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Human Error Prevention: Using the Human Error Template to Analyze Errors in a Large Transport Aircraft for Human Factors Considerations

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Abstract:

Flight crews make positive contributions to the safety of aviation operations. Pilots have to assess continuously changing situations, evaluate potential risks and make quick decisions. However, even well trained and experienced pilots make errors. Accident investigations have identified that pilots' performance is influenced significantly by the design of the flight deck interface. This research applies Hierarchical Task Analysis (HTA) and utilizes the - Human Error Template (HET) taxonomy - to collect error data from pilots during flight operations when performing a go-around in a large commercial transport aircraft. HET was originally developed in response to a requirement for formal methods to assess compliance with the new human factors certification rule for large civil aircraft introduced to reduce the incidence of design-induced error on the flight deck (EASA Certification Specification 25.1302). The HET taxonomy was applied to each bottom level task step in an HTA of the flight task in question. A total of 67 pilots participated in this research including 12 instructor pilots, 18 ground training instructor, and 37 pilots. Initial results found that participants identified 17 operational steps with between two and eight different operational errors being identified in each step by answering to the questions based either on his/her own experience or their knowledge of the same mistakes made previously by others. Sixty-five different errors were identified. The data gathered from this research will help to improve safety when performing a go-around by identifying potential errors on a step-by-step basis and allowing early remedial actions in procedures and crew coordination to be made.

Key Words: Aviation Safety, Human Errors, Hierarchical Task Analysis, Human Error Template

Introduction

For the past half century there has been a steady decline in the commercial aircraft accident rate. Nevertheless during the last decade or so the serious accident rate has remained relatively constant at approximately one per million departures (Boeing, 2008). While high levels of automation in third generation airliners have undoubtedly contributed considerable advances in safety over earlier jet transport aircraft, new types of error have emerged on these flight decks (Woods and Sarter, 1998). These types of accident are exemplified in crashes such as the Nagoya Airbus A300-600 (where the pilots could not disengage the go-around mode after its inadvertent activation; this was as a result of a combination of lack of understanding of the automation and poor design of the operating logic in the autoland system); the Cali Boeing 757 accident (where the poor interface on the flight management computer and a lack of logic checking resulted in a CFIT accident); and the Strasbourg A320 accident (where the crew inadvertently set an excessive rate of descent instead of manipulating the flight path angle as a result of both functions utilizing a common control interface and an associated poor display). Human error is now the principal threat to flight safety. In a worldwide survey of causal factors in commercial aviation accidents, in 88% of cases the crew was identified as a causal factor; in 76% of instances the crew was implicated as the primary causal factor (CAA, 1998).

The skills now required to fly a large commercial aircraft have changed considerably during the past three decades, mostly as a direct result of advances in control and display design and the technology of automation. The pilot of a modern commercial aircraft is now a manager of flight crew and of complex, highly-automated aircraft systems. The correct application of complex procedures to manage activities on the flight deck is now an essential part of ensuring flight safety. Most aspects of flight management are now highly procedurally driven. While pilot error is without doubt now the major contributory factors in aircraft accidents, a diagnosis of ‘error’ in itself this says very little. It is not an explanation; it is merely the beginning of an explanation. Dekker (2001) proposed that errors are systematically connected to many features of a pilot’s tools and tasks and that the notion of ‘error’ itself has its roots in the surrounding socio-technical system associated with aircraft operations. The question of human error or system failure alone is an oversimplification. The causes of error are many and varied and almost always involve a complex interaction between the pilot’s actions, the aircraft flight deck, the procedures to be employed and the operating environment.

During the last decade ‘design induced’ error has become of particular concern to the airworthiness authorities, particularly in the highly automated third and fourth generation airliners. A Federal Aviation Administration (FAA) commissioned study of the pilot-aircraft interface on modern flight decks (FAA, 1996) identified several major design deficiencies and shortcomings in the design process. There were criticisms of the flight deck interfaces, identifying problems such as 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 US Department of Transportation (DoT) subsequently assigned a task to the Aviation Rulemaking Advisory Committee (ARAC) to provide advice and recommendations to the FAA 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 DoT, 1999). Since

September 2007 rules and advisory material developed from ARAC tasking have been adopted by EASA (European Aviation Safety Agency) as Certification Specification (CS) 25.1302 and with supporting advisory material in AMC (Acceptable Means of Compliance) 25.1302.

