The Challenge of Aviation Emergency and Abnormal Situations

Barbara K. Burian
San Jose State University Foundation, San Jose, California

Immanuel Barshi and Key Dismukes
Ames Research Center, Moffett Field, California

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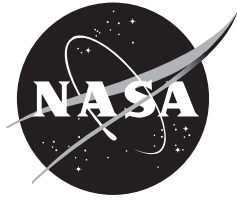- CONTRACTOR REPORT. Scientific and technical findings by NASA-sponsored contractors and grantees.

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Barbara K. Burian,
San Jose State University Foundation, San Jose, California

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The long flight had been uneventful until the aircraft was 240 miles from its destination—then everything seemed to go wrong at once. A small fire in the front galley could not be extinguished. Thick, black smoke billowed everywhere. Electrical systems began to fail and the glass cockpit displays flickered off and on randomly for over two minutes before going completely black. Despite the reduced visibility in the cockpit and the loss of the displays and systems, the crew completed a successful emergency landing and all passengers were evacuated without injury.

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The aircraft had just leveled off at its cruise altitude of 35,000 ft. when the master caution lit up. The first officer canceled the warning, scanned the overhead panel, and said, "We have a bleed failure." The captain told him to pull out the quick reference handbook and run the checklist. The first officer did so and the flight proceeded uneventfully.

****

Emergency and abnormal situations such as these occur aboard aircraft every day. They range from life-threatening and highly time-critical to mundane and relatively trivial. Crew responses to some situations are highly practiced during training. Other situations have never been practiced; they are so novel and unanticipated that no procedures have been developed to guide crews' responses. Fortunately, emergency and abnormal situations aboard aircraft rarely result in accidents. Yet even when the aircraft lands safely, shortcomings are often evident in checklists, procedures, training, crew coordination and response, and the way the situations are managed (Burian & Barshi, 2003); these shortcomings decrease the margin of safety.

What influences the manner in which an emergency or abnormal situation will be handled? The procedures and checklists crews use to respond to the situation are obviously central factors, but to answer this question fully, we must first examine pertinent issues within six, inter-related areas:

1. specific aspects of emergency or abnormal situations,
2. training for emergency and abnormal situations,
3. economic and regulatory pressures in aviation,
4. human performance capabilities and limitations under high workload and stress,
5. aircraft systems and automation, and
6. philosophies and policies within the aviation industry

After reviewing relevant issues in these areas, we discuss how these issues relate to the design and development of procedures and checklists and ultimately to crew response, coordination, and management of emergency and abnormal situations in aviation.

Specific Aspects of Emergency or Abnormal Situations

As illustrated by the two scenarios described at the beginning of this paper, emergency and abnormal situations vary along several dimensions. One important dimension is the level of risk and the threat to the crew's ability to maintain safe, controlled flight. The speed with which a crew must respond can also differ greatly across situations. Determining the degree of time criticality and level of threat is crucial and can be especially difficult when the cues presented to the crew are contradictory or ambiguous. Is the odd smell and small cloud that appears and then quickly disappears an indication of a fire, or merely commonplace output from the air conditioning system? The crew of Swissair 111 was unable to tell initially (Transportation Safety Board of Canada, 2003).

The degree of complexity, amount of increased workload, and degree to which a situation is novel or familiar are other dimensions along which these situations may vary. Many non-normal situations involve a single, well-isolated malfunction. However, even these situations often go beyond the scope of published procedures and checklists (Tremaud, 2002) and this challenges crews to determine the most appropriate responses. Situations involving multiple, and perhaps unrelated, system failures can be even more challenging. The ways in which these different dimensions come together in a single event greatly influence how the event is handled and its outcome.

It is also important to keep in mind that some situations may be so dire and time-critical or may unfold so quickly that all energy and attention must be given to controlling and landing the airplane with few resources to spare for even consulting a checklist. Such was the case on April 28, 1988, when an 18-foot section of fuselage separated from a B737-200 that was leveling off at 24,000 ft. (National Transportation Safety Board (NTSB), 1989). The crew of this flight estimate that they completed—largely from memory—all or significant parts of 17 different checklists in the 13 minutes it took for them to complete an emergency descent and landing. One of the crew from this flight reported that she only had time to refer to the emergency and abnormal checklists twice during the event—once to find the reference speed for a flaps 5 landing and then once more to complete the emergency evacuation after the landing had been completed (M. Tompkins, personal communication, April 25, 2003).

