PROMOTING AUTONOMOUS CONTROL IN CIVIL TRANSPORTS AS A PROPOSAL FOR THE FLIGHT COMMAND SYSTEM

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Abstract

The fatal accidents rate in the civil transports have been keeping almost the same level for over these 10 years. Statistics shows that the human factors are the most predominant causes, which leads us the importance of a harmony between an advanced aircraft, especially in the automation, and a pilot.

Author proposes to introduce an autonomous concept to the flight control to promote the automation for minimizing human interface area as small as possible, as Flight Command System. This should be accompanied with Human Centered Cockpit, which has intuitively recognizable devices for the situation awareness of the aircraft, and errors free design.

The autonomous control concept is applied to Air Traffic Control System to be compatible to the aircraft system for reducing human-relating accidents. The system is also realized with the one source control by a server computer of the related network, and the digital communication.

As for the autonomous logic, some expert-like sequence control could be a candidate, which is enough to be verified during the next chance of development phase, because the core technology is already in our hands.

The pilots and controllers in the system are expected to play more important roles as a mission and safety manager, with final authority for the system.

1. Introduction

Although the aircraft is said to be one of the most safe transportation media, the accidents are really disastrous, once we encountered. Thus we have to be possibly challenging to eliminate the tragedy as less as possible, being in line with the policy of the USA, toward the current status in which there is not so much progress in improving the situation operated by 4th generation of transports.

The statistics for the accident reports are expressed the rate by 10^{-6} scale in the longitudinal axis, whereas the systems are certified by 10^{-9}. This indicates that we are requested to handle the problem as an overall system, not only as an aircraft. The statistics show us also that the human-errors and the system-related human factors are the most effective objectives to face at to seek the counter-measures for reducing the tragedies. The system automation has been one of the most popular mean to counter the kind of problems so far. Although there have been worries of 'Modern Times' any days, the more automation seems to be again the true answer. The more automation today means the evolution of the automation, the author considers, through the concept of autonomous control.

And another way to follow the challenge is to secure the higher system operational reliabilities beyond the figure itself regulated. The reliability analyses are based on our past experiences. There are sometimes in-appropriateness to analyze the problems new to us. The fault tolerant concept in this case is the mighty tool to promote the securely reliable system configuration.

2. Accidents Analyses

2.1 Automation Surprise

In early 90's, Aviation Week & Space Technology defined Automation Surprises as the interaction problems between a pilot and an automated system of an aircraft in accidents of civil transports. On Apr.26 1994, A300 in China Airline crashed on the runway at Nagoya Airport in Japan, which is reported due to a pilot's conflict with the automation of the system, i.e. a typical automation surprise. We still have similar accidents category these days, whereas the introductory mishaps for the late 4th generation transports have been diminishing through the efforts by the training like CRM or LOFT etc. by the related organization. The magazine pointed out also that there still are conflicts or problems in handling the automated system, such as the programming errors, over-reliance of automation, surprise or loss of situation awareness, and so forth in late 90's.[1]

According to the current statistics of Accidents Reports by The Boeing Company, the rate for the fatal accidents is not reducing these days.(cf. Fig.1)[2] This means that the accidents are increasing in actual figure in ballooning annual seat-miles. The statistics tells us also that Loss of Control and Controlled into Terrain (CFIT) are two major categories, and the Human factors are the primary causes for the transport accidents for these 10 years.(cf. Fig.2)[2]

It is very important to design the system to eliminate the human errors, basing on the human engineering. As for the system relating human

