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HUMAN PERFORMANCE CONSIDERATIONS IN THE USE AND DESIGN OF AIRCRAFT CHECKLISTS

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CONTENTS

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1. PURPOSE

This report is intended to assist Part 121 and Part 135, operators in the design, development, and use of aircraft flightdeck checklists, and to increase awareness of the impact of human performance as it relates to the use of checklists. In addition, the report presents guidelines for checklist design.

2. RELATED FEDERAL AVIATION REGULATIONS SECTIONS

Part 21.5, Airplane or Rotorcraft Flight Manual

Part 25.1585, Operating Procedures

Part 121.315, Cockpit Check Procedure

Part 121.542, Flight Crewmember Duties

Part 135.83, Operating Information Required

Part 135.100, Flight Crewmember Duties

3. BACKGROUND

The small number of accidents that occur each year, when compared to hours flown, reflects a strong dedication by operators and pilots to provide an accident free environment. However, as the overall accident rates have declined over the years and flight safety has shown significant improvement, the percentage of accidents that result from flightcrew action or inaction has remained relatively constant in the majority of fatal air carrier accidents.

A National Transportation Safety Board (NTSB) Safety Study of 37 major accidents of U.S. air carriers between 1978 and 1990, identified a need to increase human factors awareness related to checklist usage and design. The study cited the improper use or the failure to use a checklist as the probable cause or contributing factor in several aircraft accidents during the pre-departure and departure phases of operation.[1]

Ten of the thirty-seven accidents studied by the NTSB occurred during the takeoff phase of operation. Their analyses indicate that a significant number of errors contributing to these accidents were made during the

[1] **NTSB Safety Study, A Review of Flightcrew-involved, Major Accidents of U.S. Air Carriers, 1978 through 1990**

preceding taxi phase. Eight (80 percent) of the accidents that occurred during takeoff involved errors that were classified by the NTSB as causal; six (60 percent) included procedural errors that were classified as causal: uninitiated or inadequately performed checklists. These checklist-related errors resulted in attempted takeoffs with mis-trimmed control surfaces, flaps and slats not extended for takeoff, incorrect use of engine anti-ice systems, and locked controls.

An additional review of NTSB accident data, conducted by the FAA's Office of Integrated Safety Analysis, revealed that during the period 1983 to 1993, approximately 279 aircraft accidents occurred where the checklist was not used or followed during CFR Part 91, 121, and 135 operations. In addition, a small number of accidents involved checklists that were inadequate for the aircraft or failed to include critical steps required for safe operation. The 279 accidents were responsible for approximately 215 fatalities and over 260 injuries.

Analysis of incident reports submitted by flightcrews to the Aviation Safety Reporting System (ASRS), also indicate that misuse and/or failure to use the normal checklist is a continuing problem, both for air carriers and commuter operators during ground operations. Several of the errors identified by the National Transportation Safety Board (NTSB) as causal or contributing in previous accidents continue to be identified by flightcrews as still occurring.

The final analysis of accident and crew reported incidents suggests that human performance, and its potential to create error, should be given full consideration throughout the checklist design phase and emphasized in crew training.

4. DEFINITIONS

Abbreviated Procedure: A list of sequential procedural steps without an amplified description or amplified set of instructions.

Accepted: Used to describe a document, manual, or checklist which does not have, or is not required to have, FAA approval.

Airplane Flight Manual (AFM): An approved airplane flight manual prepared by the manufacturer and approved by the FAA Aircraft Certification Office (ACO) under the provisions of FAR Part 21.5.

Alternate: Used to described a procedure or checklist, it refers to a procedure which may be employed instead of another procedure. Alternate procedures may either be normal, non normal or abnormal procedures.

Amplified Procedure: A description of sequential procedural steps with detailed explanatory descriptions and/or instructions accompanying each step.

Approved: Used to describe a document, manual, or checklist, it means that a regulation requires FAA approval and that the FAA has evaluated and specifically approved the document, manual, or checklist.

Caution: An instruction concerning a hazard that if ignored could result in damage to an aircraft component or system - which would make continued safe flight improbable.

Checklist: A formal list used to identify, schedule, compare, or verify a group of elements or actions. A checklist is used as a visual or oral aid that enables the user to enhance short-term human memory.

Company Flight Manual (CFM): An approved aircraft flight manual developed by, or for, a specific operator for a specific aircraft type and which is approved by the FAA, in accordance with the provisions of FAR Parts 121.141(b) or 135.81(c).

Emergency: When emergency is used to describe a procedure or checklist, it refers to a non-routine operation in which certain procedures or actions must be taken to protect the crew and the passengers, or the aircraft, from a serious hazard or potential hazard.

High Workload Environment: Any environment in which multiple demands on the flightcrew necessitate the prioritizing of work functions. For example, IFR operations below 10,000 feet during arrival or departure from a terminal area (including taxiing) are considered to be high workload environments.

Immediate Action: An action that must be taken in response to a non-routine event so quickly that reference to a checklist is not practical because of a potential loss of aircraft control, incapacitation of a crewmember, damage to or loss of an aircraft component or system, which would make continued safe flight improbable.

Non normal or Abnormal: Used to describe a procedure or checklist in reference to a non-routine operation in which certain procedures or actions must be taken to maintain an acceptable level of systems integrity or airworthiness.

Normal Checklist: A checklist comprised of all of the phase checklists used sequentially in routine flight operations.

Normal: Used to describe a procedure or checklist in reference to a routine operation.

Phase Checklist: A checklist used to establish and/or verify aircraft configuration during a specific phase of flight. An example of a phase checklist is an "after-takeoff checklist."

Pilot-Flying (PF): The pilot who is controlling the path of the aircraft at any given time, whether or not the aircraft is in flight or on the ground.

Pilot-Not-Flying (PNF): The pilot who is not controlling the path of the aircraft.

Policy: A written requirement established by an operator's management which is expected to be complied with by appropriate employee personnel. A policy may be stated within a procedure or stated separately. A written requirement such as, "No aircraft may depart on a cross-country flight without a spare case of oil" is an example of policy.

Procedure: A logical progression of actions and/or decisions in a fixed sequence which is prescribed by an operator to achieve a specified objective.

Recommendation: A preferred technique or action described by the operator which employees are expected to follow whenever practical. A recommendation is not a policy statement.

Rotorcraft Flight Manual (RFM): An approved rotorcraft flight manual prepared by the manufacturer and approved by the FAA Aircraft Certification Office (ACO) under the provisions of FAR Part 21.5.

Supplemental: Used to describe a procedure or checklist with reference to a procedure which may be employed in addition to a normal, non normal, or abnormal procedure. Supplemental procedures may either be normal or non normal procedures.

Systems Management: The management of those systems which sustain the mechanical functions of the aircraft as opposed to the management of the aircraft's thrust, flight path, or aerodynamic configuration.

Technique: A method of accomplishing a procedural step or maneuver.

Warning: An instruction about a hazard that, if ignored, could result in injury, loss of aircraft control, or loss of life.

5. ANALYSIS OF CHECKLIST ERROR INCIDENT DATA

The National Transportation Safety Board (NTSB), based on accident studies, has recommended that more emphasis be placed on checklist development and use.[2] A review of incident reports provided by flightcrews to the Aviation Safety Reporting System (ASRS) operated by NASA for the FAA, also suggests that more emphasis should to be placed on the use of checklists.

Other than information obtained during the investigation of an aircraft accident in which the aircraft was equipped with recording devices, it is difficult to obtain specific data concerning the commission of human error. The ASRS has proven to be a valuable source of information that is being reported by crewmembers that have experienced an incident involving checklist error. Although the ASRS reports do not provide for follow-up on specifics, they do provide trend information that is invaluable in identifying potential problem areas.

A review of approximately 300 randomly selected ASRS "checklist" related reports suggests that many of the same errors that have been identified by the NTSB as causal or contributing to past accidents continue to be reported as occurring on the flightdeck.[3] The significant areas in which checklist errors have been, and continue to be identified by flightcrews reporting to ASRS, include the following:

(a) Crew failed to use the checklist.

