UNIVERSITY OF MIAMI

HUMAN FACTORS OF FLIGHT DECK CHECKLISTS: THE NORMAL CHECKLIST

By

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The improper use of flight deck checklist was determined as one of the probable causes of two air transport accidents by the National Transportation Safety Board. The report objectives were to identify the physical and psychological factors that might contribute to the misuse or non-use of the normal checklist. Information regarding this report was obtained through flight observations, interviews with line pilots and searches on aviation incident/accident databases.

The lack of an indicator (pointer) to aid in sequencing checklist items, the lack of a storage and retrieval system as well as the absence of a feedback system to indicated completion of a checklist items were found as the engineering design deficiencies of the paper checklist. The incompatibility of checklist process to the operational system in which the crew and plane operates is another deficiency of some checklists. However, the most important factor in checklist usage was found to be the way in which flight crews perceive its importance. Therefore every effort should be made by the designer to accommodate the human strength and limitation while conducting this procedure.

TABLE OF CONTENTS

Chapter 1..... 1

1.1. Introduction..... 1

1.2. Objectives..... 10

1.3. Methods..... 10

1.3.1. Field Studies..... 11

1.3.2. Interviews with Line Pilots..... 11

1.3.3. Incidents/Accidents Data Base..... 12

1.3.4. Other Sources..... 14

Chapter 2..... 15

2.1. What is a Checklist?..... 15

2.1.2. Abnormal and expanded checklist..... 17

2.1.3. Checklist Errors, Mistakes, and Slips..... 18

2.2. Checklist Devices..... 19

2.2.1. Memory and Mnemonics..... 20

2.2.2. Scroll Checklist..... 22

2.2.3. Mechanical and Electro-mechanical..... 23

2.2.4. Vocal Checklist..... 25

2.2.5. Computer Aided Checklist..... 28

2.2.6. Experiments with Computer Aided Checklists. 31

2.2.7. Monitoring Computers and Checklist Usage... 32

2.2.8. Checklist within the Feedback loop..... 34

Chapter 3..... 35

3.1. Checklist's "Philosophy of Use"..... 35

3.1.1. The Airline "Culture"..... 35
3.1.2. Redundancy..... 36
3.1.3. The Device..... 37
3.1.4. The Method..... 37
3.1.5. The Items on the List..... 40
3.1.6. The pilot population..... 42
3.1.7. Type of Operation..... 42
3.1.8. Automation..... 44
3.1.9. Recommended Philosophy..... 45
3.2 Certification of Checklist..... 47
3.2.1. The Airframe Manufacturer..... 47
3.2.2. The Airline..... 48
3.2.3. Daily Use..... 50
3.3. Standardization of Checklist..... 53
3.4. Airlines Merges, Acquisitions and Checklist..... 58
3.4.1. Checklist Changes..... 60

Chapter 4..... 62
4.1. Checklist Initiation..... 62
4.1.1. Checklist "Cues"..... 63
4.1.2. Taxi Checklist..... 64
4.2. Challenge-Response..... 65
4.2.1. Memory Guided Checklist..... 65
4.2.2. Verification..... 66
4.2.3. "Short-Cutting" the checklist..... 67
4.3. Distractions..... 68

7.2.1. Latent Failures in High Risk Systems.....

Chapter 8.....140

8.1. Conclusions.....140

References.....142

Appendix A.....148

A.1 Proposed Guidelines.....148

Appendix B.....151

B.1. Cover Letter for Pilot Interviews.....151

B.2. Checklist Interview Questionnaire.....152

Appendix C.....154

C.1 Graphic Design of a paper checklist.....154

C.1.1. Layout and Organization of the Checklist on the Card.....157

C.1.2. Typography.....158

C.1.3. Reading Hygiene.....170

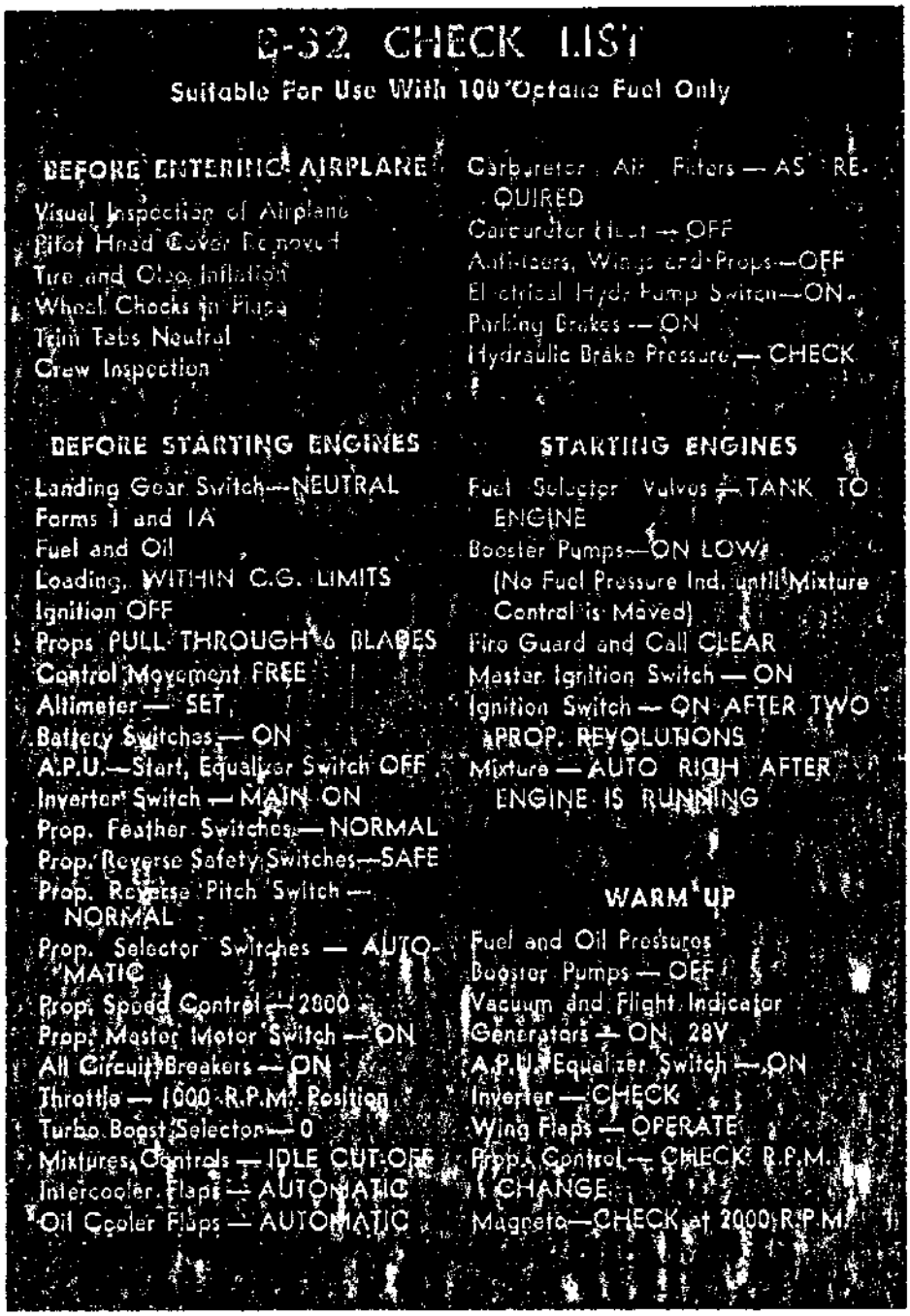
Chapter 1

1.1. INTRODUCTION

The use of flight deck checklist is a virtually inborn process to any pilot regardless of his tenure. It is one of the few devices that are common to almost all types of airplanes. Its basic function is to provide a step-by-step memory guide for preparing (configuring) the plane. This function is generally accepted and followed by all pilots, whether they are flying basic trainers or modern jet airliners.

Historically, the first checklist was probably implemented as one conscientious pilot "came down" with some remark about complexity and forgetfulness, realizing that he could no longer commit to memory all the required steps of configuring a complicated plane. Yet, aviation has advanced from those early days where a statement such as "do not trust any altitude instrument" was published as part of checklist and operational procedures for the US Air Service, to an era where onboard computers calculate and execute precise Vertical Navigation (VNAV) (Air Service, 1920). Nevertheless, the checklist has not undergone any conceptual re-thinking or design changes. In this respect, a B-32

Figure 1



C-32 CHECK LIST

Suitable For Use With 100 Octane Fuel Only

BEFORE ENTERING AIRPLANE

Visual Inspection of Airplane
Pitot Head Cover Removed
Tire and Oleo Inflation
Wheel Chocks in Place
Trim Tabs Neutral
Crew Inspection

BEFORE STARTING ENGINES

Landing Gear Switch—NEUTRAL
Forms 1 and 1A
Fuel and Oil
Loading, WITHIN C.G. LIMITS
Ignition OFF
Props PULL THROUGH 6 BLADES
Control Movement FREE
Altimeter — SET
Battery Switches — ON
A.P.U.—Start, Equalizer Switch OFF
Inverter Switch — MAIN ON
Prop. Feather Switches — NORMAL
Prop. Reverse Safety Switches—SAFE
Prop. Reverse Pitch Switch — NORMAL
Prop. Selector Switches — AUTOMATIC
Prop. Speed Control — 2800
Prop. Master Motor Switch — ON
All Circuit Breakers — ON
Throttle — 1000 R.P.M. Position
Turbo Boost Selector — 0
Mixtures, Controls — IDLE CUT-OFF
Intercooler Flaps — AUTOMATIC
Oil Cooler Flaps — AUTOMATIC
Carburetor Air Filters — AS REQUIRED
Carburetor Heat — OFF
Anti-Icers, Wings and Props—OFF
Electrical Hyde Pump Switch—ON
Parking Brakes — ON
Hydraulic Brake Pressure — CHECK

STARTING ENGINES

Fuel Selector Valves — TANK TO ENGINE
Booster Pumps—ON LOW
(No Fuel Pressure Ind. until Mixture Control is Moved)
Fire Guard and Call CLEAR
Master Ignition Switch — ON
Ignition Switch — ON AFTER TWO PROP. REVOLUTIONS
Mixture — AUTO RICH AFTER ENGINE IS RUNNING

WARM UP

Fuel and Oil Pressures
Booster Pumps — OFF
Vacuum and Flight Indicator
Generators — ON 28V
A.P.U. Equalizer Switch — ON
Inverter — CHECK
Wing Flaps — OPERATE
Prop. Control — CHECK R.P.M. CHANGE
Magneto—CHECK at 2000 R.P.M.

Courtesy of the Smithsonian Institution National Air and Space Museum

checklist from 1943 is not much different in its concept and design from a modern airline checklist (Figure 1).

