RESEARCH ON FAILURE SIMULATION OF CIVIL AIRCRAFT FLIGHT MANAGEMENT SYSTEM

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Keywords: *Failure simulation flight test, Failure embedded, Failure response, FMS*

Abstract

It is focused upon the research on the civil aircraft failure simulation integrated with Flight management system (FMS). The research includes the failures embedded in the system based FMS's control and management, failure responses, and their exercising influence upon other subsystems. The different response characteristics and failure tolerance levels under multi-failure modalities of FMS are checked through simulation tests by setting different multi-failure modalities. The responses to embedded failures about subsystems referred to FMS in civil aircraft are testified and verified, and the flight performances and safety qualities of civil aircraft integrated with FMS are evaluated. So the failure simulation flight test technology with FMS in accordance with airworthiness is testified and could be applied to authoritative flight tests for a new type airplane.

1 Introduction

How to make scientific researches on the different failure principles, failure happened conditions, failure responses and etc. while navigation systems, actuators and key mechanical rotation gears (such as rudders, flaps and etc.) are complexly composed and interconnected together under the FMS control and its flight management environment is an important part of FMS development and research test. From the current literatures issued the research work is not enough and scientific research content is limited for the failure simulation researches on the highly integrated airplane flight management system. Most literatures are concerning digital simulation researches on the failure diagnoses of aircraft and or airplane engine systems[1][2], and there are seldom researches on the integrated FMS failure simulations.

Here the goal and scientific aim at the principal research on, in airborne avionics systems or equipment, failures embedded, failures recurred, failure responses, and their exercising influence upon other subsystems, and laying the foundation for civil aircraft FMS airworthiness flight test technology[3]. And the test result confidence is improved through the hardware in the loop simulation test and failure simulation flight test verification. The achievements from this research work will make up the shortage of airborne integrated FMS failure simulation researches about civil transportation airplanes[4].

2 Failures Classification

From the system configuration failures may be classified hard failures and soft failures[5]. The former refers to the faults from elements and devices, the latter from the programmed procedures running in the system in which the program may inhere, or serve as user's application.

FMS's failures are mainly caused from subsystems' failures. Because each subsystem in FMS is a more complicated airborne avionics equipment, its failure mode is so difficult to classify. The purpose of this research work is for the verification of function lack and estimation of flight safety under some trouble with a civil airplane FMS. Hence the failures may be classified according to the system outputs after the failures happened. Based upon the failure modalities classified about FMS and relative systems there exist the following failure classifications listed, FMC (flight management computer) failures (A series), IRS (inertia reference system) failures (B series), FCS (flight control system) failures (C series), A/T (auto-throttle) failures (D series), EFIS failures (E series), ADC (atmosphere data computer) failures (F series), DME/VOR/OMEGA failures (G series), ILS/MLS/ADF failures (H series), fuel oil volume indicator failures (I series), fuel oil system failures (J series), landing gear system failures (K series), thrust system failures (L series), and other sensing equipment failures (M series), where A series is mainly caused by FMC inactivation, interface faults and random disturbance, and B series by IRS faults[6], interface faults, random disturbance, system's cumulative errors, C series by FCS inactivation, one of three channels of auto-pilots inactivation, yaw damping inactivation, altitude or velocity control system inactivation, gliding landing control system inactivation, rudder control inactivation, D series by A/T inactivation, throttling faults, inefficient thrust rating value, N1 signal of the engine 1 (or 2) off normal, flap position signals off normal.

From the above failures happened combination and arrangement, there are both a single failure mode and a composed failures mode. From the period of duration of failures happened, there are both fixed failures and temporal failures. The former are inevitable failures caused by diseased electronic elements and devices in electronic circuits, inner short circuit, software design faults, and the latter are caused by external factors, such as voltage pulsation in electric networks[7], EMI, or dry joints in electric circuits. The latter failures have a short period of duration, and could be eliminated automatically without artificial interference.

3 Failure Feature Bank Configuration

The failure feature bank is a set of conception which is a fault feature information presented by a special system and its elements in relation to all fault modes. The failure causes vary with systems and elements according to their complex degrees[8][9]. So it is impossible to take an account of all fault features especially in simulation tests.

