Concept for Hull-Loss Free Aircraft
– Fuzzy Expert for More Advanced Automation in Flight Control

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Abstract

What is discussed here is a pursuit for the ultra safety transport in the operation, targeting mainly to eliminate human related accidents.

The Concept for the Hull-Loss Free Aircraft is presented as the ultra safety aircraft in the operation. Those are consisted of the highly reliable structure and systems based on the fault tolerant design concept, the more automation based on the autonomous control law, and the compatible Air Traffic Control (ATC) system based on the autonomous control and digital communication with the aircraft.

The author reminds the importance to place the Flight Command System as a top layer in the flight control for the autonomous operation of the aircraft, including to the ATC interface, and stresses the effectiveness of the Fuzzy Expert System as core control logic to complete the autonomous control in the aircraft. The example of the computer simulation by the logic for the collision avoidance in the air is presented.

The co-existence by an autonomous system and a pilot is referred to have well possibility, taking into consideration that the human body and brain has unconscious, and autonomous controls in many ways.

The one-man pilot, the windowless cockpit, 10^{-12} failures/flight hour system reliability requirement for a critical failure as a specification, the autonomous controlled ATC with the digital interface with the aircraft, etc. are proposed in the extension of the discussion.

1. Introduction

According to the Boeing statistics[1)], the accident rates for the civil transports have not changed so much for over 10 years (cf. Fig.1-Fig.3). FAA reports that the situation has been improving through their efforts to fight with the figure to reduce to 80% in these 10 years as a government policy. [2)] It is understood

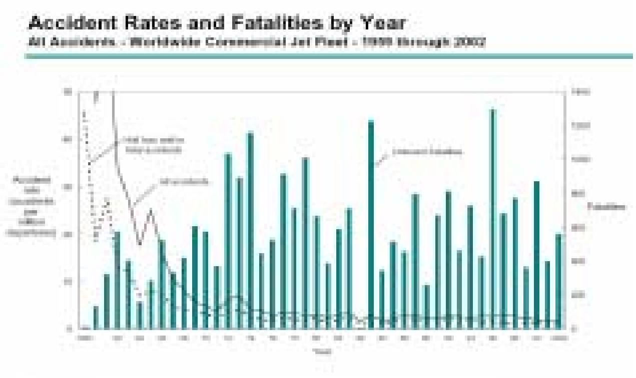


Fig. 1 Accident Rates-General

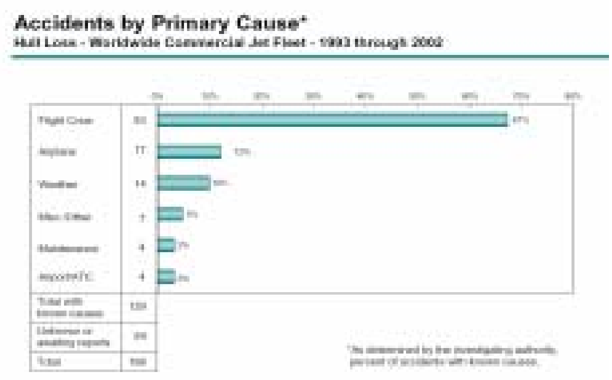
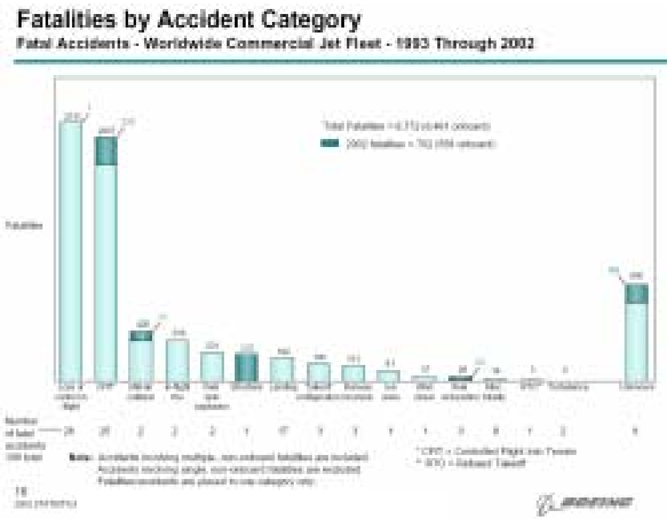


Fig.2 Accidents-Primary Cause

to be a true story locally for the advanced nations, however, that is still slight improvement and the total figure worldwide has not been changed from the level of 10^{-7} critical accidents per flight hour. Our common target is to acquire the much small figure for the accident rates to enhance the aviation safety. The human factors



occupy as many as 67% as a primary cause due to the statistics. We can find also Loss of Control and CFIT (Controlled Flight into Terrain) as major categories for the accidents.