The normal flight-deck checklist is a set of different operations the pilot has to perform in order to pre-configure the airplane for certain macro-tasks such as ENGINE START, TAXI, LANDING etc. For each macro-task there are several micro-tasks or "items", to be accomplished and verified by the flight crews. All macro tasks checklists (task-checklists) form the normal checklist, which is presented in the cockpit. There are several methods of conducting ("running") a checklist. The differences between each method are mainly in the process of running the checklist and in the device in use. In general, most checklist procedures are conducted by:

1) Reading or hearing the checklist item (micro task)
2) Accomplishing the item--either by verification of the correct setting or by execution of the item
3) Responding to the outcome of the action performed

As the item is accomplished the next item on the list is read, and so on until the task-checklist is completed.

The need to improve flight deck documentation and associated procedures has long been recognized in the aviation field (Hawkins, 1987; Ruffel Smith, 1979). Similar views, and emphasis for cockpit discipline while using checklists, are also cited in working papers presented in International Air Transport Association (IATA) technical

conferences and other aviation safety organizations. However, not much has been done in this area as the inadequacy of many airlines' flight documentation portrays.

While conducting this research, the author encountered several occasions where a statement such as "checklists, they are simple and straight forward, what is there to study about them?" was made. Although it is appealing to sympathize with the above statement, a closer look into the usage of checklists and the controversy that surrounds them will detail a device and an associated procedure that, in addition to its basic function as a memory guide, is also a generator and coordinator for many operational tasks. Nevertheless, its importance and vulnerability have long been neglected.

The Boeing company had studied the causes for airplane hull-loss from the beginning of jet transport in 1959 until 1985. This survey showed that the crew-caused factor dominated all other accident factors by a margin of 60 per cent (see Figure 2). Focusing on the crew-caused factor, a study of accidents reports from 1977 to 1984 was undertaken by the same company. A total of 93 accidents were used to classify and quantify the significant crew-caused factors presented in Table-A. The data reveals that 26% of all fatal accidents could have been avoided by properly monitoring and cross checking other crew members; an additional 33% could have been prevented if pilots would have not deviated from

Figure 2

Primary cause factors-Hull loss accidents

Primary Cause Factors—Hull Loss Accidents*

Worldwide Commercial Jet Fleet

Primary Factor	No. of Accidents Total	No. of Accidents Last 10 yrs	Percent of Total Accidents With Known Causes (1959-1986 / Last 10 years)
Flightcrew	236	89	73.5% / 70.6%
Airplane	39	17	12.1% / 13.4%
Maintenance	5	3	1.6% / 2.4%
Weather	17	7	5.3% / 5.6%
Airport/ATC	14	6	4.3% / 4.8%
Misc (other)	10	4	3.1% / 3.2%
Total With Known Causes	321	126	
Unknown or Awaiting Reports	48	21	
Total	369	147	

*Excludes:
- Sabotage
- Military action

1959-1986
Last 10 years (1977-1986)

(Adopted from Lautman and Gallimore, 1989, Figure 1, p. 1)

basic procedures. Both factors are the basis of the checklist procedure (Lautman and Gallimore, 1989; Sears, 1989).

TABLE-A Significant crew-cause factors and percentage of presence in 93 major accidents

33% - Pilot deviated from basic operational procedures.
26% - Inadequate cross check by 2nd crew member.
9% - Crews not conditioned for proper response during abnormal conditions.
6% - Pilot did not recognize the need for go-around.
4% - Pilot incapacitation.
4% - Inadequate piloting skills.
3% - Crew errors during training flights.
3% - Pilot not trained to respond promptly to GPWS command.
3% - Pilot unable to execute safe landing or go-around when runway sighting is lost below MDA or DH.
3% - Operational procedures did not require use of available approach aids.
3% - Captain inexperienced in aircraft type.

(Adopted from Lautman and Gallimore, 1989, table I, p. 2)

In the last 24 months, there have been two accidents where the misuse of checklist was determined as one of the probable causes by the National Transportation Safety Board (NTSB). In the first accident, a Northwest Airlines MD-80 crashed shortly after takeoff from Detroit Metro Airport (Michigan) following a no-flap/no-slat takeoff (NTSB, 1988a). In the second accident, a commuter airplane crashed immediately after takeoff, due to flight-crew failure to apply maximum takeoff power (NTSB, 1988b). Furthermore, an

ongoing investigation of a Delta Air Lines Boeing-727 crash in Dallas, Texas, is also focusing on the crew's setting of flaps and slats (Proctor, 1988).

This present clustering of checklist related accidents has lead the author (as well as others) to believe that there are some problems with the use and concept of this device in modern transport aircraft. While the above accidents have prompted this research, a survey of past checklist incidents disclosed similar symptoms. Nevertheless, the causes of many checklist related accidents were not pointed directly by the investigators toward the checklist as a concept, rather it was usually blamed on the hardware and the individuals involved.

In testimony given in front of the Safety Board, investigating the Northwest flight 255 accident mentioned before, E. L. Wiener stated with respect to checklist presentation "...that he did not know of any human factors research on how a checklist should be designed..." (NTSB, 1988a p. 62). The same dearth of research and information, pertaining to use and design of current checklists (as opposed to future design), was encountered by the author while performing an intensive data base search on U.S sources and Western-European sources.

The Safety Board recognized the importance of checklist usage and its critical role in safety of flight operations as indicated in a 1969 recommendation following a Pan

American World Airways B-707 crash after a no-flaps takeoff (NTSB, 1969). This recommendation called for "Air carrier cockpit checklists to be reviewed in an effort to insure that each list provides a means of reminding the crew, immediately prior to takeoff, that all items critical for safe flight have been accomplished" (NTSB recommendation A-69-012).

Unfortunately, it took 18 years and one fatal accident before the Safety Board recognized the problems with the human factors of the checklist display and procedure. In two recent recommendations following the Northwest Flight 255 accident and the commuter airline accident, the NTSB recommended that the Federal Aviation Administration (FAA) convene a human-performance research group to determine "...if there is any type or method of presenting a checklist which produces better performance on part of user personnel"; and for the FAA to recommend a checklist typography criteria for commercial operators (NTSB recommendations A-88-068 and A-88-072 respectively).

It is disturbing to note that until today (July, 1989) these last two recommendations have not been truly accomplished. Only a brief circular to commercial operators requires FAA inspectors to review checklists and to ensure that "flight crew checklist used by air carriers should include the appropriate actions necessary for normal and emergency procedures, printed in clear concise and legible

form" (Air carrier operations bulletin part 135 No.88-5 "flight crew checklist"). However, no information regarding what is "clear, concise and legible form" is detailed or explained in this bulletin.

Therefore, the author began this study by concentrating on the basic human factors of checklist design as a display per se. However, the evolution of this research had demonstrated that this is only the peripheral cover of the problem. The core emerged as the concept behind the checklist that has led some pilots to use the checklist improperly or not to use it at all. This concept must be first understood and later attended to in order to optimize the use of this device and thereby enhance flight safety.

Checklist problems have been known to prevail in many other high risk industries such as the marine industry and the process industries. The capsize of the English ferry Herald of Free Enterprize is a typical example of a marine checklist accident. The Roll-on/Roll-off vessel departed the loading ramp in Zeebrugge port (Belgium) on March 6, 1987, with the bow doors left unintentionally open. As the ship increased speed just outside the harbour, water entered and flooded the lower car deck, leading to rapid capsize (2 minutes). 150 passengers and 38 crew members lost their life due to an omission of a pre-departure action. (Report of formal investigation, 1987). The nuclear industry has its own share of checklist problems too, operators use paper

checklists for normal and abnormal operations as well as for scheduled maintenance tasks (Swain and Guttman, 1983; H.P. Van-Cott, personal communication, September 13, 1988).

The problem is common to many, yet it is traditional that those industries consult and look upon the aviation industry for answers to bilateral problems.

1.2. OBJECTIVES

The objectives of this study are as follows:

- To understand the role of the checklist in the operation of a modern air transport aircraft.
- To identify the factors that might contribute to the misuse or non-use of checklist.
- To study the evolution of checklist from the manufacturer to its daily use by the line pilot.

1.3. METHODS

The intent of this research is to further understand the role of the flight deck checklist within the complex interaction of checklist procedures, operators, cockpit systems, management, and the regulating agency (FAA).

information concerning this study was obtained from the following resources:

1. Field studies
2. Interviews with line pilots from seven major US carriers

3. Incident/accidents reports obtained from the following agencies and organizations:
   a) NASA's Aviation Safety Reporting System (ASRS)
   b) National Transportation Safety Board (NTSB)
   c) International Civil Aviation Organization (ICAO)
4. Interviews with officials from government agencies (FAA, NTSB)
5. Interviews with human-factors researchers in the field of aviation
6. Information obtained from aircraft and avionics manufacturing companies
7. General literature in the fields of aviation, psychology, typography and human performance

1.3.1. Field Studies

Two field studies were conducted at one major US carrier. The field study was aimed at observing (from the cockpit jumpseat) flight crews of B-737 and B-757 in their regular daily line operation. The author flew 58 flight segments in the above planes totaling 110 hours, observing more than 30 different crews. In addition, several similar observations were conducted in flight simulators of A-310 and A-320.

1.3.2. Interviews with Line Pilots

Face-to-face and telephone interviews with line pilots from seven major US carriers were conducted by the author and coordinated by the Air Line Pilot Association (ALPA). The pilots were asked to explain the method of conducting

the checklist at their company, and then were asked several standardized questions about the checklist procedures (the list of interview questions is given in Appendix A).

Pilots were assured that this information would not be identifiable and that the interview notes would be destroyed upon completion of the project. During jumpseat observation, no record was kept of flight crew names, flight numbers, or dates, to assure confidentiality.

There was no attempt to tabulate or statistically analyze the information obtained from the field studies and from the pilots' interviews. Rather, this information was used to generate hypotheses and to identify problems associated with the daily use of checklist.

1.3.3. Incidents/Accidents Data Bases

NTSB. Information regarding investigated and documented checklist accidents and incidents for US carriers was obtained from the NTSB accident/incident database (1983-1988) and recommendation database (1969-1988). This information was supplemented by obtaining published and unpublished Aviation Accident Reports (AAR) from the agency.

ICAO. A similar search was conducted on the ICAO database which contains world-wide accident reports. This database comprises 1200 reports from 1970 to the present.

Although sometimes tempted to conduct a statistical analysis on the above reports, this was not done. It was felt that such analysis would not aid in determining the

factors that contribute to the checklist incident, mainly because most reports detail the outcome of the accident/incident, and not what type of checklist error contributed to the accident.

