ENHANCEMENTS OF FLIGHT MANAGEMENT SYSTEM WITH INTEROPERABILITY

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Abstract

Although modern aircraft is equipped with more and more advanced avionics, it is still vulnerable to human errors. We are developing the next generation of Flight Management System with enhanced interoperability by a set of 'proficiency curves'. The purpose is to setup a 'phantom crew', who invites flight crew to talk, think and take action. It is different from the traditional user-friendly design and is called 'partner-friendly design'.

1 Introduction

Driven by the development of new electronics technology and Communication Navigation Surveillance / Air Traffic Management (CNS/ATM) environment, civil avionics are going to be the integral element within the CNS/ATM system.

The trend to an integrated system is through, from hardware, software to application, with the characteristics of multi-mode and/or function built in one platform.

The advanced automation system is an aide to human but human error is ubiquitous, inevitable and a part of daily flight operations. More attention should be paid on it while avionics become to the bigger and integrated system. Today's system design concepts should address the needs for increasing automation of flight environment and safer flight community.

Meanwhile, the flight environment is changing. "In keeping with the origins and pioneering spirit of the early days of aviation, the general orientation was masculine, Western and unreflectively self-confident. It took quite a few years for us to realize, not mention accept, that culturally mediated operational differences in aviation were a reality—rather than an unfortunate departure from the unarticulated normative standard rooted in the masculine Western model." Capt. Neil Johnston of the Aerospace Psychology Research Group based at Trinity College, Dublin, Ireland, says in his foreword in the book of Tapping Diverse Talent in Aviation by Turney, Mary Ann [1].

In modern airliners industries, flight operations are different than before. The management realized that their employees become more divergent than in the past. In China, at early times, the employees usually have similar background, for instance, all pilots came from the unique flight school or from the Air Force. They enjoyed the same flight culture.

Thanks to the flight simulator plus other modern flight training facilities, today we even got the graduates for line pilot pool that may has no any aviation background before they touch the computer screens for flight courses. They grow up faster than in classic flight schools, even the aircraft they fly are bigger, heaver and more complex before.

2 Issues in Existing Avionics System

Avionics are borne and fostered as the assistant of flight crew with the capabilities from positioning, navigation to control of aircraft. The functionality is therefore focused on navigation, communication, display, indication, control and warning.

The functionality, quality and reliability of the existing avionics are pretty good. It is almost impossible to result a flight accident due to a single inherent failure and or fault in avionic system.

However, flight accidents and their behaviors show no much change even the avionics have been upgraded several generations in past decades. Modern aircraft is still vulnerable and exposed to human error although avionics play more and more important role between flight crew and aircraft.

On March 12, 2003, the tail of a Boeing 747-412 struck the runway and incurred substantial damage during the takeoff rotation. The local accident investigation commission concluded that the accident was caused by erroneously low takeoff reference speeds being entered into the airborne Flight Management System (FMS). The flight dispatch paperwork read a takeoff gross weight of 347.4 tonnes, but the first officer incorrectly wrote 247.4 tonnes thus introducing a calculation error of 100 tonnes. The first officer then independently determined a takeoff speed rotation speed, or Vr, of 130 knots based on the incorrect takeoff gross weight. At the airplane's actual takeoff gross weight of 347.4 tonnes, the takeoff rotation speed, as determined by the FMS, was 163 knots.

The local accident investigation commission then expressed concern that, because the FMS is not designed to detect and annunciate incorrect entries, it is incumbent on the flight crew to detect any such errors. The commission also recommended that because takeoff gross weight is used as a basis for takeoff reference speeds, the FMS software should be changed to ensure any entries, such as V speeds and gross weight that are mismatched by a small percentage are either challenged or prevented. [2]

Surveying local flight safety reports recent years we found the fact that human errors were the one of major causes in Undesired Aircraft States (UAS) from bad initial lift-off to heavy landing.

Our local airlines offered us another sample for study: its one Airbus A340 took off in normal conditions, steered by the first officer. The captain felt the rate was slower than required during rotation thus he helped in rotation of airplane. During takeoff he thought the attitude was too high and then pushed the nose down. But it was too late the aircraft experienced tail struck and finally landed safely.