Perhaps the true significance of the establishment this regulation is that for the first time, there is a specific regulatory requirement for 'good' human factors on the flight deck. It is an attempt to eradicate many aspects of pilot error at source. However, such rules relating to design can only address the fabric of the airframe and its systems so the new regulation can only minimise the likelihood of error as a result of poor interface design. It cannot consider errors resulting from such factors as poor the inappropriate implementation of procedures, etc. From a human factors viewpoint, which assumes that the root causes of human error are often many and inter-related, the new regulations have only addressed one component of the wider problem. The design of the flight deck interfaces cannot be separated from the aircraft's operating procedures. Complex flight deck interfaces, while potentially more flexible, are also potentially more error prone (there are far more opportunities for error). Analysis of aircraft accident investigation reports has suggested that, inappropriate system design, incompatible cockpit display layout, and unsuitable Standard Operating Procedures (SOPs) are major factors causing accidents (FAA, 1996).

With regard to checklists and procedures various axioms have been developed over the years. For example, Reason (1988) observed that the larger the number of steps in a procedure, the greater the probability that one of them will be omitted or repeated; the greater the information loading in a particular step, the more likely that it will not be completed to the standard required; steps that do not follow on from each other (i.e. are not functionally related) are more likely to be omitted; a step is more likely to be omitted if instructions are given verbally (for example in the 'challenge and response' format used on the flight deck); and interruptions during a task which contains many steps are most likely to cause errors. Li and Harris (2006) found that 30% of accidents relevant to 'violations' in military aviation included intentionally ignoring standard operating procedures (SOPs); neglecting SOPs; applying improper SOPs; and diverting from SOPs. The figure was higher in commercial aviation, with almost 70% of accidents including some aspect of a deviation (or non-adherence) to SOPs (Li, Harris and Yu, 2008).

Formal error identification techniques implicitly consider both the design of the flight deck interfaces and the procedures required to operate them simultaneously. They can be applied at early design stages to help avoid design induced error during the flight deck design process but they can also be used subsequently during flight operations to diagnose problems with SOPs and provide a basis for well-founded revisions. Formal error identification analysis is not new. It has been used in the nuclear and petrochemical industries for many years. Most formal error identification methods operate in a similar way. They are usually based on a task analysis followed by the subsequent assessment of the user interfaces and task steps to assess their error potential. However, it should be noted that formal error prediction methodologies only really address Reasons' skill-based (and perhaps some rule-based) errors within a fairly well defined and proceduralized context. Hence they can only help in protecting against errors which relate either to the flight deck interfaces or their directly associated operating procedures.

HET (Human Error Template), developed by Marshall, Stanton, Young, Salmon, Harris, Demagalski, Waldmann and Dekker (2003) is a human error identification (HEI) technique designed specifically for application on the aircraft flight deck. Advisory Circular AC25.1309-1A (FAA, 1988) suggested that the reliable quantitative estimation of the probability of crew error was not possible. As a result, HET was developed specifically for the *identification* of potential errors using formal methods, *not* their quantification. It was developed as a diagnostic tool intended as an aid for the early identification of design induced errors, and as a formal method to demonstrate the inclusion of human factors issues in the design and certification process of aircraft flight decks. HET has been demonstrated to be a reliable and valid methodology (see Stanton, Harris, Salmon, Demagalski, Marshall, Young, Dekker, and Waldmann, 2006; Stanton, Salmon, Harris, Marshall, Demagalski, Young, Waldmann and Dekker, 2009). It has been benchmarked against three existing techniques (SHERPA – Systematic Human Error Reduction and Prediction Approach; Embry, 1986; Human Error HAZOP – Hazard and Operability study, Whalley, 1988; and HEIST – Human Error In Systems Tool, Kirwan, 1988) and outperformed all of them in a validation study comparing predicted errors to actual errors reported during an approach and landing task in a modern, highly automated commercial aircraft. The HET method has been proven to be simple to learn and use, requiring very little training and it is also designed to be a convenient method to apply in a field study. The error taxonomy used is comprehensive as it is based largely on existing error taxonomies from a number of HEI methods but has been adapted and extended specifically for the aerospace environment.