ASRS. Another, yet much unique, source of information regarding field operations is NASA's Aviation Safety Reporting System (ASRS). This organization and its database utilizes a voluntary reporting system where pilots, controllers, and others can submit subjective accounts about safety-related aviation incidents. Subsequently, the information derived from this database is not verified, and may reflect reporting bias. Moreover, it often contains errors, especially in cases where the reporter is personally culpable (Wiener, 1989).

Nevertheless, the real power of the ASRS lies in the report narrative. Here pilots detail incidents and situations; they explain what happened, why it happened, and sometimes also add suggestion for improvements. The usefulness of this database for identifying significant problems and potential solutions was cited by the Presidential Task Force on Aircraft Crew Complement, ...We do recommend, however, that the implications of the ASRS findings for cockpit system design, certification, and flight crew operation procedures be seriously considered" (McLucas, Drinkwater and Leaf, 1981, p. 24).

Again, the information obtained from a search (1981-'89) on the ASRS database was not analyzed statistically because of the reporting bias that is concealed in the database. The narratives used in the paper are not representative of all checklist-related reports. Rather, the report narratives quoted in this paper were used to ascertain and amplify problems associated with the use of checklist in air transport operations.

1.3.4. Other Sources

Interviews with human factors specialists, individuals in the aviation industry, safety, and several government agencies were for the most part conducted through use of the telephone or by correspondence. Research and reports from the literature used in this project relate to areas such as human factors, aviation and aviation safety, human performance, and study of risk management.

Information regarding this research was also gathered from operational procedures of different airlines (flight manuals, procedures, checklist, etc.), in order to determine how different carriers confront this procedure and the affect of different checklist concepts on flight crews.

Chapter 2

This chapter will discuss the major concepts of checklist use and the objectives of this procedure. In addition, the different checklist devices currently in use will be reviewed.

2.1. WHAT IS A CHECKLIST?

The major function of the checklist is to ensure that the crew will properly configure the plane for flight, and maintain this level of quality every flight. The process of conducting a checklist occurs at all phases of flight, and in particular, prior to the critical phases (TAKEOFF, APPROACH, LANDING). These flight phases usually comprise only 27 per cent of average flight duration, yet 76.3 per cent of hull-lose accidents occur during these phases (Lautman and Gallimore, 1989).

2.1.1 Checklist Objectives

In analyzing the functions of the checklist, the author believes that in most cases the checklist is intended to achieve the following objectives:

1. Aid the pilot in recalling the process of configuring the plane.
2. Provide a standard foundation for an optimum level of

verification, that will defeat any reduction in the flight crew's psychological and physical condition.

3. Provide convenient sequence of motor movement and eye fixations along the cockpit display panels.
4. Provide sequential framework to meet internal and external cockpit operational-requirements.
5. Allow mutual supervision between crew members.
6. Enhancement of a team (crew) concept for configuring the plane by keeping all crew members in the loop.
7. Dictate the duties of each crew member to facilitate optimum crew coordination as well as logical distribution of workload in the cockpit.
8. Serve as a quality-control tool by flight management and government over the pilots in the process of configuring the plane for flight (Wiener, private communication 1989).

Another objective of the checklist, yet often overlooked, is the promotion of a positive "attitude" toward the use of the checklist. For this to happen, the checklist must be well grounded within the "present day" operational environment and the operator must have a sound realization of its importance instead of being a nuisance (Nagano, 1975).

From the above objectives, the checklist can be viewed in human-factors terms as an additional interface between the human and the machine. This interface controls the method

and sequence of checking the plane configuration. This is why the checklist has transformed from a simple memory aid to an important and critical procedure with its own inherent advantages and disadvantages.

2.1.2. Abnormal and Expanded Checklist

In addition to the normal checklist, other checklists are also used in the flight deck and during training. These are the abnormal checklists and the expanded checklist (the term abnormal is broadened here to include non-normal and emergency checklist). The abnormal checklist is intended to aid the pilot during emergencies and malfunctions of the airplane systems. This checklist is an attempt to predetermine a few of these events that may occur during flight due to mechanical as well as human failure. To cope with such situations, this checklist procedure is (1) used as a memory guide, (2) used to reduce variability among pilots, and (3) used to enhance coordination during these high workload and stressful circumstances.

From the similarity of the above objectives to the objectives of the normal checklist, it is clear that there is much in common between the concept and design of these checklists. The principal difference, however, lies in frequency of use. The abnormal checklist is very rarely performed by flight-crews during revenue flight; pilots are aware of its criticalness, and very much aware that misuse or non-use of the abnormal checklist can transform an

incident into an accident. The normal checklist, on the other hand, is performed routinely in every flight, thereby it is rationalized as less critical by many, and is much more prone to resistance and misuse.

Both checklists are part of the Standard Operating Procedures (SOP) of the aircraft, as operated by the airline. In most airlines, the flight checklist is presented in the cockpit as a simple paper card, while the emergency checklist is detailed in the SOP manual or a Quick Reference Handbook (QRH).

Many carriers include elaborate explanations of the normal and the abnormal checklist in the SOP manual. This document, called the expanded checklist, follows the same steps as the normal and abnormal checklists, but in more details. The expanded checklist is used for training and as a supplement to the normal and abnormal checklist.

2.1.3 Checklist Errors, Mistakes, and Slips

The term "human error" engulfs all those occasions in which a planned activity (physical and mental) failed to achieve the intended outcome, and this failure can not be attributed to the intervention of an uncontrollable factor. "Planned actions may fail to achieve their desired goals for two reasons: because the actions did not go as planned (slips); or because the plan was inadequate (mistake)" (Reason, 1989).

Mistakes can occur in the planning stage (design) of a checklist. For example, In 1988 a Dornier 228-201 used by Midway Commuter, experienced a loss of directional control while taxiing and collided with another aircraft on the ramp. During the NTSB investigation, it was found that the checklist was redesigned and two items were left out: hydraulic nose wheel test, and brake test (NTSB, 1988c). Here a mistake in the planning stage led to this accident.

Slips are errors that occur during the execution of a planned sequence. These errors that usually occur while performing the checklist can be further divided into errors of omission and errors of sequencing. Error of omission are the most common errors in checklist use (Swain and Guttman, 1983). For example, the operator reads a checklist item "Engine oil quantity", looks at the gauge to verify this information, and then returns to the written checklist, but returns to the wrong place on the list and skips an item. Errors of sequencing occur when the checklist order is not controlled and items are not checked in the proper sequence.

2.2 CHECKLIST DEVICES

Different types of checklist devices have evolved over the years; they range from use of mnemonics to the use of a computer-aided checklist. The use of each type will be discussed, and advantages and disadvantages of each will be mentioned.

2.2.1. Memory and Mnemonics

In several types of operation the checklist is memorized by the pilots and no checklist device is used. Acronyms of codes are routinely used to assist the pilot in remembering the checklist items. For example, one acronym is GUMP (Gas, Undercarriage, Mixture, Pitch) another is TMPFF (Trim, Mixture, Pitch, Fuel, Flaps) (Dwiggins, 1982). This type of checklist is common in general aviation and in the military, but is illegal in commercial air transport. The advantage of memory-guided checklists is that there is no device to manipulate. Their disadvantages are that they are totally dependent on memory and require some semantic decoding.

Paper Checklist

This is the most common type of checklist used today in commercial operations. Because of the high prevalence of this type of checklist in the air transport industry, it will be the focus of this report.

The paper checklist is a very simple device; it consists of a list of items written on a paper card (see Figure 3). In most cases, the card is held in the pilot's hand, or clipped to the yoke (B-737/757). In other cases, it is glued to the instrument panel (A-310), or written on a placard located on the yoke.

There are several disadvantages to the use of a paper checklist. The main one is the lack of a pointer to show accomplished and non-accomplished items. Other disadvantages

Figure 3

Northwest MD-80 checklist

NORTHWEST

MD-80

EXTERNAL ELECTRIC & PNEUMATIC SOURCE - START

PNEUMATIC X-FEEDS ..... BOTH CLOSED
PNEUMATIC AIR SOURCE ..... CONNECTED & ON
PNEUMATIC X-FEEDS ..... OPEN
PNEUMATIC PRESSURE (25 PSI MIN) ..... CKD
COMPLETE - BEFORE START CHECKLIST

AFTER ENGINES STABILIZED

PNEUMATIC X-FEEDS ..... BOTH CLOSED
ELECTRIC POWER ..... *CKD
EXTERNAL ELECTRIC & PNEUMATIC ... DISCONNECTED
COMPLETE - AFTER START CHECKLIST

BEFORE START

BRAKES ..... SET
WINDSHIELD HEAT ..... *ON
FUEL PUMPS ..... *(AS REQ)
CABIN PRESSURE CONTROLLER ..... *SET
AUX HYDRAULIC PUMP & PRESSURE ..... *ON & CKD
CIRCUIT BREAKERS ..... **CKD
AUTOLAND ..... CKD
TAKEOFF WARNING ..... CKD
RADIOS, ALTIMETERS & FLIGHT DIR .... **CKD & SET
FUEL & OIL ..... **(QUANTITIES) & RESET

IGNITION ..... ON
SEAT BELT SIGN ..... ON
BEACON ..... ON

AFTER START

ANNUNCIATOR ..... CKD
IGNITION ..... *OFF
ELECTRIC POWER ..... *CKD
APU AIR ..... *(AS REQ)
AIR CONDITIONING SUPPLY SWITCHES ..... *AUTO
PNEUMATIC X-FEED ..... *ONE CLOSED
TRANSFER PUMP & HYDRAULIC SYSTEMS .... *ON & CKD

TAXI

FLAPS ..... **(SETTING)
TRIM ..... **(SETTING)
EPR & AIRSPEED BUGS ..... **(SETTINGS)
ARTS ..... (AS REQ)
FLIGHT INSTRUMENTS ..... **(HDG) & SLAVING
CONTROLS & ELEVATOR POWER ..... *CKD-TOP
CKD-BOTTOM

DELAYED ENGINE START

BRAKES & IGNITION ..... (AS REQ) & ON

DELAYED AFTER START

ANNUNCIATOR ..... CKD
IGNITION ..... *OFF
ELECTRIC POWER ..... *CKD
APU AIR ..... *OFF
AIR CONDITIONING SUPPLY SWITCHES ... *AUTO

ENGINE ANTI-ICE & FUEL HEAT ..... (AS REQ)
PNEUMATIC X-FEEDS ..... *CLOSED
APU ..... *(AS REQ)

BEFORE TAKEOFF

FLIGHT ATTENDANT ..... *NOTIFIED
TRANSPONDER/TCAS ..... *(AS REQ)
ANNUNCIATOR ..... CKD
IGNITION ..... ON

CLIMB

NO SMOKE SIGN ..... *(AS REQ)
IGNITION ..... *(AS REQ)
FUEL PUMPS ..... *(AS REQ)
CABIN PRESSURE CONTROLLER ..... *CKD
SYNC ..... *ON
HYDRAULIC PUMPS ..... *OFF & LOW
FLAP TAKEOFF SELECTOR ..... *STOWED

IN-RANGE

ALTIMETERS ..... **(SETTING) & X-CKD
EPR ..... *(GA)
AIRSPEED BUG ..... **(SETTING)
SEAT BELT SIGN ..... *ON
CABIN PRESSURE CONTROLLER ..... *CKD
HYDRAULIC PUMPS ..... *ON & HIGH

Adopted from NTSB, 1988a, Appendix E, p. 138

are the lack of a memory system to store unaccomplished items, and the need to occupy one hand in holding the checklist. This limitation is more critical while using the abnormal checklist, yet less critical while using the normal checklist.

