RESEARCH BRIEF

Research Request:

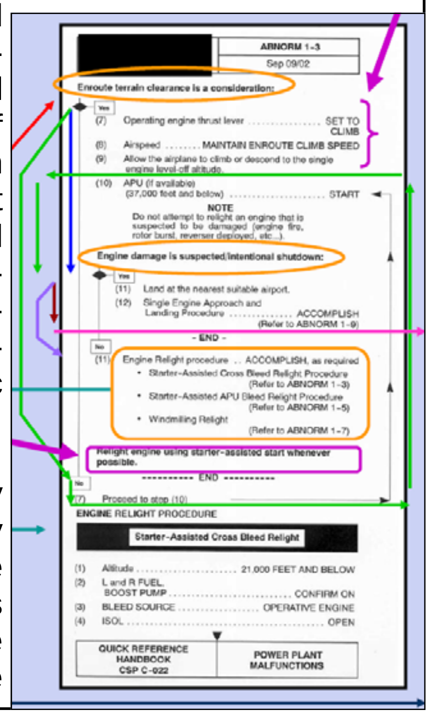
Cockpit Checklist Fundamentals

Research Response:

The following research report is a summary of information gathered relating to cockpit checklist usage philosophy, construction, and industry practices. Critical points of consideration are highlighted from industry research completed by NASA and the FAA. A sampling of current operator procedures were also reviewed to provide additional insight. Below is a synopsis of the data gathered, followed by pertinent excerpts from multiple sources describing checklist usage influences and techniques.

Synopsis

The first point of consideration with respect to checklist usage is the importance of maintaining control of the aircraft at all times, a point stressed repeatedly in NASA research as well as manufacturer and operator procedures. The reality that there is no such thing as a perfect checklist is also emphasized throughout all existing research. One airline policy illustrates the point by stating, “The procedures in this manual cannot adequately address every possible combination of failures, emergency situations or flight conditions. If an emergency arises for which these procedures are not adequate or do not apply, the crew’s best judgment and experience should prevail.” The quantity of potential variables in an aircraft emergency situation is too great to remain fixed to a single, usable checklist. Therefore checklists are designed into segments addressing a specific procedure, aircraft emergency evacuation for example.



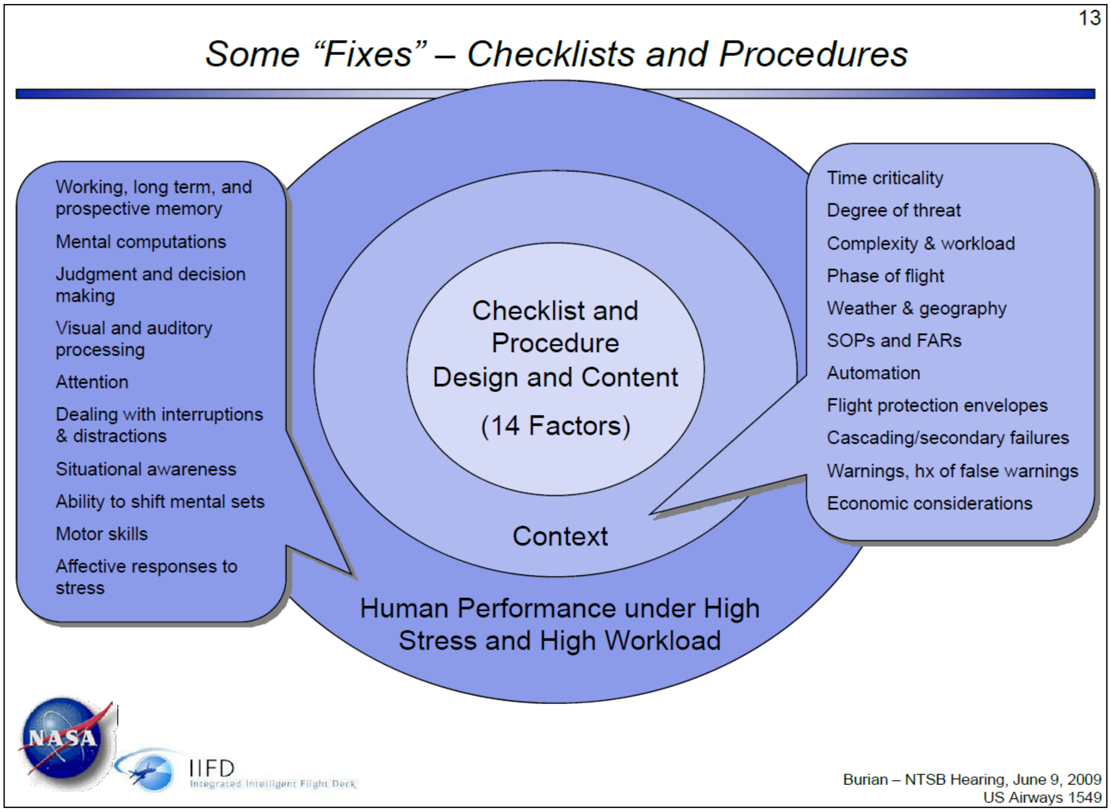
Checklist usage philosophy has been trending strongly towards a reduction in the use of mandatory memory items for crewmembers. Available references indicate the presence of memory items is typically limited to 1-3 items per emergency or abnormal situation. Memory items are not recommended for normal operating checklists. The most common emergencies warranting memory items are: engine fire/failure/severe damage, rapid depressurization, smoke in cabin/cockpit, and runaway pitch/trim and roll trim. Upon completion of the memory items, the remaining steps for each of these events require the use of a Quick Reference Handbook (QRH) or Emergency and Abnormal Checklist (EAC).