The International Air Transport Association (IATA) analyzed data from 240 member airlines and found about 50% of accidents in 2007 occurred during the phrases of final approach and landing, a period which comprises (on average) only 4% of the total flight time. Most pilots are trained that executing a go-around is the prudent course of action when a landing is not progressing normally and a safe outcome is not assured. This is best practice but it isn't always a straightforward decision (Li and Harris, 2008). Knowing how to execute the go-around maneuver and being proficient in its execution are extremely important but still more is required. Pilots must possess the skill and knowledge to decide *when* to execute a go-around. Many accidents have happened as a result of hesitating too much before deciding to abort the landing. This research applies the Human Error Template (Marshall, Stanton, Young, Salmon, Harris, Demagalski, Waldmann and Dekker (2003) to the retrospective analysis of go-around procedures in a large commercial aircraft to identify potential areas for improvement in the design of the SOPs involved.

Method

Participants: Sixty-seven pilots participated in this research including 25 captains and 42 first officers. Twenty-one pilots had in excess of 10,000 flight hours; 18 pilots had between 5,000 and 9,999 hours; 17 pilots had between 2,000 and 4,999 hours and 11 pilots had below 1,999 flying hours. There were 12 instructor pilots, 18 ground training instructors and 37 pilots with teaching experience. The age range of participants was between 28 and 60. All participants held a type-rating for the large jet transport aircraft under consideration.

Description of the task: The first step in this research was conducting a hierarchical task analysis (HTA) to define clearly the task under analysis. The purpose of the task analysis in this study was an initial step in the process of reviewing the integration of hardware design, standard operations procedures and pilots' actions during a go-around. The task analysis undertaken was for the go-around on a large, four-engined, inter-continental jet transport aircraft (aircraft X)

Task decomposition: Go-around operations can be considered as the required actions to be made by a pilot to achieve the associated goal and based on the SOPs. Once the overall task goal (safely performing go-around) had been specified, the next step was to break this overall goal down into meaningful sub-goals, which together formed the tasks required to achieve the overall goal (Annett, 2005). In the task, 'safely performing a go-around', this overall goal was broken down into the sub-goals, for example: 1.1 Press TO/GA Switches; 1.2 Set Flaps Lever to 20; 1.3 Rotate to Go-around Attitude; 1.4 Verify Thrust Increase; 1.5 Gear up; 1.6 Select Roll Mode; 1.7 Select Pitch Mode; and 1.8 Follow Missed Approach Procedures. The analysis of each task goal was broken down into further sub-goals, and this process continued until an appropriate operation was reached. The bottom level of any branch in a HTA should always be an operation. For example, the sub-goal 1.7 Select Pitch Mode was broken down into the following operations: 1.7.1 Select Pitch Mode; 1.7.2 Verify Pitch Mode Annunciation; and 1.7.3 Maintain Proper Pitch Attitude. Seventeen bottom level tasks were identified in this analysis.

Classifying Modes of Error: HET is a checklist style approach to error prediction utilizing an error taxonomy comprised of 12 basic error modes. The taxonomy was developed from reported instances of actual pilots and extant error modes used in contemporary HEI methods. The HET taxonomy is applied to each bottom level task step in a hierarchical task analysis (HTA) of the flight task in question. The technique requires the analyst to indicate which of the HET error modes are credible (if any) for each task step, based upon their judgment (Harris, Stanton, Marshall, Young, Demagalski & Salmon, 2005. There are 12 basic HET error modes: 'Failure to execute', 'Task execution incomplete', 'Task executed in the wrong direction', 'Wrong task executed', 'Task repeated', 'Task executed on the wrong interface element', 'Task executed too early', 'Task executed too late', 'Task executed too much', 'Task executed too little', 'Misread Information', and 'Others'. A full description of the methodology and all materials can be found in Marshall, Stanton, Young, Salmon, Harris, Demagalski, Waldmann and Dekker (2003).