2.2.2. Scroll Checklist

The scroll checklist consists of a narrow strip of paper that scrolls between two reels. The reels and paper are contained inside a box fitted with a window and a lubber-line. After completing an item on the checklist the pilot rotates the reels to position the next item on the lubber line (Figure 4). This type of checklist is common in United States Air Force (USAF) transport aircraft (C-9, C-141, C-5).

The main advantage of the scroll checklist is that it has a pointer system. One disadvantage of the scroll checklist is that, due to its relatively small size and orientation, it is difficult for the pilot to see the checklist devices which are mounted on the copilot and on the engineer panels. Nevertheless, these checklist devices are highly regarded by flight crews of these types of aircraft (G. Sexton, personal communication, October, 1988)

2.2.3. Mechanical and Electro-Mechanical Checklists

A mechanical checklist consists of a small panel that contains several plastic slides moving over a list of checklist items (see Figure 5). As the item is accomplished,

Figure 4

Scroll checklist

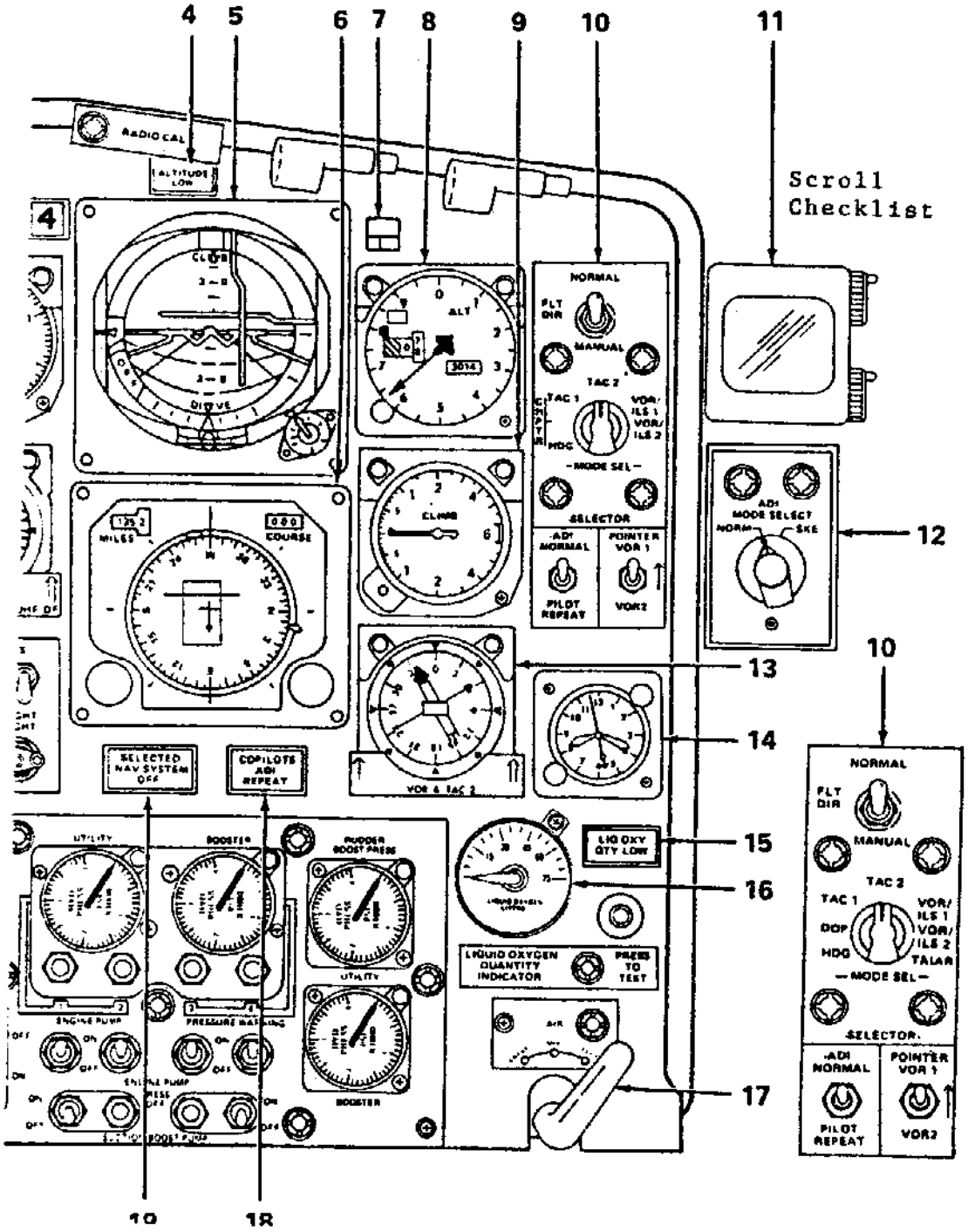
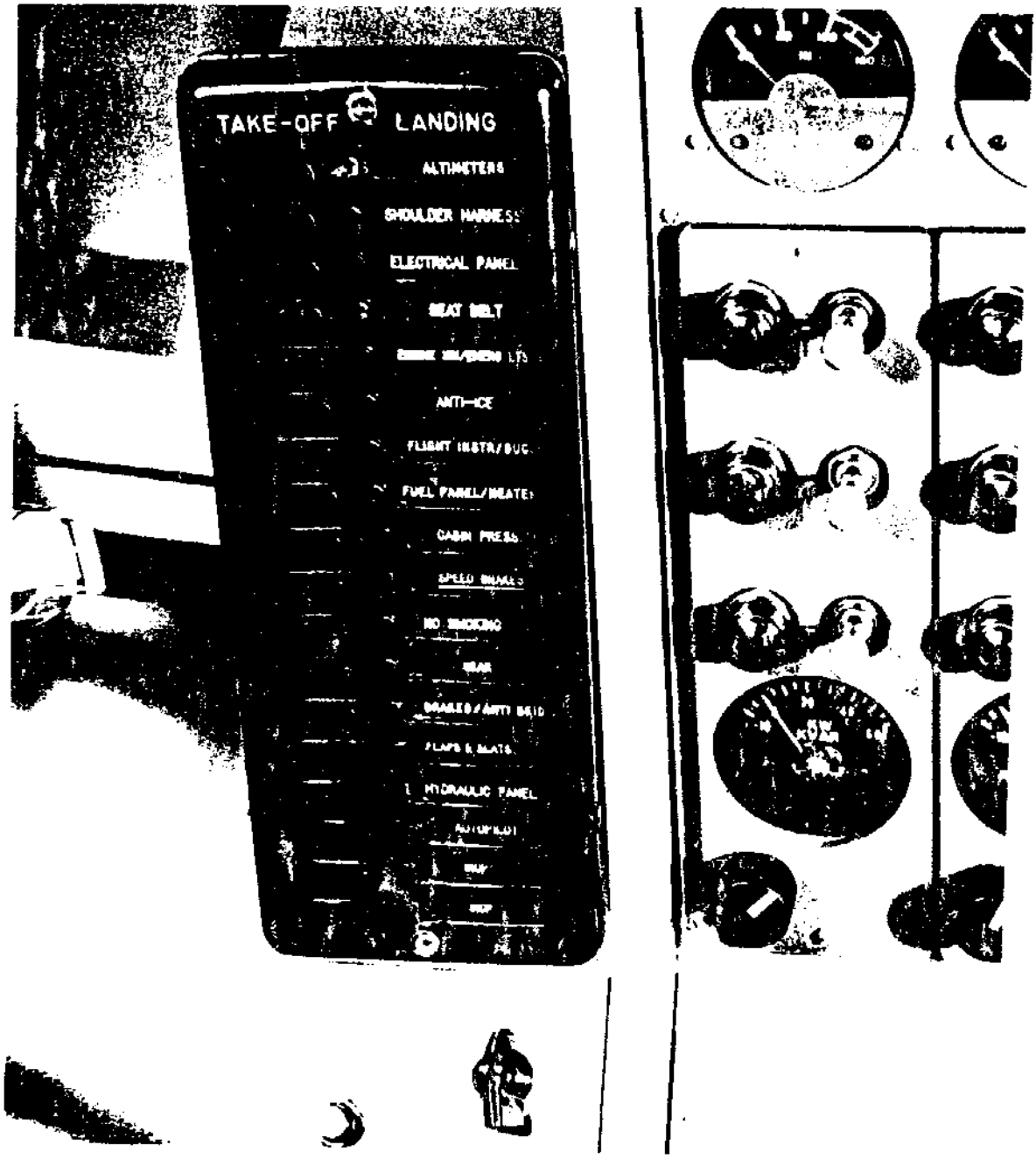


Figure 5

Mechanical checklist



the slide is moved to cover the item's nomenclature. Consequently, only the non-accomplished items are displayed.

Very similar in concept is the electro-mechanical checklist. This device is made of a small panel with an internally lighted list of items. Alongside each item, a toggle switch is mounted. When the item is accomplished, the switch is turned off, and the light below the item's nomenclature is extinguished to indicate that the item has been completed (Figure 6).

The mechanical and electro-mechanical devices are used by only one major US company for the BEFORE TAKEOFF and LANDING task-checklists. The rest of the task-checklists are performed from a paper card. The advantage of these checklists is that they have a pointer system, and allow presentation of skipped items.

2.2.4. Vocal Checklist

A vocal checklist is a unit that generates audible checklist-calls preprogrammed by the manufacturer or the user. Utilizing a rotary switch, the pilot can chose between 24 different normal and abnormal task checklists (see Figure 7).