(b) Crew overlooked item(s) on the checklist.

(c) Crew failed to verify settings visually.

(d) Checklist flow was interrupted by outside sources.

(e) Operator's or aircraft manufacturer's checklist contained error(s) or was incomplete.

It is important to note that the top three items listed previously are the same items that have been identified by the NTSB as causal or contributing in several major accidents.

Additional analysis was conducted to determine the extent of checklist error and its impact on ground operations. Two-hundred randomly selected ASRS checklist error reports revealed several safety concerns. The reports were selected

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[2] **NTSB Safety Study, NTSB/SS-94/01**
[3] **ASRS Search Request Nos. 3469, 3409, and 3482**

based on the use of key words by the reporter and divided into two specific groups. One contained reports in which the reporting crewmember made reference to "flaps and/or slats" and "checklist", and the other group of reports contained only general references to "checklists".[4]

In the "flap and/or slat" group, twenty-seven reports provided specific references to crew checklist performance failure. Eighteen of these incidents (66 percent), occurred during the taxi/takeoff phase of operation in which the crew failed to select the correct flap and/or slat setting required for takeoff. In each report the crew was alerted through the activation of a flight deck alarm system that the aircraft was not configured properly. In each reported case, the takeoff was aborted or the crew delayed on the runway until the aircraft was properly configured.

In over fifty percent of these incidents, the reporters suggested that they became complacent. Each reported that the crew could have caught the error if they had performed a visual verification of flap and/or slat indicators as part of a last minute scan of critical flight components before takeoff.

The general reference group identified sixty-one occurrences of failure to monitor and cross check flight deck activity, misuse or failure to use checklists, and missed or overlooked items on the checklist following distraction or interruption. Analysis of the reports indicate that these occurrences were most common when:

a. The crew was nearing the end of the work day;

b. The crew was rushing to make a scheduled departure time; or,

c. The crew had not completed all checklist items, and did not decline an air traffic control takeoff clearance because departure traffic was backed up behind them and they did not want to cause delays.

In several cases, reporters stated that when the crew was rushed, the checklist was either done from memory; was given a cursory effort; or, as reflected in nearly 15 percent of the reports, was initiated but never completed.

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[4] **ASRS Search Request No. 3469**

In many situations the reporter indicated that they are strong advocates of checklists and for some unknown reason had strayed from a personal policy or technique that they had developed to remind them to conduct a certain function or conduct a visual check for verification. In most of these reports, the individual was of the opinion that the incident was a rare occurrence. However, each reporter had something in common with the previous. All were impacted by one or more human factor(s) and failed to recognize a deterioration in personal performance.

6. THE NEED FOR CHECKLISTS

The majority of the information contained in the following sections are a compilation of information obtained from reports prepared by the National Aeronautics and Space Administration (NASA), the FAA, and other research efforts.[5] A complete listing of references and other materials that pertain to the preparation of this document are contained in Appendix II.

The complexity of today's aircraft requires a systematic approach to operation. The pilot and crew in fact, are an intregal part of an aircraft system. Like any other complex system, when a system component fails, the entire system may be subject to failure.

Checklists have been the foundation of pilot standardization and cockpit safety for years. Such procedures, when applied in a disciplined and standard manner, are intended to support human performance by providing a firm foundation for the task, one which the pilot and crew can depend on during a "low" in performance. The checklist is an aid to the memory and helps to ensure that critical items necessary for the safe operation of aircraft are not overlooked or forgotten.

However, 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.

Pilots who develop strong cockpit discipline, foster team work, and make a concerted effort to comply with tried and tested operational procedures are seldom surprised by an

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[5] **Information contained in these studies was gathered through observed pilots use of checklists, analyzed incident/accident reports, and observed simulator sessions.**

occurrence that was not anticipated. From a human factors point of view, the checklist is an important interface between the human and the aircraft. In addition to assisting the crew to configure and operate the aircraft properly, the checklist provides a method and a sequence for verifying the overall system operation. 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.

A positive attitude must be promoted toward the use of checklists and each crewmember should consider its importance. The procedures that are used on the flight deck today are the result of experience, research, and unfortunately, the findings of causal or contributing factors gathered from previous accidents or incidents. Many of the procedures used today were developed and implemented to avoid recurrence of undesirable events.

Many training programs have been developed and implemented by the FAA and aircraft operators to continue to reduce the number of aircraft accidents and incidents. Airline conducted training, e.g., Crew Resource Management (CRM), Line-Oriented Flight Training (LOFT), training conducted by professional flight training sources, and others have played a significant role in increasing the efficiency of flightcrew personnel's performance.

While these programs have contributed to an overall increase in the level of safety that currently exists in aviation, accident and ASRS trend information indicate a special need for continued attention to human factors and their impact on flight operations.

7. HUMAN FACTORS CONSIDERATIONS: HOW THEY AFFECT CHECKLIST PERFORMANCE

In the past, accidents and incidents were frequently attribited to "pilot error" when nothing else could be identified as the cause. Today, "pilot error" is not a sufficiently descriptive explanation of cause. Humans are very flexible in adapting to changing conditions. Human performance is variable; it fluctuates and may produce errors which should be clearly identified and understood.

To reduce human error in aircraft operations, a move was made in the aviation industry to standardize aircraft controls, instruments, charting, and other areas as much as possible. This effort, intended to reduce variance in human behavior also addressed the use of checklists in aircraft.

While the NTSB and ASRS reports suggest that flightcrews 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.

a. Fatigue/Stress

The terms "fatigue" and "stress" are often used interchangeably and are difficult to define and measure. The degree or extent of fatigue/stress on the human is individually determined because they affect each person differently. Within this document fatigue is defined as a physical condition that is a normal result of the lack of physical fitness or conditioning; or sleep loss; or missed meals that may cause a low blood sugar level; or any combination thereof. A condition that can be minimized by adequate rest and sleep, regular exercise, and maintaining a proper diet.

Fatigue continues to be one of the prime concerns to flight safety, as it may not be apparent to a pilot until errors are committed. Many of the decision errors made in the performance of flying tasks may be attributed to fatigue.

Although a normal occurrence, fatigue can reduce the coordination and alertness vital to safe pilot performance. Fatigue is the result of many influences. Regardless of its cause, the sensation of fatigue should be a warning of impending task overload and the need for compensatory measures to avoid that overload. The most common of these compensations is load shedding or load reduction; a fatigued individual tends to rank tasks to be accomplished according to their percieved importance and sheds or deletes those of a lower priority. The individual may also refuse to accept new tasks or inputs or may devote less time to each of the present tasks. This can directly impact the successful completion of checklist tasking.

Stress is a concern as it can impair pilot performance in very subtle ways. Difficulties in one's personal life or at work can occupy the thought process enough to markedly decrease alertness. Certain emotionally upsetting events, including a serious argument, death of a family member or friend, divorce or separation, or financial problems, can render a pilot unable to operate an aircraft safely.

The emotions of anger, depression, and anxiety from such events not only decrease alertness, but may also lead to taking risks. Any pilot who experiences such an emotionally upsetting event should recognize that the risk of error is increased if he or she elects to fly under these conditions.

Job related stress can be reduced through proper training and the development of good pilot operating skill and technique. Aggressive training programs can increase confidence and decrease on-the-job stress.

Fatigue and mental stress can become an extremely hazardous combination. Emotional stress, normal workload requirements, noise, mechanical or ATC delays, and crew duty limitations, can create an environment conducive to the load shedding process. This can lead to "getting behind the aircraft."

Pilots that fail to recognize the onset of fatigue or stress may expose themselves and others to human error. During these periods, performance can fall off, judgment can become impaired, and there is an increased risk that short-cutting procedures, e.g., checklists, may occur.

b. Interruption/Distraction: Task Management

Reconstruction of arrival and departure scenarios suggest that certain phases of ground operation and flight have a higher potential for checklist error than others.