Training for Emergency and Abnormal Situations

Training is another important factor that significantly affects how an emergency or abnormal situation is handled. Training under Appendix H of FAR Part 121 is generally driven by the need to complete FAA mandated maneuvers. To maximize the amount of simulator training that can be completed in a limited amount of time, flight crews are typically presented with one malfunction after another. The crews are often not allowed to see a situation through to its completion before the simulator is reset and the next system malfunction is presented. Training under the Advanced Qualification Program (AQP) allows more flexibility but here too, time constraints and cost tend to restrict the range and depth of training for emergencies to only the most common malfunctions and procedures (Berman and Geven, 2005). Under both AQP and Part 121, crews rarely, if ever, face a situation in the simulator for which there is no checklist or procedure, even though this can be the case in actual emergencies (e.g., NTSB, 1990). Additionally, crews do not typically encounter a simulated event for which the checklist procedures do not work as expected—the light on the overhead panel goes out, the crossfeed opens, the engine fire is contained.[1]

Thus, the degree to which training truly reflects real life emergency and abnormal situations, with all of their real-world demands, is often limited. It is typically only in LOFT or LOE simulator sessions, if even then, that crews might be required to avoid other traffic or deal with deteriorating weather conditions while responding to an emergency or abnormal situation. It is also difficult, if not impossible, for instructors to play the parts of ATC, cabin crew, dispatchers, and maintenance personnel realistically, while also running the simulator and observing the crews' performance. Therefore, flight crews generally do not get to practice fully communicating and coordinating with all of these various parties while dealing with simulated emergency situations.

Despite these limitations, however, flight crews do benefit from the training for emergency and abnormal events that they currently receive. In a review of 107 reports involving emergency or abnormal situations filed with the Aviation Safety Reporting System (ASRS), we found 25 described situations that appear to have been handled quite well (Burian and Barshi, 2003).[2] For example, one pilot reported:

> All known procedures were followed and were adequate, and prior training for
> this situation is considered appropriate. The successful outcome of this emergency
> was due to the professional conduct of the entire crew. (ASRS Report, Accession #464512)

Nineteen of these 25 reports involved what might be called "textbook" abnormal or emergency situations—those situations that generally involve only a single system malfunction (as opposed to multiple problems), are highly trained and practiced in a simulator, and for which good checklists exist. The following excerpt illustrates such a situation:

> Our simulator training really paid off. This was my first engine shutdown in 20
> years of flying and it felt like I had done it a thousand times before! (ASRS Report,
> Accession #466167)

The encouraging news to be taken from these reports is that most flight crews appear to be able to respond well to textbook emergencies—handling of the emergency goes smoothly and as planned. The less encouraging news is that most of the ASRS reports we reviewed described events that were not textbook emergencies ($n = 85$), and the vast majority of these ($n = 79$) involved a problem with the way in which the flight crew or others responded to the situation, and/or with the materials and resources they were to use (see Table 1).

Table 1. Type of Emergency by How it was Managed

	Textbook Emergency	Non-Textbook Emergency	Totals
Handled Well	19	6	25
Not Handled Well	3	79	82
Totals	22	85	107

Economic and Regulatory Pressures

As mentioned above, regulatory and economic pressures significantly affect training for emergencies. To a large degree, regulatory requirements dictate what <u>is</u> trained and, in a vicious circle, economic pressures then dictate that what is not required by regulation is <u>not</u> trained. The latter occurs because the training "footprint," or time devoted to training, is regarded by most airlines as being fixed at a certain number of days per year, depending upon the type of the training (i.e., initial, recurrent, upgrade, etc.; personal communication, B. Berman, October 28, 2004). Pulling crews off the line to participate in training has tremendous economic impact on an airline and adding to the training footprint is avoided if at all possible.

Economic pressures can affect the handling of emergency or abnormal situations in other ways as well. For example, the materials made available to the crews to use when responding to these situations may be limited to only those deemed absolutely necessary. In one ASRS report, the pilot described having to land at an alternate airport and indicated relief that a landing at a different airport, over-flown earlier in the flight, had not been necessary. The pilot's company did not provide approach plates to that over-flown airport—approach plates were available only for those airports to which the company provided service (Burian & Barshi, 2003).