The most effective way to improve the situation is to face at those major factors first.

The author proposes the more advanced automation system for the aircraft with the fault tolerant design concept as the Hull-Loss Free Aircraft Concept to realize 10^{-9} level of safety in the operation. This is the total system concept, including the operation and maintenance sectors for the aircraft, as well as the aircraft itself, to target the total safety for the aircraft operation. Here discussed is mainly from the points of the flight controls of the aircraft.

2. Concept for Hull-Loss Free Aircraft

2.1 General Concept

The concept for the hull-loss free aircraft is defined in this paper as the aircraft total system

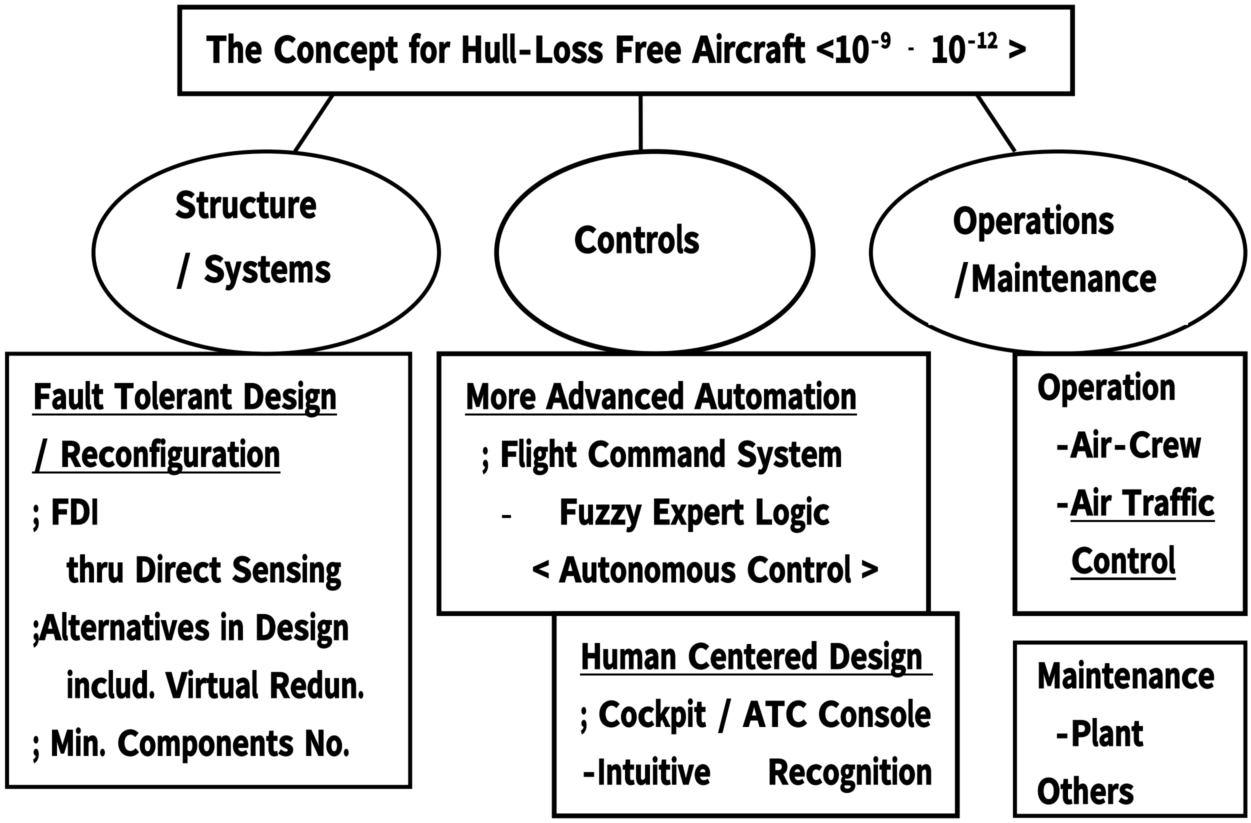


Figure Concept of Hull-Loss Free Aircraft

which statistics for the critical accidents is shown by 10^{-9} or higher reliability figure in its longitudinal axis of the statistics report.
The fundamental concept is based on the following sub-concepts summarized in the Fig.4.