Unless the weather has created a special challenge, the arrival phase is generally less demanding on the crew. The task loading associated with the arrival sequence to an airport is generally spread over a longer time period. It may begin as much as 75 miles or more from the airport and the cues for initiating the checklist are normally more pronounced, e.g., descending out of cruise altitude, perform "DESCENT" checklist; at or near the final approach fix complete the "BEFORE LANDING" checks.

Based on a review of NTSB accident reports and ASRS incident reports, the flight deck crew is most vulnerable to interruption and/or distraction from the "BEFORE START" phase through "PUSH BACK", "START", "TAXI", and "BEFORE TAKEOFF" phases of operation. These phases of operation can be the most hurried. Often the events that take place during the pre departure phase of operation do not occur in a logical sequence, requiring a greater sense of situational awareness and team work and presenting opportunities for checklist interruption.

Before taxi, numerous activities are in progress in and around the aircraft. The crew can be distracted or interrupted by boarding passengers, baggage loading, fuelers, push-back crews, mechanics, and flight attendants. All are necessary functions that have the potential to cause distraction or interruption, but are necessary activities before the aircraft can depart. The crew has little control over these activities and occasionally the checklist process is dependent on external activity being completed, e.g., waiting for cargo doors to be closed or the arrival of fuel, etc.

While the crew is waiting for these activities to be completed, a "hold" may be placed on the checklist process. When this occurs the crew should have a provision for retaining the hold point--a memory jogger to remind them that the checklist has not been completed.

It is recommended that anytime a checklist flow has been interrupted or an item placed on hold, the checklist should not be stowed. It should be kept in hand. If it must be laid down to allow the crewmember to perform other functions it should be placed in a conspicuous area visible to all crewmembers, e.g., in the throttle/power quadrant area or clipped to the control yoke as a reminder that the list has not been completed. Other methods, e.g., hand written notes placed in the power quadrant area, the placing of a clean, empty styrofoam coffee cup inverted over a power lever or something as simple as placing a paper clip along the border of the list at the appropriate spot can serve as effective reminders. Reportedly, each of these methods has been effective as reminders and memory joggers with other flightcrew personnel. Whatever method works for the individual crewmember is acceptable as long as that person has a method for memory recall. If there is doubt as to where the flow was interrupted the chance of error is reduced if the crew returns to the beginning of the task list being performed.

A key to help reduce being side tracked from checklist duties following a checklist hold, interruption, or distraction is not to stow the checklist until all items in the flow are complete. Several researchers are in agreement, from a human factors perspective, that if the checklist is interrupted or placed on hold, returning it to its normal storage place increases the possibility that the crewmember may forget to resume that portion of the list.

Many of the distractions or interruptions occurring on the ramp area can be reduced to a minimum by the aircraft operators through training of support personnel. Operators should ensure that company ground support personnel who communicate directly with flightcrews are familiar with the procedures used on the flight deck and the need to avoid interrupting the crew during a checklist flow. Persons entering the flight deck to talk to the crew should make their presence known and unless an emergency exists, refrain from interrupting any flight deck activity or talking to the crew until the crew indicates that they have completed their task and acknowledges their presence.

Additionally, all cabin crewmembers should be fully briefed on the contents of FAR, Part 121.542, Flight Crewmember Duties, or Part 135.100, Flight Crewmember Duties, (as appropriate) more commonly referred to as the "sterile cockpit" rule. As a minimum the briefing should include the reason for the rule, and the potential impact on safety should the cabin crew interrupt or distract any member of the flight deck crew during checklist or other essential activity. At the same time the operator should exercise care to ensure that the cabin crew members are not reluctant to talk to the cockpit when issues that they believe may be related to the safe operation of the aircraft are detected.

As the crew begins the "Push Back", "Engine Start" and "Taxi" phases a new set of potential distractions and interruptions enter the picture, particularly as the aircraft enters the airport operational area. The cockpit crew members may be forced to divide their attention among completing cockpit duties (checklists), the monitor of air traffic control, observing and avoiding other taxiing aircraft, ground vehicles, and listening for the the company dispatch who may be providing new load or weather data.

Throughout the "TAXI" phase of operation the potential for error can be significant. Depending on when and where it is performed, the checklist flow can interrupt or distract the crew from other cockpit duties, i.e., the monitoring and attention required for external operations. Simultaneously, these outside activities can interrupt checklist use. This can easily force the flight deck crew into functioning as individuals in the cockpit instead of a team. Crews should be cautioned that when the continuity of performing monitor and cross checks is interrupted, the safety margin may also be reduced.

A recent report published by NASA, concerning checklists suggests that "TAXI" checklists should be completed as close as possible to the gate and as far away as possible from the active runways and adjacent taxiways.[6]

c. 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.[7]

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[6] **Degani, Wiener (1990)**

[7] **Miller (1956), Wickens (1988), Flach (1988).**

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.[8] 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.

d. Pressure On-The-Job

Pressure for "on time performance" can be a factor that may carry over into the cockpit and affect flight deck activity. The NTSB reported in its January 1994, safety study that seventeen or 55 percent of 31 air carrier accidents for which flight time information was available had departed late or were operating behind schedule before the accident. In contrast, between 17 and 35 percent of an illustrative sample of non-accident flights were running late.

Pilots should be cautioned that as pressure mounts and they allow the pace to quicken to make an on time departure they may be increasing the possibility of error. Laboratory research has demonstrated that there is a very definable relationship between response-time and error-rate[9]. This may have an effect on checklist performance and the relationship between the speed of performing the checklist and the quality (accuracy) of the check. For example: if the pilot scans the appropriate control and instrument panels rapidly because of time pressure, the accuracy of his or her perception may suffer and the probability of error will increase.

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[8] **Wickens, et al, (1988)**
[9] **Degani, Wiener, (1990)**

Overall, the study of crew reported incidents and NTSB accident data suggest that ground operations between the parking area/terminal and the runway areas require strict attention to duties. Even taxiing to the parking area after landing has been identified as an area in which the checklist can distract from crew duties. Several incidents have been reported in which the crew taxied across an active runway or initiated a wrong turn while other crewmembers were performing "After Landing" checklist tasks.

e. Cues For Initiating Checklists

Although it is normally the Captain or Pilot-in-command's responsibility to call for the checklist, in the absence of specific operator guidance, each crewmember should develop their own internal and external cues as to when the checklist should be initiated. For example; the "Before Start" checklist can be cued by the completion of passenger loading (internal cue); the "Taxi" checklist can be cued by receipt of a taxi clearance and the "Before Takeoff" checklist can be cued by reaching the hold line associated with the departure runway.

For economic considerations and to ensure minimum fuel consumption before take off, aircraft operators or pilots may elect to delay starting all engines until the aircraft has reached a point on the taxi route. Delayed engine starts may be cued based on taxi progress (external cue) to the runway.

In the absence of specific company policy or procedure, cueing the checklist is a personal technique. It can fail if a crewmembers is preoccupied with other tasks. However, if each crewmember develops his or her own cues for checklist initiation, the chances that the cues will be identical for each crewmember is remote. Such a system provides a means of backing each other up in the cockpit.

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.

Although a given task can be effectively accomplished at any time within the window, it appears that there is an advantage to conducting the task early. Researchers conducted a study to evaluate task-scheduling strategies of airline pilots flying DC-9 and MD-88 aircraft in a full mission simulation. They reported that crews who scheduled their task early within the window tended to be rated as high performing crews. Conversely, crews who scheduled their tasks late within the window tended to be low performing crews.

The research concluded that "scheduling a task early in the window of opportunity is the optimal task scheduling strategy".