Because of economic concerns, flight crews may also feel some reluctance to divert to an alternate airport at all, or may divert to one where maintenance or other services are available rather than one that is closer, even when the level of threat may be high. Alternately, as illustrated in the following excerpt from an accident cockpit voice recording (CVR) transcript, it was the dispatcher who preferred that a diversion not be made (it is likely that the dispatcher did not understand the severity of the crew's flight control problems at the time):

> Dispatch: ...uh current San Francisco weather one eight zero at six, nine miles, few at fifteen hundred, broken twenty eight hundred, overcast thirty four hundred...uh, if uh you want to land at LA of course for safety reasons we will do that, uh, we'll uh tell you though that if we land in LA uh, we'll be looking at probably an hour to an hour and a half, we have a major flow program going right now...uh, that's for ATC back in San Francisco.

> Captain: Well, uh, yu, you eh, huh...boy you put me in a spot here, um...I really didn't want to hear about the flow being the reason you're calling us 'cause I'm concerned about overflying suitable airports. (NTSB, 2002)

Pilots' fears of reporting requirements or regulatory action may affect their decisions whether or not to declare an emergency with ATC (Barshi and Kowalski, 2003), and real or perceived pressures from companies can also have profound implications for how situations are handled.

> Had there been an actual engine fire, the fear of being punished by my employer for causing a customer delay may have raised safety concerns because of my reluctance to perform the required engine shutdown. (ASRS Report, Accession #465051)

Human Performance under High Stress and Workload

Most emergency and abnormal situations increase the workload on the flight deck. Sometimes this increase is transitory and limited, other times it is large and continues for the remainder of the flight. CVR transcripts of many accidents clearly show just how high crew workload can be during an emergency, especially one that is highly time-critical (e.g., NTSB, 1998). ASRS reports illustrate a similar increase in workload following an incident. The crew who filed the following report were dealing with an electrical failure during approach and landing:

> The…events took place over a time span of less than 4 minutes during a critical phase of flight…the events occurred simultaneously with radio transmissions, configuration changes, airspeed changes and constantly changing altitude… What we learned from this event is that running the emergency checklists may not be a classical situation where one has plenty of time for analysis and application of curative measures. (Accession #437830)

In high workload situations, crew errors and less-than-optimal responses often can be linked directly to inherent limitations in human cognitive processes. These are limitations all humans experience when faced with threat, are under stress, or are overloaded with essential tasks. Even simple things can be easily overlooked in non-normal situations as shown in the following excerpt from an ASRS report describing response to a pressurization problem:

> We did find communication difficult and the use of oxygen masks, intercom, trying to talk to ATC was a handful. At night made it that much harder to read/accomplish checklist items. Turning cockpit lights on sooner would have helped. (Accession #472755)

To someone who was not involved in the incident, it might seem obvious that cockpit lights should be turned on to allow the checklist items to be read more easily. Seemingly obvious actions are not so obvious, however, when one is overloaded with tasks in a stressful situation. Also, the effects of some stressful situations may not end once the situation has concluded. Some ASRS reports have described crews who were distracted or made errors during flights flown directly following the successful handling of some fairly serious emergency situations, because they were still thinking of or affected by the earlier events (Burian & Barshi, 2003).

Laboratory studies and a few studies of human performance in real-world situations reveal that cognitive performance is significantly compromised under stress. When experiencing stress, human attention narrows—a phenomenon referred to as tunneling (Bundesen, 1990). Tunneling restricts scanning the full range of environmental cues, causing the individual to focus narrowly on what are perceived to be the most salient or threatening cues (Wickens, 1984). Thus, under stress a pilot may focus on a single cockpit indicator and not notice other indications also relevant to their situation.

Additionally, working memory capacity and the length of time information can be held in working memory decreases under stress (Baddeley, 1986). Working memory is the crucial resource that allows individuals to hold and manipulate information cognitively. When working memory capacity is exceeded, individuals' ability to analyze situations and devise solutions is drastically impaired.

Therefore, when experiencing stress and high workload, crews are vulnerable to missing important cues related to their situation and are likely to experience difficulty pulling together disparate pieces of information and making sense of them. This is especially true when some of that information is incomplete, ambiguous, or contradictory. Pilots' problem-solving abilities may be impaired, and they will generally have difficulty performing complex mental calculations (Hendy, Farrell, & East, 2001), such as figuring landing distances on a wet runway with reduced flaps. In contrast, well-learned motor skills, such as those demonstrated by experienced pilots when operating flight controls, are quite robust and are much less affected by stress (Cohen & Weinstein, 1981).