PRISM research indicates currently designed action responses to emergency events begin with the immediate use of a QRH. For example, in the case of unplanned evacuation procedures, crew members are expected to be completely familiar with their assigned duties, but not rely on memory items. It is noteworthy to mention some airlines specifically have ground evacuation procedures posted in a designated area of the cockpit. Because of the decreased emphasis on memory items, some airlines use tests to evaluate a crewmember's efficiency locating checklist items during given emergency situations. Crewmembers are expected to have detailed knowledge of checklist items during oral examinations by displaying a thorough understanding of what is being accomplished and the effect it has on the aircraft. During training crews learn how to access each chapter and checklist and become familiar with all the procedures contained in the QRH.

The trend in memory item reduction is grounded in research that points to the numerous drawbacks associated with relying purely upon human memory. High stress and heavy workload situations significantly degrade the mind's capability to recall information and causes "tunneling". Tunneling, or fixation, occurs because humans tend to focus on the particular threat occurring at the moment, and ignore others perceived subconsciously as less significant. This concept was first borne out in a landmark accident that occurred in 1972, when Eastern Airlines Flight 401 impacted the everglades in a CFIT event. The entire crew of three focused on troubleshooting a landing gear problem, and failed to notice the autopilot disconnected.

Although the elimination of memory items is commonplace, some emergencies warrant immediate action due to their critical nature. Current research does not provide definitive guidance on exactly which items should be produced from memory; however, it is evident only serious, time critical events currently have memory items. The industry trend of reducing memory items is as a result of lessons learned from accidents and validation thorough human factors research.

Methodology for checklist execution varies and depends upon the phase of flight. For example, a preflight checklist is typically accomplished via a "do-list" (or do-verify) method. However, critical phases of flight typically call for a "challenge and reply" (or challenge-do-verify) method. Another method of checklist completion is the "flow-check", in which checklist items are completed by memory or "flow" and then verified by using the checklist. This is a very common method, across numerous phases of flight. Furthermore, many airlines use a "silent" checklist procedure for the after-takeoff and after landing phases of flight, because they are determined to be less critical and can be efficiently and effectively accomplished by one crewmember. For example, the captain would call for the after landing checklist, the first officer will perform it and provide a verbal response confirming its completion. Phases of a flight call for different methods of checklist execution based on significance of potential error. Additionally, regardless of the chosen execution method, errors may still occur. Current FAA regulations specify most operators use the “do-verify” method for normal checklists, and a



“challenge-do-verify” method for abnormal and emergency checklists. The FAA’s current stance for commercial operators (91K, 121, 125, 135) is, “POIs should not approve or accept the do-verify method for non-normal or emergency procedures unless the operator can provide substantial evidence that the method is effective for this application” (8900.1 Volume 3, Chapter 32, Section 12).

Even if a policy demands using checklists for all cockpit actions, flight crews can miss required items. The more predictable an action is, the more likely an error will occur. Routinely performing the same event, in the same order, opens the possibility for crewmembers to be more passive in the checklist process. Such was the case in the accident of Delta Airlines Flight 1141 in 1988. The flight crew did not extend the airplane’s flaps or slats for takeoff; however, the proper checklist callouts were made. The investigators reported “...the time between the checklist challenge and responses was less that one second, with little time to accomplish actions required to satisfy the proper response.” A classic example of going through the motions. Fatigue and other physiological factors can further enhance this error potential. This is exemplified one NASA report, “Often, the pilot flying would answer with the proper response immediately when he/she heard the challenge call from the pilot not flying, not verifying that the item called was set accordingly. This was evident in high workload phases of flight such as during the approach for landing."

Research Excerpts

The Challenge of Aviation Emergency and Abnormal Situations (June 2005)

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- 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.
  - 4/28/1988- An 18-foot section of fuselage separated from a B737-200 that was leveling off at 24,000 ft. 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.
- 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, B.; and Geven, R.: The Current State of Pilot Training for Emergency and Abnormal Situations. Manuscript in preparation, 2005.).
- Unfortunately, no guidance or standards exist for checklist developers concerning the best balance between minimal length of checklists and providing sufficient information.
- 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.
- 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.

- 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.

Aeronautical Emergency and Abnormal Checklists: Expectations and Realities (2006)

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- Analyses have led to what some may consider to be a shocking conclusion: there is no such thing as "a perfect checklist."