The design of evaluating format: These 17 bottom level tasks are broken down into 65 operational items to be evaluated by all participants using a structured questionnaire. The questionnaire format asked participants if they had ever made the reported error (tick 'ME') and if they also had observed any one else who had made the error (tick 'OTHER'). It was hoped that this format would increased the participant's confidence in being able to report errors. For example, if they had made the error themselves but had no desire to admit to making the error, they could tick the 'OTHERS' box.

Results and Discussion

Participants responded to items based upon 17 sub-tasks in which each step could include any one (or more) of 12 different types of human errors (see Table 1). Each sub-task consisted of operational behaviors for participants to evaluate based on his/her own experience (ME) or if he/she knew someone who had committed the errors (OTHERS).

Table 1: The Results for the Human Error Modes in Aircraft X when performing a go-around. Numbers in the cells show percentage (%) of respondents reporting that error mode in each task step.

Error Modes Sub-task for performing Go-around by HTA		Fail to execute	Task execution incomplete	Task executed in wrong direction	Wrong task executed	Task repeated	Task executed on wrong interface element	Task executed too early	Task executed too late	Task executed too much	Task executed too little	Misread information	Other
1.1.1	Press TO/GA Switches	33.93	16.07	7.14	26.79	16.07	7.14	16.07	25.00	1.79	0.00	1.79	3.57
1.1.2	Thrust has advanced	26.79	48.21	0.00	0.00	0.00	0.00	5.36	5.36	10.71	0.00	5.36	8.93
1.2.1	PF command ‘flap 20	42.86	12.50	0.00	5.36	0.00	0.00	3.57	42.86	1.79	1.79	0.00	0.00
1.2.2	PM place flap lever to 20	19.64	14.29	10.71	5.36	0.00	3.57	5.36	19.64	3.57	0.00	0.00	7.14
1.3.1	Verify TO/GA mode annunciation	48.21	26.79	1.79	1.79	0.00	5.36	0.00	8.93	0.00	1.79	12.50	7.14
1.3.2	Rotate to proper pitch attitude	5.36	39.29	3.57	1.79	1.79	0.00	5.36	25.00	35.71	8.93	3.57	1.79
1.4.1	Verify adequate thrust for go-around	53.57	39.29	7.14	5.36	0.00	0.00	3.57	8.93	1.79	3.57	10.71	3.57
1.4.2	Announce ‘go-around’ thrust set’	62.50	26.79	0.00	1.79	0.00	0.00	1.79	12.50	0.00	3.57	0.00	0.00
1.5.1	Verify positive rate of climb	32.14	19.64	7.14	0.00	0.00	0.00	1.79	23.21	0.00	0.00	0.00	12.50
1.5.2	Place gear lever to up	39.29	7.14	5.36	3.57	0.00	1.79	19.64	42.86	0.00	0.00	0.00	8.93
1.6.1	Select Roll mode	26.79	14.29	14.29	10.71	0.00	8.93	5.36	51.79	0.00	0.00	3.57	3.57
1.6.2	Verify Roll mode annunciation	35.71	23.21	1.79	3.57	0.00	0.00	0.00	17.86	0.00	3.57	3.57	8.93
1.6.3	Turn into correct track	5.36	28.57	10.71	5.36	0.00	1.79	5.36	41.07	3.57	0.00	0.00	3.57
1.7.1	Select Pitch mode	23.21	26.79	23.21	5.36	0.00	3.57	8.93	50.00	1.79	1.79	3.57	3.57
1.7.2	Verify Pitch mode annunciation	26.79	26.79	3.57	3.57	0.00	0.00	1.79	21.43	0.00	3.57	0.00	10.71
1.7.3	Maintain proper pitch attitude	12.50	46.43	12.50	1.79	0.00	1.79	1.79	21.43	7.14	8.93	3.57	1.79
1.8	Follow M/A Procedure	10.71	50.00	25.00	17.86	0.00	7.14	8.93	30.36	0.00	0.00	12.50	3.57

There were 19 task steps with a very high percentage of errors during go-around (defined as being when the average number of errors for both ME and OTHERS was over 40%) - see Table 2. The most common error mode for pilots performing the go-around was ‘Failure to execute’; the second highest was ‘Task execution incomplete’; the third highest as ‘Task executed too late’ (see Table 2). The most commonly occurring operational error of pilots when performing the go-around was 'forgot to call **Go-around Thrust Set**' (average 69.41%); the second highest was 'not using auto-flight system when available and appropriate' (average 60.45%); the third most common error reported was 'did not engage LNAV mode on time failed to capture' (average 53.73%).