1) High reliability Structure and Systems
   - Fault Tolerant Design Concept
   -System Reconfiguration in the case of failure
2) More Automation for System Control, with Autonomous Core Logic and with a Pilot
   -Flight Command System in the top hierarchy of the flight control system
   -Autonomous Control with Air Traffic Control
3) Human Center Cockpit
   -Intuitively Recognizable Display System
4) Compatible Digitalized Air Traffic System

The superficial features of the concept are one man pilot control and a windowless cockpit, etc.

2.2 Aircraft System

2.2.1 Flight Control System

1) Flight Command System

At the former ICAS meeting, the author proposed that the flight control system of the transport should have the Flight Command System in the highest layer of the flight control, by which the aircraft system is operated autonomously for the mission in accordance with the intuitively recognizable display system, interfacing with the ATC system (cf. Fig.5) .[3)]
The flight command system controls autonomously the flight management system (FMS), the auto-pilot, and the fundamental flight control system, etc of the lower layers.

The current FMS has a capability to take over the role to let the aircraft fly from take off to landing in a preprogrammed way, however, the negotiation with ATC and the decision to apply a new flight plan is the area for the autonomous control by the Flight Command System.

a) Phase1: Decision Making Phase -While flying by FMS, the situation is examined if the aircraft should change the original flight plan, gathering the information from ATC or self-detection. At this phase, the decision making process with the fuzzy factors for the if-conditions is considered. If there were a slight of possibility of a collision with a protected zone, a change decision

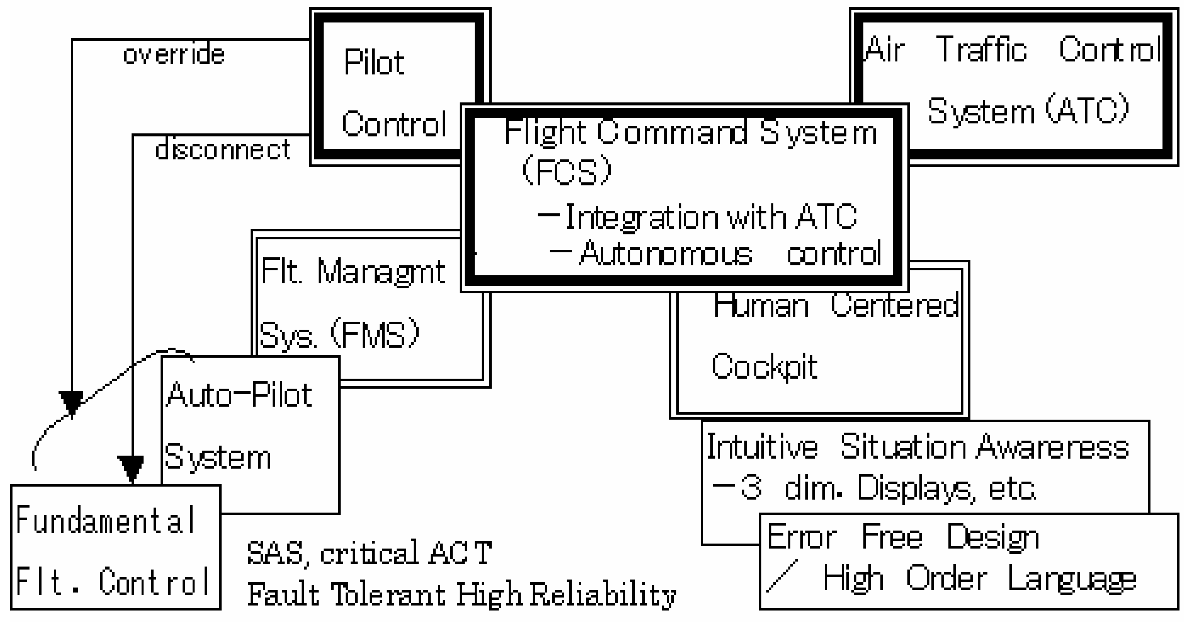


Figure The Concept of Flight Command System would be made for the original flight plan.

b) Phase2: Execution Phase -After a decision of altering the flight plan, the concrete change action takes place. And after the completion of this phase, the FMS will resume the flight control (cf.Fig.6).