The methods for failure feature bank construction may be divided into a test statistic, a test simulating, and a simulation computation. The failure feature bank based upon a statistic method is special for some typical system in which the failure information is gathered in running. And then the bank is set up according to failure attributes, which is the most reliable failure feature bank. Another sort of bank is formed by use of diagrammatical representation in which variable outputs and their curves of the system are used to describe failure features exited in the system. The latter mode of failure feature representation could convey much more failure information. By use of the diagrammatical representation not only the failure features could be extracted but also the performances or functions about systems or their elements with faults could be observed. Fig.1 shows one failure feature bank configuration applied in this work.

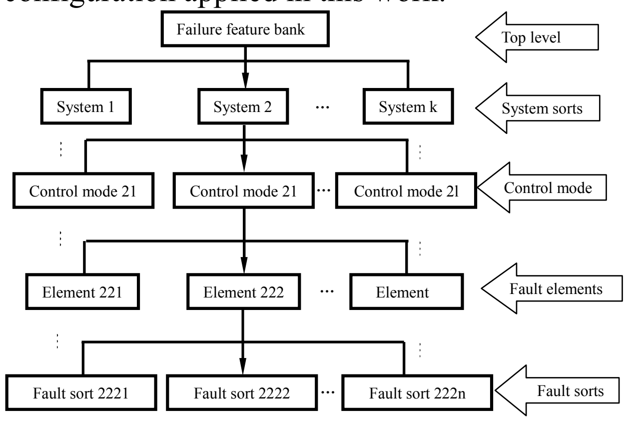

Fig. 1. Fault Feature Bank Configuration

4 Failure Simulation Flight Test Configuration

To make a failure simulation experiment on FMS, an off-line simulation configuration is used to model diagrammatically and simulate a system with FMS in accordance with time conveniently so that a modeling on FMS is identified with its engineering block diagram.

The simulation configuration based Simulink about a three dimensions of guidance flight with FMS on transportation aircraft[10] is illustrated in Fig.2.

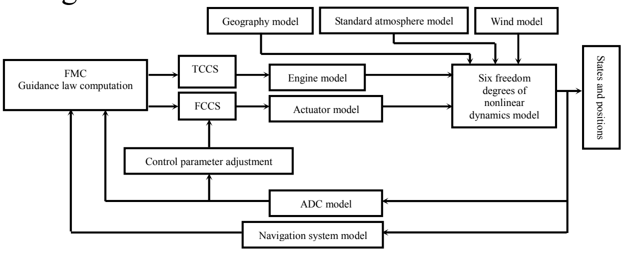

Fig. 2. Flight Simulation Configuration With FMS

Where TCCS: thrust control computer system, FCCS: flight control computer system. Fig.3 shows an engineering configuration diagram for Simulink simulation.

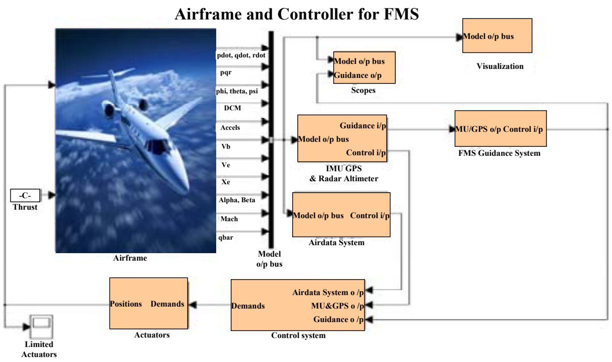

Fig. 3. The Whole Flight Simulation Engineering Diagram

Where the Airframe simulation block contains aerodynamics model, kinematics model, dynamics model, environment model and (α+β+M) computation model. The IMU+GPS+RADAR ALTIMETER block is used to compute navigation parameters, and give flight guidance and control commands. The Airdata System block is applied to simulate ADC, and deliver atmosphere measured data. The FMS Guidance System block is used to produce flight guidance commands by FMS. The Control System block is used for the simulation of FCS and Autopilot[11]. The Actuator block is used to simulate motivators and actuators, and give the driving commands of rudders for completing a closed circuit of auto-flight control of aircraft.

The modeling for physical ambience contains wind model, atmosphere model and gravity model as showed in Fig.4. Where the atmosphere model is per 1976 COESA-extended U.S. Standard Atmosphere Model, the gravity model per WGS84 Gravity Model, and the wind models are in accordance with the FAA windshear model, discrete wind gust model and dryden wind turbulence model per MIL-F-8785C, as showed in Fig.5.