Table 2: The occurred rates of error break down by detail operational behaviors for Aircraft X Performing Go-around (shown the average error over 40% for both ME and OTHERS)

Modes of Error	**Description of Errors Occurred during Go-Around**	**Occurrence rate**		
		ME	OTHERS	AVERAGE
Fail to execute	Q5. Failed to check thrust level	38.81%	56.72%	47.76%
Task execute incomplete	Q8.Thrust lever were not advanced manually when the auto-throttles became inoperative	29.85%	53.73%	41.79%
Fail to execute	Q9. Failed to command 'flap 20' due to pilot's negligence	25.37%	67.16%	46.26%
Fail to execute	Q15. Failed to check whether TO/GA mode was being activated	44.78%	46.27%	45.53%
Task execute too late	Q17. Late rotation, over / under rotation.	46.27%	50.75%	48.51%
Task execute incomplete	Q18. No check for primary flight display	26.87%	56.72%	41.79%
Fail to execute	Q23. Failed to check go-around thrust setting	53.73%	52.24%	52.99%
Task execute too late	Q25. Did not identify and correct speed deviations on time	46.27%	47.76%	47.015%
Fail to execute	**Q26. Forgot to call 'go-around thrust set'**	**68.66%**	**70.15%**	**69.41% (1)**
Task execute too late	Q27. Did not identify and correct go-around thrust deviations on time	35.82%	58.21%	47.02%
Fail to execute	Q30. Forgot to put the landing gear up until being reminded	40.30%	59.70%	50%
Task execute too late	**Q33. Did not engage LNAV mode on time failed to capture**	**49.25%**	**58.21%**	**53.73% (3)**
Fail to execute	Q37 Failed to check whether LNAV/ HDG was being activated	31.34%	64.18%	47.76%
Task execute on wrong interface	Q39. Mixed up the IAS/HDG bugs on the MCP	34.33%	49.25%	41.79%
Fail to execute	Q42. Did not engage VNAV mode on time failed to capture	44.78%	62.96%	53.37%
Task execute incomplete	Q46. No check whether VNAV or FLCH was being activated	38.81%	56.72%	47.76%
Task execute incomplete	Q48. Did not monitor the altitude at appropriate time	38.81%	55.22%	47.02%
Task execute too little	Q62 Poor instrument scan	43.28%	55.22%	49.25%
Task execute incomplete	**Q65. Not using auto-flight system when available and appropriate.**	**55.22%**	**65.67%**	**60.45% (2)**

These 17 bottom level sub-tasks were further evaluated by all participants. For each credible error identified a description of the form that the error would take was required and the outcome or consequence associated with the error was determined. The likelihood of the error was estimated using a very simple scale (low, medium or high) as was the criticality of the error (low, medium or high). If an error was given a high rating for both likelihood and criticality, the task step was then rated as a 'fail', meaning that the procedure involved should be examined further and it should be considered for revision (see example given in Table 3). As an example, the qualitative data relevant to the descriptions and consequences of failing to perform properly the task step relating to task 1.3.2 ‘**Rotate to proper pitch attitude**’ (which was assessed as a ‘fail’) can be found in Table 4.

Table 3: An example of Human Error Template output from Sub-task Step 1.3.2 ‘**Rotate to proper pitch attitude**’ for performing a go-around.