Two push buttons-- "proceed" and "acknowledge" are mounted on the yoke. Once an item is completed and "acknowledged", the "proceed" button is pressed to allow the next item to be generated. If a "proceed" is pressed without prior acknowledgement, the device will repeat the checklist

Figure 6

Electro-Mechanical checklist

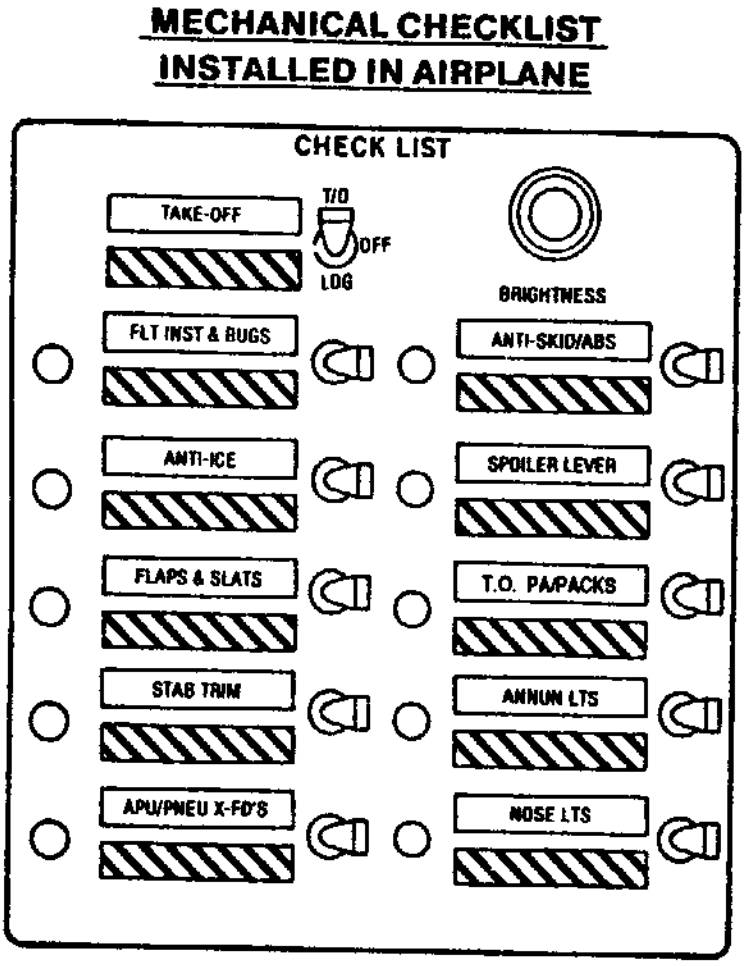
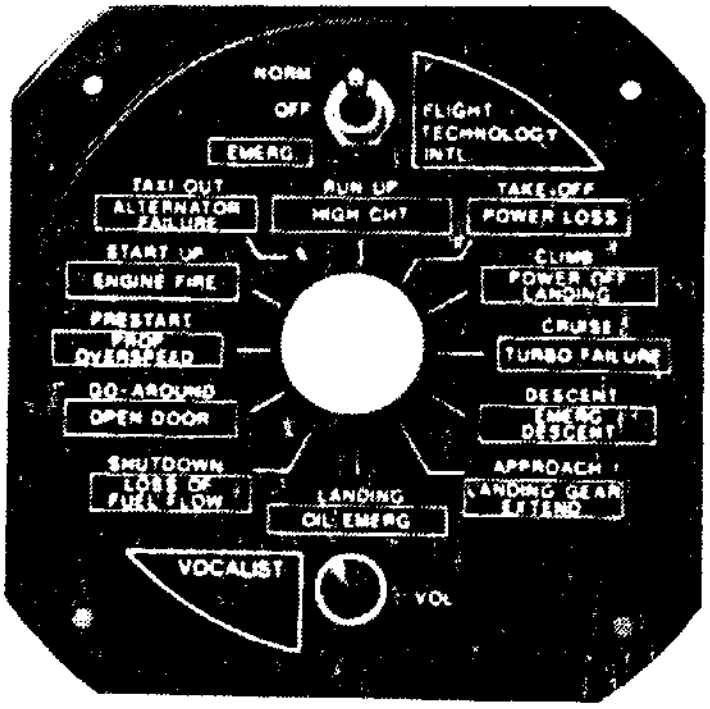


Figure 7

Vocal checklist



item once again. The pilot can also intentionally skip an item and save it for later recall. The saved item will be move to the bottom of the list and will be generated at later time.

One company that manufactures this unit has made provisions to prioritize the aircraft radio and cockpit communication (intercom) over the audible checklist. However, the author feels that the major drawback of this system is that it is a complete audio system. The checklist can be masked and blended into cockpit communications, and vice versa. The vocal checklists are mainly designed for General Aviation. However, they can be easily used in commercial air transport operations.

2.2.5. Computer Aided Checklist

With the introduction of computer-generated graphic radars and electronic displays, the option to include the checklist on these displays became available. There are two distinct categories of computer-aided checklist. The first is merely a display and pointer system, while the second is a display and a pointer system that is part of the feedback loop. In other words, the computer informs the pilot that the checklist item has been accomplished and the unit/system is in its desired position.

Display and pointer checklist. In the majority of these systems the pilot can choose between the emergency mode and normal mode. In each mode an index page with all task

checklists is presented. Using a cursor, the desired checklist is selected from the index page (see Figure 8).

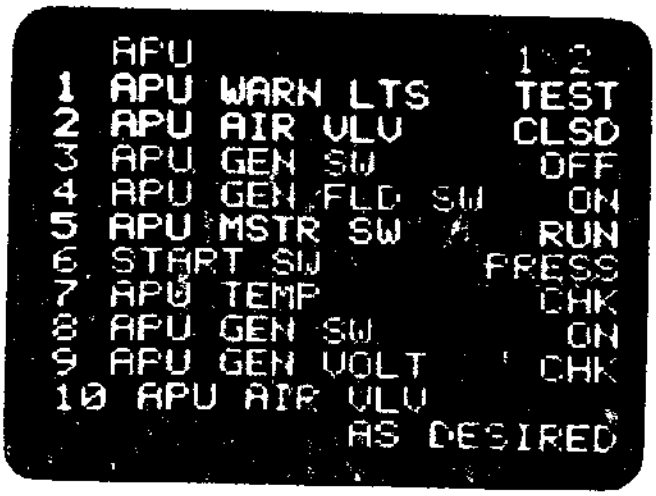
Immediately after selection of the task-checklist, all checklist items appear on the screen. As the cursor is moved to the item being considered, the color of the item changes. Once the item is accomplished by the pilot and acknowledged, the color of the item will change again to indicate a completed item. Intentionally skipped items remain in the initial color and can be recalled later. In most systems, the user cannot advance to the next task-checklist until all skipped items are recalled and checked. Nevertheless, in one company's device, it is possible to switch between different task-checklists prior to completing them. However, this action will erase the list of skipped items from memory.

It is not the objective of this discussion to critique any of the manufacturers of these checklist system. However, the author wishes to make one remark regarding the non-standardization of display colors. One major manufacturers uses the color green to indicate accomplished items while the other manufacturer uses the same color to indicate non-accomplished items. This, the author believes, can lead to some confusion among flight crews.

Due to the complexity and price of the above systems it is mostly found in commercial and corporate aviation. However, simple weather-scopes that can display checklist items are also prevalent in general aviation.

Figure 8

Display and pointer checklist



2.2.6. Experiments with Computer Aided Checklists

Rouse and Rouse (1980) conducted an experiment to evaluate the use of an onboard computer for checklist presentation. The display retrieved the procedures from its database and provided a pointer by dimming the already accomplished items on the screen. The results showed that this computer-aided procedure is superior to a paper checklist in error-rate and execution-time.

In a second experiment Rouse, Rouse and Hammer (1982) compared between a computer-aided checklist, which was part of the feedback loop, and a paper checklist. The use of normal and abnormal procedures was evaluated several scenarios in a commuter airplane flight simulator. The results showed that the computer-aided checklist was significantly better in error-rate. Conversely, the paper checklist was significantly faster than the computer-aided checklist in execution time. Rouse et al. (1982) explained that the slower execution time for computer-aided checklist "...is likely to be eliminated by training and/or redesign of the keyboard" (p. 462).

The advantages of a computer-aided checklist, regardless whether or not it is integrated to the feedback loop, are quite obvious. The device aids the pilot by providing a pointer, storing skipped items, and eliminating the need to

occupy one hand in holding the checklist card. However, there are also some disadvantages to be considered:

1) Limited monitor size.
2) Non-adjustable distance of the CRT from the operator eyes.
3) Inferior alphanumeric quality.

The above limitation result in a small amount of lines per display page. Therefore, the operator cannot view all of the already-accomplished items, since some have already scrolled up. Even more important, the operator cannot preview and mentally prepare for upcoming items.

The above disadvantages hamper the operational flexibility of this device for abnormal procedures. However, the rigid step-by-step procedure of the normal checklist is less affected by the above limitations. In addition, some of these limitations can be corrected with the use of computer windows and by improving screen resolution.

2.2.7. Monitoring computers and checklist usage

One of the important topics regarding checklist-information presented by onboard computers is the "recall" function. It requires much attention from human-factors specialists as well as user-training to reduce the likelihood of losing skipped items, or not retrieving information that exists in the computer, yet not displayed

to the pilot because of screen limitations. One ASRS report describe such misunderstanding,

> Departing San Diego we were informed by tower that someone had called on ground frequency to say that it appeared we had a hatch open on the aircraft. As the aircraft was not pressurizing, I leveled off and the captain recalled information on the EICAS <Boeing's Engine Indication and Crew Alerting System (EICAS)--an onboard monitoring computer>[1]. The display now informed us of two doors open....I had erased all information from the CRT while doing the fire warning test section of the BEFORE ENGINE START checklist, as I was trained to do, to determine that you have a valid fire test and to have a clean CRT for engine start. I did not manually recall advisory information to the CRT, as I had been led to believe, during my training, that the electric power change-over from ground/APU to engine driven generators was electronically sensed and that my messages that applied would be automatically displayed. My understanding that the manual recall was merely a backup if the automatic function was in error....An informal survey among my peer group flying this airplane leads me to believe that I am not alone in this misconception[2]. (ASRS #54596)

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1. Editorial insertions made for clarity of quoted text, are delimited throughout the text by the symbol < >.
2. Some of the ASRS reports were slightly edited for better comprehension, these editing corrections are not marked in text.

2.2.8. Computer aided checklist within the feedback loop

The Airbus A-320, probably the most advanced commercial transport airplane today, utilizes its Electronic Centralized. Aircraft Monitoring (ECAM) computers to aid the crew in configuring the plane for takeoff and landing. The critical items in the TAKEOFF and LANDING checklist appear on the CRT prior to those phases of flight. In addition, the computer utilizes a pointer to indicate accomplished items and informs the pilot the status of each of the checklist items. Once items are accomplished, the computer uses its logic to fade these items and clear the screen.