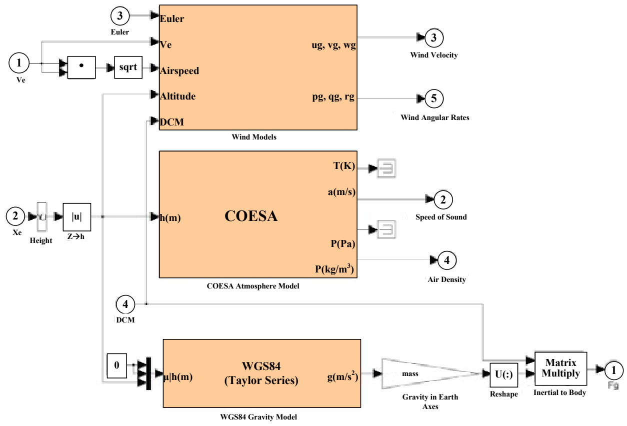

Fig. 4. The Physical Ambience Modeling

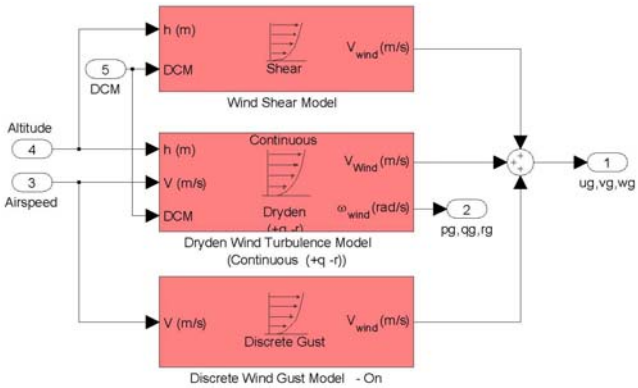

Fig. 5. The Windshear-turbulence-gust Modeling

5 The failure injection test tactics

The input and output domains for failure injection tests are first determined when we make the tests of failure injection. If the input domain is expressed by means of failures collection F and failure inspiration collection I after failure injection, and the output domain by means of feedback collection O and measurement collection M, the O collection is the response to a target system after failure injection, and the M collection is the desired response to a target system after failure injection. The four elements method {F, I, O, M} is used to describe failure injection test tactics. So the failure injection test is in fact the application of failure injection test tactics to determine {F, I, O,

M}. Each failure injection test is the inspiration of the failure to be injected from F of the input domain, and then the analysis of O collection in the output domain according to M collection.
For each failure injection test, select an input sub-collection (f, i), where f ∈F, i ∈I. If F collection and I collection are non-correlative, f and i may be selected independently, and the time for failure injection is according to the system running time. If F collection and I collection are correlative, the special state in I collection is used as a trigger condition for failure injection, and the time while the special test state occurred as the time failure injection. Because failures from airborne systems and equipment vary differently[12], the failures equivalently classified in conjunction with limitless failures injection are taken to realize an overall failures injection for airborne systems and equipment so as to reduce test times and test cost when a series of failure injections are generated. After finishing a failure injection test, compare O collection with M collection and then draw the results of the above failure injection response. Fig.6 illustrates the failure injection test tactics.