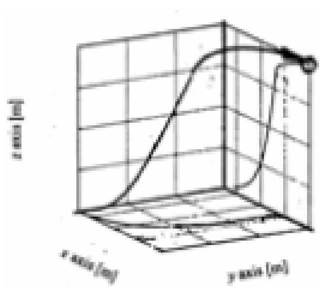


Fig. 6 Phase 2

As a pilot is required to supervise and control the aircraft mission, the intuitively recognizable displays are mandatory to be equipped to give the pilot an accurate situational awareness.

2) Fault Tolerant Design Concept

a) Structure

The control surfaces and stabilizers for the flight control should be planned at the initial design phase of the aircraft arrangement to keep the control capability even in the case of a failure of some structure for the control through the alternative function.

The engines could also be an alternative for a pitch and lateral control of the aircraft. The rudder, for example, might as well have separate surfaces to cope with the case for the surface failure, such as a break-off.

When the aircraft had a failure in the structure for the control, the survived parts are picked up and reconfigured to keep to be maneuvered the aircraft. The fault detection, isolation and identification (FDI) technology is also very important, in this case.

Although the aircraft structure in general should be designed under the concept of the fault tolerant design, this is not described in this paper.

b) Aircraft System

The every subsystem of the aircraft is to be designed in the fault tolerant concept, including the flight control system. The failures at the sensors, computers, actuators, and so forth, in the flight control system can be detected and processed to keep the function of the system within the system. However, the control surface failure, above mentioned, is beyond the capability to cope with by the flight control system only. There are some of such cases to be asked to apply the total aircraft design concept.

For this sense, each system can handle with the failure of the system by themselves with 10^{-9} reliability for the critical failure.

The most of the current 10^{-9} systems of the transport have a triple redundancy for the electric or electronic portion and a dual redundancy for the mechanical portion in general as a system configuration. This redundancy level seems to be a maximum for curbing the system overhead. Another basic policy for the redundancy management of the system is to have highly reliable parts, as highly as possible, and conform the system with a minimum number of parts. Each component of the system carries plural functions to be alternative for the case in need. In this case also, the technology for the FDI and the system reconfiguration are important.

As for the sensors system, for example, the skewed type arrangement of the component sensor and the virtual sensors applied with Kalman Filter might contribute to the effective sub-system to conform.

c) Reconfiguration of Systems or Control Laws

The high reliability design and the fault tolerant design are not the same concept, but the author asserts we can get more reliable design through the fault tolerant concept. At the same time, the fault tolerant and the reconfiguration is a different idea, but we can get both of high mission reliability and low failure rates through structuring the fault tolerant system with minimum hardware and software in highly reliable system. This means that it is required to reconfigure the system to maintain the system function.

The Society of Japanese Aerospace Companies (SJAC) released the report this March for the study of the reconfiguration law in the case of failures in the control system, including the control surfaces.[4] What is introduced there is the way to apply neural network for the FDI of the failure conditions, and the optimum robust control after reallocation of the effectiveness of the control surfaces for a reconfiguration control law which is a kind of LTR, and again neural network to set the optimal flight path for surviving to the nearest airport.

As for the reconfiguration control, the sliding mode control is also checked for the robust and optimal controllability, and in the adaptability for the case of failure in the control surface.[5]

We have to consider the aircraft control in normal state, and in the failure states, as well. The latter part of this paper mainly concerns to the control law in the normal operational condition of the aircraft. When it comes to the control at failures, the timely FDI is necessary. The author believes that the failure detection by some hardware seems to be better, for it requires a very short detection time, and that the simpler reconfiguration control law is better, as long as it is adequate enough to be optimal and robust, like LTR method.

2.2.2 Cockpit System

The author is describing to apply the autonomous control for the aircraft operation through the Flight Command System. However, the level of autonomy should be cited as not in a complete one. It is very difficult to consider the complete autonomy for the civil transport, which requires to be certified through experiences for a certain time. Furthermore, no-man transport does not have a room to be accepted from the public for the time being.[6] We need thus a pilot to control and supervise the mission achievement. Although the reason why the autonomous law is applied is to reduce the human interface area as much as possible, there still is an interface area. So it is very important to set an adequate way or devices for a pilot work in the cockpit system, where the pilot could immediately grasp the situation without a mistake, and carry out the supervising tasks smoothly. The key feature for the purpose is the display systems, by which the pilot grasps the 3 dimensional flight information, integrated with map and weather and ATC information, through which the pilot could get a good SA (Situational Awareness), and recognize his conditions intuitively and immediately.

The advanced EGPWS (Enhanced Ground Proximity Warning System) is equipped with the display of 2 dimension by altitude and range with map information, which seems to be desirable for the intuitively recognition.

