United States Patent

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PROPELLION CONTROLLED AIRCRAFT
COMPUTER

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See application file for complete search history.

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Abstrac

A low-cost, easily retrofit Propulsion Controlled Aircraft (PCA) system for use on a wide range of commercial and military aircraft consists of an propulsion controlled aircraft computer that reads in aircraft data including aircraft state, pilot commands and other related data, calculates aircraft throttle position for a given maneuver commanded by the pilot, and then displays both current and calculated throttle position on a cockpit display to show the pilot where to move throttles to achieve the commanded maneuver, or is automatically sent digitally to command the engines directly.

10 Claims, 3 Drawing Sheets
PCAC Display for 4 Engine Aircraft

Throttle Limit

Current Throttle Position

Commanded Throttle Position

FIG. 2
PROPULSION CONTROLLED AIRCRAFT COMPUTER

STATEMENT OF GOVERNMENT INTEREST

This invention described herein was made by employees of the United States Government and may be manufactured and used by or for the Government for Government purposes without the payment of any royalties thereon or therefore.

BACKGROUND

a. Field of Invention

The invention relates to aircraft flight-control systems and, more particularly, to a computer-assisted propulsion control system that enables a pilot to land a plane safely when its normal control surfaces such as elevators, rudders, and ailerons are disabled.

b. Background of the Invention

Aircraft flight-control systems are designed with redundancy to ensure low probability of failure. Nevertheless, there have been several instances of major flight-control-system failures. In these situations engine thrust becomes the last remaining mode of flight control. It is possible for pilots to control an aircraft using thrust by manually moving the throttles to maintain or change flight path and heading angles. However, this places a high work load on the pilots which may result in a crash and loss of life. The challenge lies in creating a means of sufficient degree of thrust-modulation control to safely fly and land a stricken airplane without causing a high pilot workload.

Propulsion Controlled Aircraft (PCA) is a computer-assisted engine control system that enables a pilot to land a plane safely when its normal control surfaces such as elevators, rudders, and ailerons are disabled. PCA is a damage mitigation technology that utilizes propulsive thrust for aircraft control in the event of partial or total loss of flight controls due to any failure including loss of hydraulics. Whether used in military or commercial aircraft, PCA has the potential to reduce the number of aircraft accidents due to loss of flight controls.

In the recent past, a PCA system has been developed and disclosed in U.S. Pat. No. 5,330,131 by Frank W. Burcham et al. (incorporated herein by this reference) based upon a program modification of an otherwise normal Flight Control Computer (FCC) that, in the event of a failure of the normal flight control system of a multiengine airplane, substitutes normal pitch axis control with symmetric control of the engines through their FCC driven servos using pitch attitude and pitch rate sensed by gyros to provide the feedback signals necessary to track a pitch command signal. That patented flight control system requires extensive modification not only of the FCC but also of each full-authority digital engine control (FADEC) computer for each engine.

More recently U.S. Pat. No. 6,041,273 to Burken et al. issued Mar. 21, 2000 disclosed an emergency control aircraft system using thrust modulation that compares the input flight path angle signal from a pilot thumbwheel with a sensed flight path angle to produce an error signal, an ultimately, an aircraft thrust control signal to drive a throttle servo for all engines. This effectively serves as an emergency backup system for a PCA that requires only program modification of the FCC without any changes in engine computers.

U.S. Pat. No. 6,126,111 to Burcham et al. issued Oct. 3, 2000 shows a further refinement to the foregoing emergency flight control system that additionally uses lateral fuel transfer to allow a pilot to regain control over an aircraft under emergency conditions. Here, where aircraft propulsion is available only through engines on one side of the aircraft, lateral fuel transfer provides the means by which the center of gravity of the aircraft can be moved over to the wing associated with the operating engine, thus inducing a moment that balances the moment from the remaining engine, allowing the pilot to regain control over the aircraft.

Unfortunately, all of the foregoing and all other known current implementations of PCA require expensive modifications to aircraft software and hardware as well as recertification of the aircraft. It would be greatly advantageous to provide a PCA capability at a fraction of the cost of full implementation for widespread commercial and military deployment.

SUMMARY OF THE INVENTION

It is, therefore, an object of the present invention to provide a cost-effective computer-assisted propulsion control system that enables a pilot to land a plane safely when its normal control surface such as elevators, rudders, and ailerons are disabled.

It is another object to provide a propulsion control system that avoids expensive modifications to aircraft software and hardware or the need for major recertification of the aircraft.