Scenario: Go-around at XXX International Airport			**Task step: 1.3.2 Rotate to proper pitch attitude**								
Error mode	**Tick**	**Description**	**Outcome**	**Likelihood**			**Criticality**			**PASS**	**FAIL**
				H	M	L	H	M	L		
Fail to execute	V	Pilot’s incapability when A/P engaged	A/C not climbing and speed increasing	**V**			**V**				**V**
Task execution incomplete	V	Failed to trim to prevent excessive pitch up /failed to trim to reduce forward pressure	Not enough climb rate/speed too high	**V**			**V**				**V**
Task executed in wrong direction	V	Failed to rotate to target go-around pitch first or follow F/D without crosscheck SPD	Affect go-around performance SPD too high/ too low		**V**			**V**		**V**	
Wrong task executed	V	Banking instead of pitching up	A/C not climbing but rolling, may cause wings not level		**V**			**V**		**V**	
Task repeated											
Task executed on wrong interface element											
Task executed too early	V	Rotate to proper pitch too rapidly	Airspeed low		**V**		**V**			**V**	
Task executed too late	V	Rotate to proper pitch too slowly	Affect go-around performance may cause not enough climb rate	**V**			**V**				**V**
Task executed too much	V	Increase pitch too high	Airspeed low	**V**				**V**		**V**	
Task executed too little	V	Increase pitch not enough	Not enough climb rate	**V**					**V**	**V**	
Misread information	V	Misreading pitch attitude	May cause unstable climb rate			**V**			**V**	**V**	
Other											

Table 4: The qualitative data containing the descriptions and consequences of the error for sub-task ‘**Rotate to proper pitch attitude**’ when performing a go-around.

Scenario ： **Performing a Go-around at XXX International Airport**			Operational step ： **1.3.2 Rotate to proper pitch attitude**	
Error Mode	**Description**	Frequency	**Outcome**	Frequency
Fail to execute	PF’s negligence from surrounding interference (2) A/C not rotated when manual fly (1) Pilot’s incapability or system failure when A/P engaged (2) Pitch up too late or too fast (3) Panic (5) Distraction. Unanticipated go-around (2)	15	Not satisfy the go-around climbing rate /Speed up too much (2) Close to TERR (1) A/C did not climb (3) Over speed or under speed (1) No go around pitch (3) Wrong attitude (3) Stall (2)	15
Task execution incomplete	Not enough pitch (3) Under/over rotate or rotate at an improper pitch attitude for go around (1) PF’s negligence (2) Did not follow FD pitch (1) Failed to trim to prevent excessive pitch up /failed to trim to reduce forward pressure (2) Distraction. Unanticipated go-around (2)	11	Not enough climb rate or speed too high (2) Not satisfy the go-around climbing rate (2) Climb gradient not enough or lose altitude (1) A/C over pitch which increase pilot’s workload (2) over speed or under speed (1) No go around pitch (1) Wrong attitude (2)	11
Task executed too late	PF’s negligence (2) Late rotate when go around thrust set (1) Rotate to proper pitch too slowly (5) Panic (3) Pilot’s control input later than pitch change because thrust advanced (2)	13	Not enough climb rate (1) Speed up too much (3) Close to TERR (1) A/C continue to sink (2) Affect go-around performance (2) Wrong attitude (4)	13

Many of the errors observed during the go-around show an interaction between procedures and the design of the flight deck. They are not simply the product or either poor design or inadequate SOPs alone. For example, the responses to Question 8 (Table 2) suggested that on many occasions the thrust levers were not advanced manually when the auto-throttles became inoperative. There could be several reasons for this. For example, when a pilot decides to go-around, the first step is to press the TO/GA switches that will activate the correct mode of the autothrust system. However, to control thrust manually, pilots need to press the autothrust disengage switches. Since the TO/GA switches and autothrust disengage switches are next to one another, pilots may accidentally press the wrong switch, which would cause the thrust levers not to advance during the go-around. The following are some related incidents related to the sub-task of ‘Press TO/GA Switches’, (1) Pilot retried to push the TO/GA switch immediately, aircraft continued the go-around operation; (2) Pilot failed to press TO/GA switch, aircraft touched down on the runway due to no go-around thrust and cause hard landing incident; (3) Aircraft became unstable during approach due to unsuccessful go-around. Aircraft went into incorrect pitch attitude, either below normal path or climb to high pitch angle attitude; (4) Flight director (F/D) did not display go-around pitch because of autoflight display system (AFDS) was not triggered; it wouldn't provide correct pitch guidance because pitch mode annunciation did not change to go-around mode. However, the error data also show a failure to follow the required procedures in this instance in Question 23 ('failed to check go-around thrust setting') which should pick up the failure of the thrust levers to advance to the appropriate setting. Such confusion of system interface components is not new. Chapanis (1999) recalls his work in the early 1940's where he investigating the problem of pilots and co-pilots retracting the landing gear instead of the landing flaps after landing in the Boeing B-17. His investigations revealed that the toggle switches for the gear and the flaps were both identical and next to each other. He proposed coding solutions to the problem: separate the switches (spatial coding) and/or shape the switches to represent the part they control (shape coding) enabling the pilot to tell either by looking at or touching the switch what function it controlled. This was particularly important especially in a stressful situation (for example, after the stresses of a combat mission, or in this case, when performing a go-around).