It is said that The CFIT is caused from the special disorientation. The cockpit, where is to be independent to the outer condition of weather or time of day and night, and give the circumstances to concentrate the flight instruments to control the aircraft and to do other management works to complete the flight mission, would be an ideal office for a pilot as a top director in the flight. This is led to the windowless cockpit. The human centered design is the most important key word in any cases.[7]

2.3 Operation

2.3.1 Air Traffic Control

We had the accidents over Barden Barden in south of Germany in 2002, and over Yaizu in Japan in 2001. Those are reported to be related to the ATC Controller. On the other hand, the developing new system of FANS (Future Air Navigation System) is increasing the controller’s workload. Besides the ATC should be improved, it should have an adaptability to interface with the digitally advancing aircraft in the area of automation.

First of all, the key communication between ATC and Aircraft should move to a digital way completely. The ATC Controller’s works are also to be shifted to a more automation, applying the autonomous control for the core logic and with the intuitively recognizable display systems in the console for the controllers.

2.3.2 Maintenance and operation

In order to get really safe flight of actually no accidents, whole of the related area should be involved. The complete maintenance, and operation for the aircraft are to be important without doubt, however, the detail discussion for the area is skipped in this paper.

3. Fuzzy Expert System for Autonomous Control

3.1 Flight Control System in the aircraft

3.1.1 Level of Autonomous Control

When we refer to the word of autonomous control in the aircraft, there seems to be various level of it, and used exclusively to the area of unmanned aircraft so far. The function of base-return, way-points navigation, or auto-sequenced auto-pilot flight beyond the line of sight or in the case of radio linkage failure, etc. is called as the autonomous control. Most of them are based on the preprogrammed auto-sequence control. However, few of them are equipped with really autonomous control, by which the aircraft can judge the situation, and make an action by themselves for achieving the mission, or for a smooth flight on a route having other traffics with. The unmanned aircrafts seem to be on the way to seek their own autonomous control through the advanced type of the auto-sequence control, which could be a complete autonomous control, basing on the Expert System, “if-condition” were well and completely prepared.

The Expert System thus gets some level of evaluation, however, it is very hard to be verified whether the “if-condition” covers whole of the concerning area completely. Although what is discussed above is for the UAV, we could apply the same logic for the civil transport after the verification for the integrity and the safety of it, with the experiments.

3.1.2 Introduction of Fuzzy Logic

We can discuss the completely autonomous control under the Fuzzy Concept as follows. The flow chart of the control and if-then matters are prepared through the Expert Concept. The incompleteness of the Expert System designed is compensated by the introduction of the Fuzzy Concept. The application of the fuzziness to each of if –conditions covers the area where is not described by the conditions explicitly.

This is defined here as Fuzzy-Expert System, which is deemed as a true autonomous control logic, for the defined “if-then” covers whole of the conditions the aircraft would be estimated to encounter. The logic can actually judge the situation, and lead actions for the aircraft by itself.

3.1.3 Simulation Example for the Logic

1) Collision Avoidance Flight Path

Here cited is one example of the execution of the logic in the case of collision avoidance at phase 2 above mentioned. Each of the own aircraft and the intruder aircraft has a protected zone around the aircraft, which has 4,000ft in diameter, 600ft in height.[5)] Every aircraft is requested to be outside the zone anytime to avoid the collision in the air. The estimation of the movement of the intruder is based on both informations of the intent-base, which is from the flight plan and the state-base, which is analyzed from the observation or report of the current flying state of the aircraft

The simulation is carried out to set the flight path to avoid the intruder by setting a various situation for the two aircrafts (cf.Fig.7).

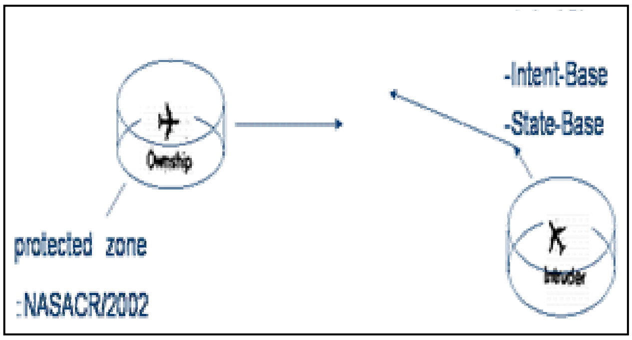


Fig.7 Protected Zone for Collision Avoidance

2) Membership Function

As for membership functions, the distance and the time between the own aircraft and the intruder aircraft are selected. And the turning rate of the own aircraft for avoiding the intruder is picked up as a function of corrective action. The fuzzy rule selected, are shown at Fig.8, and Fig.9.