- Expectation: Crews will correctly interpret the cues available to them and will know which checklist to accomplish for their situation.
- Reality: Unfortunately, it is not uncommon for crews to misconstrue abnormal condition cues.
  - For example, an alert message indicating low oil pressure can easily lead crews into accomplishing a Low Oil Pressure checklist when in fact, an engine has ceased to operate, causing the oil pressure to be low, and the Loss of an Engine checklist is the proper one to complete.

- Expectation: A checklist will exist for the situation encountered.
- Reality: In truth, it is not possible for checklist designers to anticipate every conceivable failure or malfunction that might occur on an aircraft.
  - In March of 2000, two alerts were displayed in the cockpit of a B737-700 as it climbed through 1000 feet after takeoff. The alerts indicated that the airspeed and altitude displayed on the captain's panel did not agree with those values displayed on the first officer's panel. The climb and cruise pages on the flight management computer display lacked any data output and the progress page showed no distances or times between route segments. As the situation unfolded a variety of other anomalies were noted: the captain's altimeter indicated a climb but lagged behind the first officer's altimeter, the wind readout arrows on the captain's and first officer's displays differed by almost 180o, and the captain's altimeter and airspeed indicators finally disappeared from the cockpit displays all together. The captain consulted emergency and abnormal checklists but could find no checklist that pertained to their situation. Fortunately, this flight occurred during good weather conditions and was able to return to the airport from which they had just departed. Upon landing, maintenance personnel discovered that a vane that protrudes from the outside of the aircraft, which pro-

vides airspeed and altitude information to the computers for the captain's cockpit displays, was badly damaged.

- Expectation: Crews will remember the correct title of the checklist they wish to perform and will know how to locate it.
- Reality: Flight crews often do not recall the titles given to a specific checklist, which causes a delay in identifying it in a table of contents, index, or electronic checklist menu. Additionally, checklists are not always located where flight crews can find them easily.
  - In 1980, the crew of Saudi Arabian Airlines flight 163 unsuccessfully searched for a cargo fire checklist for several minutes in the "Abnormal" section of their Quick Reference Handbook (QRH – a manual comprised of checklists). The investigation into this accident revealed that the checklist the crew was looking for but never found was filed in the "Emergency" section of the QRH instead, and all 301 people on board perished (Flight Safety Focus, 1985).

- Expectation: Crews will access and use available emergency and abnormal checklists.
- Reality: Most often, when crews are faced with an emergency or abnormal situation, they will try to locate and complete the checklists appropriate for their condition.
  - In 1988, as a B737-200 was leveling off at 24,000 ft., an 18-foot section of fuselage separated from the aircraft. (National Transportation Safety Board (NTSB), 1989). In the 13 minutes that it took the flight crew to perform an emergency descent and landing, they completed all or significant parts of 17 different checklists—largely from memory. During the descent, the crew only had time to consult the emergency and abnormal checklists once, to find the reference speed for a landing with reduced flaps (M. Tompkins, personal communication, April 25, 2003).

- Some situations unfold so quickly or are so time-critical that all the crews' attention must be devoted to controlling and landing the airplane with little or no time to spare for consulting an emergency checklist. There may also be rare occasions in which the emergency situation itself renders available checklists inaccessible to the crew.
  - For example, in 1989, the flight crew of United 811 experienced an explosive decompression over the ocean at approximately 22,500 thousand feet after departing Honolulu, Hawaii

- Expectation: Adequate time will be available to complete all actions included in a checklist.
- Reality: Emergencies are often complicated; therefore, associated checklist completion may take much longer than anticipated.
  - The Transportation Safety Board (TSB) of Canada estimated that the in-flight smoke and fire checklists used by the flight crew of Swissair 111 in 1998, could have taken as much as 30 minutes or more to accomplish. The aircraft crashed into the ocean approximately 20 minutes after the crew first detected an unusual odor on the flight deck (TSB of Canada, 2003).

- Expectation: Crews' cognitive capabilities will be unimpaired during emergency and abnormal conditions and they will be able to perform complex mental calculations without difficulty.

- Reality: Au (2005) studied the ability of pilots to accurately recall and perform items from emergency and abnormal checklists that must be accomplished without reference to a printed checklist (i.e., memory items). He found that pilots committed numerous errors in recalling the memory items correctly even during conditions that were not stressful. Similarly, during simulator training sessions several crews were observed having difficulty applying multipliers to landing distances as required when experiencing various system failures. Cognitive performance limitations under high workload and stress are often not considered when developers design emergency and abnormal checklists. Tunneling and fixation of attention, restrictions in working memory, difficulty in shifting mental sets, and other cognitive processing difficulties can commonly occur with the high stress and workload of emergency and abnormal situations. Much can be done with the design of checklists to accommodate these limitations. For example, a few air carriers have eliminated the need for memory items by printing those steps on a card that can be readily accessed by flight crews. Once these steps have been completed by referencing the card, any remaining checklist items are then located in the QRH for completion.
- Conclusion: Designing an emergency or abnormal checklist that is clear, complete, easy to execute, and that supports flexible crew response to multiple scenarios is very difficult, and little guidance exists for checklist developers about how to design the best product possible.