Stress-induced limitations on human performance capabilities are often overlooked when considering how crews respond to emergency and abnormal situations. These limitations have important implications for the most effective designs of non-normal procedures and checklists and the design of training for non-normal situations. Berman, Dismukes, and Loukopoulos (2005) conducted an in-depth analysis of human cognitive performance issues in airline accidents. Their analysis demonstrates that normal cognitive limitations experienced by all humans when dealing with stress, concurrent task demands, and time pressure, underlie those errors made by crews when responding to emergency or abnormal situations. We return later to the implications that human performance limitations have for appropriate checklist design.

Aircraft Systems and Automation

The handling of emergency and abnormal situations can also be affected by various automated aircraft systems, flight-envelope protection, and warning systems. For example, in 1991, at Gottrora, Sweden, an MD-81 ingested ice during takeoff, which damaged the engine fan stages. The engines soon began surging and the automatic thrust restoration (ATR) feature on the aircraft increased the engine power without the pilots' knowledge. This increased the intensity of surging which, in turn, contributed to the failure of both engines. During the investigation of this accident it was discovered that the pilots and the air carrier were unaware that the ATR feature even existed on the aircraft (Martensson, 1995).

The numbers and types of warnings and warning systems aboard modern aircraft have greatly increased in recent years (Hawkins, 2001). The large number of warnings can result in information overload as crews attempt to makes sense of the various alerts and respond properly. This is especially true when multiple or contradictory warnings are presented in close succession or at the same time (Dorneich, et al., 2002). Additionally, the use of automation can be confusing for crews under normal operations, such as when the automation modes change without crew awareness (Sarter & Woods, 1995). Under non-normal conditions, problems with the use of automation can be exacerbated.

All of these issues were involved in 1996, when erroneous information was sent to a B757 captain's airspeed indicator and center autopilot by the left air data computer due to a blocked pitot tube. The autopilot responded to this erroneous information by commanding an 18-degree nose-up attitude, and the autothrottles responded by moving to a very low power setting. The crew was tremendously confused by contradictory overspeed and stall warnings and conflicting airspeed indications on the captain's, first officer's, and back-up displays. Although the crew agreed that the airspeed indicated on the back-up display was correct, they never attempted to fly the aircraft manually by reference to the back-up airspeed indicator. Instead, the first officer selected Altitude Hold on the mode control panel in an attempt to level off and stabilize the aircraft; however, the power setting was too low to maintain altitude and the aircraft crashed soon afterward (Walters & Sumwalt, 2000).

It can be difficult for flight crews to determine the most appropriate level of automation to use during emergency and abnormal situations. In some cases, automation can help reduce the workload that crews face as they both continue to fly the aircraft and respond to a problem. In other cases, as is evidenced in the accident just described, attempting to use some aspects of automation can impair a crew's ability to respond appropriately to an emergency or abnormal situation.

Additionally, pilots may become so accustomed to using automation to fly the aircraft that they may have trouble reverting to manual flying when required by an emergency, because of the degradation of unpracticed hand-flying skills. The following excerpt from an ASRS report describes such a situation:

> We were both very absorbed in flying the aircraft by hand as it's something we
> don't often do. In the process of working through the checklist and trying to get
> the EFIS back up, we ended up approximately 30 miles from XXX at FL 330.
> (Accession #468861).

Finally, crews have difficulty determining the correct response when they receive a warning that has a long-standing and known history of being unreliable, as the following ASRS report excerpt describes:

> The cargo compartment smoke alarm system has a maintenance history of false
> warnings. The frequency of these reports is going to lead some crews to ignore
> the warnings. (Accession #426361)

Indeed, Blake (2000) found that between 1994 and 1999, the ratio of false cargo smoke alarms to real cargo smoke alarms was 200 to 1. Making an unnecessary diversion and emergency landing when an alarm is false can have tremendous costs, as well as safety implications: crews attempting to land at unfamiliar airports (possibly without the proper approach plates); additional fuel costs; rescheduling of passengers, aircraft and crew; passengers' ill-will; and possible injuries during evacuation. However, not diverting, when a fire really is on board, can have even greater costs and safety ramifications (for a detailed discussion of false smoke alarms and the decision to divert in smoke, fire, and fumes events, see Burian, 2005).