Applied fuzzy rule is shown in the Fig.10.

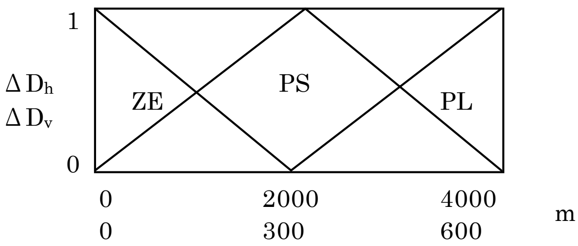


Fig. 8 Membership Function-1

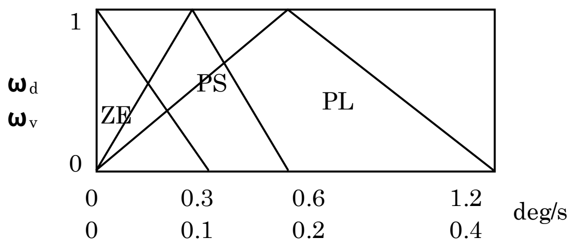


Fig.9 Membership Function-2

ω_d ω_v		ΔD_h ,ΔD_v		
		ZE	PS	PL
T_h T_v	ZE	ZE	PL	PL
	PS	ZE	PS	PL
	PL	ZE	PS	PS

3) Simulation Result

The simulation result through MATLAB is shown in the Fig.11. It is understood that the own aircraft avoids the intruder successfully.

The current transport is obligated to equipped the TCAS (Traffic Collision Avoidance System), so the system detects a danger and warns a pilot within the range. The avoidance action by the logic can take a smooth flight course in correction from much earlier time, and in much longer range.

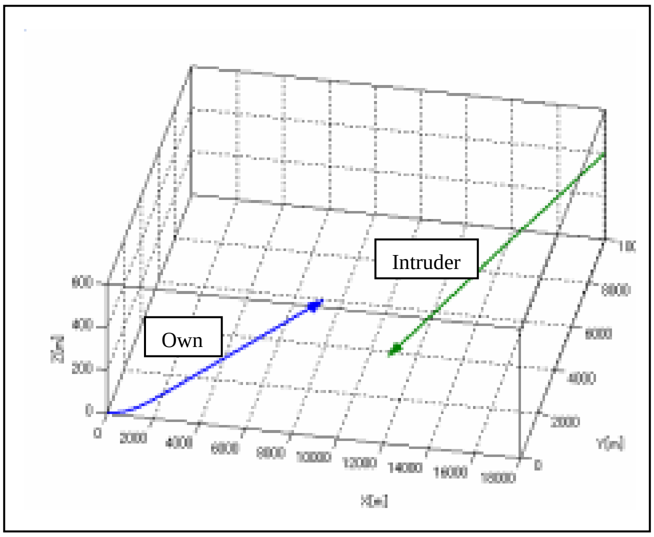
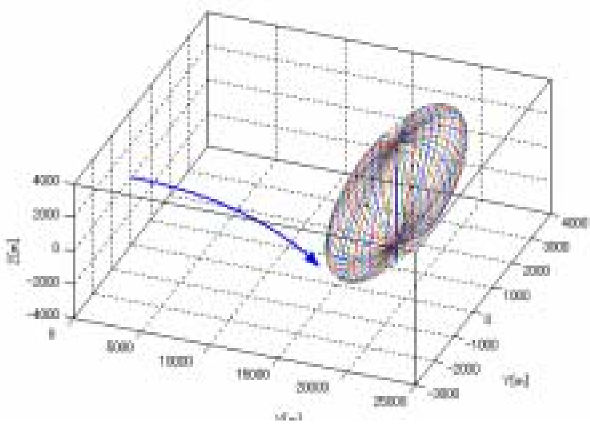


Fig.11 Example- Collision Avoidance / MATLAB

4) Other Example and Evaluation

Fig.12 shows the corrective flight course to avoid the hazardous weather zone.



Those explain that the logic could work well.

After these actions, the FMS resumes the control and continues the mission of the aircraft.

The problem for the calculated flight path is that the author does not consider if it is an optimum or not. He thinks that some membership function should be considered with, for the deviation from the optimal course, which is calculated through, say , the inverse problem, in separate ways for achieving a temporal optimization, at least.