Although the checklist portion of the ECAM can be programmed to include all of the normal task-checklists, Airbus Industries has opted to program only the critical items of the TAKEOFF and LANDING task-checklists. As a consequence, the normal checklist must be conducted from a paper checklist.

Chapter 3

Different checklist concepts are used by the airlines, and they have a marked affect on checklist design. These concepts and methods will be discussed in the following section. In addition, the process of certifying the checklist according to the FAA regulation will be detailed.

3.1. CHECKLIST'S "PHILOSOPHY OF USE"

The use of the flight deck checklist during line operation is not limited to the device in use; it also pertains to the concept behind this procedure. These concepts are sometimes referred to as the "checklist philosophy of use". This philosophy, or, more accurately, the manner in which operator, checklist procedures and machine interact, varies between airlines, officials of regulatory agencies and airframe manufacturers, each one advocating his own philosophy of use.

3.1.1. The Airline "culture"

In most cases, the checklist philosophy of use is the outgrowth of the company's "culture". This broad term includes many factors that contribute to the overall operational concept of the airline. Some of these factors are the outcome of management style, such as supervision

concepts, delegation of responsibilities in the chain of command, punitive actions, etc. Other factors involve traditional methods of operation, pre-defined work policies, and management priorities. The culture of the airline leads, in many cases, to the practice by which flight management and training departments direct and edify flight operations.

3.1.2. Redundancy

The key word in the philosophy and use of any checklist is redundancy. Redundancy is the concept behind many aviation system and subsystems (Nagel, 1987; Sears, 1986). Sanders and McCormick (1987) state that "because humans are often the weak link in the system, it is common to see human-machine system designed to provide parallel redundancy" (p. 18). A similar principle of backup and redundancy is applied in the checklist procedure. There are two types of redundancies in the checklist process. The first is the redundancy between the initial configuration of the aircraft (setup) and the use of the checklist to backup and check this configuration (configuration-redundancy). The second is the redundancy between the various operators supervising one another while conducting the checklist (mutual-redundancy).

Both of the above redundancies require human action. This complicates the application of reliability and redundancy concepts of system design. For example, when a system engineer decides to place two hardware/software components

in parallel, and each component has a reliability of 0.8 (or a failure probability of 0.2), he can increase the reliability of the whole system up to 0.96 ($1-0.2^2$). However, when the same concept is applied to the human redundancies in the checklist procedure (configuration and mutual redundancy) the results are not the same. In some extreme cases, human redundancy can even decrease the reliability of the system. Accommodating and supporting the human redundancy imbedded in the checklist is one of the major objectives of checklist philosophy and design.

To understand how the checklist philosophy is shaped and used in flight operations, it is possible to divide it into several main components.

3.1.3. The Device

It is apparent that the type of checklist device is a factor in the philosophy of the checklist. The different checklist devices in use are detailed above. However, since almost all commercial carriers in the US use the paper checklist, the following discussion will focus on this particular device and its different philosophies of use.

3.1.4. The Method

There are two main methods of conducting the checklist--the "challenge-response" and the "do list". Each one is the outcome of a different operational philosophy. Nevertheless, there is no absolute boundary line for each method, and variations as well as combinations of these philosophies

exist.

Challenge-Response. In this method, which can be more accurately termed "challenge-verification-response", the checklist is a backup for the initial configuration of the plane. Here, the pilots use their memory and other techniques to initially configure the plane. After finishing this configuration stage, the pilots use the checklist to verify that several critical items have been previously accomplished. The process of conducting this checklist method is as follows: Pilot-A calls the checklist item from the printed list; pilot-B and pilot-A together verify that the item is set properly; and then pilot-B calls the verified status of the item, and so on. Hence, both configuration and mutual redundancies are employed by this method.

Do-list. This method can be better termed "call-do-response". In this method, the checklist is used to guide the pilot in actually configuring or setting up the plane in a step-by-step "cook book" approach. Therefore, the configuration redundancy employed in backing up the initial set up is eliminated in this method. The process of conducting this method is as follows: Pilot-A calls for an item; pilot-B positions or sets the item to the correct position, and then announces the new status of the item. Once the item is accomplished, the next item is read and so on.

Most do-list checklists of transport aircraft are very detailed and time-consuming, and their operational flexibility is reduced. The philosophy behind this method is very stringent in dictating the precise way of configuring the airplane. Not surprisingly, this method is widely used by the military for many types of transport airplanes. The scroll checklist discussed previously blends quite satisfactorily with this checklist method.

Combined. Several checklists used in the airline industry employ a combination of do-list and challenge-response methods. In most cases, the challenge-response is the dominant method, while the do-list method is used for ENGINE START and for the SECURE task-checklist. The logic behind this combined method (usually employed in two-pilot cockpit) is to reduce the workload on the captain by enabling the first-officer to do some of the task-checklist without the captain's verification.

The do-list and challenge-response methods are almost standard in the airline industry. Most carriers, however, favor the challenge-response or the combined method. In a recent questionnaire sent by Boeing to a selected sample of 20 world wide companies, the following responses (table-B) were obtained regarding checklist implementation methods (Boeing, 1989).

TABLE-B Tabulation of different checklist method used by 20 different airlines

Method	No. of operators
Challenge-and-response	12
do-list	1
Combined	7

3.1.5. The Items of the List

The question of which checklist items should be presented on the checklist presented is a cardinal question in checklist philosophy. Some will argue that most of the configuration items that are required in operating the plane should be presented in the checklist. Others will argue that since the checklist is a redundant task, only the critical and most important items should be presented on the checklist. This statement leads to another controversy--which items are critical and important enough to be registered on the checklist. For example, the "shoulder harness" check: some argue that this is a critical item that should be listed on the checklist. Others argue that the chances of an accident propagating directly from such omission are is very slim, and the use of the shoulder harness is second nature for the pilot population.

From a purely mathematical and system-engineering approach, the first argument appears correct. If the

checklist procedure is supposed to verify that the plane is configured correctly, then all items involved should be checked. This approach, especially if a legal department is involved, can lead to a very long and detailed checklist. The opponents of the above approach argue that a long and detailed checklist is no guarantee of safety. Indeed, it may carry with it the risk that some pilots might choose not to use the checklist or conduct it poorly. This outcome will effect the insignificant as well as the highly critical items in the checklist, and therefore defeat the purpose of the whole procedure.

From a human performance and psychological approach, the second argument seems more appropriate. If the procedure is to be used by humans in the cockpit, the checklist should accommodate human nature--its capabilities as well as its limitations. However, this approach may also subsequently yield problems. The plane may not be configured correctly in the setup phase, but this will pass unnoticed while conducting the checklist. Therefore, the philosophy of any checklist must detail what type of items should be presented. Likewise, and this is far more difficult, it should state what kind of items should not be presented.

Flight management, in this context, is in a dilemma. On one hand there is almost no method of assuring that the pilot will configure the plane properly, except to fully trust the pilot's experience, discipline, training, etc. On

the other hand, the FAA mandates a procedure (the checklist) designated to explicitly confirm this task. Hence, it seems rational that management would exploit the checklist to ensure itself that all configuration tasks are properly completed.

In sum, it appears that there is a trade-off between the different concepts regarding the level of checklist verification. The objective is to find the fulcrum point. This, when considering human variability and the fact the human lives might be at stake, is a very difficult decision at which to arrive.

3.1.6. The Pilot Population

Society, parental models, and education all lead to different discipline and behavior attributes among populations. The airline philosophy of a checklist should address theses unique attributes of its pilot group in order to optimize the use of the procedure. The same attributes should be used to predicate the need characteristics of managerial and supervisory control (Meshkati, 1988).

3.1.7. Type of Operation

There are conspicuous differences between long-haul and short-haul operation in regards to checklist philosophy and use. These differences have a marked affect on checklist philosophy and on checklist behavior.

Short haul. Pilots who fly short flight-segments (legs) perform the flight checklist as much as 5-8 times per

day and as many as 20-30 times per "trip" (3-4 flying days make up a trip, the work unit of an airline pilot). Therefore, a requirement to conduct a long and meticulous checklist for each flight may lead some to deviate from the prescribed procedures, and to perform only what he/she perceives as the critical items (or "killer items" as pilots call them).

It is wrong to infer from the above that crew members do not configure the plane properly. Rather, the point is that in cases where a lengthy checklist procedure is in conflict with the operational environment, the checklist may not be performed as prescribed in the SOP. For example, one company's DC-9-50 checklist contained 81 check items (challenge-response) for the ENGINE START to TAKEOFF task-checklists. Not surprisingly, pilots from this company expressed concern about poor checklist discipline in this type of operation, mainly because it takes so much time to perform this checklist.

Long haul. In this type of operation, the reverse condition occurs. Pilots who fly long routes perform the flight checklist only once or twice a day, and as little as 4-8 times per trip. In addition, the realization of the importance of the checklist is much higher in over-water operations because of the limited ability to divert to alternate airports following an omission or malfunction. Therefore, in general, crew members engaged in long-haul

operations are less resistant to a long and detailed checklist.

3.1.8. Automation

The use of computers in the flight deck allows for automated monitoring of flight status and better feedback to the pilot (Wiener, 1989). The onboard computers alert the crew when certain configuration items have not been accomplished and displays the actual status of the plane. The computer can be used to verify that all items have been accomplished ("recall" of the EICAS in Boeing 767/757 models) and thereby substantially reduce the size of the checklist.

This has led airplane manufacturers and operators to alter their checklist philosophies to coincide with the capability of the system monitoring computers. The Boeing's B-757 normal checklist philosophy states that,

> Normal checklists are used to verify that certain critical procedural steps have been accomplished. Only procedural steps which, if omitted, would have a direct and adverse impact on normal operation are included. Items annunciated by the Crew Alerting System (EICAS) are not included." (Boeing B-757 flight manual, 1985)

Not all carriers agree with the above statement, and some require their flight crews to check items in parallel with the automatic checks performed by the onboard computer. The concern here is the level of reliance on automation. The advocates of complete use of computer capabilities argue that the computer is far more reliable than the human in

monitoring, that the computer reduces workload, and that it decreases checklist distractions (due to reduced time frame). Opponents argue that regardless of software and hardware redundancies, computers sometimes do fail, and even worse, they collapse instantaneously. As an example, they point at the failure of the Central Aural Warning System (CAWS) of the Northwest MD-80, an engineering safeguard that was designed to warn the pilots of improper takeoff configuration. Another example is the significant amount of inoperative takeoff warning systems found in a recent tests of B-727's belonging to several companies (Herald Wire Services, 1988).

The differences in automation philosophy between airlines can be scrutinized by comparing the number of items in the ground phase (ENGINE START through BEFORE TAKEOFF) of the B-757 checklist (which utilizes an onboard monitoring computer). One company's checklist includes 50 items that the pilots are required to check in this phase. Another company's checklist has only 13 items for the same phase (omitting ACRAS and other unique items in this comparison).