In summary, a well managed crew schedules the required tasks within a window of opportunity in a way that it will not be done too early or too late. For example, if one wishes to obtain the arrival ATIS, there is no point in doing this task too early; the information may change by the time the aircraft will start the approach, particularly during rapid changing weather. On the other hand, there may be penalties for obtaining the ATIS information so late, since it is required for planning purposes.[10]

f. 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.

g. Aircraft Maintenance

Several reports have been received by the ASRS in which the reporter indicated that while on a stop-over, maintenance was performed on the aircraft that required hands-on work on the flight deck. The reporters revealed that work performed, normally while trouble shooting, required the changing of switch positions, instrument control settings, deactivation of circuit breakers etc., without the crew's knowledge. In each reported instance the flightcrew was not present in the cockpit when the changes were made and ,reportedly the crew was not advised of any changes.

[10] **Degani, Wiener, (1994)**

In all cases, the items affected were contained on the aircraft acceptance checklist for the first flight of the day, but they were not listed on the normal stop-over checklist. Consequently, the discrepancy was not detected until later in the flight.

To avoid the possibility of a mishap resulting from hands-on work performed on the flight deck while the crew is not present, each operator should develop a procedure requiring maintenance personnel to notify the crew that work has been performed on the flightdeck. Notification can be either through direct communication with the crew or by using some type of highly visible posting method affixed directly to the
control yoke or over the face of a primary cockpit instrument.

h. 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.[11]

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.

8. <u>OBTAINING CHECKLIST ACCEPTANCE/APPROVAL</u>: THE PROCESS

The process for developing a crew checklist begins with the manufacturer who designs, builds, and tests the aircraft. Recommended operating procedures and related checklists are developed and tested by the manufacturer and published in the Aircraft Flight Manual (AFM) under the provisions of Title 14 Code of Federal Regulations (CFR), Part 25.

[11] **Degani, Wiener, (1990)**

Certification of the aircraft under Part 25, only allows that the aircraft was manufactured and tested to certain specifications and is ready to be operated.

Before the aircraft can be operated under either 14 CFR Part 121 or Part 135, the operator must comply with all of the applicable sections of the appropriate regulation. The development of a flightcrew checklist is a provision that must be complied with by all Part 121 and 135 operators. In addition to development of crew checklists the operator must obtain approval or acceptance from the FAA's Principal Operations Inspector (POI) before it can be used.

The POI is a representative of the FAA assigned to each operator. The POI and staff are available to assist and advise the operator on matters concerning the safe operation of aircraft. In addition, they provide regulatory oversight from the initial operator certification process through all phases of operation, including flightcrew training, compliance with company operational policies, maintenance and inspection of aircraft, and the development or approval of all flightcrew checklists.

Although the manufacturer may have provided a checklist in the AFM, it was not approved for use during the Part 25 certification process. When a Part 121 operator proposes to use an AFM checklist, the POI must review and approve that checklist. The same applies when a Part 135 operator proposes to use an AFM checklist, however; the POI need only review the checklist and determine that it is acceptable for that operators use.

Only after the operator has demonstrated compliance with the regulations, will operating approval be issued by the FAA. The final approval for an operator developed crew checklist and future changes or modifications to that checklist require the approval or acceptance by the FAA.

9. 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.[12] 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.[13] 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 elimate 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

[12] **Degani, Wiener, (1990)**
[13] **Degani, Wiener, (1990)**

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.

b. Checklist Content

Traditionally, aircraft checklists have been divided into three categories. These are referred to as "Normal", "Nonnormal", or "Abnormal", and "Emergency". In some instances, these categories may be further divided into subcategories such as "Alternate" and "Supplemental".

The "Normal" checklist is typically a listing of action items to be performed and verified at a particular point in a routine operation (without malfunctions). It is comprised of all the phases of flight and used sequentially in routine flight operations.

The "Nonnormal" or "Abnormal" checklist is developed and used for non-routine operations in which certain procedures or actions must be taken to maintain an acceptable level of systems integrity or airworthiness;

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.

Operators should ensure aircraft checklists are limited to action items or verification items. The checklist should not contain elaboration or explanation of procedures. During the development of a checklist the operator should consider the following:

(1) A normal checklist is typically a listing of action items to be performed and verified at a particular point in the flight. Normal checklist items do not necessarily represent a procedural step and may even represent completion of a entire procedure. For example, the item "Gear; Up and Locked" could indicate the gear handle has been raised, the gear indications checked, the gear handle has been placed in the neutral position to check the up-locks, and that the handle has been returned to the up position.

(2) Non normal and emergency checklists should contain each sequential step of a procedure.

c. Criticality of Checklist Items

Very little data are available concerning placement priority of items on the checklist. However, some researchers agree that the more critical an item, the closer it should be to the top of the list. Their rationale is that critical checks should be completed earlier in the ground phase in order to decouple the critical items from the takeoff segment as well as to allow enough time (buffers) for the crew to detect and recover from a configuration failure.[14] In most cases, the captain or pilot-in-command will call for the checklist when the workload is less than peak. The further the crew progresses through the checklist, the greater the possibility becomes for interruption.

When possible, checklist items should be ranked in criticality according to the potential effect of a crewmember's failing to perform the action. Critical items are those items which, if not correctly performed, have a direct, adverse effect on safety.

An item may be considered "critical" on one checklist but "non-critical" on another. For example, a flightcrews' failure to set the flaps while accomplishing the "Before Takeoff" checklist was the cause of a major accident. However, a crews failure to retract the flaps while performing the "After Landing" checklist may have little effect on safety.

The operator should analyze each phase of flight to identify critical items for that phase and to ensure that all critical items are included on the checklist.

d. Diversion of the Flightcrew's Attention

The flightcrew's attention is often diverted from other tasks when performing a checklist. In order to minimize a head down posture and diversion time in the cockpit, the checklist should be kept as short as practical.

As items are added to the checklist the potential for interruption or diversion increase. Operators should compare the benefit of adding additional items to the possible adverse effects this may have.

Normally, the FAA will withhold approval or acceptance of a checklist that contains items not associated with aircraft operations.

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[14] **Degani, Wiener, (1990)**

e. Aircraft Sophistication and Checklists

The degree of technological sophistication in the design of aircraft directly affects the checklist. In older aircraft, the flightcrew must manually select and monitor most items. In more advanced aircraft the same items are accomplished and monitored by automatic systems which relieve the flightcrew of these tasks. Checklists for these aircraft tend to be shorter and simpler and may require a more careful task analysis for the operational requirements of the specific aircraft.

f. Fleet Standardization

Operators should standardize checklist items and the sequence of items to the extent allowed by individual aircraft differences across all aircraft in the fleet. Checklists for technologically sophisticated aircraft are typically shorter and simpler than those for older aircraft. The items on checklists for advanced aircraft, however, are normally present on checklists for aircraft with older technology.

It is FAA policy to require operators to evaluate the feasibility of placing common checklist items on checklists with standard titles for all aircraft (such as before start, before takeoff, or before landing checklists). Items should appear in a standard sequence to the degree possible. The FAA will not normally approve placing an item on a checklist which is not required for a specific aircraft solely because the item is required in other aircraft of the fleet. Exceptions may be made if the operator provides adequate justification.

10. 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 flightcrew 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.

a. 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.

b. Mechanical or Electronic Checklists

These devices differ in format from paper, hand-held checklists, but not in the design method or use. The CDV and DV methods addressed in this document can be applied to any type of checklist. Operators are encouraged to use such devices.

c. Verification

During the design of the checklist it is important to keep in mind that all checklist designs are subject to human error. Crewmembers may omit and skip checklist items or erroneously respond to a checklist at times believing that an item or a task was accomplished when it was not. At other times, crewmembers may see what they expect to see rather than what is actually accomplished or indicated.

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 instrument 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.[15]

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[15] **Degani, Wiener, (1990)**

11. <u>FAA POLICIES AND RECOMMENDATIONS FOR MANAGING THE ACCOMPLISHMENT OF CHECKLISTS</u>[16]

The FAA's policy requires each operator to provide specific crewmember responsibility for monitoring, verifying, and managing the accomplishment of checklists. These responsibilities may appear as policy statements or as specific directives and must be contained in the appropriate operator's manual.

a. Objective of Policy Statements and Directives

The primary objective of the operator's policy statements or directives is to assist in the standardization of crewmember interaction. These statements should include, but not be limited to, the following items:

(1) Flightcrew responsibilities for maintaining aircraft control, analyzing situations, and for requesting the appropriate checklist in normal and emergency situations.