Philosophies, Policies and Practices

Almost everyone in the industry—from the manufacturer to the simulator instructor to the vice president of flight operations to the pilot on the line—has definite ideas about how various emergency and abnormal situations should be managed. These ideas derive from individual experiences, beliefs, and perspectives related to various cost-benefit trade-offs. Typically, these ideas are not expressed in an explicit written philosophy or policy. And yet, they are evident in choices made throughout the aviation industry, choices such as: 1) the directions and information given to crews in checklists, 2) the types of scenarios emphasized during training, 3) the degree of emphasis placed on crews strictly completing all relevant non-normal checklists, and 4) how workload is distributed on the flight deck during an emergency. Related to these four choices:

1) Does a checklist direct the crew to complete a number of troubleshooting and diagnostic actions or does it direct them to stabilize the aircraft and continue flight without completing such steps?

2) During training, does a simulator instructor expect crews to don smoke masks and goggles and actually practice coordinating and initiating an evacuation with "cabin crew"? Or, are the pilots allowed to

respond to smoke and fire events in the simulator without using their masks and goggles and to only pretend that they have communicated and coordinated evacuations without ever really having done so?

3) Does a vice president of flight operations expect crews to complete all pertinent non-normal checklists for every non-normal situation or are crews expected to decide when or whether to complete any or all such checklists based upon the particulars of their given situation?

4) Does a captain choose to fly the aircraft and tell the first officer to complete the checklists during an emergency or does the captain complete the emergency checklists and have the first officer do the flying?

Clearly, such philosophies, policies, and practices have tremendous influence on how real-life emergency and abnormal situations are managed.

Design of Emergency and Abnormal Checklists and Procedures

Our review of issues within the six interrelated areas above provides a context for considering the design of checklists and procedures that guide and direct crew responses to emergency and abnormal situations.

It is, of course, impossible to develop procedures and checklists for every possible situation. If it were somehow possible, the quick reference handbook (QRH), where the paper versions of these checklists are typically compiled, would be so large that finding the proper checklists would be exceedingly difficult. Likewise, it would be difficult to remember that some of these procedures even existed, especially when workload and stress are high. It might also be impossible to write checklists for situations in which multiple, unrelated failures have occurred. Nonetheless, checklists and procedures should exist for emergency or abnormal situations that are common or can be reasonably predicted.

> There was no checklist in the aircraft or company publications that addressed a
> "landing gear cannot be retracted" scenario. Had there been one, the problem
> may have been easily rectified. (ASRS Report, Accession #468755)

Likewise, it is important that emergency and abnormal checklists and procedures exist for all phases of flight in which they might be needed. A checklist written to address a problem with hydraulics that occurs while an aircraft is in flight may not be appropriate to use to respond to a hydraulics problem that occurs during taxi (Burian & Barshi, 2003). The following excerpt from an ASRS report is another illustration of this problem:

> Accomplishing the [immediate action] item for cockpit/cabin smoke on the ground
> in the XXX aircraft induces the abnormal procedure of equipment overheat due to
> the step of the turning off left and right recirculation fans, the left recirculation fan
> being the primary equipment cooling on the ground. (ASRS Report, Accession #473359)

In this example, checklist actions that were appropriate for use during flight caused other abnormal conditions to occur when they were completed while the aircraft was on the ground.

Checklists and procedures must also include all of the necessary steps or information required to respond to an emergency or abnormal situation, and they must be consistent with guidance given to crews in other documents (Burian, Dismukes, & Barshi, 2003). For example, in an ASRS report a pilot described having consulted an abnormal/emergency checklist in response to an alert that occurred during taxi-out.

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The checklist identified the alert as a maintenance item with no flight-related consequences. However, the minimum equipment list (MEL) identified the same alert as a "no takeoff" item, which the crew did not discover until after taking off (Accession #471564). Maintaining consistency across different documents as well as updating and revising procedures in a timely manner can be especially challenging for many companies (Seamster & Kanki, 2002). It can also be difficult for companies to inform crews of revisions to procedures and to be sure that all pilots have received any necessary training on the new procedures by the time they go into effect.