3.1.9. Recommended Philosophy

Apart from the airframe manufacturer and airlines philosophies, the Air Transport Association (ATA), an industry-wide trade organization, has also stated its recommended checklist philosophy,

> Checklist should contain, in abbreviated form, all the information required by the trained flight crew to

> operate the airplane in most normal and non-normal situations. Normal checklists should be organized by phases of flight. The checklist should contain the minimum cues required for the trained crew-member to verify that the appropriate actions have been completed. Only procedural steps which, if omitted have direct and adverse impact on normal operations, are included. Items annunciated by crew alerting systems are not included (ATA, 1986).

It is interesting to note the similarity of this philosophy statement to the one advocated by Boeing regarding length of checklist and level of reliance on automation.

In sum, it is very tempting for any flight management or outside entity (media, legal, etc.) to argue that all configuration tasks performed in the cockpit are equally important and, therefore, almost all items should be presented and checked with the checklist procedure. This argument is easy to defend in a legal battle, since it immediately shifts the responsibility away from management and designer to the side of the front-line operators--the pilots.

On the other hand, the minimal checklist might fit more easily into the operational environment. However, a consensus can never be reached as to which items are critical and important enough to be included on the checklist. Furthermore, the success of this approach is quite difficult to measure in everyday line operation, and is even more difficult to defend after an accident. The

optimum, of course, lies somewhere in the grey area between the two extremes.

The philosophy of the checklist is probably the most important factor in its design. The author argues that, regardless of how well the checklist display is designed, if the pilot chooses to short-cut the checklist, he will certainly do so. The danger of this practice is that along with the insignificant items some of the critical ones might be skipped too.

3.2. CERTIFICATION OF CHECKLIST

The certification process of each checklist is unique because each airline's checklist is tailormade by the designer to suit its operational concept. Nevertheless, many entities help to shape the checklist before it is actually operated by line pilots. We will follow this process from the manufacturer to the daily use of the aircraft by the carrier.

3.2.1. The Airframe Manufacturer

The process begins with the airframe manufacturer which designs the plane, and determines its operational concept. This operational concept is the source from which the checklist is derived. After the first checklist is designed, it passes through a process of modification and later "fine tuning" in flight testing.

The FAA certifies the plane under Federal Aviation

Regulation (FAR) Part 25, which "...prescribes airworthiness standards for the issue of type certificates, and changes for those certificates, for transport category airplanes" (FAR Part 25.1-- Applicability). In addition, "...information and instructions regarding the peculiarities of normal operations (including starting and warming the engines, taxiing, operations of wing flaps, landing gear, and the automatic pilot)" are also certified under this regulation (FAR Part 25.1585). By complying with Part 25 regulations the plane is certified to fly. However, it is not certified to be operated by the customer, the airline.

3.2.2. The Airline

Once the plane is sold to the airline, the second certification process takes place. This certification process (Part 121--large commercial transports) is aimed at certifying the airline to operate the airplane.

The fleet-manager for a new airplane is responsible for the acceptance program of the aircraft in the carrier. The manager (or the designer) takes the manufacturer's previously approved procedures, and modifies them to coincide with the operational concepts of the airline.

The Part 121 certification process is conducted by the Principal Operation Investigator (POI) of the carrier. This individual and his staff are the FAA's representatives to carriers. They are responsible for initial certification, follow-on procedural changes, and act as the regulatory

watchdog for the carrier.

FAR 121.315 Cockpit check procedure

> (a) Each certificate holder shall provide an approved cockpit check procedure for each type of aircraft.
> (b) The approved procedures must include each item necessary for flight crew-members to check for safety before starting engines, taking off, or landing, and in engine and system emergencies. The procedure must be designed so that a flight crew-member will not need to rely upon his memory for items to be checked.
> (c) The approved procedures must be readily usable in the cockpit of each aircraft and the flight crew shall follow them when operating the aircraft.

The above regulation is the only statement pertaining to the use of checklist by air transport carriers as given by the federal government. It does not comment about the concept, method, type, or presentation of the checklist. Rather, it states the need for such a list, and mandates its existence in the cockpit. Furthermore, it leaves almost all aspects of checklist construction for the airline to design, and the POI to determine if he wishes to approve it or not.

For Part 135 operators (regional carriers or commuter airlines), the checklist must only agree with the FAA-approved training program for the applicable commuter airline. There is no formal approval of checklist changes, however, the duty to see that the checklist agrees with the training program lies with the POI (NTSB 1988b).

With the ambiguity of the FAR 121.315, and with almost no FAA internal guidelines for checklist construction, the POI has almost total authority over the approval of the checklist. He may approve or dismiss it according to his <u>own</u> philosophy of checklist usage. A note should be made here that most POI are not veteran air transport pilots.

The above subjective differences have led to some degree of non-standardization in checklist design and approval. In addition, they have brought about some contradicting situations. For example, checklist items that were made mandatory by one carrier's POI were not required by another POI. Nonetheless, both carriers fly the exactly the same plane.

Differences between FAR Part 25 (individual use) and Part 121 (commercial airline operation) have also led to several conflicts between flight management and the POI. In one instance, flight management of one company pointed at the FAA approved checklist procedure used by the manufacturer (Part 25), and wanted to use the same checklist for its regular operations (Part 121). The FAA did not approve this checklist because of the Part (121, 25) differences, and required the flight management to make changes in the checklist.

3.2.3. Daily Use

Once the checklist is approved by the POI under Part 121, it can be used for flight operations. However, changes and

modifications do not stop here, for they continue throughout the "life" of the airplane in the company. Each change proposed by the company must be presented to the POI and receive his stamp of approval. There are different types of checklist changes, some of which will be detailed below.

Manufacturer. The first type of checklist changes are those initiated by the manufacturer. These changes are mainly due to knowledge gained about the airplane in line operations (as opposed to flight testing). Although some changes in checklist following the introduction of a new airplane are expected, frequent changes can have a negative effect on the realization of the checklist's importance by the flight crews. Furthermore, pilots may revert to earlier checklist procedures. This type of problem was cited by the Safety Board (NTSB, 1988b) following an investigation of British Aerospace Corporation (BAc) J-31 commuter accident mentioned earlier,

> ...frequent revision of checklists for newly-acquired aircraft are understandable, but the fact that this <normal checklist> had been changed seven times between January and May 1987 suggests to the Safety Board that it original design <BAc> and approval <FAA> may have been inadequate and may have caused confusion among flight crews. (p. 22)

Conceptual changes. The second type of checklist changes arise from conceptual changes. For example, one airline that performs mainly short-haul operations has opted to adopt the B-757 checklist concept (minimal checklist of only critical items) to its fleet of B-737 planes. These changes have led

to a new philosophy of checklist now advocated by the airline's training department, and a clear reduction in the amount of checklist items.

Line changes. The third type of checklist changes are due to frequent problems in performing item(s) on the checklist, or tasks associated with them. These changes must be applied with extreme caution, because too many changes will tend to have adverse side effects on flight crews.

Some, upon being made aware of a pilot making an error that is related to plane configuration, may feel that, since one pilot could make the mistake, then the only way to prevent others pilots from making the same error is new provisions on the checklist. For example, several reports to the FAA stated that on two occasions B-757's belonging to one carrier have landed with the flight attendants standing in the aisles. The company's procedure was to use the automatic function of the "no smoking" sign (activated when the landing gear is lowered) to alert the flight attendants to prepare the cabin for landing, and no manual action or checklist item was used. Subsequently, the POI assigned to the company mandated that this task would be done manually prior to every landing and that this item would be included in the BEFORE LANDING checklist.

As a result of two incidents (neither of which led to injury), a simple automatic feature that was designed to relieve the flight crews of this task during a high workload

phases of the flight was made manual and added to the checklist. Regardless whether or not this incident was due to an error on the part of the flight crew, the whole checklist concept had suffered because of over-emphasis of an uncritical item.

Hardware and software changes in cockpit related system can also lead to checklist changes, i.e. installation of an Electronic Flight Instrumentation System (EFIS), navigational system, etc. When a company makes a significant change to the checklist, such action "...should be coordinated with the manufacturer to ensure that proposed operational procedures are adequately evaluated <by the manufacturer>" (Sears, 1989).

In sum, the checklist is involved in many phases of the flight. Therefore, it will be constantly changed and modified, making it a very dynamic procedure. However, in some cases its unique role in the operation of the aircraft is incorrectly used as a "dumping ground", either to resolve discipline problems and/or to show other regulating entities that an attempt to attack a problem has been made. By doing this, problems are not solved; instead the importance attached to the checklist by the pilot is reduced, leading to additional and possibly more severe problems.

3.3. STANDARDIZATION OF CHECKLIST

The standardization between different aircraft within the

company fleet is a factor that is part of the operational concept of the airline. It is obvious that a conscientious flight manager will set a goal to minimize the differences in operational procedures between fleets to aid pilots in transitioning (transferring) from one fleet to another. Not surprisingly, 16 airlines out of 20 that where surveyed by Boeing for having a lower-than-average crew-caused accident-rate have responded that "...document philosophy and format is the same for all airplane types operated" (Boeing, 1989).

Although the benefit of this approach to flight safety is quite clear, over-emphasis on this issue can hamper the effectiveness of the checklist. This is usually apparent when checklist sequence in the cockpit does not correspond to the location of items, and when some items which are not significant in a certain airplane are added for the sake of standardization within other airplanes.

Standardized procedures that are common to three-pilot cockpits of older generation airplanes (L-1011, DC-10, B-747-200) are sometimes not compatible with newer generation airplanes employing two-pilot cockpits (B-757, A-320). Attempts to enforce standardized procedures that belong to older generation airplanes on the checklist procedure of a modern airplane may result in poor checklist design, and even safety problems.

Most of the new planes that fly today, and those that will fly in the next decade, are modern derivatives of older

airframes (DC-9 -->MD-80, B-737-200-->B-737-300-EFIS). However, these modern planes differ from their counterparts in power plants and cockpit systems (EFIS, FMC, etc.). There are many questions arising in the industry today as to how to consider these fleets that are very similar in shape, yet very different in technology. Some opt to treat them as completely different planes, having separate training schools, and bidding processes ("separate status"). Others regard them as having equal status. Similar problems arise in checklist design. The main question being whether the checklist should be standardized between the derivatives or whether each derivative should have its own checklist.