(2) The specified crewmember responsible for initiating each checklist.

(3) The specified time when each checklist is to be initiated.

(4) The specified crewmember responsible for accomplishing each item on the checklist.

(5) The specified crewmember responsible for ensuring that each checklist is completed and for reporting that completion to the crew.

(6) Crewmember responsibilities for bringing to the attention of the pilot-in-command and the rest of the crew any observed deviation from prescribed procedures.

b. Methods for Managing Checklist Accomplishment

The information contained in this section provides a discussion of recommended methods that may be used for managing checklist accomplishment. These methods are not all-inclusive nor should they be interpreted as the only methods acceptable to the FAA.

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[16] **The information contained in Section 11, is obtained from FAA Order 8400.10, Air Transportation Operations Inspector's Handbook, Volume 3, Chapter 15, Section 5. This section presents the guidelines used by POI's in their evaluation of operator developed checklists.**

(1) For single-pilot aircraft it is recommended that operators mount the before-takeoff and the before landing checklists on the instrument panel by means of a placard. When aircraft characteristics allow, the operator should develop touch-verification procedures which contain a requirement that the pilot touch each control to verify it is in the correct position.

(2) 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.

(3) For three-crewmember aircraft the recommended method is for the SIC to read the flight engineer (FE) portion of the before-engine-start checklist, so that the PIC can observe and verify the configuration of the flight engineer panel as the FE responds to each item on the checklist. Since the PNF is the crewmember most subject to interruptions from radio communications, it is recommended that the FE should read all normal checklists and verify that each pilot action has been taken when the aircraft is in motion. The FE should have the explicit task of verifying that critical items have been performed by the pilots, whether or not the FE has verbal responses for those items. In those non normal or emergency situations which involve significant activity by the FE, it is recommended that the PNF read the checklist and verify FE actions while the FE performs and responds to the items.

(4) For all aircraft, the crewmember responsible for reading the checklist should be responsible for ensuring that the checklist is completed systematically and expeditiously. This crewmember should be responsible for managing interruptions, cross-checking controls and indicators to ensure that the required actions have been accomplished, and for reporting that the checklist has been completed.

(5) The pilot-flying (PF) should not be distracted from controlling the aircraft to perform a checklist items that another crewmember can accomplish. The PF should activate only those switches or controls (other than the manual or automatic flight controls, throttles, and nose wheel steering) that are not within practical reach of another crewmember. Only one pilot should be in a head-down posture at any time.

(6) In the prestart phase, flight guidance and navigation checklist items are considered critical items. A response should be required from both pilots (and FE if applicable) when the same setting is required for more than one device (such as computers, flight instruments, and altimeters).

Inertial platform alignment and computer programming should be accomplished by one crewmember and independently confirmed by another. As many of these checklist items as possible should be accomplished and verified before the aircraft is moved.

(7) In the taxi and pre takeoff phases, aircraft configuration (such as flaps, trim, and speed brakes) and flight guidance items (such as heading, flight-director, altitude select panel settings, and airspeed bugs) are critical. All flightcrew members should be required to respond to applicable checklist items.

(8) On approach, flight guidance checklist items are critical. At least two crewmembers should be required to confirm and respond to these items. A response should be required when the same setting is required on two separate devices (such as computers, flight instruments, or altimeters).

(9) All checklist items that are critical in the before-landing phase vary with the type aircraft involved. The landing gear and flaps are critical items and should require a confirmation and response by both pilots.

(10) All checklists, except the after-takeoff and after-landing checklists, should be accomplished by one crewmember reading the checklist items and a second crewmember confirming and responding to each item. All critical items on the before-takeoff and before-landing checklists should require confirmation and response by at least two crewmembers.

(11) All checklists must be designed so that the flightcrew can maintain an adequate scan and monitor air traffic control communications while simultaneously controlling the aircraft. The recommended method is for the operator to group the systems management checklist items after the configuration, thrust, and flight guidance items for each phase of flight. When systems management items must be accomplished in a high workload environment, it is recommended they be accomplished by a single crewmember. Usually the after-take off and after-landing non-critical items can be accomplished silently.

(12) Operators should direct crewmembers to refrain from In

addition, crewmembers should be directed that when they observe that another crewmember is not taking or has not taken a required action, they must be required to inform the crewmember, the pilot-in-command, or the whole crew, as appropriate.

(13) Checklists should not be depended on to initiate changes in aircraft configuration. Operators should key aircraft configuration changes to specific operational events. For example, direct the landing gear to be extended at glide slope intercept. For any adjustment of configuration, a command from the PF and an acknowledgment from the crewmember taking the action is required.

(14) Crewmembers frequently cannot complete a checklist because of interruption or an item on the checklist has not yet been accomplished. Operators are required to develop policies for the management of these situations. For short delays, the recommended policy is for the flightcrew to hold the checklist until the interruption is over and the item can be completed. When the checklist item is completed, the challenge should be repeated, the proper response given, and the checklist resumed.

When mechanical or electronic devices allow checklist items to be accomplished in a random sequence an operator should develop a policy appropriate to the system used.

Operator policies that allow flightcrews to skip checklist items that have not been completed and then depend on memory to accomplish them later are not considered for acceptance or approval.

(15) Operating procedures must be established to ensure that the correct checklist sequence is re-established when unusual events interrupt the normal sequence of a flight. For example, crewmember actions during normal sequences of flight are interrupted on taxi-out. In such a case, operators should require that the flightcrew return to an earlier point on the checklist and reaccomplish the checklist.

c. Development and Sequencing of Checklist Items

Operators should ensure that checklists are developed from a careful task analysis and are consistent with the procedures section of the operators flight manual. Phase checklist items must be in an appropriate and logical sequence. When a checklist represents an abbreviated procedure, that checklist must follow the procedural sequence.

The following guidelines are used by FAA personnel to evaluate individual topics of checklist design.

(1) Operators should standardize the sequence of checklist items as much as possible across aircraft types.

(2) When the operator has a choice as to where an item should be placed on a checklist, it should be placed at a point where the crew workload is lowest.

(3) Operators should keep checklists as short as possible to minimize interruptions.

(a) Operators should sequence checklist items to minimize interruptions of checklist accomplishment. For example, sequencing the "INS NAV MODE" as the first item on the engine-start checklist may allow the flightcrew to call for and complete the before-engine start checklist at a convenient time even though INS alignment is not complete.

(b) Two short checklists may be preferable to a single long one. Operators may place a line or otherwise mark a checklist where the checklist can be held until a specific event occurs. This practice in essence creates two separate checklists.

(4) Operators must include required preflight tests on checklists but should design checklists to preclude the unnecessary testing of systems.

(a) Warning systems with built-in test and automatic monitor circuits do not need to be checked or included on checklists unless required by the AFM or RFM.

(b) Many test switches in the cockpit are designed for use by maintenance personnel. Operators should not require flightcrew members to perform these tests as a normal procedure.

(c) The grouping of required functional checks on a specific checklist which is performed before the first flight of the day, or at some other logical interval, and not repeated on subsequent flights may be approved on a case by case basis.

(5) Operators must clearly identify decision points and indicate the correct alternative action to be taken or alternative sequence of actions to be taken after each decision point. If the effect of adverse weather requires an alternate action, the operator should design the checklist to account for that alternate action. For example, if the auto throttles are normally engaged for takeoff except when engine anti-ice is being used, the checklist should contain a requirement that the throttles cannot be engaged with the engine anti-ice on.

d. 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 flightcrew'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 flightcrew 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 flightcrew is on oxygen and has established interphone communications.

e. Checklist Terminology

Operators should ensure that their aircraft checklists contain terminology that is tightly controlled to ensure clarity and common understanding. The following recommendations should be considered when developing checklists.