According to the present invention, the above-described and other objects are accomplished by providing a low cost system and method of implementing Propulsion Controlled Aircraft (PCA) technology on a wide range of commercial and military aircraft. The system is an intelligent Propulsion Controlled Aircraft Computer (PCAC) that reads in aircraft data including aircraft state, pilot commands and other related data. The system runs a software program that calculates aircraft throttle position for a given maneuver (heading change, climb, descent, flare, etc.). The calculated aircraft throttle position for the given maneuver is then displayed on a cockpit display to show the pilot where to move throttles to achieve the commanded maneuver, or is automatically sent to command the engines (in aircraft equipped with engines capable of receiving digital command signals). The PCAC may be a conventional computer platform such as a standard laptop PC with peripheral slot. A Bus Monitor card is inserted in the peripheral slot for communications over the aircraft data buses. The Bus Monitor card reads the aircraft data buses to provide aircraft state and pilot commands. The system also includes a display which may be on the laptop or separate display closer to the pilots. The PCAC runs a software program comprising three major software subroutines. A first software subroutine monitors the aircraft data bus (via the Bus Monitor card) and processes data from the Bus Monitor card. The software also comprises a second PCA subroutine that calculates necessary throttle command based on current aircraft state and desired maneuvers. A third subroutine formats the calculated throttle command as well as the actual monitored aircraft data and, based on aircraft state and desired maneuvers, generates a PCA display showing current and commanded throttle position to show the pilot where to move throttles to achieve the commanded maneuver. Alternatively the third subroutine may generate a PCA command signal that is directly communicated to the engines for automatic control (in aircraft equipped with engines capable of receiving PCA signals). In either case the system can be retrofitted to any aircraft (military or commercial), which has
a data bus. Thus, no changes are required to aircraft control
software and only minimal hardware changes.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a system block diagram of the PCAC 10 with
aircraft connections to existing aircraft data buses 20 and
optionally to aircraft power 40.

FIG. 2 is a screen shot of the display format compiled by
the PCAC display subroutine for a four-engine aircraft.

FIG. 3 is a diagram of an exemplary implementation for a
PCAC 10 to C-17/F-117 Electronic Engine Control (EEC)
interface.

DETAILED DESCRIPTION OF THE PREFERRED
EMBODIMENT

The present invention is an intelligent Propulsion Control-
led Aircraft Computer (PCAC) for implementing Propul-
sion Controlled Aircraft (PCA) technology in a low cost way
on a wide range of commercial and military aircraft. The
PCAC reads the existing aircraft data buses, runs a PCA
algorithm to calculate throttle commands necessary for a
given thrust-control maneuver, and then drives a display with
a readout that makes a throttle-controlled landing possible for
the pilot. More specifically, the PCAC reads in aircraft data
including aircraft state, pilot commands and other related
data. If the pilot commands include a desired maneuver
(heading change, climb, descent, flare, etc.), the PCAC then
calculated aircraft throttle position necessary to complete the
desired maneuver and then generates a display to show the
pilot where to move throttles to achieve the commanded
maneuver. As an alternative to the visual display, the system
is also capable of deploying command signals to automati-
cally control the engines (in aircraft equipped with engines
capable of receiving PCA signals). The PCAC may be a
conventional computer platform running software to be
described.

FIG. 1 is a system block diagram of the PCAC 10 with
aircraft connections to the existing aircraft data buses 20 and
optionally to aircraft power 40. The presently-preferred
PCAC 10 is a standard laptop with PCI peripheral slot
equipped with a conventional Bus Monitor card inserted in
the peripheral slot. An SBS Technologies™ PCMCIA2 bus
monitor card is suited for present purposes, and the selected
card may alternatively be a MIL-STD-1553 data bus (for
military aircraft) or an ARINC 429 or 629 bus (commercial
aircraft). The PCAC 10 via its bus monitor card monitors the
aircraft data buses 20 to provide aircraft state and pilot com-
mands. The PCAC 10 is most easily installed on an existing
aircraft by connecting cables from the PCAC bus monitor
card to the aircraft’s “mod block.” Mod blocks are standard on
most commercial and military aircraft and are used to access
the aircraft data bus for testing and data collection.

The PCAC 10 also includes a display which can be the
either the lap top display itself, or an optional remote display
30 such as a separate, smaller monitor, closer to the pilots. A
remote display 30 may provide better visual access to the
pilot, but may incur larger modifications to the aircraft.

As mentioned, the PCAC 10 may optionally be connected
to the aircraft power bus 40. Connecting the PCAC 10 to
aircraft power, if available, avoids possible time delays and
ensures that power is always available.

The PCAC 10 runs a software program comprising three
major PCA software subroutines. All three PCA software
subroutines may be written in standard programming lan-
guage such as C++. The software PCA subroutines include:
1) a data bus monitoring subroutine that processes aircraft state
data collected by PCAC 10 via the bus monitor card; 2) a PCA
subroutine that calculates necessary throttle command based
on the aircraft state data collected by the data bus monitoring
subroutine, in view of desired maneuvers; and 3) a PCAC
Display subroutine that takes the calculated throttle com-
mmand from the PCA subroutine and graphically displays both
current throttle position and desired throttle position needed
to achieve the desired maneuvers. Each of these subroutines is
described in more detail.

