Design Induced Errors on the Modern Flight Deck During Approach and Landing

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Abstract

Human factors certification criteria are being developed for large civil aircraft to replace the interim policies currently in place for this purpose. The objective of these initiatives is to reduce the incidence of design induced error. Many formal error identification and prediction techniques currently exist, however none of these have been validated for their use in an aviation context due to a lack of validation data. Accident and incident reports do not contain sufficient detail in this respect. This paper describes a survey of commercial pilots to collect data on common, design induced errors on a modern flight deck during the approach and landing phases of flight. These data will subsequently be used in the validation of a formal error prediction technique for use on the flight deck.

Introduction

Estimates vary, but up to 75% of all aircraft accidents have a human factors component in them. Human error is now the primary risk to flight safety (Civil Aviation Authority 1998). In July 1999 The US Department of Transportation gave notice of a new task assigned to the Aviation Rulemaking Advisory Committee (ARAC). This was to provide advice and recommendations to the FAA (Federal Aviation Administration) administrator to 'review the existing material in FAR/JAR 25 and make recommendations about what regulatory standards and/or advisory material should be updated or developed to consistently address design-related flight crew performance vulnerabilities and prevention (detection, tolerance and recovery) of flight crew error' (US Department of Transportation 1999). Put more succinctly, rules are being developed in Europe by the JAA (Joint Airworthiness Authorities) and the USA for the human factors certification of flight decks. These rules will be applied to both the Type Certification and Supplemental Type Certification processes for large transport aircraft.

The initial stimulus for the regulatory initiative came from the 1996 FAA Human Factors Team Report on the Interfaces between Flightcrews and Modern Flight Deck

Systems (Federal Aviation Administration 1996). This itself was stimulated by accidents such as the Nagoya Airbus A300-600, the Cali Boeing 757 and the Air Inter A320 accident in 1992. The report made many criticisms of flight deck interfaces in modern aircraft, identifying problems in many systems.These included pilots' autoflight mode awareness/ indication; energy awareness; position/terrain awareness; confusing and unclear display symbology and nomenclature; a lack of consistency in FMS interfaces and conventions, and poor compatibility between flight deck systems.

The FAA Human Factors Team Report also made many criticisms of the flight deck design process. For example, the report identified a lack of human factors expertise on design teams, which also had a lack of authority over the design decisions made. There was too much emphasis on the physical ergonomics of the flight deck, and not enough on the cognitive ergonomics. Fifty-one recommendations came out of the report, including (from a regulatory perspective):

- 'The FAA should require the evaluation of flight deck designs for susceptibility to design-induced flightcrew errors and the consequences of those errors as part of the type certification process', and
- 'The FAA should establish regulatory and associated material to require the use of a flight deck certification review process that addresses human performance considerations'

In 2001 the JAA issued an interim policy document (Joint Airworthiness Authorities 2001) that will remain in existence for the foreseeable future, until the new harmonised human factors regulations are set into place. This interim policy applies only to novel interfaces on the flight deck in new build aircraft and aircraft requiring a supplemental type certificate. The guidance notes issued with the policy suggest methods by which compliance with the new

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policy can be demonstrated, essentially requiring a formal risk and error assessment of the novel interface.

There are many formal error prediction techniques available, mostly developed either directly or indirectly from the requirements of the nuclear and/or petrochemical industries. A comprehensive overview of these techniques can be found elsewhere [Kirwin 1998a and 1998b). However the predictions made by these techniques have yet to be validated to check their accuracy in the complex, dynamic application of the modern commercial aircraft flight deck. Indeed, many of these techniques have only been subject to cursory validations. One of the fundamental problems of validating these techniques is obtaining ecologically-valid and reliable criterion data (Kirwin 1996).

Accidents are very infrequent events and furthermore, investigation reports do not contain sufficient detail to establish the design-induced errors that may have contributed to the sequence of events. Incident data are much more plentiful, however, these reports contain even fewer details about the pilots' interactions with their equipment than accident reports. Previous validation studies have concentrated on assessing the predictive validity (in terms of the human error potential) of certain formal error prediction techniques against the probability of known events (Kirwan, Kennedy, Taylor-Adams, and Lambert 1997). Kirwan (1990) argued that all human reliability assessments have three main objectives at their core: human error identification, error quantification and error reduction. Kirwan suggested that although the greatest research emphasis has been placed on the second of these components perhaps more emphasis should have been placed on the first to identify all potential significant types of error. As he points out, unless all significant errors are identified the probability of error generated by formal techniques will be underestimated.