3.2 Air Traffic Control System

3.2.1 Compatibility with the Aircraft

The ATC is requested to be digitally compatible enough to communicate with the Flight Command System of the aircraft. The typical communication patterns are to be coded. However, the conversation between a controller and a pilot is complicated and varies depending on the situation. The author deems most of them could be untouched from coding, to let them keep to have a conversation as one of the ways to keep them alert in control.

3.2.2 Digital Autonomous Traffic Control

The ATC is developing to FANS, which is represented by the free flight, to cope with the increasing demands for the air transportation in the world. At the same time the automation of the control is also advancing, but the control basis for the system is the controller's skill, and the analogue type of the conversation.

Reflecting that the trend of the accidents relating to the ATC is the same as the one for the aircrafts, the situation, letting the counter measures go first for eliminating the human factors, is also the same.

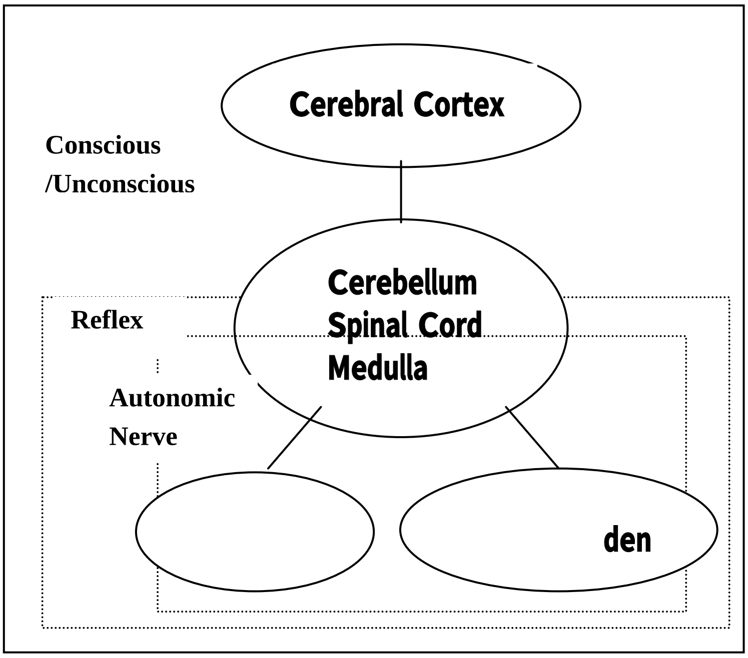
The top control logic for the ATC should go to autonomous, whatever logic is applied. The controller plays a role for a supervisor and a final authority for the control. The controller console should be advanced to give intuitively recognizable display systems.

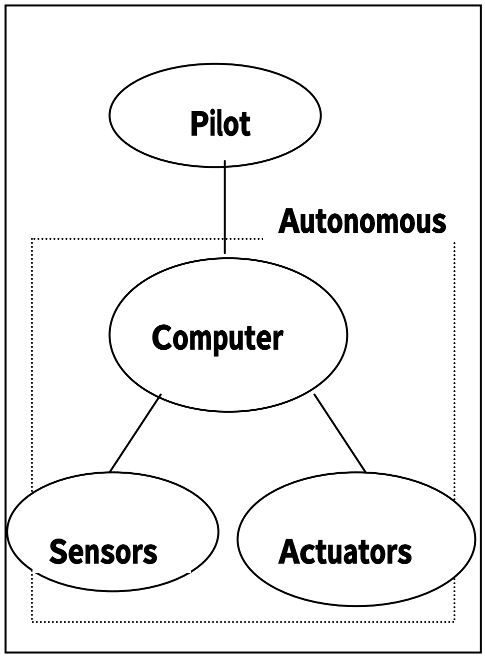
4. Man and Autonomous Machine Interface

4.1 Human Control under Unconsciousness

We, Human, has a will, and control ourselves consciously. We receive many signals from the receptors, such as eyes, ears, skin, muscles, tendons, etc. These sensory codes are processed in nerve systems through the cerebellum to the cerebral cortex. The frontal lobe finally activates muscles and tendons with mind (cf. Fig.13).

However, we also have the unconscious controls in many ways as in the following type.





Body **Fig.14 Man-Machine Interface**

1) Unconscious Control in Normal Routing

Although the normal sensing, the signal processing, and the activation by the cerebral control is occurring, there are the case that the actions are carried out unconsciously. Our brain is functioned normally and has every thing to do with the deeds, in this case. For example, we experience sometimes to get back ourselves, while driving in our daily life, and not to be able to remember how we well drove the car so far, following the traffic rules.