Even experienced, well-trained and rested pilots using a well-designed flight deck interface will make errors in certain situations. As a result, CS 25.1302 requires that 'to the extent practicable, the installed equipment must enable the flight crew to manage errors resulting from flight crew interaction with the equipment that can be reasonably expected in service, assuming flight crews acting in good faith'. To comply with the requirement for error management (which is actually closely associated with procedural design) the flight deck interfaces are required to meet the following criteria. They should:

- Enable the flight crew to detect and/or recover from error; or
- Ensure that effects of flight crew errors on the aeroplane functions or capabilities are evident to the flight crew and continued safe flight and landing is possible; or
- Discourage flight crew errors by using switch guards, interlocks, confirmation actions, or similar means, or preclude the effects of errors through system logic and/or redundant, robust, or fault tolerant system design.

However, many of the procedural errors observed are not direct products of the flight deck interface. They are mostly errors of omission (a failure to do something). As examples, see Table 2, questions 5, 9, 15, 23, 30, etc. Some of these errors in the execution of the SOPs could be mitigated by changes to the aircraft's interfaces and warning systems (and indeed some are – for example a speed warning on the landing gear position – question 30; better interface design – question 39; better mode indication – question 46). These all address the first bullet point in the previous list, enabling the crew to detect or recover from error. However, many of the errors listed in Table 2 would not be mitigated by better design (for example questions 48 and 62). Simplifying or re-distributing the go-around procedures between the flight crew members may, however, have a beneficial effect as a result of either re-distributing workload (allowing more time for other tasks, such as monitoring the flight instruments) or reducing the number of procedural steps each pilot is required to execute (see Reason, 1988).

Both Reason (1990) and Dekker (2001) have proposed that human behavior is governed by the interplay between psychological and situational factors. The opportunities for error are created through a complex interaction between the aircraft flight deck interfaces; system design, the task; the procedures to be employed and the operating environment. It is naïve to assume that simply improving one component (such as the flight deck interfaces) will have a major effect in reducing error by considering it in isolation. With regard to the HET methodology employed (Marshall, Stanton, Young, Salmon, Harris, Demagalski, Waldmann and Dekker, 2003) prior this study it has always been used in a prospective manner to predict design induced error on the flight deck. This study also demonstrates that it can be used in the opposite manner, to structure data collection and provide an analysis taxonomy for the retrospective collection of error data. Looking ahead, the HET methodology can also be applied to prospectively test any revised SOPs to assess their error potential prior to instigating them, thereby avoiding the requirement for an error history to develop re-evaluation of the revised procedures is possible.

Conclusion

By the use of a scientific HTA approach to evaluate current SOPs design together with error analysis, interface layout and operating procedures, the flight safety will be enhanced and a user-friendly task environment can be achieved. This research utilized the HET error identification methodology (originally developed to assess design induced error as part of the compliance methodologies under AMC 25.1302) in a retrospective manner to assess error potential in existing SOPs when performing a go-around in a large commercial jet transport aircraft. Pilots committed three basic types of error with a high likelihood of occurrence during this maneuver: ‘Fail to execute’; ‘Task execution incomplete’; and ‘Task executed too late’. Many of these errors were dormant in the design of the procedures or resulted from an interaction between the procedures and some aspects of the flight deck design. It is hoped that the implementation of new human factors certification standards and analysis of associated procedures using a validated formal error prediction methodology will help to ensure that many of these potential errors will be eliminated in the future.

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