> Briefing message—stabilizer [immediate action] items. This message has appeared on XXX flight plans for at least 5 months, if not 6 months. This is supposedly a critical emergency procedure that is to be committed to memory, yet there has been no change whatsoever to the XXX operating manual on the subject. No revisions. No change bulletin. Nothing. During the last 6 months, there have been several bulletins issued, yet nothing on this critical [immediate action item] change. Is the caution text supposed to be memorized? Is the note at the bottom supposed to be memorized? The lack of consistent publication of this [immediate action] item is only bound to cause problems for the airline and crews if there is an actual problem. (ASRS Report, Accession #478230)

Human performance capabilities and limitations under high stress and workload should also influence the design and content of emergency and abnormal checklists and procedures. Obviously, attention should be given to the wording, organization, and structure of these checklists to ensure that directions and information are complete, clear, and easy to follow and understand.

> I called for the QRH for the loss of hydraulic pressure. While the Captain read the QRH procedure, he was having some difficulty identifying the exact nature of the failure as well as the proper corrective action. While attempting to help the Captain with the QRH, I missed the 11,000 ft. crossing restriction…To prevent similar situations in the future, I feel that more time should be spent on QRH familiarization during training. The QRH [for this type of aircraft] is a bit confusing in places and actually contains mistakes. (ASRS Report, Accession #440922)

Checklists should be written so as to minimize the memory load on pilots. Also, narrowing of attention can be anticipated in stressful situations and counteracted by explicitly calling attention to issues that crews should consider in evaluating situations and selecting options.

However, there are a number of dilemmas with which checklist designers must grapple when considering human capabilities and limitations. Taking into account the degree of time criticality or level of threat a situation poses makes such dilemmas all the more complex. For example, some crew actions in response to highly time-critical situations may require their performance from memory, without reference to a printed checklist. However, under stress, normally reliable memory processes can fail. Which items on a checklist absolutely must be performed by memory, if any, and which should or could be performed by reference to a printed checklist? The research community has yet to provide checklist designers with definitive answers. Nonetheless, several airlines and some manufacturers are revising their procedures to minimize the use of memory checklist items (Berman and Geven, 2005).

Similarly, it might appear desirable for emergency checklists to be as short as possible, especially for those situations that are likely to be highly time-critical. A short checklist should increase the likelihood that crews will be able to complete all the essential actions while still devoting sufficient attention to flying the aircraft and executing an emergency landing, if necessary. However, we know from accident

and incident reports that crews may not easily remember the implications that a particular malfunction might have for their continued flight, particularly when under increased workload and stress (e.g., NTSB, 1996). For example, a seemingly simple hydraulics malfunction in flight might have consequences for setting flaps during approach and for braking and steering ability during rollout. During the increased workload of approach and landing, some of these consequences may be forgotten. Thus, on one hand, it is desirable to limit detail to keep an emergency checklist as short as possible, but, on the other hand, it is helpful to remind crews of information they may not easily recall. Unfortunately, no guidance or standards exist for checklist developers concerning the best balance between minimal length of checklists and providing sufficient information.

The need to navigate within a checklist, or to switch between non-normal and normal checklists, can also be problematic for crews. It is easy to lose one's place or jump to the wrong item or checklist when dealing with the many distractions, interruptions, and competing demands for attention that typically occur during emergency or abnormal situations. However, trying to integrate all the information needed from multiple checklists into a single checklist may make the procedure quite lengthy and difficult to follow.

Some types of electronic checklists may resolve a number of the difficulties and problems associated with paper checklists (Boorman, 2000). Sensors located through an aircraft can be linked to some types of electronic checklists, thus allowing the exact checklist for a particular condition to be displayed automatically. This may reduce the number of memory items needed as the time and effort involved in accessing an automatically displayed checklist is significantly reduced from that required to locate a particular paper checklist. Pilots can more easily keep track of which items have and have not been completed through the use of different colors on an electronic checklist, the use of markers, or by completed items disappearing from the checklist display. Linking within and between checklists can send pilots to the correct branch of items or proper additional checklists when jumping is required; this can greatly reduce the likelihood that interruptions and distractions will induce checklist navigation errors. Even with the advantages of electronic checklists, however, other obstacles remain, such as difficulty in locating a particular checklist that cannot be displayed automatically or limitations in the amount of information that can be displayed on a screen. Also, economic realities may constrain many companies from making a shift from paper to electronic checklists.