This is called ‘dual inputs’, according to Airbus’ definition. Because of the nature of fly-by-wire and side stick systems, the Pilot-Not-Flying should not make control inputs to correct the Pilot-Flying’s handing of the aircraft.

When a take-over becomes necessary during flight, the Pilot-Not-Flying must call clearly “I have control”, and press the side stick priority pushbutton, keeping it pressed until the transfer of control is clearly established, according to Airbus’ information.

In the later version of flight crew training manual, Airbus emphasized the principle of side stick and priority pushbutton. When the Pilot-Flying makes an input on the side stick, an order (an electrical signal) is sent to the fly-by-wire computer. If the Pilot-Not-Flying also acts on the stick, then both signals/orders are added.

Discussion with our flight crew shows the reasons of their not announcing first and pushing the priority bush buttons are as follows:

- Thought his own action was correct
- Worried about the time of transferring for taking control if use the priority function
- Worried about to hurt the Pilot-Fling’s reputation by calling out to “I take control”

The basic task sharing principle for aircraft operation is that only one pilot is Pilot-Flying at a time. However, feedback gained from line operations indicates that dual inputs still occur periodically. Therefore, Airbus offers, as an option, a package of dual input indicators and warning, which operate when both side sticks are deflected simultaneously. This package includes two visual indications and an aural warning function. This made the complementariness of current side stick priority indications on the glare shield lights.

3 Human Error Model and Solutions

International Civil Aeronautics Organization (ICAO) Human Factor documents [3] describe the human Error Models as follows:

- Intentional non-compliance error
- Procedural error
- Communication error
- Proficiency error
- Operational decision error

The system design of avionics therefore should be updated because the existing solutions are not oriented to deal with them directly. They only warn flight crew if the data input and output are beyond the limits of performance profile. However, human error may make such a flight accident even if the error-led data is within the performance profile of the aircraft.

For example, a wrong value of takeoff weight may be input and causes the tail struck, but is within the performance chart thus the existing system never makes any precaution or warning to the flight crew.

The industries have made lot effort to minimize human error from flight crew for years.

Since early 1970s, Federal Aviation Administration (FAA) developed a system tool called Cockpit Resource Management (CRM) and then updated into ‘crew resource management’ after realizing the teamwork is spreading into almost every field in civil aviation. CRM, according to FAA documents, is to enhance flight crews’ efficiency by a coordinated teamwork. “Investigations into the causes of air carrier accidents have shown that human error is a contributing factor in 60 to 80 percent of all carrier incidents and accidents…Many problems encountered by flight crews have very little to do with the technical aspects of operating in a multi-person cockpit. Instead, problems are associated with poor group decision-making, ineffective communication, inadequate leadership, and poor task or resource management.”[4]

Due to the difficulty, cost and time of changing human attitude and behavior, the industries have also developed Standard Operating Procedures (SOPs) to setup effective crew coordination and crew performance to achieve consistently safe operations through adherence to SOPs that are clear, comprehensive, and readily available to flight crewmembers [5].

The industries also introduce an additional means, Flight Operational Quality Assurance (FOQA) program, for addressing safety problems and identifying potential safety hazards. FOQA is a voluntary safety program that is designed to make commercial aviation safer by allowing commercial airlines and pilots to share de-identified aggregate information with the FAA so that the FAA can monitor national trends in aircraft operations and target its resources to address operational risk issues [6].