Even though it is a term that is becoming increasingly commonly used, it is difficult to define precisely what constitutes a 'design-induced' error. This is one of the problems that are currently being addressed by the Human Factors Harmonisation Working Group as part of the certification effort. From the aircraft certification perspective there is a fundamental philosophical assumption that poor interface design increases the likelihood of error and *vice versa, after all,* it is the fabric of the aircraft that is subject to the certification process. Human error is one symptom of design or operational deficiencies. Unfortunately, it is acknowledged that it is difficult (or impossible) to quantify the contributions of other factors, such as training, the pilot's physiological state, operational procedures and the environment, *etc.* to making an error. However, it has been readily demonstrated in many studies that when all other things are held constant, some human-machine interface configurations encourage higher error rates than others. The assumption also underlies the notion of usability and is inherent in most formal probabilistic risk and error assessment methods. Nevertheless, design-induced error remains difficult to define although it may also be argued that development of a precise definition does little to remove the fundamental problem that needs to be addressed.

The object of this research was to identify (*not* quantify) design induced errors on the flight deck., as it can easily be argued that the most common errors committed are not necessarily the errors most likely to result in an accident, and there is also not yet an exhaustive list of such errors. These data are critical for the validation process of any formal error identification technique, yet such basic, low-level data do not exist. The companion paper to this paper [Salmon, Stanton, and Young 2002) describe the initial results of studies to assess the use of existing human error techniques to predict pilot error. SHERPA (Systematic Human Error Reduction and Prediction Approach (Embrey 1986)) was chosen as the best technique for the identification of the sources of design-induced error on the civil flight deck.

Method

A Hierarchical Task Analysis (HTA) was conducted for the approach phase of a flight in Aircraft X (a modern, highly automated, 'glass cockpit', medium capacity airliner). From the HTA, a formal error analysis was undertaken [12] to make a comprehensive prediction of all the possible errors that could be made during the landing phase of flight using the Flight Control Unit (FCU) as the main controlling interface. Several other necessary systems were also included, such as the speed brake and flaps, which are important during the landing phase of flight.

Initially it was intended to develop the questionnaire for this research through interactions with a large numbers of pilots who fly Aircraft X, however as a result of the unfortunate events of September 2001, access to flight crew for this pilot study was limited. To avoid delaying the research, the HTA was used to develop questions for the survey combined with observations made during earlier orientation flights and interviews with pilots.

These questions were entered into a questionnaire, the aim of which was to obtain some estimate of the overall frequency of occurrence of the design induced errors predicted from the HTA. To achieve this, respondents were asked if they had ever made the error themselves, and also if they knew of anyone else who had made the error. As it was probable that the list of questions was not an exhaustive list of every error, space was provided for reporting additional errors or for further comments to be given.

Following an initial administration to a sample of senior pilots to check for errors and refine the questionnaire, the final instrument was sent to pilots, all of whom were currently flying Aircraft X for one of three UK Airlines.

Following the return of the questionnaires, a number of clarification interviews were conducted to further understand the qualitative comments received on the questionnaire.

Results

Forty-six completed questionnaires were returned. Of the respondents the majority were Captains (45.7%) or First Officers (37%) with the remainder being Training Captains or unknown (13.3%). The respondents had a range of total flying hours from 610 to 17,050 with a mean of 6,832.4 hours. With regard to hours on Aircraft X, experience ranged from 150 to 6,500 hours with a mean time on the aircraft type of 1,184.89 hours.

Only the results to questions where a significant number of pilots identified the error are presented here and considered particularly important for later discussion.

In the following tables a 'ME' response indicates that the respondent has made the error in question themselves, whilst an 'OTHER' response indicates that they have seen someone else make the error, or that they are aware of someone who has.