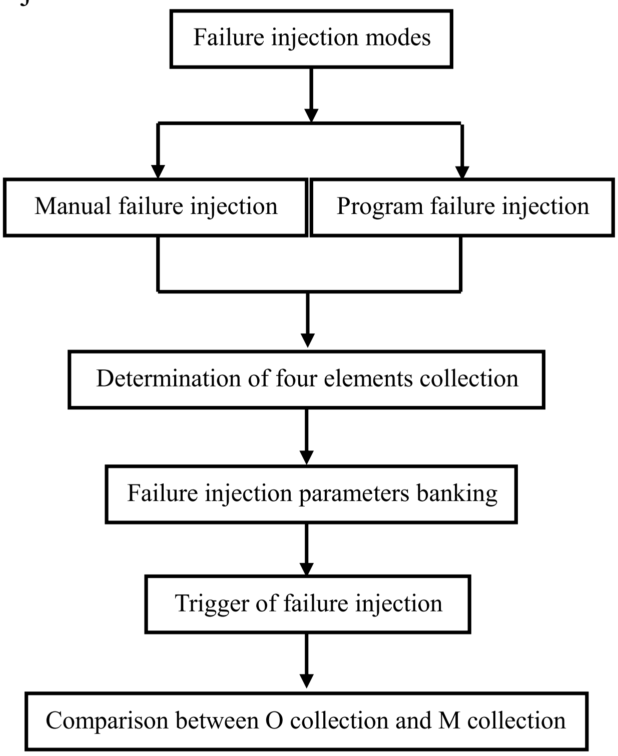

Fig.6. The Failure Injection Test Tactics

6 Experiments and Result Analysis

To make a full research of the response excited by relative faults from FMS, it is necessary to model flight dynamics, actuators, flight control system, INS-GPS[13], ADC, flight guidance system, ambience and etc. respectively. And for each modeling it is also necessary to set up various faults, fault driving sources, excitation variables and excitation amplitudes. To analyze the flight simulation experiments on failure responses, here are the failure simulation flight test results.

6.1 The Fault Responses to FMS Flareout Control Gain Distorting

The flight guidance block is showed in Fig.7 where there is a channel of flight flareout guidance besides a channel of glide guidance. For the flight flareout guidance channel, distorted increments are set to simulate the control parameters varying with interference, circuit parameters distorting and etc as to test the faults response of the flight flareout channel to the flight guidance system. While the gain of the flight flareout channel was increased step by step from 25 to 9800, the aircraft lost its velocity suddenly, and then the roll angle jumped from 0 degree to 650 degrees, the angle of attack bounced between ±180 degrees in seconds, the maximum amplitude of the Eulerian motion angles achieved 650 degrees some seconds, the flying stopped instantly so that the flight guidance block got lost its guidance function. The flight simulation experiment curves with faults embedded are illustrated in Fig.8.

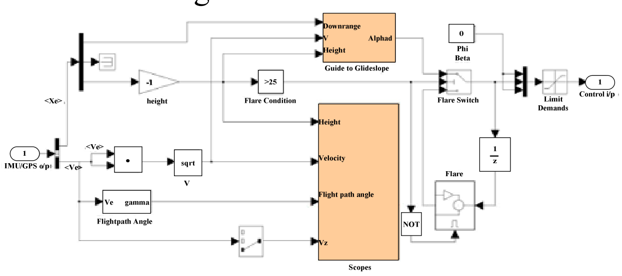

Fig.7. Flight Guidance Simulation Block

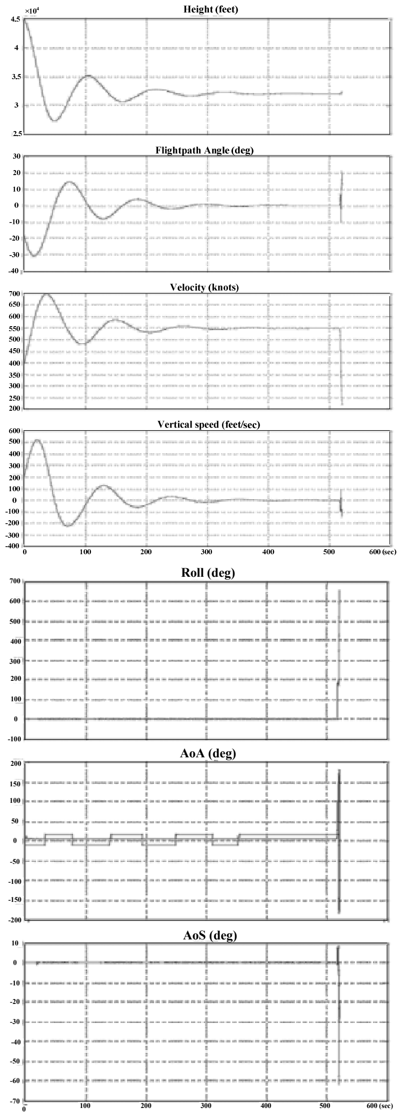

Fig.8. Flight Simulation Curves

6.2 The Flight Guidance System Response to INS Faults

Compared with the flight guidance system, the flight navigation system block involves seven channels of navigation parameters as showed in Fig.9[14]. Interruption faults are interpolated into the seven channels respectively so as to check flight responses. The flight simulation experiment results are showed in Table 1 from which it can be seen that INS outputs have closed relation with flight guidance, and especially for the flight altitudes and airspeeds in an inertial system flight guidance is more important[15].