1. The data bus monitoring subroutine uses conventional
call functions (embedded in the operating system) to a
Dynamically Linked Library (DLL) to read selected parameters
from the aircraft data bus. Conventional bus monitor
cards such as the SBS Technologies™ PCMCIA2 bus moni-
tor card are packaged with a DLL that is installed on PCAC 10
to read the selected parameters from the aircraft data buses 20,
and for present purposes these parameters includes both air-
craft state parameters as well as pilot commands. The aircraft
state parameters include pitch angle, roll angle, pitch rate,
roll rate, angle of attack, airspeed, and throttle positions. The pilot
commands include commanded flight path angle, com-
mmanded roll angle, and commanded heading. The data bus
monitoring subroutine uses the call functions to DLL Library
to read these parameters from the aircraft data bus.

2. The foregoing aircraft state parameters and pilot com-
mands are then made available to the PCA subroutine, which
then calculates the throttle command required to obtain the
pilot commanded aircraft state. The calculations of throttle
command required to obtain the pilot-commanded aircraft
state as employed in the present PCA algorithm have been
determined empirically using MATLAB™ by Mathworks in
a flight simulator of the target aircraft. Once the correlation
of throttle commands are developed, they may be easily auto-
coded into a C++ PCA subroutine which is then loaded on
the PCAC 10.

3. The PCAC display subroutine is designed to take the
output from the PCA subroutine above and display current
throttle positions and limits based on the original data from
the aircraft data bus. The PCAC display subroutine also
shows commanded throttle positions based on the calcula-
tions in the PCA subroutine above.

In operation, the PCAC 10 is powered on and the main
PCAC software is run to initiate the three subroutines. The
data bus monitoring subroutine will begin to make call func-
tions to the DLL to read the selected parameters from the
aircraft data bus, and the PCA subroutine will begin to
calculate throttle commands for current commanded aircraft
state. Thus for example, if a pilot commands a new aircraft
state such as a 15 degree left bank (typically using the aircraft
mode control panel), this command is read from the data bus
by the PCAC 10 which then calculates the throttle command
required for this maneuver. The new throttle command is then
displayed on the PCAC 10 or remote display 30 according to
a particular display format that allows the pilot to easily adjust
the actual throttle positions manually to the commanded
throttle position in order to complete a desired maneuver.

FIG. 2 is a screen shot of the display format compiled by
the PCAC display subroutine in a four-engine aircraft. As
indicated the PCAC display subroutine shows throttle limit,
current throttle position, and commanded throttle position in
a bar-graph format for each of the four engines based on the
calculations in the PCA subroutine above. This allows the
pilot to easily adjust the actual throttle positions manually to
the commanded throttle position in order to complete a
desired maneuver. The PCAC display subroutine that gener-
ates the FIG. 2 display may be authored using C++ Studio™,
a tool for building interactive, real time graphical displays using open-source GLTM graphics language. The pilot must then manually move the throttles to the new position to complete the desired maneuver.

A number of variations on the basic concept will now be described. For example, instead of using a display 30, the PCAC 10 can be used to drive the engines directly to complete the commanded maneuver. In this case all throttle commands are sent directly to the electronic engine control (EEC) of the aircraft for implementation. This will require a minor interface to the electronic engine control but not the flight control software.

Also many aircraft currently have electronic flight computers already installed in their cockpit for various functions, and some of these computers already have access to data bus parameters. Thus, instead of using a dedicated computer for PCAC 10 it may be possible to rely on an existing onboard computer for the above-functionality.

A specific example of the above-described propulsion control system (inclusive of PCAC 10) will now be described which provides a digital throttle input to the existing C-17/F117 Electronic Engine Control (EEC) unit.

FIG. 3 is a detailed diagram of the PCAC 10 to C-17/F117 Electronic Engine Control (EEC) interface. The C-17/F117 currently employs two Electronic Engine Controls (EEC Channel A and Channel B) which provide throttle commands to the engines via an analog signal from the pilots throttle quadrant or from an ARINC-429 digital signal from the flight control computer converted to an analog signal. For this implementation the C-17/F117 Electronic Engine Control (EEC) is adapted to translate the ARINC-429 digitally driven signal from the PCAC 10 into existing analog Throttle Resolver Angle (TRA) inputs, instead of the signal from the aircraft flight control computer. In this case the PCAC 10 is equipped with 3A Condor ARINC-429 receiver/transmitter bus card and four channels of this card are coupled to one aircraft EEC (Channel A) to establish digital control of the engines. The PCAC 10 then effectively becomes the source of the ARINC-429 bus signals.