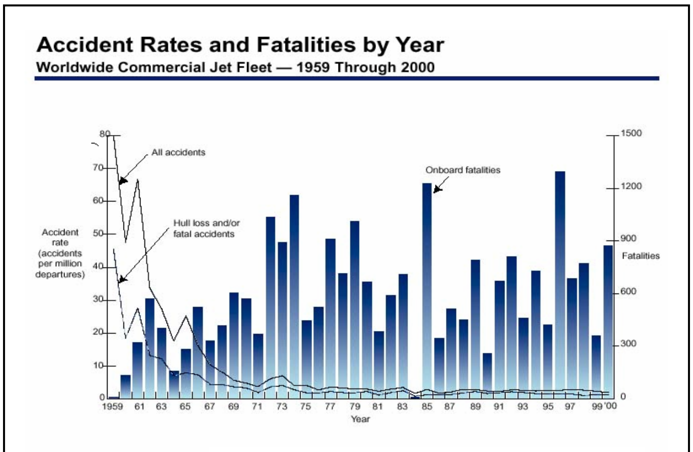

Fig.1 Accident Rates

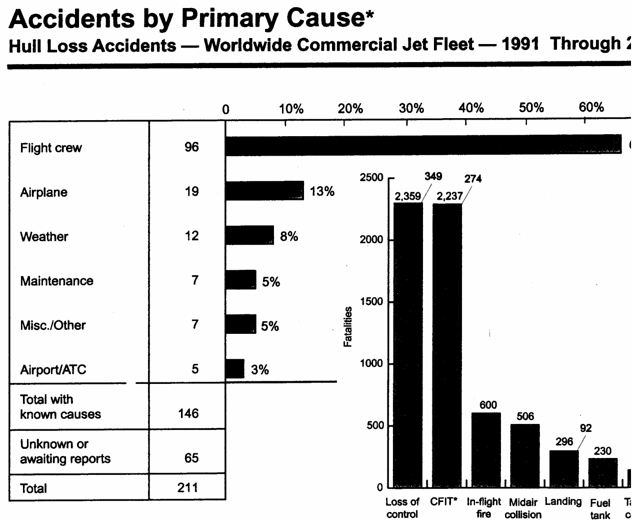

Fig.2 Primary Cause and Category

factors, the importance for the simple interfaces with the handlers is to be focused.

The accident at Pusan, in South Korea by B-767 in China Airline on Apr.15 2003 was allegedly caused from CFIT. The EGPWS (Enhanced Ground Proximity Warning System)[6] is expected much to eliminate the same kind of problems by letting be aware the pilot of the situation clearly without misunderstanding or against a biased conception of a pilot as for CFIT. And the equipment is on the way to be regulated on board for the transports as a countermeasure.

2.2 Air Traffic Control / Management

On Jan.31 2001, over Yaizu-city in Japan, two B-747's of Japan Air Line caused the accident almost-collided due to the mis-control by Traffic Controllers and the insufficient communication between the controllers and the pilots, according to the formal accident report.

As an another example, there was the accident on the wrong runway, where a collision with a construction vehicle happened during the take off roll, in bad weather condition, at Taipei in Taiwan by Singapore Airline in Oct. 31 2000.

The problems ATC is relating are happening both in the air, and on the ground.

Although the percentage of the fatal accidents caused from ATC matter is small, there are allegedly so many incidents of the same kind as mentioned above. As the kind of incidents grow to the accidents anytime, the importance is cited to eliminate the potential causes.

From the analyses, Human is understood to be a final key both in the aircraft system and in the air traffic control system.

3. Understanding for Current Aircraft and Traffic Control System

3.1 Aircraft System

In most of the recent transports, the progress of automation has come to be integrated with the management of a flight through FMS (Flight Management System). FMS is operated to conform a flight plan in an optimal way through pilot inputs by using every mode of Auto Pilot. As a result, the current advanced aircraft would be operated by the FMS itself through out the flight phases, except a landing.

The cockpit has been improved much at the same time, with larger and integrated displays under the glass cockpit concept through Human Centered Design. Two men crew and an integrated console has been a common sense, and a windowless cockpit is under discussion.

In the flight control system, FMS conforms the outmost loop in control. As an outer loop, we have Auto Pilot, by which we realize a keeping and capturing capabilities for the flight condition. In inner loop, we can find the controls to improve the inherent characteristics in stability by SAS (Stability augmented System) or controllability by CAS (Control Augmentation System), as well as by ACT (Active Control Technology), say, in Gust Load Alleviation, Ride Quality Improvement, etc. adding on the basic fight controls. The control structure conforms a hierarchy, but not in so explicit way.

An integrated automation with ATC through autonomous control is estimated as a path for progress of the system. Although the autonomous is the author's opinion, the coming control should be positioned in the top hierarchy in the control by redefining the structure clearly.