Design Guidance for Emergency and Abnormal Checklists in Aviation (2006)

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- It can be extremely challenging to develop effective checklists for use by flight crews during emergency and abnormal situations. Relatively little guidance is available from the human factors community and developers generally use aircraft system requirements, historical precedent, and their own best judgment to guide their design decisions.
- Checklist length and workload are especially important emergency and abnormal checklist design features. Checklist length pertains to both the physical length of a checklist and the amount of time it takes to read checklist information and complete checklist actions (i.e., the "timing" length or duration).
- Checklists should also be designed to conform with air carrier standard operating procedures (SOPs) and aviation regulations. However, crews should be reminded in checklists that SOPs and regulations can and should be violated to the extent necessary if the safety of the aircraft and crew warrants doing so in an emergency.
- Other operational requirements, such as those related to different phases of flight, dealing with adverse weather (including icing conditions), and flying over mountainous terrain or oceans, comprise another set of external checklist design factors influencing emergency and abnormal checklist design. The failure of an engine dur-

ing flight has different implications for the crew when the aircraft is at cruise altitude over the Rocky Mountains as compared to when the aircraft is at cruise altitude over Kansas. Both kinds of implications need to be accounted for in the checklist for this condition. Similarly, pilots have encountered difficulties when checklists they were to use in response to a hydraulic failure were written for such failures in flight rather than when the hydraulics failed while the aircraft was taxiing on the ground (Aviation Safety Reporting System, 2001). Checklist designers need to make sure that actions are included in a checklist for all phases of flight during which the checklist might be needed.

- High workload and stress have negative effects on a human's ability to hold and manipulate information in working memory, perform mental calculations, and to shift mental sets when performing different tasks concurrently (Burian, Barshi, & Dismukes, 2005). And yet, it is not uncommon to find checklists that require crews to perform multiple steps from memory and to mentally perform complex mathematical calculations in response to system malfunctions (Burian, 2005).
- Furthermore, when under stress, humans have a natural tendency to fixate on cues that are associated with a particular threat, such as a fuel gage with a rapidly decreasing quantity indicated. This fixation or tunneling can cause crews to miss other cues and information that has importance for their emergency or abnormal situation, and to lose perspective on the status of the overall situation, i.e., situation awareness (Burian, Barshi, & Dismukes, 2005).
- The final set of external checklist design factors pertains to the various philosophies and policies held by those who develop these checklists, flight crew training, and economic constraints. For example, one US air carrier has adopted the "get in-stay in" philosophy regarding emergency and abnormal checklist use. This means that all information the crew might need to see a situation through to its completion is included with or integrated into a single emergency checklist.
- Overall Purpose of Emergency and Abnormal Checklists. The final major aspect of emergency and abnormal checklist design that comprises the model pertains to the degree to which a checklist serves its overall purpose: to guide and direct flight crew response to an emergency or abnormal situation. For example, does a checklist assist crews to manage and distribute workload, maintain awareness of the overall situation, make appropriate decisions accordingly, and facilitate communication and coordination with other parties such as ATC and cabin crew? Checklist actions should also be evaluated regarding the degree to which they are consistent with and complement any checklists or procedures used by cabin crews when responding to the same emergency or abnormal situation.

Cockpit Checklists: Concepts, Design, and Use (1993)

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Earl L. Wiener
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- We believe that normal checklists are intended to achieve the following objectives:
  - Provide a standard foundation for verifying aircraft configuration that will attempt

to defeat any reduction in the flight crew's psychological and physical condition.

- Provide a sequential framework to meet internal and external cockpit operational requirements.
- Allow mutual supervision (cross checking) among crew members.
- Dictate the duties of each crew member in order to facilitate optimum crew coordination as well as logical distribution of cockpit workload.
- Enhance a team concept for configuring the plane by keeping all crew members “in the loop.”
- Serve as a quality control tool by flight management and government regulators over the flight crews.

The Method

- There are two dominant methods of conducting (“running”) a checklist—the do-list and the challenge-response. Each is the product of a different operational philosophy.
- Do-list. This method can be better termed “call-do-response.” The checklist itself is used to lead and direct the pilot in configuring the aircraft, using a step-by-step “cookbook” approach. The setup redundancy is eliminated here, and therefore, a skipped item can easily pass unnoticed once the sequence is interrupted.
- Challenge-response. In this method, which can be more accurately termed “challenge verification- response,” the checklist is a backup procedure. First, the pilots configure the plane according to memory. Only then, the pilots use the checklist to verify that all the items listed on the checklist have been correctly accomplished. This is the most common checklist method used today by commercial operators.