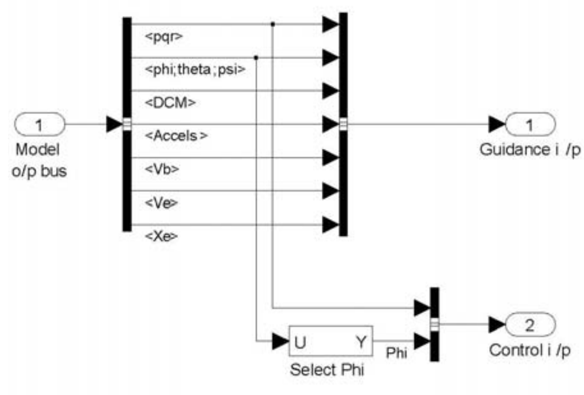

Fig.9. The Navigation System Block

Table 1 Responses to Navigation Faults

No.	Signal sort	Status	Flight response	Notes
1	<Vb>	off	Normally	Vb：Airspeed
2	<Ve>	off	Fail	Ve：Inertial airspeed
3	<Xe>	off	Fail	Xe：Inertial coordinates
4	<p q r>	off	Normally	p：Body roll angular speed q：Body pitch angular speed r：Body yaw angular speed
5	<phi; theta; psi>	off	Normally	phi：Eulerian roll angle theta：Eulerian pitch angle psi：Eulerian azimuth angle
6	<DCM >	off	Normally	DCM：direction cosine matrix
7	<Accel s>	off	Normally	Accels：Three axes of acceleration

6.3 The FMS Guidance Response to Discrete Wind Gusts

The parameters about discrete wind gusts contain the instant gusts begin, three dimensions of gust field distribution, three dimensions of gust amplitude. The parameters of a given gust model are as follows:

Gust instant beginning the 20th s, three dimensions of gust strengths 120m, 120m, 80m, three dimensions of gust amplitudes 3.5m/s, 3.0m/s, 3.0m/s. To compare gust influence degrees to FMS guidance performances, change both the strengths and amplitudes based the normal gust parameters so as to examine the causes leading to the faults in a cruise guidance against gusts.

Given three dimensions of gust strengths 1200m, 1200m, 800m, and given three dimensions of gust amplitudes 30.5m/s, 30m/s, 30m/s. Fig.10 shows the flight parameters in vertical section under the discrete wind gust mode 1. Although the engine thrust kept constant, the crash happened at the 520ths after three dimensions of gust strengths and amplitudes increased 10 times. From flight attitude responses it can be seen that the roll angle and slide angle diverged gradually while discrete wind gusts enlarged enough both the strength and amplitude. When the roll angle became larger more two times than the usual, and the slide angle more five times than the usual while normal cruise guidance flying, the airspeed dropped abruptly leading to a final crash.