FAA then developed a helpful tool called as Line Operations Safety Audit (LOSA) to improve the situation. Then it became the basis of ICAO Document 9803, Line Operations Safety Audit, which was published in 2002. [7]

LOSA uses the model called Threat-and-Error Management (TEM) which assumes that threats and errors are integral parts of daily flight operations and must be managed.
However, we have been thinking and taking action to improve the inside of machine as follows.
The key point of LOSA, for example, may be the trust between the flight crew and management. That will be impossible to perform the LOSA if the crew has no trust on the observer who takes the jump seat, watch and record every thing behind the flight crew. LOSA and other systemic tools are based on the "no punitive" policy which may be challenge for some line operations.
The cultural difference exists everywhere in civil aviation world because the air transportation almost reaches every corner of various social backgrounds and traditions.
Failed to implement the standardized operation is just a case. SOPs, the purpose of procedural steps, are to setup a book-pilot with a detailed formula and defined operational items, for instance, to make the normal, anomalous and emergency SOPs for every flight phase.
Unfortunately, while SOPs work greatly but never perfectly. Flight crewmembers always make deviation. They do so because of their expectation to fly and control, instead of following the machine with text, according to our interview with local airlines. Pilots believe that adherent SOPs is not the unique path to fly the aircraft. They have other ways to do the same work with a reasonable cause, from time saving, safety and personal skills.
The interview indicates the personal skills for flying may play the more important role in the interface of human and machine, especially in the place where skill is not in violation of the constraints, procedures and regulations, along with the introduction of more advanced avionics suites. We can not simply increase the content of SOPs to cover every corner in such a huge and complex system. Thus the deviation and/or skip from SOPs occur increasingly in daily cockpit operations if the system design has been on the current way.
This may be a good reason to introduce other tools, CRM, FOQA and LOSA, etc to reveal the secret of how and when flight crew makes errors. Therefore, it may be unwise to develop every detail for all moments which flight crew may meet in their life cycle. Instead we should pay more attention to develop a great machine for human crew. When the human make decision and changes, the machine can issue some advices, warning and finally fail-passive for any extreme case which is met or made by the human with inadvertent, unintentional and/or defective manipulation.
Operational or human error may be inevitable; the challenge to us is to dig into the system to learn the inevitable consequence. The result may be a technical one, or an organizational one. For example, we take the fashion of design so called user-centered one and have to take the users, the human, as the integral part of the entire system, including human behaviors, and errors, instead of only the style of interface-friendly, or design the machine whose work-flow follows the way of human being.
Human error from flight crew may be managed significantly if we update the solution of the existing avionics system based on the existing airborne resources.

4 Key Points in FMS System Design

Above all, flight is a human-machine integrated system. That must be supported in architecture, infrastructure and operation. The FMS is the top interface of machine with the flight crew during routine flights. To make a predictable operation shall be a reasonable practice in development of the next generation of airborne automation, if the human can not be perfect.
Procedural error may be considered as the door to error input. We can trap the human error if we can manage the procedural error. We are developing the next generation of FMS for CNS/ATM environment with such enhancement as follows:

- Enhanced precaution to flight crew if a significant human error is input into FMS. This means the new FMS can offer cross-checks and get the strategic review, not only the performance profile with one input.
  For example, we input a weight value of 247 tonnes for take off and the FMS will check the flight plan, saying we will have a 12 hours flight according to the flight plan. Thus FMS can issue a warning for the impossible mission simply because the airplane is unable to fly 12 hours with only the take off weight of 247 tonnes, according to the built-in performance database in the FMS.
- Enhanced interoperability with flight crew in the phase of data preparation. For example, when a likely error is input, the FMS asks the flight crew to ensure that input and tell them what will mostly be the result by that input.
  That happens during approaching. While cruise is almost smooth and predictable, the approach phase is often challengeable to flight crew. The air traffic is heavy, the flight level changes, your neighbor traffic is not on time, thus you may want to or be asked to make a expedite speed reduction. That action may include the extension of flaps and then landing gears, with a violation of speed limits. The new FMS is in such a design that it calculates in advance to void any possibilities in violation of the maximum speed limits and therefore make sure to follow the desired path and speed targets.
- Retrospect of raw data. Human error may not result a FMS or system error

but must be a kind of UASs. The retrospect of raw data offers a hand to the flight crew to find out the error in raw data ASAP, save the time to rescue the flight in the correct direction.