Another importance for the present transport is to be designed in very high reliability, to the level of 10^{-9} for a critical failure as regulated in FAR, for example. The complicated redundancy management is carried out for seeking as high as possible in reliability, by the number of parts or components as fewer as possible, including considerations for avoiding an one-point failure in the configuration of the hardware and the software.[5]

The very high reliable system in operations is a base for a safe aircraft. And no problem caused from pilot interfaces is our target.

3.2 Air Traffic Management System

Air Traffic Control System is supported by many controllers who are specified to the specific area, from the taxi-out from a terminal at a departing airport to the taxi-in to a terminal of an arrival airport. Almost every airport has the ground control, the departure and arrival control, and the terminal control, with the air route controls or the radar controls, and FIR (Flight Information Range) for the specific purposes. Each of those is controlling the traffic for the specified area, relaying the information for each of aircrafts from one to another. As a result, many controllers are relating to the control for one aircraft from its departure to arrival. The tight communication among controllers is accordingly required very much for controlling one aircraft consistently and securely.

The current Air Traffic Control System has progressed to Air Traffic Management (ATM) for reliable and safe control in the growing traffic without a mistake. And Future Air Traffic and Navigation System (FANS) are on the way in worldwide to control effectively the growing traffic, by allowing, for example, a direct flight.

Besides the current movement toward FANS and ATM, the system ensures the traffic control safe and the reliability is to be sought to avoid the problems relating to human interfaces as much as possible by improving the devices, like displays at the controller's console, for example.

As for the way for conveying the directions and communication among related person, the voice communication has been used for many years. This might have caused troublesome cases by mis-communication or mis-interpretation between a pilot and a controller. The troublesome works for a pilot to select each radio frequency have been also an accident potential.

4. Considerations for System Improvement

4.1 General Idea

As we have a human interface with system as a problem area, the simple and direct idea for improving the situation is to get rid of or to reduce the human interface area. However, the unmanned type of civil transport is too early to be realized at the present technical level. We need a pilot or a controller as a final authority or a director, by also the reason for configuring a highly reliable system with minimum cost.

To minimize the interface area between a human and a system is to promote the automation further. The system would be complicated through the advancement of the automation, however, it is important to keep it simple superficially, to say the least, for the system operation. The FMS has worked for automating a flight of navigation of an aircraft itself from a point of flight management with the optimal concept of minimum fuel or time, using segments of Auto Pilot. As the current system is growing in too complicated modes, we are required to simplify them just like some airline seeking for 'the appropriate auto modes'.[1,4]

The target we should aim for near future is to integrate the system with the mission or the navigation controlled by Pilots and Air Traffic Controllers with limited modes, without going to a more intricate system.

Those are to be realized by the concept of autonomous control. The autonomous is an evolution for the automation, through which we could get a more progressed but simple system. The simplification is also possible by generating one big mode through grouping several modes for a leg of flight. What pilots know are those big modes only.

Author dares to assert that we could better have a bigger black-boxed system as the outmost loop of the control conformed by FCS, FMS, Auto-Pilot, and so on, for maneuvering an aircraft with simple methods from a viewpoint of a pilot, although the black box should be transparent.

As long as we have to let a human be remained in the control loop, the human centered design for the interface area is a mandatory concept for eliminating error potential. And the more the system progresses in automation, the less a pilot is alert as a tendency in maneuvering an aircraft. Thus, we have to offer the intuitively recognizable circumstances or tools for the pilots to judge or be aware of the situation as precise as possible. 3 or 4 dimensional displays with map and weather information for the aircraft on the console of the cockpit are one of those devices.

4.2 Proposal of Flight Command System for The Aircraft Control System

The current flight control system of a transport is composed of SAS, CAS, ACT, Auto-Pilot, and FMS, etc. Those are conformed in hierarchy in concept by the inner loop or the outer loop control of the system.

