 1999 tests were flown in a very limited portion of the NF-15B's flight envelope, from about Mach 0.6 to Mach 0.9 at 15,000 feeet altitude and from about Mach 0.85 to Mach 1.4 at 35,000 feet altitude.

2002 Risk Reduction Flights:

These flights are intended to provide information to develop and refine the Parameter Identification/Estimation (PID) algorithm. The PID algorithm requires accurate measurements of the inputs and the response of the aircraft. The NASA NF-15B #837 aircraft instrumentation system has been improved to provide better measurements. During this flight phase, data will be collected for analysis on the ground. This data will be processed by the PID algorithm to not only validate the PID algorithm, but to provide a representative input to the Dynamic Cell Structure (DCS) algorithm. These flight tests will ensure that the PID and DCS software will work when it is installed in the aircraft.

Target goals

- Functional check flight of aircraft.
- Checkout of new instrumentation on the aircraft.
- Calibration for new air data system nose boom;
- Initial parameter identification (PID) data, using newly-installed Airborne Research Test System (ARTS) II research flight control computer.
- Handling quality maneuvers with the pre-trained neural network data—completing data set that was not completed in the 1999 tests;

Flight test plan

- 10 flights over roughly six weeks, with considerable time spent in between each flight for data reduction and analysis.

Generation I Flight Test:

Flight tests of the Generation I software will occur in early 2003. Prior to beginning the Generation I flight tests, a faster processor will be added to the NASA NF-15B #837 aircraft to host the Dynamic Cell Structure (DCS) self-learning portions of the Generation I system. These tests will demonstrate the PID and DCS software in a research flight control computer during flight. The system will demonstrate the ability to compensate for erroneous wind tunnel data. In addition, simulated failures will be introduced to show the ability of the system to adapt to changes in aircraft behavior.

Generation II Flight Test:

Generation II flight tests are presently scheduled for early 2004. The performance of this system will be directly compared with the performance of Generation I. It is expected that the Generation II system will provide quicker response to simulated failures.

For More Information Contact:

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