Table 1: Setting the speed brake

Question	Me	Other
Q10 Moved the flap lever instead of the speed brake lever when intended to apply the speed brake	0.0%	6.5%

Table 2: Airspeed

Question	Me	Other
Q14 Initially, dialled in an incorrect airspeed on the Flight Control Unit by turning the knob in the wrong direction	39.1%	37.0%
Q16 Having entered the desired airspeed, pushed or pulled the switch in the opposite way to the one that you wanted	26.1%	26.1%
Q17 Adjusted the heading knob instead of the speed knob	78.3%	65.2%

Table 3: Tracking localiser

Question	Me	Other
Q25 Incorrectly adjusted heading knob to regain localiser and activated the change	4.3%	4.3%

Table 4: Changing headings

Question	Me	Other
Q32 Entered a heading on the Flight Control Unit and failed to activate it at the appropriate time	34.8%	34.8%

Table 5: Altitude

Question	Me	Other
Q38 Entered the wrong altitude on the Flight Control Unit and activated it	15.2%	17.4%
Q40 Entered an incorrect altitude because the 100/1000 feet knob wasn't clicked over	26.1%	28.3%
Q41 Believed that you were descending in flight path angle and found that you were in fact in Vertical speed mode or vice versa.	8.7%	13.0%

Table 6: Engaging Approach System

Question	Me	Other
Q43 Tried to engage APPR (Approach) too late so that it failed to capture	28.3%	30.4%
Q44 Pressed the wrong button when intending to engage APPR such as EXPED (Expedite)	6.5%	8.7%

Table 7: Flap selection

Question	Me	Other
Q55 Checked the flap position and misread it	4.3%	4.3%
Q57 Moved the flap lever further or not as far as intended	17.4%	6.5%

Table 8: Lowering landing gear

Question	Me	Other
Q60 Omitted to put the landing gear down until reminded	19.6%	37.0%

Table 9: Other

Question	Me	Other
Q61 Had an incorrect barometric air pressure set	45.7%	45.7%
Q65 Set an altitude "out of the way" and then out of habit pulled the altitude knob	15.2%	32.6%

Discussion

The programme of research to identify design induced errors at the early stages of development using formal error identification techniques, required the identification of the errors that were being made on the flight deck as a result of poor design. In many cases, the types of errors that were investigated were the kind of errors that cannot explicitly be linked to incidents or accidents because of the paucity of the data in the investigation reports, rather than not being important errors *per se.* However, they also represent daily issues for pilots as they make these mistakes, which they then have to correct.

Even when the error made does lead to an incident or accident, the report usually does not go into sufficient detail to highlight the specific design-related error issues that caused the incident. There are, however, some exceptions. For example, the Air Inter A320 accident in 1992 was the result of a pilot entering a rate of descent in the Flight Control Unit (FCU) whilst in the wrong mode. Question 41 asked pilots if they have made the same error, 8.7% of pilots surveyed had made the same error themselves and 13.0% had seen others do it. If it has led to a crash, and pilots are still doing it, the issue must be raised of why this error can still be made which could again lead to a repeat accident. The research literature now clearly shows that having multiple modes on the same control interface is unwise and can lead to mode confusion and design-induced errors (Sherry et al. 2001).

Many of the errors that were found were the types of errors that most pilots were aware of and have simply had to accept on the flight deck. It is hoped that human factors certification standards would help to ensure that many of these errors are not included on future aircraft.

Many examples of poor design, which almost encourage error, can be found by looking at Standard Operating Procedures (SOPs). Having to develop a SOP or train pilots to ensure that they don't do something accidentally in the cockpit is often an indirect admittance of poor design. Many errors that exist should not have to be detected and managed but should not have been there to begin with.

The SOPs are frequently used as a "work around" to ensure that the chance of a previously made known error reoccurring is reduced. An example would be the cross checking of altimeter setting during approach between the left and right hand seat. Aircraft X will allow a certain difference to exist between the pressure settings on the two sides, if the difference is not great enough to trigger a pressure setting warning. Almost half of the pilots at some time reported having had an "incorrect barometric air pressure set" (Q61). The location of the pressure switch is also close to the Vertical Speed (V/S) knob, and pilots have been known to press that by mistake. This results not in a change in the altitude on the Primary Flight Display, but in a climb/descent.