As seen in FIG. 3 the laptop PCAC 10 coupled through its onboard ARINC-429 receiver/transmitter bus card to the two channels A & B of the spare low speed ARINC-429 receiver/transmitter and on to the existing aircraft EEC via the aircraft data bus 20. The PCAC 10 is also coupled the aircraft’s data bus 20 (here a Mil Std 1553 data bus) to monitor aircraft state, pilot commands and throttle position. The PCAC 10 is running the software comprising the three major software subroutines: 1) data bus monitoring; 2) PCA subroutine; and 3) PCAC Display.

In operation, the PCAC 10 reads the aircraft data bus 20, and runs the three software PCA subroutines (described above). The PCA subroutine calculates necessary throttle command based on the aircraft state data collected by the data bus monitoring subroutine, in view of desired maneuvers, and the PCAC Display subroutine graphically displays both current throttle position and desired throttle position as shown in FIG. 2 needed to achieve the desired maneuvers. Optionally, the PCAC 10 may output an engine command directly to the EEC for direct control. In this case, in order for the PCAC 10 to provide a digital throttle input to the existing C-17/F117 Electronic Engine Control (EEC) unit, certain software modifications are necessary to the C-17/F117 Electronic Engine Control (EEC) interface. The EEC software is modified to check for signal validity, correct limits and other parameters, engage digital throttle control, and to then send throttle control commands to the engine. Specifically, in the context of the C-17/F117 implementation, the PCAC 10 monitors all ARINC-429-bus communications from the aircraft EEC. When bus communication is detected at the PCAC 10, the prescribed digital throttle engagement sequence is followed by the prescribed disengagement sequence.

Either way, the PCAC 10 enables a pilot to land a plane safely when its normal control surfaces such as elevators, rudders, and ailerons are disabled, and yet expensive modifications to aircraft software and hardware or the need for major recertification of the aircraft are unnecessary. It should now be apparent that the foregoing system provides a capability at a fraction of the cost of full implementation for widespread commercial and military deployment.

Having now fully set forth the preferred embodiment and certain modifications of the concept underlying the present invention, various other embodiments as well as certain variations and modifications of the embodiments herein shown and described will obviously occur to those skilled in the art upon becoming familiar with said underlying concept. It is to be understood, therefore, that the invention may be practiced otherwise than as specifically set forth herein.

Claims:

1. A Propulsion Controlled Aircraft (PCA) system, comprising:
   a Propulsion Controlled Aircraft Computer (PCAC)
   a Bus Monitor card in said PCAC and connected to an existing aircraft communications bus for monitoring of aircraft state and pilot commands thereon;
   a display monitor;
   a software program resident on said Propulsion Controlled Aircraft Computer (PCAC), and further including,
   a first software subroutine for monitoring the aircraft state, pilot commands and throttle position;
   a second software subroutine for calculating necessary throttle position based on the aircraft state and pilot commands to complete a desired maneuver, and
   a third software subroutine for formatting the calculated throttle position as well as the actual monitored aircraft data and, based on aircraft state and desired maneuvers, generating a PCA output for throttle position.

2. The Propulsion Controlled Aircraft (PCA) system according to claim 1, wherein said PCA output comprises a graphical display showing current and commanded throttle position to show the pilot where to move throttles to achieve the commanded maneuver.

3. The Propulsion Controlled Aircraft (PCA) system according to claim 1, wherein said PCA includes a display monitor, and said software is adapted to display both of said actual aircraft throttle position and intended aircraft throttle position for completing a desired maneuver.

4. The Propulsion Controlled Aircraft (PCA) system according to claim 1, wherein said PCA output comprises a throttle command to an existing electronic engine control (EEC) in said aircraft.

5. The Propulsion Controlled Aircraft (PCA) system according to claim 1, wherein said software is adapted to display both of said actual aircraft throttle position and intended aircraft throttle position for each of a plurality of engines on said aircraft.

6. The Propulsion Controlled Aircraft (PCA) system according to claim 5, wherein said software is adapted to display throttle limit, current throttle position, and commanded throttle position for each aircraft engine.

7. The Propulsion Controlled Aircraft (PCA) system according to claim 6, wherein said software is adapted to
display throttle limit, current throttle position, and commanded throttle position in a bar-graph format for each of the aircraft engines.

8. The Propulsion Controlled Aircraft (PCA) system according to claim 1, wherein said Propulsion Controlled Aircraft Computer (PCAC) is adapted to transmit throttle commands directly to an existing electronic engine control (EEC) of the aircraft for implementation.

9. The Propulsion Controlled Aircraft (PCA) system according to claim 1, wherein said PCAC is a laptop computer equipped with a bus monitor card.

10. The Propulsion Controlled Aircraft (PCA) system according to claim 1, wherein said PCAC is an existing onboard-aircraft computer.

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