SUMMARY OF OBSERVATIONS

- The purpose of the field observations was to study and comprehend the system in its purest form, i.e., during routine airline cockpit operations. Observations of 42 flight crews gave us an insight into the process, the techniques, and the potential problems associated with checklist usage in the operational setting.
- Memory-guided checklist. There is temptation, on the part of experienced pilots, to memorize a checklist and avoid the burden of reading it from the card. In several instances during night operation, we observed that the checklist card was drawn out of its slot (above the glare shield), but no light was turned on to allow reading. Consequently, the checklist was performed from memory. A similar habit was observed in both day and night operation: the pilot would stretch his hand out and touch the checklist card situated on the glare shield, but would not draw the checklist out of its slot. It is interesting to note here that pilots had a habit pattern of associating a motor action (reaching for the checklist card) with the checklist procedure.
- Verification. In some cockpits, the task of verification was left only to the pilot responding to the checklist. The pilot making the challenge calls read the checklist items but did not move his eyes away from the list to cross-check his partner. Therefore, the mutual redundancy embedded in the checklist procedure was not utilized. Often, the pilot flying would answer with the proper response immediately

when he/she heard the challenge call from the pilot not flying, not verifying that the item called was set accordingly. This was evident in high workload phases of flight such as during the approach for landing. In this case, the pilot must rely on his memory to judge whether checklist items were set correctly. The setup redundancy embedded in the procedure was lost.

- Several pilots who were interviewed stated that they have their own checklist procedure which they perform from memory just prior to takeoff to assure themselves that the plane is configured correctly. They viewed this as an additional safeguard against a poorly conducted checklist procedure. We found similar techniques during our observations. These memory techniques have some inherent hazards:
  - They are dependent on the availability of time after the quick completion of the checklist.
  - They are vulnerable to distractions such as air traffic control (ATC) communications, outside scan, starting an engine during TAXI segment, and more.
  - They are based on memory, and not on a step-by-step challenge-and-response procedure.
- “Short-cutting” the checklist. Several pilots deviated from the challenge-and-response method to a much faster routine, calling several challenge items together in one “chunk,” while the other pilot would reply with a series of chunked responses. This technique undermines the concept behind the step-by-step challenge-and-response method. It is also dependent on the pilot’s short-term and long-term memory as to the completion and order of checklist items. This dependency, in fact, is exactly what the checklist procedure is supposed to prevent. Interestingly, Swain and Guttman (1983) found the same routine employed by nuclear power plant operators. They defined this non-standard technique as “performing several steps and then checking them off all at once on the checklist” (chap. 16, p. 2).
- When the normal checklists were lengthy, there was a tendency to perform the items while reading the checklist as a “do-list” in an effort to overcome a long and time consuming procedure. However, by doing so, the crew sacrificed the setup redundancy embedded in the checklist. While this short-cutting technique pertained to non-critical configuration items, it can easily “migrate” to those items that are crucial to the safety of the flight.
- Many pilots interviewed by the authors stated that at one time or another they had seen a checklist item in the improper status, yet they perceived it as being in the correct status and replied accordingly. This phenomenon figured prominently in the investigation of the Delta Air Lines Flight 1141 accident in which the flight crew did not extend the airplane’s flaps or slats for takeoff (NTSB, 1989). Yet, the proper checklist callouts for the takeoff flap handle position, flap indicator dial, and slat extension light were made (they were recorded on the cockpit voice recorder). During the analysis of this accident, the NTSB investigators measured the recorded time delay between the second officer’s challenge (“flaps”) and the first officer reply (“fifteen, fifteen, green light”). The investigators reported that “...the time between the checklist challenge and responses was less that one second, with little time to accomplish actions required to satisfy the proper response” (NTSB, 1989, p. 61).

GUIDELINES FOR CHECKLIST DESIGN AND USAGE

- Based on this study we propose a list of guidelines for designing and using flight-deck checklists. These considerations are not specifications, and some, when applied individually, may conflict with others. Therefore, each should be carefully evaluated for its relevance to operational constraints. We feel, however, that these guidelines can also apply, with some adjustments, to other industries.
  - Checklist responses should portray the desired status or the value of the item being considered, not just "checked" or "set."
  - The use of hands and fingers to touch, or point to, appropriate controls, switches, and displays while conducting the checklist is recommended.
  - A long checklist should be subdivided to smaller task-checklists or chunks that can be associated with systems and functions within the cockpit.
  - Sequencing of checklist items should follow the "geographical" organization of the items in the cockpit, and be performed in a logical flow.
  - Checklist items should be sequenced in parallel with internal and external activities that require input from out-of-cockpit agents such as cabin crew, ground crew, fuelers, and gate agents. We note here that this guideline could conflict with No.4.
  - The most critical items on the task-checklist should be listed as close as possible to the beginning of the task-checklist, in order to increase the likelihood of completing the item before interruptions may occur. We note that this guideline could conflict with Nos. 4 and 5 above. In most cases where this occurs, this guideline (No. 6) should take precedence.
  - Critical checklist items such as flaps/slats, trim setting, etc., that might need to be reset due to new information (arriving after their initial positioning), should be duplicated on the ground phase checklists.
  - The completion call of a task-checklist should be written as the last item on the checklist, allowing all crew members to move mentally from the checklist to other activities with the assurance that the task-checklist has been completed.
  - Critical checklists, such as the TAXI checklist, should be completed early in the ground phase in order to decouple them from the takeoff segment.
  - Checklists should be designed in such a way that their execution will not be tightly coupled with other tasks. Every effort should be made to provide buffers for recovery from failure and a way to "take up the slack" if checklist completion does not keep pace with the external and internal activities.
  - Flight crews should be made aware that the checklist procedure is highly susceptible to production pressures. These pressures set the stage for errors by possibly encouraging substandard performance, and may lead some to relegate checklist procedures to a second level of importance, or not use them at all.