(1) The challenges and responses on the checklist should be consistent with the labeling on the switches and controls in the cockpit.

(2) Terms such as "Tested", "Checked", and "Set" are acceptable terms only when they are clearly defined and consistently used.

(3) Operators should have a consistent policy concerning responses to items with variable settings. "As required"

may be printed on the checklist but should not be an authorized response. A response that gives the actual setting is appropriate. Items which require variable responses should be carefully evaluated. Such items may not actually be required on the checklist or may be more appropriately included in the system management portion of a checklist.

(4) Responses to checklist items concerning liquid or fuel quantities should be made in terms of the actual quantities on board compared to the specific quantity required, for example: "10,000 pounds required, 10,400 on board." When specific quantities are required, a response of "checked" is not acceptable. A response of "checked" is acceptable when a range of quantity is permitted and the range is marked on an indicator, such as a green arc on an oil quantity gage.

(5) Excess verbiage on checklists is discouraged. For example, a checklist item of "Reduce airspeed to 130 KIAS for best glide" can be abbreviated as:

"BEST GLIDE - 130 KIAS."

(6) Ambiguous verbiage on checklists should be avoided. For example, "takeoff power" can mean either advance the power or to retard the power.

f. Aircraft Differences

Operators are required, by the FAA, to account in the aircraft checklist for differences in various series of aircraft or in installed equipment. When there are only a few minor differences, this may be accomplished by using symbols to designate those checklist items that apply to only one series of airplanes or that apply only when the equipment is installed. When there are a significant number of differences, operators should prepare separate checklists for each series of aircraft. Policies and procedures should be established to account for differences in checklist responses when operations are conducted with equipment removed or inoperative, in accordance with minimum equipment lists (MELs).

g. Sequencing Normal Checklists and Other Checklists

Normal checklist items may be incorporated in non normal or emergency checklists to simplify cockpit management. An acceptable alternative method is to require both the normal and non normal or emergency checklists to be accomplished in a specified sequence. This method has the advantage of allowing the normal checklist to be requested and accomplished at the time that it would normally be accomplished.

Checklists should be designed so that two checklists are not in progress simultaneously. The method may depend on the degree of sophistication of the airplane involved.

In technologically-advanced aircraft with short, simple checklists, it is usually preferable to keep the normal and the non normal checklists separate. In older airplanes, however, it may be necessary to add the normal checklist items to the non normal or emergency checklist simply to keep the checklist manageable.

12. CHECKLIST FORMAT

If crew checklist performance is expected to be error free it is necessary to build the checklist around known human capability and limitations. Although research on the building of a checklist is limited, there are several known factors that must be taken into account. Format considerations include, the size of type and font used, the lighting conditions under which the checklist will have to be read by the crew, and the several age groups with different viewing abilities that may use the checklist.

The checklist must be printed in a style that will accommodate different age groups with different eye sight abilities, and it must be of sufficient contrast that will allow easy reading in low ambient light levels.

At about age 50 there is a fifty percent reduction in retinal illumination as compared to age 20.[17] This reduction in the level of retinal illumination also plays a role in slowing the rate as well as the level of dark adaptation. The thickness of the eye's lenses is the major cause of farsightedness among the middle aged and elderly. As the lens thickens, it becomes yellow and reduces the transmission of blue light through it causing older people to have more difficulty in differentiating between colors. Generally, these effects are amplified while reading text under adverse environmental conditions.

Other factors include the order in which items are placed on the list. The operator should ensure that the checklist is configured in an order that is both compatible with the aircraft's systems operational sequence and at the same time compliment the crews ability to perform tasks in a logical and consistent order.

A poorly designed checklist that is hard to read or requires constant fine tuning and modification while being actively used by flight crews may carry with it the potential to cause or contribute to an accident.

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[17] **Degani, (1992)**

a. Checklist Flow Patterns

Considering the various configurations and arrangements in the many different aircraft cockpits it is not possible to develop a universal flow pattern (Motor and Eye coordination) that will accommodate all aircraft. However, by designing a checklist flow pattern that begins at the top of a panel or aft for the overhead panels, and progresses downward (forward for overhead panels) the operator will have established a flow sequence that accommodates the majority.

Researchers agree that the establishment of this type of a flow pattern can serve as an initial step toward standardizing the checklist flow for pilots. Other benefits from the establishment of a standardized flow include, making the checklist sequence run parallel to the initial setup flow-patterns (which are done before running the checklist), and thereby simplifying the learning process and the daily use of the checklist process. The establishment of a top-to-bottom flow pattern can aid in making the checklist actions logical and consistent in motor movement of the head, arms, and hands. From a comfort stand point, it is less tiring to move the arms and the head from above to below instead of the opposite direction.[18]

It is recommended that operators validate any new design or flow pattern, in a simulator environment or through other means before the checklist is presented for use by line pilots.

13. PRESENTING THE CHECKLIST

This section focuses on several typographical and environmental factors that affect the ability of the pilot to use, and read flight deck documentation. Much of the information contained in this section has been condensed from a December, 1992 National Aeronautics and Space Administration (NASA), report entitled "On the Typography of Flight-Deck Documentation. The report represents a summary of the available literature regarding the design and typographical aspects of printed text as reported by several noted researchers.

It should be noted that most of the typography data presented in this document was collected through laboratory studies conducted in a non-aviation environment. Therefore, the information should not be interpreted as being the only acceptable print size and contrast that can be used. It should serve as a baseline in designing flight deck publications. The information presented is however, based

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[18] **Degani, Wiener, (1990)**

on the best research information available to date and should be considered during checklist development. Because of the many variables encountered in the cockpit: the effect of age on eye-sight, ambient and artificial light levels, fatigue, and other conditions, it is recommended that any new flight deck documentation design be validated in a flight simulator using copies of the new documents and a representative sample of the pilot population.

Checklist legibility, readability, and contrast are a prime concern during the formatting process. If the checklist is deficient in any of the areas that affect ease of reading, the stage my be set for the crew to miss or overlook items or, worst case, rely on memory and avoid the list entirely.

Legibility of Print enables the observer to quickly and positively identify an alphanumeric from all other letters and characters. Legibility depends on stroke width, form of characters, illumination on the page, and the contrast between the characters and the background.

Readability generally refers to the quality of the text and depends on the spacing between characters, words, and lines of text.

Contrast is the difference in color or tone between the typed letters and the adjacent background.

In many cases, the formatting of checklists requires a compromise and presents the operator with a challenge. The type size, depending on checklist size that the operator desires, may be an important decision. In most cases a large type size is preferred for legibility, however; a smaller type size may be needed to keep the checklist size manageable in the cockpit. Operators must ensure that the checklist is formatted with reasonable care and concern for the crews ability to perform the checklist with maximum accuracy. This can only be done if it is presented in a practical and usable format.

Of particular importance is the manner in which the operator presents the abnormal, alternate and emergency checklists to the crew. Deficiencies in the design of these checklists are critical because of the time limitation, workload and level of stress involved in dealing with the situation. These checklists must be in a format that allows quick retrieval and rapid identification of the correct procedure. A mistake during an emergency procedure has the potential to create a irreversible action.

a. Typeface (Fonts)

Fonts refer to the style of alphanumeric used in printing. Two major groups of fonts are recommended for use on the flight deck: roman and sans-serif. Roman is well known since it is used daily in newspapers and books. Sans-serif is a contemporary font that does not include the small strokes (serifs) that project horizontally from the top or bottom of a main stroke.

Several researchers have reported that when other typographical factors are controlled, sans-serif fonts are more legible than roman. The premise behind this statement is that absence of serifs presents a more simple and clean typeface, and therefore improves the legibility of the print.[19]

Serifs disrupt character discrimination and may add uneven appearance to the shape of strokes and characters. However, it is also evident that they somewhat aid the horizontal movement of the eye along the printed line...the serifs at the top and bottom of a character create a "railroad track" for the eye to follow along the line of print.[20]

Therefore, when using a typeface without serifs, adequate spacing between the lines of print should be used in order to prevent the eye from slipping to the adjoining line. The designer should safeguard against this factor as it may lead to misreading a sequence while reading a long list.