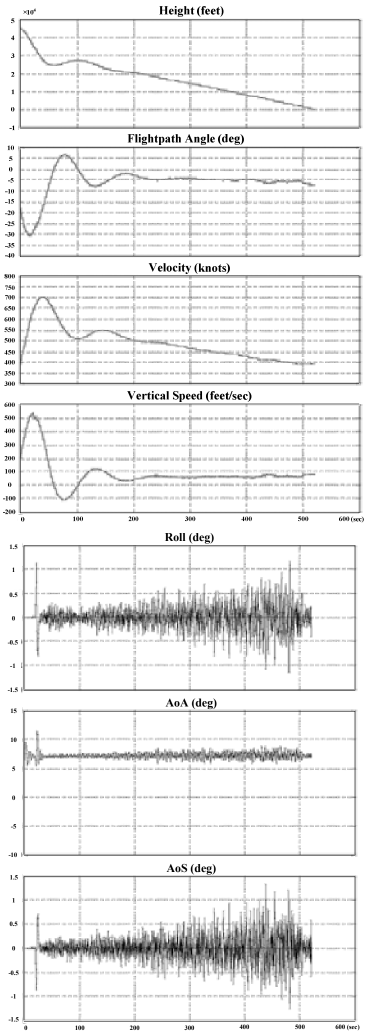

Fig.10. Flight Parameters Under the Discrete Wind Gust Mode 1

6.4 The failure simulation flight test and results for the navigation and power supply

The five attributes of faults are applied, in faults injection test, to give a description of failure modes, that is, fault position, fault type, fault duration, fault injection time and fault spectrum response[16]. There are many hard failure injection modes adopted in a flight test, such as alternatively turn on and turn off the airborne air data computer (ADC), alternatively turn on and turn off the airborne GPS and ADC, alternatively turn on and turn off the airborne FMS and so on. The failure simulation flight test results are illustrated in Fig.11 to Fig.14. Fig.11 shows the simulated failure ADC. Fig.12 shows the AHRS failure simulation while turning off its power supply for 850 seconds leading to a 7 º error amplitude for the AHRS. Fig.13 shows there is no a great impact on the AHRS at instant switching off the left and right DC collector strips. Fig.14 illustrates that the airplane is cruising at an altitude of 10000 ft covering five airports, and the GPS signals are off at WP1 waypoint then on at WP2. In Fig.14 the red line is for failure airway and the blue line for normal airway. There exists an airway deviation owing to lack of margin GPS navigation information while turning.