Pilots were bemused by the fact that such a high technology aircraft has so many pilot aids and protections programmed in, and yet still has a large number of deficiencies in the pilot interface. As one pilot commented "One of the most interesting traps I have found in Aircraft X is that the Flight Management Guidance Computer (FMGC) knows the intended Take Off (T/O) configuration for the Flaps. However, if the T/O Flap setting is made incorrectly, the T/O Config (Configuration) Push Button does not detect the discrepancy". However, the same criticism is applicable to other aircraft equally.

This demonstrates a design problem, which could lead to an error in the flap setting for take off. Indeed the saying goes that "if it can go wrong, it will go wrong". This was demonstrated in a comment from a pilot: "almost all of our Take Off's are carried out at flap setting Y, and setting this Flap has become a strong habit. If we do anything else, it requires a major effort to ensure that the flap setting is correct. I have actually got airborne with a Y flap setting when we briefed off a short Runway for Z. Both of us did not catch the mis-set flap, as seeing Y on the upper display unit is normal".

Whilst this has not caused an incident to date on Aircraft X, crews have been known to try and take off with the wrong flap set with fatal consequences. For example, in 1988, a Delta Airlines 727-200 inadvertently attempted a flapless take-off from Dallas Airport. Unfortunately, no take-off configuration warning was signalled resulting in a fatal accident.

Whilst SOPs are often devised to overcome a problem, occasionally flight crews have created their own, often ingenious, solutions-though these are not encouraged by the airline, aircraft manufacturer or regulatory bodies. Continuing on from the previous example, "There are two correct methods to help prevent this happening. The checklist now requires us to declare the flap setting verbally and the other consists of placing an empty (preferably) coffee cup on the flap handle during the brief."

Frequently, covered switches or gated levers are used as methods to reduce the chance of errors being made on the flightdeck. In line with this good practise, the designers of aircraft X have gated the flap lever so that a definite action is required to move the lever. However, our research shows that pilots still frequently make such errors (Q55 + Q57), demonstrating that not always can an engineer design out a problem, but only reduce it. If the flap lever were not gated, the chances are that these errors would occur more frequently.

Whilst the majority of the questions focused on the FCU, some also focused on other equipment used during the approach. Question 10 looked at how many people have moved the flap lever instead of the speed brake lever. Looking at the layout of Aircraft X and the shape and location of the handles, this may seem an unlikely error but 6.50% had seen others do it, and the aircraft will allow this manoeuvre. A pilot uses the speed brake when he/she wants to slow the aircraft down. Lowering flaps at too high an airspeed could overstress the airframe, leading to the flaps breaking off. Aircraft X will allow you to lower flaps when above the maximum flap extension speed.

Where there are examples of poor design, that design can exist without leading to an accident/incident for many years, until the conditions are right for it all to go wrong. The fact that the majority of such design induced errors have a low level of consequence, or will never lead to an accident/incident because of formal and informal "work arounds", does not mean that such errors are trivial enough to accept. At the very least, a number of the errors have led to go-arounds, which have costs of fuel, engine wear and tear, and stress on the passengers.

Other such errors have led to moments of high workload on the flightdeck, as the crews become aware of the error made and try to work out how to fix it, not that this is always easily possible. Whilst not directly within the remit of the questionnaire, a commonly reported problem was when crews use the "DIRECT TO" function on the FMGS, the aircraft will make an "immediate turn BEFORE the crew is able to check that the correct input is made".

Once a pilot has pulled up the required page on the FMGC with the list of possible "DIRECT TO's", the displayed page is not frozen. As soon as the aircraft gets closer to or further away from another waypoint, all the "DIRECT TO's" will move on screen. So the pilot presses the button where the "DIRECT TO" he/she required was previously and now that point has moved. Now the aircraft is going "DIRECT TO" the wrong place. There is no "Undo" button as you would commonly find in home/office PC software. This problem has been highlighted in other literature (Federal Aviation Administration 1996).

Many of the problems occurred with the parts of the FCU that control heading, airspeed and altitude. Problems occur due to the close location of the knobs and the fact that pulling or pushing them can lead to dramatically different results (as demonstrated in the Air Inter accident). Initial changes to the shape of the ends of the knobs had little effect in reducing the errors made once these problems started to come to light (according to pilots). The latest versions of Aircraft X have had a redesign which appears, from a limited number of reports by pilots, to have solved many of the problems of using the wrong knob by changing the lengths and sizes of the knobs.