NTSB REPORT (2009)

Loss of Thrust in Both Engines After Encountering a Flock of
Birds and Subsequent Ditching on the Hudson River
US Airways Flight 1549 Airbus A320-214, N106US
Weehawken, New Jersey January 15, 2009

- Because attention narrows during emergency and abnormal situations due to increased workload and stress, checklists and procedures should minimize the memory load on flight crews and that some airlines and manufacturers have reduced the number of memory items.
- Accidents and incidents have shown that pilots can become so fixated on an emergency or abnormal situation that routine items (for example, configuring for landing) are overlooked.
- Therefore, checklists should not be overly cumbersome but should still contain all of the critical items that must be accomplished and should not require pilots to rely heavily on memory items. Shorter checklists increase the likelihood that pilots can complete all pertinent items related to the emergency or abnormal situation without distracting them from other cockpit duties. Unfortunately, many checklists are designed such that pilots become "stuck" in the checklist and, therefore, complete procedures that may not be appropriate or practical for a given emergency (such as trying to restart engines). According to a NASA representative's public hearing testimony, to minimize the risk of becoming stuck in an inapplicable portion of a checklist, checklists can be designed to give pilots "opt out" points or "gates," which are conditional if-then statements. (For example, "if the aircraft is below 3,000 feet, then go to step 27.") Incorporating such points into checklists will encourage pilots to re-evaluate the situation and determine whether they are using the appropriate checklist or portion of a checklist and whether the task focus should be shifted.
- The NTSB notes that this is not the first accident in which checklist design was recognized as a safety issue. For example, after the September 2, 1998, Swissair flight 111 accident in which a seemingly innocuous smoke event evolved, after several minutes, into a sudden and severe in-flight fire, the Transportation Safety Board of Canada determined that the checklist that the flight crew attempted to use would have taken about 20 to 30 minutes to complete.137 However, only 20 minutes elapsed from the time that the on-board fire was detected until the crash occurred
- Therefore, the NTSB recommends that the FAA develop and validate comprehensive guidelines for emergency and abnormal checklist design and development. The guidelines should consider the order of critical items in the checklist (for example, starting the APU), the use of opt outs or gates to minimize the risk of flight crewmembers becoming stuck in an inappropriate checklist or portion of a checklist, the length of the checklist, the level of detail in the checklist, the time needed to complete the checklist, and the mental workload of the flight crew.

FAA: Human Performance Considerations in the Use and Design of Aircraft Checklist (1995)

- Checklists are of no value if the pilot is not committed to its use. Without discipline and dedication to using the checklist at the appropriate times, the odds are on the side of error. Crewmembers who fail to take the checklist seriously become complacent and the only thing they can rely on is memory and the fact that not all errors resulting from poor checklist discipline result in accidents. It is an important aid in helping the crew to remain focused to the task at hand by eliminating guesswork that often accompanies periods when crew attention is divided especially during periods of stress or fatigue. The checklist is an important and necessary backup for the pilot and crew.

- While the NTSB and ASRS reports suggest that flight crews need to place more emphasis on checklist usage, they also suggest other areas that require attention with due consideration for human factors. Such factors as fatigue, crew reliance on working or short term memory, crew interruption or distraction, and complacency or failure to visually verify aircraft configuration, are factors that may affect crew performance and have the potential to cause checklist error.

Working Memory

- Research indicates that the capacity of working memory is limited. Unaided, working memory can retain approximately seven (plus or minus two) unrelated items. Unless actively rehearsed, or aided by some external form of reminder or memory jogger, information contained in the working memory will generally be forgotten in 10 to 20 seconds. Depending on how incoming information is received, (tactile, visual, etc.) some information may be retained for a longer duration than other information.
- Interference is the principal cause of loss of information from the working memory. Interference can be defined as noise, incoming verbal messages or other information, e.g., communication with ATC or company sources, and an interruption and/or distraction. Due to interference, information that has been stored in the working memory either becomes forgotten or is replaced by new information. In addition, an individual's emotional state can negatively impact the ability to retain information. Many of the stress related emotions, e.g., panic, anxiety, confusion, or frustration, can negatively impact an individual's ability to maintain information in the short term memory. Because of working memory's short duration and limited capacity, pilots should develop their own system of memory joggers.
- It is recommended that anytime the crew is not clear as to their progress through the checklist the captain or pilot-in-command should, without hesitation, direct that the appropriate section of the checklist be re-accomplished from the beginning.
- Of equal importance and directly related to "cueing" is the timing of tasks performed on the flight deck. Researchers have referred to this period as the "Window of Opportunity", indicating the time period which a task can take place. For example, the window of opportunity for the DESCENT checklist may be defined as the time period between leaving the cruise altitude and arriving at 10,000 feet, allowing for variations based on vectors, restrictions, etc.