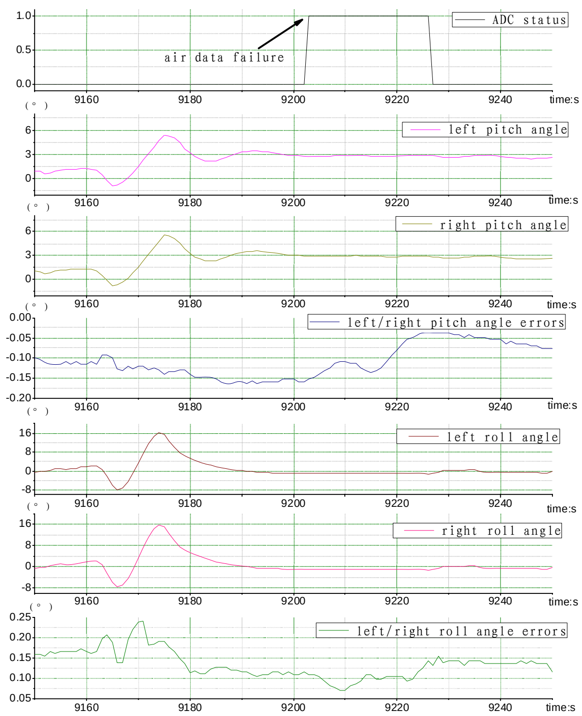

Fig.11. ADC Failure Simulation Flight Test

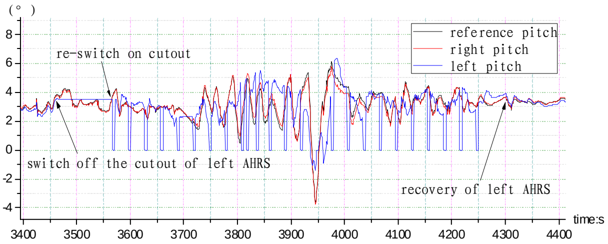

Fig.12. AHRS Failure Simulation Flight Test

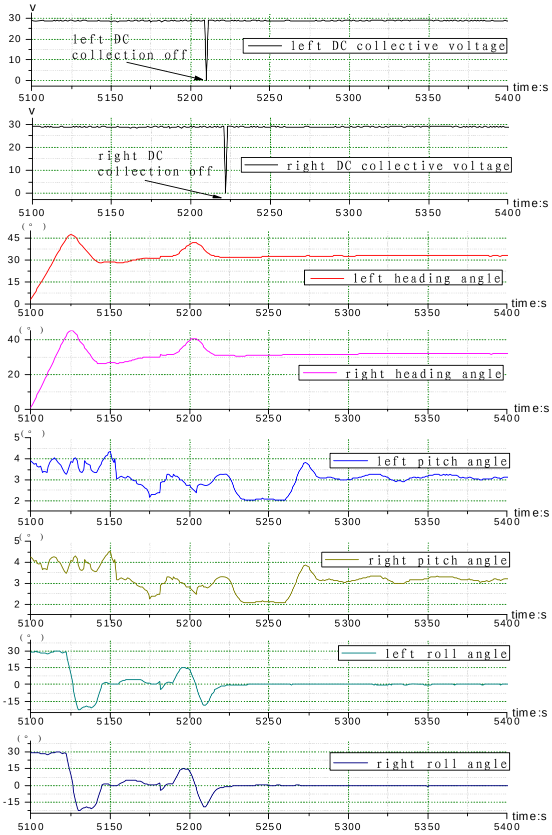

Fig.13. The Left/right DC Collector Strips Failure Simulation Test

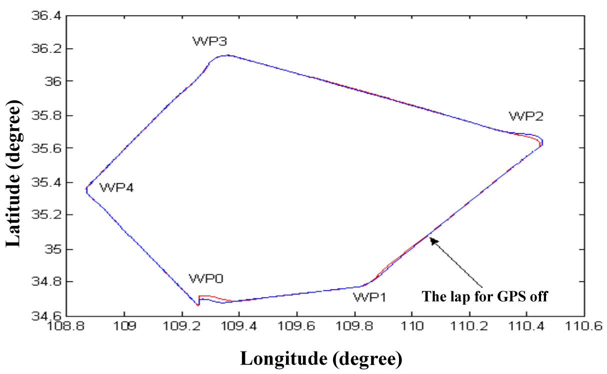

Fig.14. GPS Failure Simulation Flight Test

6.5 The double engines failure simulation flight test and results

The failure simulation flight test is performed according to a normal windmill start. If the engines fail to start at the test point (20000*ft*,200kn), change the test point to another reliable start point and then do not ignite until the *N2* is reduced steadily and the temperature among multi-stage turbines goes to ITT＝80℃. Once it fail to start again, the airplane descends by 500 *ft* step till finishing the start. Finally the right engine-out failure and the left engine –leisurely are simulated in flight at

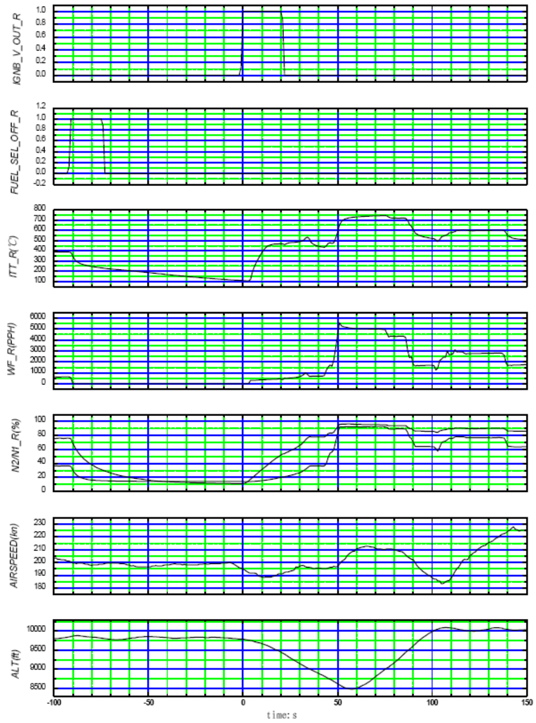

Fig.15. The Double Engines-out Failure Simulation Flight Test

the test point (10000 *ft*、200*kn*) when an engine runs leisurely and the other starts for 60 seconds. The airplane has descended 1347 *ft*. Fig.15 illustrates the failure simulation flight test course.

7 Conclusions

By use of a failure simulator flight test we could transform FMS configurations and aircraft models, expand flight test research enveloping curves and make various flight research experiments under the condition of faults inserted. And it is possible and convenient to demonstrate and verify faults embedded, faults recuperation, fault responses, and interferences and responses to faults relative to aircraft systems. With the help of a flight simulator and aircraft in flight it is capable to make wide researches on faults cut-off or isolated from FMS, faults forecasting, faults diagnosing on-line and etc. All the achieved flight test methods, measurement methods, data processing and relative research experiment achievements for civil FMS airworthiness certification may in time come into use in flight tests for the new type of ARJ21 aircraft and for the new of type of main-line aircraft.

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