A couple of the comments made that relate to the FCU are that "experienced line pilots do make a large number of these FCU errors as it is very easy to select the wrong knob, push or pull incorrectly, turn it the wrong way etc". "This last week, I had to take control and go-around after my First Officer was intercepting the Glideslope (G/S) from above and selected a higher altitude on the FCU and pulled [the knob], putting the aircraft into an operational climb".

This was also backed up by questions, which found that at least one-third of pilots had themselves (and seen others) dial in an incorrect airspeed on the FCU by turning the knob in the wrong direction (such as Question 14). Around 26% of pilots found that they had themselves had or had seen others, enter the desired airspeed, and then pushed or pulled the knob in the opposite way to the one that they had intended to (Q16). Very common was the number of pilots who adjusted the heading knob instead of the speed knob (Q17). Another common "Gotcha" (as aircrews know them) are that pilots often, especially when flying a non-precision approach will " Set an altitude "out of the way" and then out of habit pull the altitude knob" (Q65). The result of this is instead of an altitude being ready to go in case of the need for a go around, the aircraft obeys the order immediately to head to that altitude. Although these errors cannot solely be ascribed to design *per se* it can be argued that the interface is not sufficiently error-resistant, and hence promotes the likelihood of these instances.

Similar errors were found to be repeated in carrying out other tasks using the FCU where pilots had "entered the wrong altitude on the FCU and activated it" (Q38). This led to unwanted climbs or descents, often when setting a new altitude ready to activate as required and pushing or pulling out of habit. Conversely, "Entered a heading on the FCU and failed to activate it at the appropriate time" (Q32) or "Incorrectly adjusted the heading knob to regain the localiser and activated the change" (Q25). The design of the altitude knob on the FCU has a setting to change the units that altitude is entered in, from 100's to 1,000's feet, and this frequently caused errors in entering altitudes (Q40).

A design issue that needs to be addressed in the future is where to design in warnings and protections. Often pilots are lulled into a false sense of security and believe that an event will occur as expected. They often fail to notice when it doesn't happen until it is too late.

The APPR mode on the FCU can be activated, which will fly the aircraft down the glideslope. Standard operating procedure is for the aircraft systems to capture the localiser and then the APPR mode can be activated. Pilots frequently wait until it is too late to capture this (Q43), or do remember in time, but press a seldom-used button next to it (Q44), and hence fail to achieve the desired aim.

One commonly expressed view amongst pilots of many aircraft, and not just Aircraft X, in "off the record" conversations and maybe one that all manufacturers of future aircraft may want to pay attention to is "These aircraft are 13+ (years) in production and heaven knows how long in conception, why do we still hear from experienced flight deck crews, what the (expletive deleted) is it doing now".

This research is the initial stage of a larger project to develop a design induced human error prediction tool. The findings of the research are so far very encouraging. There have been lessons learned from this stage of the research which will be fed into the next and main part of the project-to assess a larger portion of the flightdeck, in more stages of flight of aircraft Y. At the end of this next phase, it is hoped to have validated formal methods that can be confidently applied at the early design stages of other aircraft, to reduce the likelihood of error.

Ideally, the questionnaire would have been developed from using large databases of reported errors. However, searches of a variety of UK and International databases were of little assistance as they currently do not collect the type of data required. At the next stage, a detailed task analysis for flying the aircraft will be conducted and access to pilots will be gained earlier on in the development of the questionnaire to obtain a higher standard of results.

Many errors found in this study are "generic" and may be found in other instances and not just in this design such as turning a knob the wrong way. However, the purpose of the technique under development is to highlight where human errors can be made as a result of the design and are likely to be made if the particular design of interface is used. It is then up to the regulatory authority to look at what that knob does and decide if it important enough to be guarded or to have software protections.

In a similar way, it can be argued that some errors may be “system design induced” such as by poor training but there must be the acceptance that training can be at times less than perfect and the design of the flightdeck needs to be tolerant to this. The aim of this research is not to develop a techniques that will apportion blame to a manufacturer but one which will aid in assuring that the chances of error have been minimised. This will be of greater benefit in the long run to the aircraft and manufacturers reputation, in the ease of being trained to fly the aircraft and hopefully in the aircraft being involved in fewer incidents and accidents.

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