For easier daily operation, one of our local airlines issued an official 'cost index' for its fleet equipped FMS. Cost index is used in FMS calculation of flight performance. That is a rate of fuel cost vs. time cost. During one flight in our local airliners, the flight crew found the cruise speed was much higher than usual but failed to found the reason immediately. They took a pretty long time in searching and thinking of. Finally they found that during keying in the value of cost index, they input erroneously the number that result a higher cruise speed.

Our new FMS will offer a menu function which makes automatic links to relative raw data. In the example above, the flight crew can check the suspected cruise speed and then the FMS will display the raw data which decided the speed.

And more the FMS will offer further raw data according to relative request. Another solution is to collect and manage data used by flight crew on FMS scratchpad and flight mode control panel under the windshield. Scratchpad is the area on control and display unit of FMS where the flight crew input daily the raw data into the FMS computer. Flight mode control panel is typically under the windshield of cockpit to allow the flight crew selects flight parameters, such speed, heading and altitude, etc.

This solution adds other benefit to flight crew. That meaning promotes or enhances the situational awareness with the capability of listing all raw data on the public area in cockpit which we name it 'Billboard'. In old cockpits, there are a lot of buttons and knobs to control the airplane. When the pilot touches the heading knob, the other flight crews know he wants to change the heading. But in later automation, computer does most things in cockpit and the rest of the flight crews may not tell his purpose immediately.

- Enhanced interoperability consists with typical cases in operation, for instance, various approaches and mountainous airports.

  During the phase of concept development, our local airlines contact us to explore the possibility to develop a localized flight pattern which may be helpful for daily operations, especially in some dedicated terminal areas where situations are usually special due to their mountain ridges, high altitude and bad weather but with lot of traffic flow at rush hours. That is typically a hot point for touring cities in southwestern China and flights are high frequent in the morning and evening, and the weather conditions change rapidly.

- Further, enhanced interoperability of FMS forms a 'proficiency curve' according to the flight plan which is made of expert flight data. Users, airlines or flight crew, may make their supplementary actions or increments. During flight, FMS compares proficiency curve with flight crew's input and make suggestions to a difference.

  Based on the database of localized flight patterns, what we are under the concept study is to envisage the possibility for the development of a set of proficiency curve. In the present automation system, there is a lack of the direct relationship to help the flight crew to make flexible and skillful response to the real world. We are developing a new FMS which will offer its resources and strong ability with the better integrated functions when the flight crew wants to make changes and corrections according to the real circumstances.

  The purpose of the enhanced interoperability does not control human activities and challenge the human decision. We are going to setup a 'phantom crew member' which invites flight crew to talk, think and take action.

  During our interview with local airlines, we found that in many cases, flight crew members are unwilling to have talks with others. There are many reasons, such as personal characteristics, ranks, relationships, language or different background of education.

  We are trying to image a phantom crew member based on our FMS. It can offer on time and various necessary responses about any human activities which may damage the normal situation and progress in the coming flight phases. FMS offers its advices and predictable situational awareness with its virtual simulation function. Therefore the FMS can issue precaution to let the flight crew envisage what will happen if they make such a decision or change.

- The phantom crew member offering proficiency curve is the virtual reality environment which can describe the behavior of Pilot-In-Flying, instead of machine. That is the point different from user-friendly or user-centered design. It is called 'partner-friendly design'.

  The feedback from our flight line indicates that the flight crew member wants to see his direct influence but many things of control logics in automation system are not designed so directly. The human crews want to see

how the automation system works. That is the prerequisite the human crew takes the automation crew as the trustworthy partner.
The human crew may have no interest in the flight guide from the electronic partner but may really have an interest to see how the electronic guy will fly in such a situation. The database can store skills collected from veteran pilots. That means a good talent pool onboard.

- All suggestions which phantom crew member made are aural-orientated instead of visual-orientated thus ensure the isolation from the classical solution of avionics for smooth transition. Flight crew uses the traditional cockpit interfaces, control display unit and electronic flight instrument system, etc. to talk with aircraft while they hear relative advice from aural system onboard which is easy to be inhibited if necessary.
- FMS saves the relative data for further analysis after landing but flight crew can erase them due to the privilege. The download data are used by ground stuff to improve the capability continuously, not for punishing flight crew.

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