Silent Checklists

- Although small in number, several ASRS reports address the use of silent checklist procedures in which the pilot-not-flying (PNF) performed the checklist improperly or not at all.
- Silent checklists quite often are performed during heavy workload periods, e.g.,

during the after takeoff climb or during the after landing taxi-in. The use of silent checklist procedures has both advantages and disadvantages. The procedure when performed by the PNF reduces the amount of activity on the flight deck that the pilot-flying (PF) normally has to contend with and allows the pilot to concentrate more on flying the aircraft. Conversely, silent checklists do not provide for the cross check and monitor that should take place between crewmembers.

- In all cases, the crewmember calling the checklist, normally the PNF, should announce when all checklist items have been accomplished, e.g., "_______ Checklist complete." This informs other crewmembers that the task has been completed and provides the opportunity for them to perform a visual cross check.

Personalizing the Checklist

- Clear and concise communication in the cockpit is essential and reduces the chance of mis-communication between crewmembers. Every effort should be made to avoid substitution of self devised terms for checklist terms, e.g., calling for "Boost Pumps" when the checklist calls for "Fuel Pumps". The use of non-standard terms can be the cause for another crewmember's failure to detect a checklist error or, may cause another crewmember to not be able to follow the checklist sequence, or cause the checklist callout to be confused with other intra-cockpit communication.
- Such communication circumvents standardization and has been linked in studies as one of the behavioral attributes frequently found in association with information transfer problems.
- Strict use of the terms presented on the checklist reduces the chance for misunderstanding of the task to be performed and its status. Any attempt on the part of a crewmember to personalize the checklist erodes the safety margin established by the procedure.

CHECKLIST DESIGN CONSIDERATIONS

- Although it may be published in a manual, a checklist is designed for independent use so that the user does not have to reference a manual. Checklists are used to ensure that a particular series of specified actions or procedures are accomplished in correct sequence and to verify that the correct configuration has been established in specified phases of flight.
- If the its design presents the crew with a challenge or obstacle to complete, and becomes work intensive, the checklist can set the stage for error. When the checklist is lengthy, there is a tendency to perform the items while reading the checklist in an effort to overcome a time-consuming procedure. This method of short-cutting can cause the crew to lose the redundancy imbedded in the checklist. While such short -cutting may not always be related to configuration items, it can easily migrate to items that are critical to the safe operation of the aircraft.
- Other pilots may deviate from accepted methods (primarily challenge-and-response) of conducting checklists to what they consider a faster method. A technique observed by researchers has been for one pilot to call several challenge items together while the other pilot replies with a series of chunked responses. This

undermines the concept behind the step-by-step process set in the challenge-response method. This method is dependent on the pilot's short and long term memory as to the order and completion of the checklist; this is exactly what the checklist is supposed to prevent.

- In addition, if the established flow patterns are not logical and the checklist itself correct and consistent with procedures prescribed in related manuals, the probability is very high that the crew may, when pressed for time, revert to their own methods, cut corners, omit items, or even worse, ignore the checklist entirely.
- A new checklist design alone will not eliminate the problems associated with checklist error. Proper consideration must be given to the task, the environment in which it is conducted, crew workload at the time the action is called for, and human performance capability. When all of these factors are properly taken into consideration along with the technical and operational issues, the checklist can be an effective tool and, under certain conditions, can reduce pilot workload.
- When commissions of error in checklist usage are detected, it can be of value for the company and the crew to analyze the error. If the error rate is to be reduced, it is important to identify the causal or contributing factors that led to the commission of the error. It is appropriate to review the crew's activities at the time the error was committed. In addition, review the company policies and/or procedures requiring the task, and the overall design and placement of items in the checklist. The objective of the review would be to reevaluate the procedural requirement to determine if it contributed to the error.
- Checklists conducted during periods of heavy workload are more subject to error. A company required procedure, though needed, may be ill placed, ill timed, or be so cumbersome that when interjected into a heavy workload environment, e.g., during ground taxi operation, it may potentially become a distraction.
- Checklists that are easy to read and use are more resistant to error and will contribute less to cockpit workload than those that are not. A correction to a specific checklist problem may lie somewhere in the way that the company develops and designs a checklist and/or provides operational information in manuals.
- The "Emergency" checklist is developed and used for non-routine operations in which certain procedures or actions must be taken to protect the crew and the passengers, or the aircraft, from a serious or potential hazard.