Author proposes the Flight Command System to realize the autonomous control mentioned above by generating the highest level of controls in hierarchy explicitly. The control is to be integrated with the navigation and weather information regulated through the Traffic Control, being accompanied with Human Centered Cockpit. Figure 3 explains the idea.[3]

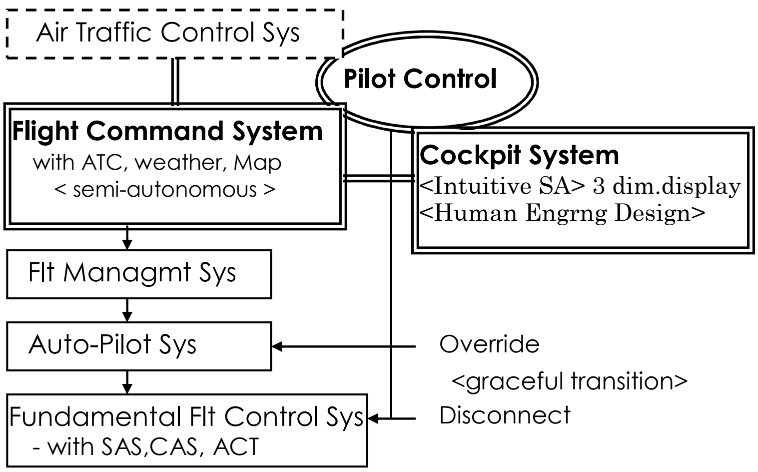

Figure 3. Concept for Flight Command System

4.2.1 Integration with ATC and Weather Information

The idea for the integration method is basically quite same as the way in FMS for a part of the auto-sequence control for navigation. It could be fundamentally evolved to an autonomous control by applying an expert-like control system with a preparation of judge tables whether the aircraft could accept the directions from the ATC or would request the alternatives, and change the flight plan through reading also the weather information, and so forth. The concept is realized by auto-sequence control for this case also, with the estimation of the optimal flight conditions by a cost function of time or fuel with the allowable threshold and the priority for a judgment. The complete expert system is said to be quite hard to be realized due to the complicatedness of the system, however, we could confine the system to the reasonable size because of the existence of a pilot, and by treating the matters in routine cases for the system. The concept is shown in the figure 4. This should be called as a semi autonomous control, due to a pilot in the loop.

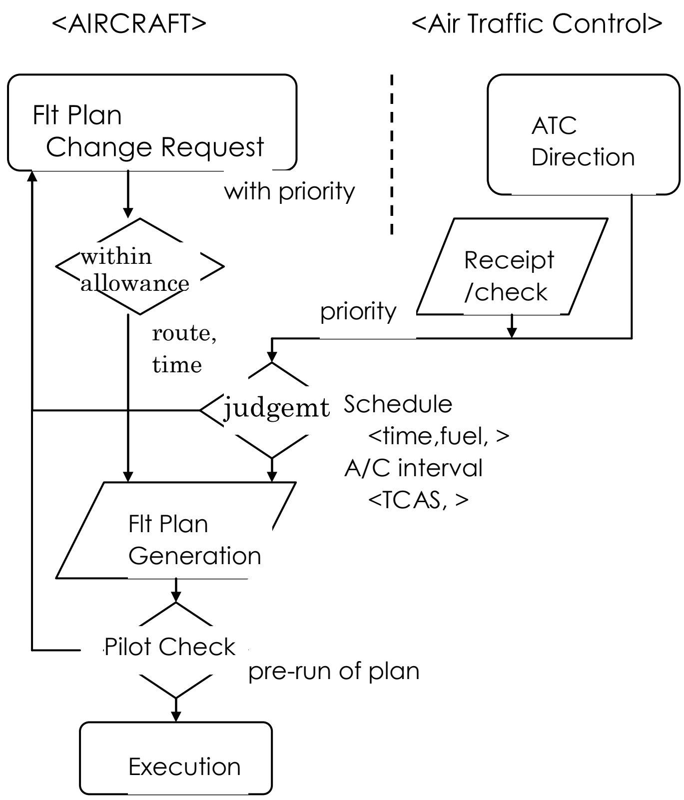

Figure 4. Expert-like Semi-Autonomous Control Logic in FCS

As for the auto-sequence control, the current FMS is constructed under the way, and the author also practiced many auto-sequence controls, such as Auto Take-Off, Navigation, Return to Base, etc. at the project of QF-104J, which is the Japanese full-scale drone program. Although a small extension exists to make it autonomous, the control concept is said to have verified the airworthiness through those experiences by the industries.