Although there is agreement between most researchers and most human factors design handbooks, that sans-serif is probably the best font, there is a difference of opinion concerning style. This is something that the operator will have to decide based on what is considered the most legible and comfortable to the eye. The only guidance available concerning this is to avoid a font that has characters that are too similar to one another, as this will reduce the legibility of the print.

One experiment conducted in 1993, evaluated two fonts: a sans-serif font (Helvetica) and a serif font (Times Roman).[21] Subjects for the experiment consisted of 120 flight crew members with experience levels ranging from 90 hours flight time to 17,000. Their age varied between 20 and 54 years. In addition, eighteen of the subjects wore glasses or contact lenses with vision corrected to normal range.

The participants were required to read aircraft manuals printed in the subject fonts while secondary tasks were interjected. In each case the tasks were performed in both simulated daylight and nighttime cockpit reading conditions.

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[19] **This paragraph is Helvetica, a sans-serif font.**
[20] **This paragraph is Roman, a serif font**
[21] **Hans de Ree, et al, (1993)**

During analysis of the collected data it was determined that the differences between fonts were small compared to the difference between daylight and nighttime conditions. On the task of reading word lists there was no significant difference in performance, but Helvetica showed slightly better results.At the end of each session the participants were surveyed as to their preference of fonts. An overwhelming number (90 percent) preferred Helvetica.

Another font related problem is the use of dot matrix printers. The font produced by these printers is very modular, especially in uppercase letters. In addition, it is difficult to discriminate between characters because of the dot construction that make up a character and the uneven spacing between dots. There are also instances that the print is almost unreadable because of an old ribbon in the printer. The use of dot matrix printers should be avoided for critical flight-deck documentation.

b. Lower-case vs. UPPER-CASE Characters

There is almost a consensus among researchers that, when other factors are controlled, lower case characters are more legible than upper-case One researcher performed an experiment to determine readers attention between upper and lowercase in newspaper headings. He reported that lower case headings were located faster than upper case headings. Another test was conducted with lower case and upper case fonts for legibility and pleasingness. It was reported that lower case was read faster and ranked higher in pleasingness.

There are several factors that contribute to the reduced legibility of upper-case words compared with lower-case.

(1) Most printed material that we read is lower-case.

(2) Readability of lower case words is superior. Lower case words are perceived at a greater distance, suggesting that the "total word form" and legibility of the elements is important while perceiving words set in lower case.

Note: When researchers compared legibility of individual characters, upper-case characters were perceived at a greater distance.

DURING READING OF UPPER-CASE WORDS, PERCEPTION OCCURS IN A CHARACTER-BY-CHARACTER ORDER, THEREBY REDUCING THE SPEED OF READING AND READABILITY OF THE ENTIRE WORD.

The pattern or shape of a familiar word is stored in the human memory. While reading text, a matching sequence occurs between the observed word and the memory patterns stored in the brain. The more unique the patterns of the word, the easier it is to perform the matching sequence.

RESEARCH SUGGESTS THAT SUCCESSIVE LINES OF PRINTED TEXT, COMPOSING A PATTERN OF "STRIPES" MAY INDUCE DISCOMFORT AND ANOMALOUS VISUAL EFFECTS TO THE READER. THE LACK OF ASCENDERS AND DESCENDERS MAY FURTHER INTENSIFY THIS EFFECT

Lower-case words consist of characters that have ascenders (the vertical stroke of "d") and descenders ("p,""q") that contribute to the unique shape and pattern of a word. This makes the lower-case word-form appear more "characteristic". Conversely, an upper-case word appears like a rectangular box with no distinguishable contour.

Another explanation of the greater legibility of lower-case text is the combination of a capital letter and lower-case characters at the beginning of a sentence and/or proper names. Research has shown that visual emphasis given to the first letter of a word will significantly improve the speed of a search. This finding is true for lower-case words as well and for uppercase words combined with a larger first character. This can be useful when a documentation designer opts to make a distinction by using typographical features such as lower and upper-case words and still maintain discriminibility and search speed.

When designing the font size for lower case text, the "x" of the font must be considered. Usually, font height (typesize) is measured from the top of the ascender (b) to the bottom of the descender (p). Nevertheless, the critical value for design is the height of the character without ascenders or descenders (e.g., "a,""c,""e,"). This height is defined as the "x" size of the font. Unfortunately, most of the graphs and data tables available for determining the font height ignore this issue.

c. Typesize

Several research documents have been written concerning character size and the factors that affect comfortable reading levels and label identification. Many things affect the comfort level of reading. The overall size of the characters, viewing distance, and illumination levels are major factors.

Normal reading distance is about 16-24 inches from the eye. However, distance may vary depending on personal preference, amount of room in the cockpit, the size print, and illumination available to the reader.

Overall, based on research and tables prepared by researchers, it appears that a font size between 0.14 and 0.20 inches is suitable for checklists and other critical documentation used on the flight deck. However, for practical reasons a single page checklist is generally desired and the range (0.14 to 0.20) may not be efficient.

Another researcher conducted experiments to evaluate typesizes for optimum reading. The sizes evaluated ranged from 0.08 to 0.14 inch, all set in lower case using a roman font. The researcher reported that a 0.11 inch type size was read significantly faster than 0.10 inch. The majority of the readers judged the 0.11 inch type size as the most legible.

It is recommended that a font size below 0.10 inch not be used for checklists or any other important flight-deck documents.

Sample checklists are provided on pages 38 and 39 for side-by-side comparison of previously discussed styles. Both are presented in the minimum font size (0.10 inch) and preferred sans-serif style. In addition, figure 1, is presented in upper-case only and figure 2, is presented in mixed upper and lower-case. Both are printed in bold type for maximum contrast.

THE REMAINDER OF THIS PAGE INTENTIONALLY LEFT BLANK

Figure 1

Sample checklist set in UPPER-case Helvetica (sans-serif) font.

BEFORE STARTING ENGINES

LOGBOOKS..CHECKED
FLIGHT RECORDER...ON
VOICE RECORDER...TESTED
CIRCUIT BREAKERS..NORMAL
ACCESSORY PANEL...CHECKED
TAKEOFF WARNING...CHECKED
HYDRAULICS...SET
EMERGENCY LIGHTS..ARMED
FUEL.......................................RELEASE MINIMUMS___LBS
....................................FOB___LBS, DISTRIBUTION NORMAL
PRESSURIZATION..SET____& AUTO
PASSENGER SIGNS..................................ON (AUTO) & OFF
AIR CONDITIONING...SET
OXYGEN MASKS.......................................(BOTH) CHECKED
INSTRUMENT SOURCE................................(BOTH) NORMAL
INSTRUMENTS.....................................(BOTH) ____NORMAL
ALTIMETERS...___IN(MB),_____FT
RESERVE BRAKES...OFF
OIL.._____QUARTS
ALTERNATE FLAPS..NORMAL
GEAR...DOWN & GREEN
RADAR..CHECKED & SET
BRAKES...SET, _____PSI
STAB TRIM CUTOUTS..NORMAL
FUEL CONTROL SWITCHES....................................CUT OFF
FIRE SWITCHES..IN
DELAYED ENGINE START.......................................BRIEFED

Figure 2

Sample checklist set in mixed UPPER and lower-case, Helvetica (sans-serif) font .