The focus and content of non-normal procedures are also influenced by the philosophies and beliefs held by the checklist developers and by economic concerns. For example, the inclusion of items directing the crew to "land at the nearest suitable airport" and where in a checklist (beginning, middle, or end) this item occurs may be influenced by concerns about unnecessary diversions and by expectations about the effectiveness of checklist actions and the likelihood of an accident (Burian, 2005). Similarly, philosophical differences are evident in the degree to which a checklist is oriented toward resolving a system malfunction versus managing the overall situation. Checklists oriented toward system malfunctions include steps to help identify the source of the problem and determine the best solution. In contrast, checklists oriented more toward situation management include fewer troubleshooting steps, if any, but do include steps such as notifying ATC, coordinating with cabin crew, or making a diversion and emergency landing.

The design and content of emergency and abnormal checklists are inextricably linked to how well they function and how pilots use them. At the International Symposium on Emergency and Abnormal Situations in Aviation, sponsored by the NASA Ames Research Center in June 2003, Captain Bill Jones, representing the Air Line Pilots Association International, likened an emergency or abnormal checklist to a parachute. To paraphrase, rarely does a military pilot pack his or her own parachute; instead, a

parachute packer is relied upon to do the job with precision and skill. The pilot fervently hopes to never need to use the parachute, but if it is required, it must work as intended and may be the only thing between the pilot and death. Likewise, emergency and abnormal checklists must be developed with precision and skill. Pilots hope that they are never needed, but when they are necessary, they must function as intended, and may be indispensable in helping to avert catastrophe.

Response to Emergency and Abnormal Situations

Clearly, many factors affect how crews respond to emergency and abnormal situations and how well those situations are resolved. In addition to the aspects already discussed, there are factors such as the personalities of the crew members, their levels of piloting experience, and any previous experiences with other emergency and abnormal situations they may have had. The handling of emergency and abnormal situations is also affected by the quality of communication and coordination among all who might be involved including flight crew, cabin crew, ATC, dispatchers, maintenance personnel, airport rescue and fire fighters, and MedLink physicians.

This paper provides an overview of many broad issues raised by non-normal situations, but does not address many details of these issues, nor does it provide solutions for the dilemmas identified. A major research effort is required to do that. To that end, a team of researchers in the Human Factors Research and Technology Division at NASA Ames Research Center has been working to better understand the issues in managing emergency and abnormal situations.

The overriding goal of the Emergency and Abnormal Situations (EAS) study[3] is to develop guidance for procedure and checklist development and certification, training, crew coordination, and situation management, drawing on knowledge of the operational environment, human performance limitations and capabilities, and cognitive vulnerabilities in real-world emergency and abnormal situations. Clearly, many issues are involved in this large domain, more than can be answered definitively by any one study—even one as large in scope as this one. However, by identifying latent vulnerabilities and delineating issues, the EAS study will lay a foundation for establishing best practices. In this way, we hope to help prevent the emergency and abnormal situations of tomorrow from becoming accidents.

Endnotes

[1] Restrictions in simulator design may limit, to some degree, the types of problems that can be presented to flight crews. For example, it may not be possible to program some simulators so that a light on the panel remains illuminated after a crew has correctly completed the pertinent checklist procedures.

[2] ASRS reports are filed voluntarily and are typically submitted when things have not gone well. Thus, the numbers presented in this paper related to these reports cannot be considered representative. They only indicate frequencies within the set of reports used in the study; they do not indicate rates of occurrence in aviation operations.

[3] The Emergency and Abnormal Situations (EAS) study is funded through the Training Element of NASA's Aviation Safety and Security Program, System Wide Accident Prevention Project. More information about EAS can be found at http://human-factors.arc.nasa.gov/eas.

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13. ABSTRACT *(Maximum 200 words)* Emergency and abnormal situations occur on flights everyday around the world. They range from minor situations readily managed to extremely serious and highly time-critical situations that deeply challenge the skills of even the most effective crews. How well crews respond to these situations is a function of several interacting sets of issues: (1) the design of non-normal procedures and checklists, (2) design of aircraft systems and automation, (3) specific aspects of the non-normal situation, such as time criticality and complexity of the situation, (4) human performance capabilities and cognitive limitations under high workload and stress, (5) design of training for non-normal situations, (6) philosophies, policies and practices within the industry, and (7) economic and regulatory constraints. Researchers and pilots working on NASA's Emergency and Abnormal Situations project are addressing these issues in a long-range study. In this paper we discuss these issues and illustrate them with examples from recent incidents and accidents.

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