One example is shown at Figure 5, which is a pattern by Auto Navigation of QF-104J, generated by a computer simulation verified the flight test later. That also explains the sequences applied through the Auto Pilot, capturing and keeping a bearing, heading, altitude, speed, so on, with the best schedule of a climb or a descent through the setting of way-points by the pilot.

4.2.2 Intuitive Situation Awareness

It is idealistic to have the complete 3 or 4 dimensions displays with mapping and weather information for a pilot to grasp the situation of the aircraft intuitively. However the cross sectional display by Altitude and Range with mapping information could be alternatives for the moment just like the display in EGPWS.

The more advancing glass and windowless cockpit are expected in near future to be realized as early as possible to enhance the idea. The intuitively recognizable objects by a glance, like figures, icons, etc. are generated on the displays, and the Higher Order Language is also a way to make it easy and secure for a pilot to input the data.

Although author defines FCS as a top hierarchy control in the flight control system of an aircraft, the intuitively recognizable cockpit system with human engineering, i.e. Human-Centered-Cockpit is inevitable for the FCS itself.

4.2.3 Pilot Position

In the autonomous control in FCS, the pilot is the final commander and the final safety manager for the flight. The pilot’s roll would become more important, and might be

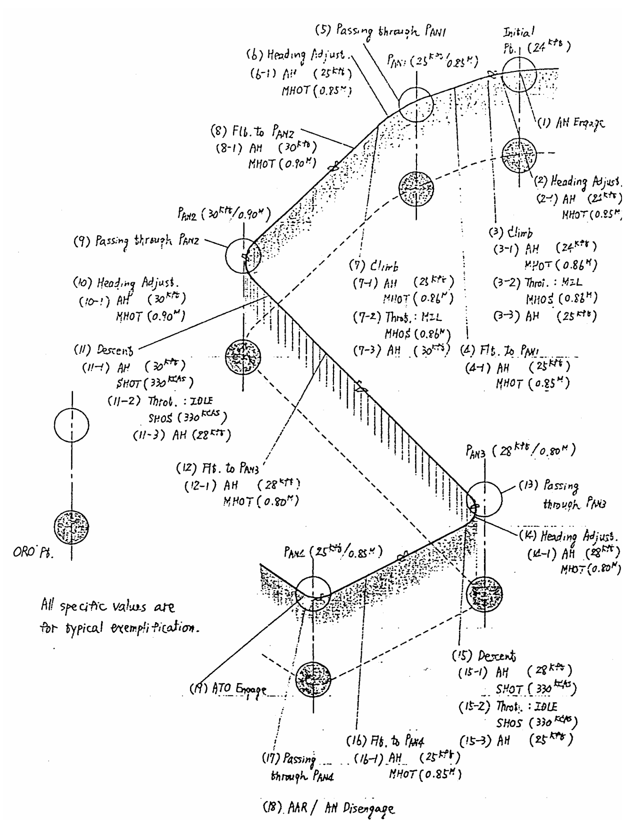

Fig.5 QF-104J Auto Navigation Simulation

expanded to a higher management level.

The pilot can retrieve the control of the aircraft anytime. The transition from the system control to the pilot control should be always smooth, in either case of Override or Disconnect.

In the case of Override, the FCS is still active. Thus, both of the control are overlapped or the pilot control get the priority by vanishing the system controls gradually, if the system find a conflict between the two controls. In the case of Disconnect, the pilot control has the priority and the system control would go to a default condition, such as of a straight and level flight, with a certain time-duration.

In the Disconnect Mode, only a pilot control with a simple Auto Pilot with the inherent control, such as SAS, CAS, ACT, and the fundamental flight control is available. In either case, a pilot could maneuver an aircraft just like he is controlling a small, simple and very easy aircraft for maneuver, taking the advanced flight control system headed by FCS as a black box.

The conception for an easy and smooth reversion to a pilot control could contribute to keep the pilot keen and alert during the flight.

As long as the FCS or the FMS could be survived in the system, they would contribute to generate the effective Advisory System to suggest a pilot what to do next, in any cases.

4.2.4 Additional Auto Modes as a Reflection of Accidents

Examining the accident reports, especially for CFIT, there should be some additional auto-modes. For example, those are the approach pattern, the landing pattern, the waiting and retrieval pattern, and the take-off pattern etc. of the flight specific to the airport and the runway direction for each. If the GPS assistant navigation would be more reliable through the augmentation by own satellites system, the extra modes mentioned above are considered very effective to eliminate the potential for the accidents, including by CFIT.