It is said that the unconscious information are as many as 10^5 times than the conscious one, according to the specialist.[8)] Most of our actions are controlled under unconsciousness, in another words.

2) Reflex - Spinal or Vertebral Reflex

The spinal code, medulla oblongata, and sometimes cerebellum take actions directly to protect our body from dangers. The cerebral has nothing to do with in this case, for it requires quick actions, still utilizing receptors information and normal activation system of our body. When we touched the heated pot, for example, de-touched the pot instantly due to the work of the bending muscle, which is not by the brain control.

3) Autonomic Nerve System

The sympathetic nerves, parasympathetic nerves and internal secretion are activating the organs of our body to keep our lives without getting a support from the cerebral cortex. Our heart has been beating without getting the directions from the brain, for example.

We can understand we are controlling ourselves without being conscious in wide area. Still, we are thinking we have a dignity to control ourselves with our own will. We are coexisting with many autonomic movements, or using the unconscious actions for the conscious actions, in another words.

4.2 Man Machine System

The conceptual figure for the man-machine interface is shown in the Fig.14. The outlook of the relation is quite same as the one in Fig.13. Even if many autonomous controls are carried out in the machine portion, a pilot could be tolerable and acceptable to carry out his own will just as the human brain.

Once the pilot admits the autonomous control system as a natural partner, and accept all it does, the pilot would not feel uneasiness in the autonomous actions, just like the reflex, or the autonomic nerve activities in our body. And he can carry out his own actions under his judge with the autonomous control machine. The important notice is to make a pilot believe an autonomous action by the machine part, which could be get through many flight simulation and actual flight tests.

4.3 The Role of a Pilot

A pilot should take over the control of the aircraft, whenever necessary. He should be always alert for that sense. We have to face at again the old problem.

When the FMS was introduced, the pilot was placed as a flying manager. The author named the pilot as a flying director, in introducing the Flight Command System. Whatever the name, the pilot should be a final authority in the aircraft in its control, and managing the mission, and responsible for the safety to the passengers.

We may be required to apply for some ideas to keep a pilot being in alert, such as to ask the pilot to practice frequent exercises at the in-flight simulation while flying, and to converse with other person, including the air traffic controller.

4.4 Problem Area

The problem areas for these discussions are, the compatibility of the autonomous system with a pilot, the test methodology for evaluation, the method for keeping the alertness, and so forth.

We have to carry out the flight simulation tests to verify the pilot’s easiness with an autonomous machine, and to find out the way for keeping alert, etc. We also have to specify a flying quality for a pilot to handle an autonomous control system.

5. Our Targets for Hull-Loss Free Aircraft in Near Future

5.1 High Reliability System Design

The higher the system or structure reliability is, the better the system safety is. The system should have to be refrained from increasing the redundancy level of it to constrain the overhead in minimum

Each component has a technology to show 10^{-4} even for an electronic part in one of these days. So 10^{-12} of the system reliability by the triple redundancy for the critical failure could be our target in near future.

5.2 Future Reconfiguration

The reconfiguration technology became mire important. Any control laws could be applicable, as long as it is optimal and robust. However, the hardware for the FDI should be developed to get the certainty, the simplicity, and the quickness. The intelligent skin, the image processing, etc. is a candidate for the technology.

5.3 Advanced Intuitive Recognition System

The whole of the cockpit system should be intuitively recognizable, irrespective to the weather outside of the aircraft. The display system gets larger and larger to whole of the cockpit. There would be no need to have windows, which is also better for stopping CFIT

6. Conclusions

Here cited is the concept for improving the current situation for the aircraft accident. The analysis shows to go to minimize the human interface area to achieve the ultra safety aircraft.

The author has asserted to go to the more automation to realize the ultra-safety aircraft, where the core control logic should be autonomous control law. The improvement of the ATC System is also expected from the point of digital interface, and of control law by an autonomous control law.

The fuzzy logic for compensating the incompleteness of the expert system is presented as being for the autonomous flight control system, with one simulation example.

The author here expressed the possibility a pilot could manipulate the autonomous flight control in the aircraft through consideration of the human body controls.

The problem area should be crashed out to have a really safe aircraft in our hands in near future, through establishing the design specification gathering the data by the flight simulation tests, etc. The very important thing for the realization is to have a project plan for it and one step forward.

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