METHODS OF CHECKLIST DESIGN

- The most frequently used method of designing checklists for aircraft with two or more persons assigned to the crew are the "challenge-do-verify" (CDV). CDV is often referred to as the challenge-response method. Another method is the "do-verify" (DV) method.
- The CDV method consists of a crewmember making a challenge before an action is initiated, taking the action, and then visually and verbally, verifying that the action has been accomplished. The CDV method is most effective when one crewmember issues the challenge and the second crewmember takes the action and responds to the first crewmember, who monitors the action and verifies that the correct action was taken. This method requires that the checklist be accomplished

methodically, one item at a time, in an unvarying sequence.

- The primary advantage of the CDV method is the deliberate and systematic manner in which each action item must be accomplished. The CDV method keeps all crewmembers involved (in the loop), provides for concurrence from a second crewmember before an action is taken, and provides positive confirmation that the action was accomplished.
- The DV method consists of the checklist being accomplished in a variable sequence without a preliminary challenge. After all the items on the checklist have been completed, the checklist is then read again while each item is verified. The DV method allows the flight crew to use flow patterns from memory to accomplish a series of actions quickly. Each individual crewmember can work independently which helps balance the workload between crewmembers. However, this method has a higher inherent risk of an item on the checklist being missed than does the CDV method and is not recommended over the CVD method.

Selection of Design Method

- Both the CDV and the DV methods are currently being used for normal checklists. Traditionally, operators have preferred the DV method for normal checklists and the CDV method for non normal and emergency checklists.
- In most circumstances non normal and emergency checklists are more effective when the CDV method is used. The correct accomplishment of the actions and procedures incorporated in the non normal and emergency checklist categories is critical and warrants an error free approach. Since these checklists are seldom used, crewmembers are usually not as familiar with the procedures contained in them. In addition, most non normal and emergency checklists do not lend themselves to developing flow patterns which crewmembers can readily recall. The CDV method enforces crew coordination, cross-checking, and verification, all of which aid the crewmember in overcoming the effects of stress.
- Generally, the FAA will not approve or accept the DV method for non normal or emergency procedures unless the operator can provide substantial evidence that the method is effective for this application.
- One strategy that helps to overcome error is to develop policies for using checklists which require stringent cross-checking and verification and reinforce those policies through crew training programs. Again, the procedures intended for checklist use should be clearly written and placed in the company's operating manual. This should provide clear direction to each crewmember as to who is responsible for the completion of specific tasks contained on the checklist, who initiates the challenges and who responds. The operator's policy concerning verification must be compatible with the operator's crew resource management philosophy.
- One of several recognized methods for reducing error and enhancing verification during a checklist flow is a procedure that requires the use of aural, visual, and tactile sensors. Announcing the checklist item out loud (the challenge) stimulates the sense of hearing and helps focus attention on the task. The pilot-in-command responds by visually checking each item then actually touching (visual and tactile), operating, or setting the control or device and announcing (the response) the instru-

ment reading or prescribed control position in question. The crewmember calling the challenge monitors and verifies the actions.

- Touching the controls and displays is an effective enhancement for the verification process. The use of the hand to guide the eye while using the flow pattern can substantially aid the checklist procedure by combining the mental sequencing process with motor movements. Furthermore, the use of the hand and finger to direct the eye to an alphanumeric display or control can aid in fixating the eyes on the specific item and prevent the eyes from wandering away from that indicator.
- For two-pilot aircraft in which only the pilot-in-command has ground steering control, the recommended method for accomplishing checklists is for the second-in-command (SIC) to read all checklists. The recommended method for those aircraft in which either pilot can steer on the ground is for the pilot-not-flying (PNF) to read all checklists. In all two-pilot aircraft, the PNF should read all checklists.

Immediate Action Items

- Immediate action items are those items accomplished from memory by crewmembers in emergency situations before the checklist is called for and read.
- (1)A flight crew's failure to correctly accomplish all immediate action items can result in a threat to continued safe flight. For example, should a crew fail to close the fuel tank valve during an engine fire procedure, leaking fuel into the engine pylon may be ignited. In such cases, the first items on the corresponding checklist must be a verification that each immediate action item has been accomplished.
- (2) In some cases, an immediate action procedure may not be incorporated in a checklist. For example, there is no point in verifying that each item of an aborted takeoff procedure has been accomplished after the aircraft has been brought to a stop. In most cases, however, there should be a "follow-on" or "clean-up" checklist to be accomplished after the situation has been brought under control.
- (3) Immediate actions may be stated as policies rather than as checklist items when appropriate. An example of an immediate action item that can be stated as a policy rather than as a checklist item is the following statement: "All flight crew members shall immediately don oxygen masks and report to the captain on interphone in the event of loss of cabin pressure." In this example the loss-of-cabin-pressure checklist would contain subsequent items based on the assumption that the flight crew is on oxygen and has established interphone communications.