4.3 Compatible Offer to Air Traffic Management System

4.3.1 One Source Control

It would be very easy and secure to control and manage one aircraft in traffic, if one controller could control the aircraft from its take off to landing. He would keep an eye on one aircraft throughout the flight consistently with the information of total traffic. This is a key factor for a safety in a traffic control. One focal point is very convenient for a pilot too, because his counterpart is always same at the gate.

If each computer of the controller of the specific area would be networked each other, the server of the network could play a role of the focal point for the aircraft. This concept is shown in the figure 6. There might be some focal points in worldwide, however, one focal point for one region is the concept.

Furthermore an autonomous traffic control can be conformed by the logic in each site of computer. The most practical and effective way to realize it in ATC also is to place controllers on

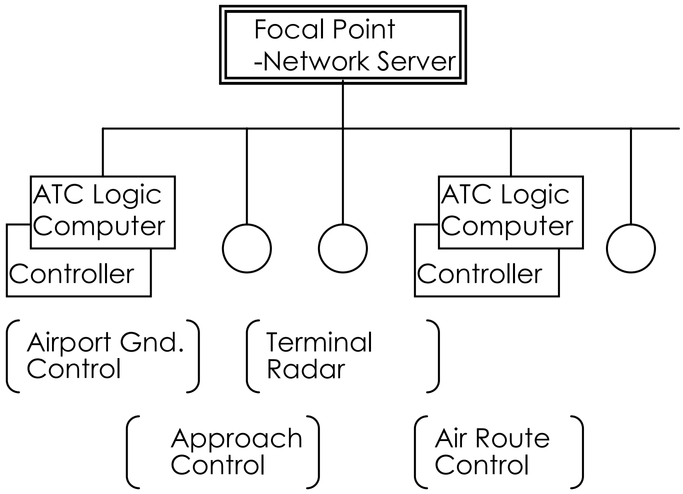

Figure 6. Concept for ATC Network

the top hierarchy as a final authority or a decision-maker.

If we could grasp the position of the aircraft in traffic in a clear-cut way through the sensors, such as GPS, Radar, etc., we would be able to fix a sequence to control the traffic with allowances for judgment, basing on regulations. The idea is explained in the figure 7.

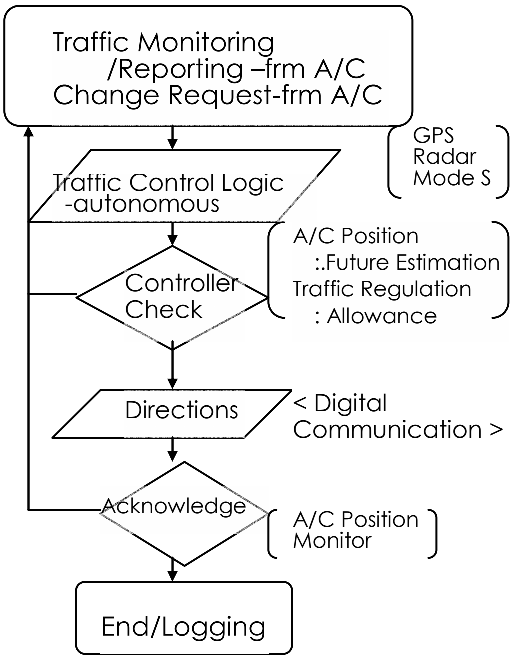

Figure 7. Semi-Autonomous ATC logic

4.3.2 Digital communication

Mis-communication and discrepancies among related person should be focused in improving. And the autonomous control concept is to be introduced to this system also for minimizing the human interface area, and for being compatible to the autonomous controlled aircraft system.

Every aircraft carries a transponder for using Mode S now, for a response to inquiries from a site on ground. A digital communication for normal and routine conversation between controller and a pilot could be possible by exchanging digital codes manually or by an automatic coding machine of voice, for example. They can exchange and confirm their jobs information without problems in communication.