BEFORE STARTING ENGINES

Logbooks..Checked
Flight Recorder ....On
Voice Recorder...Tested
Circuit Breakers..Normal
Accessory Panel.......................................Checked
Takeoff Warning.......................................Checked
Hydraulics...Set
Emergency Lights..Armed
Fuel.............................Release Minimums_____Lbs
..............................Fob____Lbs, Distribution Normal
Pressurization..................................Set____& Auto
Passenger Signs..............................on (Auto) & Off
Air Conditioning...Set
Oxygen Masks................................(Both) Checked
Instrument Source..............................(Both) Normal
Instruments.................................(Both)____ Normal
Altimeters..................................____In(Mb),____Ft
Reserve Brakes...Off
Oil...____Quarts
Alternate Flaps...Normal
Gear...Down & Green
Radar...Checked & Set
Brakes..Set,____Psi
Stab Trim Cutouts.......................................Normal
Fuel Control Switches...................................Cut Off
Fire Switches...In
Delayed Engine Start....................................Briefed

d. Stroke Width and Height-to-Width

Stroke widths affect the ability of the eye to differentiate between the stroke of the character ("I") and the space inside the character ("E,F"). The width of a stroke is a function of height of the character. Most human factors data books recommend the use of a height-to-width ratio of 5:3.

The recommended ratio is applicable only when the document is in front of the observer (a 90 degree angle between the line-of-sight and the document). Fixed displays, such as a mechanical checklist, may not be located in front of the pilot. Therefore, in designing a display that is viewed from an unfavorable angle the operator must take into account that the angle may reduce the apparent width of the character. When this situation exists a different height-to-width ratio, e.g., 5:4 should be considered.

e. Horizontal and Vertical Spacing

The vertical and horizontal spacing between characters affects the legibility and readability of the text. Increasing vertical spacing between lines reduces the probability of adverse visual effect. Researchers suggest that judgments of the clarity of text... are critically dependent on the spacing of lines, more so than the overall density of lettering on the page. The clarity of text can be increased by increasing the separation between the lines slightly and decreasing slightly the mean horizontal spacing between the centers of letters, within the limits of conventional typography. In addition, the opening of vertical space between lines reduces the chance of optical bridging between adjacent lines... a critical factor for the design of any list type document.

The recommended vertical space between lines is 25-33 percent of the overall size of the font. The horizontal space between characters should not be less than one stroke width. As for word spacing, the gap between characters should be large enough to allow grouping of words. This is achieved when the word space is 25 percent of the overall height and not less than one stroke width.

f. Connector Line Length

A connecting line between the challenge and the required response is an important item in checklist design (Challenge.......Response). Researchers indicate that a common problem in checklist design is the large gap between the challenge and the response.

The wider the gap, the greater the chance that the reader will make a mistake through perceptual misalignment. The connector line guides the readers eyes across the page.

Although the connector line assists the reader it should be noted that as the distance between columns of information is widened and connector line length is increased, the line becomes less effective. Checklists that are designed to cover the entire page of an 8.5 by 11 inch piece of paper are more prone to misalignment.

g. Use of *Italics*, Bold, and Underline

Several experiments have been conducted to determine the effects of different type faces on legibility. One experiment indicated that the reading of materials in italic face was 2.7 percent slower than roman lower-case of the same height. In addition, 96 percent of a 224 subject group judged italic to be less legible than a regular roman font.

Another study was conducted in which it was determined that bold face text was read at the same speed as lower-case text. However, 70 percent of the subjects commented about the unpleasingness of the text as compared to the roman font.

Additional experiments indicate that bold and medium face do not differ in readability, even under low illumination; suggesting that there is no apparent advantage in printing long chunks of text in bold face. Nevertheless, bold face can be safely and advantageously used for contrast and emphasis. Although faces can highlight a specific item on a document, over usage of this typographical technique can be inefficient. Employing too many faces for contrast, emphasis, and attention may be confusing and can reduce the legibility, and readability of the printed material.

It is recommended that the designer avoid using long strings of text set in italics and remain throughout the checklist with one or two typefaces.

h. Quality of Paper and Print

The quality of the paper that the checklist is printed on is important for two reasons.

First, if the checklist paper is printed on both sides, it is difficult to read if the print on the back side shows through the paper. Paper checklists should be printed on a thick opaque paper that, when back lighted, will prevent the print on the other side from showing through and blurring the print on the front.

The second, is the quality of the actual print. Black print on a white background is preferred. The print should be clear and the boundaries between strokes and spaces should be sharp and distinguishable.

i. Copying the Checklist

Operators should exercise care if they attempt to reproduce checklists on commercial copy machines. To avoid any degradation of the reproduction quality only an unlaminated original should be copied.

Reproduction from non-original copies may reduce the vertical spacing between characters and reduce stroke discrimination, thereby, affecting the reading quality. When copies are made from non-original copies a certain amount of definition is lost. If copies are made from documents that have been laminated the quality of light transmission necessary for the reproduction process may affect both contrast and legibility of the copy.

14. THE CUMULATIVE EFFECT OF IMPROPER TYPOGRAPHY

For a given printed document, the combination of two or more non-optimal or marginal conditions will have a greater affect on legibility and/or readability. The designer should avoid combining non-desirable conditions as they can reduce the overall efficiency of using the checklist.

CHECKLIST DEVICES

Over the years several types of checklists and aids for completing checklists have been developed. Each has inherent advantages and disadvantages. This document does not recommend any one device over the other as they all satisfy the requirements contained in Federal regulation.

The following pages provide a listing of the more common methods of providing flightcrew checklists and their related advantages and disadvantages.

PAPER CHECKLIST

ADVANTAGES	**DISADVANTAGES**
1. Easy to stow	1. Easily damaged or worn may lose its legibility
2. Inexpensive to produce	2. Easy to misplace
3. Inexpensive to update	3. Easy to remove from aircraft
	4. May be difficult to read if type size or fonts are not adequate
	5. May be difficult to read under low ambient light if paper and print are not of sufficient contrast
	6. No memory or recall feature
	7. No automatic means of noting progress if interrupted or distracted
	8. Hand held
	9. Promotes head down posture

CHECKLIST DEVICES

LAMINATED PAPER/CARD CHECKLIST (MOST COMMON)

ADVANTAGES	DISADVANTAGES
1. Withstands hard use	1. Easy to misplace
2. Retains legibility longer	2. May be difficult to read if type size and fonts are not adequate
3. Easy to stow	3. Readability may be hindered by surface glare
	4. Easy to misplace or remove from the aircraft
	5. No memory or recall feature
	6. No automatic means of noting progress if interrupted or distracted
	7. Hand held
	8. Promotes head down to read

CHECKLIST DEVICES

SCROLL TYPE CHECKLIST
(Common in military aircraft)

ADVANTAGES	**DISADVANTAGES**
1. Permanent mount	1. No memory or recall feature if items are deferred
2. Promotes head up posture	2. Back lighting required
3. Has a reference line to mark progress	3. Normally mounted on the pilot side of the aircraft or at the flight engineer's panel. Size of print, type font, and distance from other crewmembers may affect readability
4. Easy to update	4. Cost and expense of installation
5. Remains in full view of the crew as a reminder to perform the checklist	

CHECKLIST DEVICES

ELECTROMECHANICAL

ADVANTAGES	DISADVANTAGES
1. Provides a systematic means of recall if items are deferred	1. Limited to the number of task items.
2. Provides a clear view to crewmembers of checklist status	2. Cost and expense of installation.
3. Promotes head up posture	3. Back lighting required
4. Permanently mounted, can not be removed from aircraft or misplaced	4. Limited to only critical items. Requires the use of a supplemental list
5. Provides back lighting for easier reading in low ambient light	
6. Does not require the user to hold it	
7. No surface glare	
8. Will not loose its legibility through normal wear	
9. Remains in full view of the crew as a reminder to perform the checklist	

CHECKLIST DEVICES

ELECTRONIC/AUTOMATED (CRT)

ADVANTAGES	DISADVANTAGES
1. Is stationary in the aircraft. Can not be lost	1. May displace or share time with other needed displays, e.g., Radar
2. Can not be removed from the aircraft	2. Requires head down posture to read and operate
3. Depending on the system some are equipped with sensors that verify checklist items completed	3. May be hard to locate a list or return to a certain point
4. Retains legibility	4. Cost and expense of installation
5. Provides a systematic recall if items are deferred	
6. Does not require the user to hold it	
7. Provides immediate status of items	

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