As for an abnormal conversation, or some peculiar communication to a specific situation, the voice itself could be remained in operation, which surely be more effective for an exchange of the abnormality, because the conversation would be carried out with more keen attention.

4.4 Fault Tolerant System Concept

The ultra-highly operational system and no human error system are two keys to support the ultra-highly safe air-transportation system.

It is regulated to design the system with 10^{-9} or over in the case of the critical failures. As the current technical level is about 10^{-6} for mechanical components, and about 10^{-4} at best, for electrical components, the 10^{-9} system requires the over dual redundancy configuration.

It is very hard to define the reliability level for the software. But there is redundant software in redundant hardware for the computer. The Boeing began to conform the system, applying the dissimilar software to avoid the one point failure for the redundant software in B-777.

As long as we have a component, it is inevitable to have a failure with certain rate. So it is very important to configure the system with parts as fewer as possible, and with each part as high as possible in reliability. We are led to the Fault Tolerant Design Concept by those reasons.

4.4.1 General System Design

If we could suppress the impacts from the failures in the system and could continue the operation, we would be able to realize the highly safe and secure system in executing the mission.

As a general design for the aircraft, we can define some split surfaces for control, for example, by which we can give the alternatives in function for the system control. So we can conform the re-structured system for mission execution by giving several functions to a component of the system or as the system.

4.4.2 Hardware System

The skewed array motion sensors are one example for high reliability devices with fewer parts. If we conformed the integrated sensors system for control, we could keep to get the output even with two or three failures of the sensors, using Kalman Filter, for example, to generate the lacked information.

4.4.2 Software system

The fault tolerant concept would also be practiced with using a re-structurable control law, which would be a sole way to achieve actually the high operationally reliable systems, including the human interface area. If we could identify the failure condition of the aircraft, we would be able to conform the robust control, optimal to the new situation through a re-structure of the logic.

Identification of failure states by an adaptive control requires time. The intelligent material, optical fibered skin for the control surface, for example, might offer clear-cut out-put for damaged information. Once we could define the failure condition, we would be able to change easily the cost function for the optimal control, in LQG/LTR, for example.

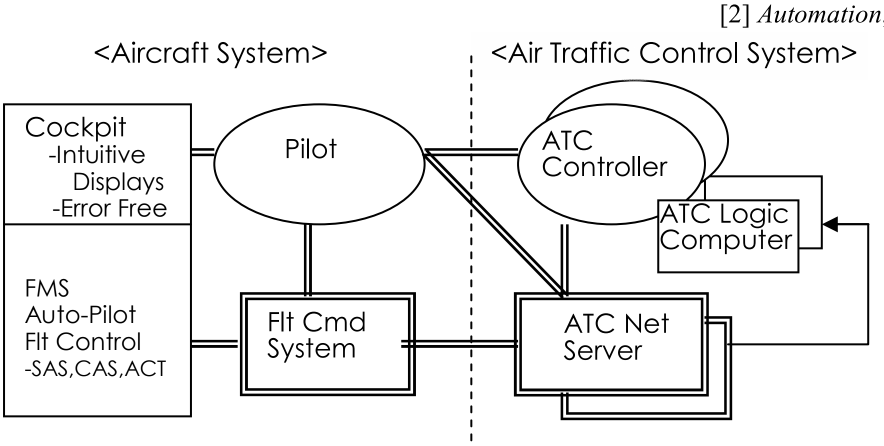

Figure 8. Aircraft Total Transportation Control

5. Future Perspectives for Air Transportation System

The proposed total control system for the air transportation is shown on the figure 8, as a concept.

The flight command system would work with the ATC logic computer through the network server. A counterpart for the aircraft pilot is the ATC controller, who is also the final authority for the system.

6. Conclusion

Author proposed the Flight Command System for the aircraft flight control system to reduce the accident rate of the civil transport, relating with the automation system. This is based on the idea that we could get the highly safe transport by promoting the automation further through applying the autonomous control for minimizing the human interface area.

The position of FCS is placed at top over FMS in the control hierarchy, and the autonomous control logic would be conformed by some expert-like auto-sequence controls, which are already proven the airworthiness through many existing programs.

Author expects the FCS would be applied in the coming transport program for making certain to get a surely safe aircraft, and give an innovation to ATC also.

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