One ASRS report details the effect of this problem on flight operations,

> During this phase of flight the flaps/slats handle was selected to 5 degrees while 15 degrees was required. This improper selection was initially missed on the checklist, however it was corrected before the taxi checklist was called complete...such positioning errors may be a result of the following:
>
> 1) When the flight crew operated 3 series of aircraft within a single aircraft type rating, with variations on each series.
> 2) Operating of these aircraft on a daily basis.
> 3) Transfer of crew-members from aircraft to aircraft on a rapid fast moving flight schedule.
>
> Such errors may be reduced with some of the following suggestions: A type of regulatory environment for cockpit standards....Careful review of the cockpit checklist corrected the flap setting problem, However, such may not always be the case... (ASRS #92957)

Management and training departments can try to soften this effect, as the following example concerning derivatives illustrates. The weather radar of the MD-80 (a modern

derivative of the DC-9) operates on low transmission power, and there is no need to shut-off the radar on the ramp during intermediate stops. However, the DC-9 radar has a high power transmission and it is a requirement that the radar be shut-off on the ramp for the safety of ground crews. While both planes were in operation in one company and under the same "status", flight management decided to require flight crews of the MD-80 to shut off the radar in intermediate stops, and thereby reduce the possibility of a former MD-80 pilot reverting to older habit pattern while flying a DC-9.

TWO/THREE-PILOT COCKPIT

The prevalence of the two-pilot cockpit airplanes in the present and in future cockpits has a substantial affect on the philosophy of checklist use. Therefore, the effect of crew complement on checklist usage will be discussed below.

Airline checklist philosophies have evolved during the era of multi-crew cockpits. Consequently, the traditional paper checklist and the challenge-response method are the outcome of these operational environments. In the three-pilot cockpit the flight engineer assumes a major role in the checklist procedure, and in its management. This non-piloting crew member is responsible for the plane's systems and is less occupied with outside actions such as communication, ATC instructions, taxiing, etc. Situated

behind the pilots and at hands reach from most systems controls, the flight engineer is able to be the conductor of this whole procedure, and serve as its quality control inspector,

> This captain had told me the day before to use flaps 15 for the takeoff data card unless 5 degrees looked better. So when checking this takeoff the differences between 5 degrees and 15 degrees were insignificant so I wrote 15 on the card very plainly, and 5 dump was directly above it. The captain and the first officer knowing our gross weight was higher then average both figured I would give a 5 degrees flap takeoff card, so they both said later that they focused on the 5 beside dump. I caught the 5 degrees flap during the final checklist. (ASRS #48912)

In the design of the two-pilot cockpit, the position of the flight engineer was eliminated, and his duties were either absorbed by cockpit automation, or by other crew members (McLucas et. al, 1981). This transformation necessitated changes in task assignment, cockpit management, and subsequently checklist philosophy.

To cope with the new situation, several airlines relaxed the checklist in the taxiing and flight phases by allowing the pilot not manipulating the controls (usually the F/O) to challenge himself and respond to himself. Thus, these airlines have eliminated the mutual redundancy which is part of the traditional checklist procedure. On the other hand, they minimized the amount of distraction produced by checklist-use in those phase.

The checklist procedure in the two-pilot cockpit is very different from the procedure in a three-pilot cockpit. Some

argue that the quality of this procedure (paper checklist and challenge-response method) in two-man crew is below the appropriate standards because some aspects of mutual redundancy are eliminated. Others argue that this elimination of redundancy is offset by automation.

3.4. AIRLINES MERGES, ACQUISITIONS AND CHECKLIST USE

In the last 11 years since the Airline Deregulation Act of 1978, numerous companies have been taken over, merged, and sold to other companies. The amalgamation of two organizations with different operating methods, and the subsequently the amalgamation of amalgamation two pilots groups, pose many problems to the management of the new airline. Some of these problems affect checklist use and will be discussed below.

After a merger or a takeover, an adjustment period takes place. During this period the major company inspects the operational procedures of the merged company, and initiates a program to standardize ("mirror image") the procedures and checklists of the acquired airline. The new standardized procedures are, of course, based on the philosophy of the major company, which is sometimes very different from the philosophy of the acquired company.

During this period of financial difficulties following mergers or acquisitions, the personnel of the acquired company may go through a period of emotional anxiety that

affects their performance. In particular, flight crews may go through a painful process involving financial uncertainty, base and route changes, and collapse of existing seniority structure (Lautman and Gallimore, 1989).

This stage is well-detailed by several reports sent to the ASRS following such situations,

> ...Went to crew room for flight release, and got the new information concerning company buy-out. Upset again like the last four years. Two choices: sign up or no job....I began the checklist but was interrupted by passing on the buy-out news to the flight attendants. First officer and I continued the discussion and did not finish the last item on the checklist (required papers on board). When I looked at the fuel gauges and totalizer I must have seen 9.9 instead of the required 19.0 plus....Over ALS VOR, our first fuel check point, fuel gauges where showing approximate 4000 lbs total....Flight officer looked for fuel slip. It was not onboard.
> Contributing factors: Over the last four years our airline has gone through many changes. Upstart airlines, scab pilots, route and cities dropped, over half out aircraft sold and ESOP failed even with 50 per cent pay cuts and working concessions...Over these years none of the employees knew if the next week we will have jobs. Tension among employees is very high these days. At the beginning of this trip flight officer even mentioned if anything (accident) where to happen it would be between now and the final outcome of the buy-out. (ASRS, #55218)

In addition to the emotional anxiety discussed above, Flight crews must also adapt to new operational philosophies, procedures, work rules and regulations. This anxiety and resistance to change sometimes manifest themselves in poor pilot-group morale and anger toward the new company. This anger is usually transferred or displaced away from its source to other tracks. Displacement of feelings is defined by the American Psychiatric Association

glossary as "a defence mechanism, operating unconsciously, in which emotions, ideas, or wishes are transferred from their original object to a more acceptable substitute; often used to allay anxiety." (Werner, Campbell, Fraizer, Stone, and Edgerton, 1984, p. 30).

Some of this displaced anger, the author believes, finds itself unconsciously directed toward the checklist for several reasons:

1. the checklist is a normal and routinely performed procedure.
2. It is a "safe" procedure to eliminate (because of the many redundancies).
3. It is <u>mandated</u> by the acquired company, however, no provisions for on-site enforcement are visible.

Therefore, the checklist is an attractive site to displace the anger toward the new circumstance with almost no chance of punitive action.

3.4.1. Checklist Changes

The effect of changes in checklist procedures and habit patterns on flight crews can be seen in the following example,

> Our company was bought by a competitor about a year and a half ago. The new airline has specific policies, procedures and philosophies that differ from the former airline that I believe contributed significantly to this incident. At the former airline, the F/O's were taught to automatically extend flaps and slats when the aircraft was saluted away by the ramp agent. The new airline allows slats/flaps extension only after the aircraft is away from the ramp and upon command of the captain....Upon reaching the outbound taxiway and due to

> a long line of aircraft waiting I shut down number one engine to save fuel. We couldn't complete the taxi checklist (which includes flaps/slats) because company procedures prohibit accomplishing this task while taxiing on one engine. My former airline used a single engine taxi before takeoff checklist, which assured extension of flaps/slats....Per company procedures I called for the before takeoff checklist rolling onto the takeoff runway. I knew the next landing aircraft was rapidly approaching the runway....I advanced the power levers and immediately the voice warning system said "Flaps/Slats". At this point it was obvious we had not accomplished the taxi checklist....For purpose of standardization, the new airline did not accept any of the former airline operating policies or procedures (including checklist), even though there were 22 years of operation with the former airline--and many checklist improvements over that time to assure the safety of operations....There is an obvious need for proper authorities to consider factors such as past practices before approving checklists on airlines that have been merged or bought out.

The above problems that result from mergers and acquisitions have a profound effect on flight safety in general, and use of checklist in particular. These difficulties "require anticipation and alertness on part of management to minimize the impact on safety" (Lautman and Gallimore, 1989, p. 8). It also requires a great deal of sensitivity and understanding from the acquiring operational management to accommodate these difficulties. The author feels that if there is a good argument for a nationwide standardized checklist, this issue will certainly augment it.

Chapter 4

Until now we have discussed the use of different methods and concepts of performing the checklist. In this section we will discuss the process of conducting the task-checklist. This process can be divided into three steps. The first step is the initiation, usually called by the Pilot in Command (PIC), in the ground phase and/or the Pilot Flying (PF) in the airborne phase. The second step is the routine of calls and responses. The third and last step is the completion of the task-checklist. The processes associated the above tasks will be discussed below.

4.1. CHECKLIST INITIATION

Initiation is one of the factors that makes the checklist vulnerable to human error because it is the responsibility of the human operator to initiate this task using his long term memory, habit patterns, and, in extreme cases, backup from the other pilots in the cockpit. Checklist activity is almost always going to be performed in conjunction with other cockpit tasks such as radar monitoring, looking for traffic, operating systems in the cockpit, etc. (Monan, 1979).

The initiation of the checklist requires the pilot (PIC, PF) to judge when to call for the task-checklist, and to recall if previous checklists have been done and properly completed. This process, when coupled with high workload, stress, and schedule-pressures might lead to checklist initiation mistakes. There are several factors that have an affect on checklist initiation. Some of these factors will be discussed below.

4.1.1. Checklist "Cues"

Many pilots use internal as well as external cockpit cues to aid them in initiating the checklist. For example, the BEFORE START can be cued with the closing of the passenger door; the AFTER START can be cued with the completion of the last engine start; the BEFORE TAKEOFF checklist can be cued by reaching the hold line before the runway; the DESCENT checklist can be cued at transitioning altitude of 18,000 feet; the AFTER LANDING can be cued by crossing the taxiway separation-line and receiving taxi instructions.

Checklist cues are not part of the SOP's, rather they are more a personal technique among pilots. There are some problems with this technique: cues are not always present, applicable, and they can be easily missed. For example, many pilots that were interviewed said that they cue the initiation of the TAXI checklist when the airplane starts to roll on the ramp. However, sometimes this cued initiation is delayed while crew members are establishing radio contact

with ATC, taxiing through congested areas on the ramp, communicating with company, etc. All the above are potential distractions that may require the pilot to delay checklist initiation. But by now, the outside cue is gone.

This is what may have happen to the crew of Northwest Flight 255. Testimony from other Northwest flight crews showed that they usually complete the TAXI checklist within the first 1-2 minutes of the taxi phase. However, due to several interruptions in the checklist progress (new weather information, checking aircraft and runway data), the TAXI checklist was not completed within the first minutes of the taxi.

> By this time the airplane's location on the airport was such that the external cues and references available to the flight crew were not those normally associated with the initiation of the TAXI checklist at Detroit-Metro <Airport>. (NTSB, 1988a, p. 58)

4.1.2. TAXI Checklist

The taxi checklist is one of the most complicated task checklists to initiate as well as to perform. The term "taxi checklist" is broadened here to include the TAXI checklist and also the AFTER LANDING checklist (which is also performed while taxiing). TAXI checklists are difficult to manage mainly because "they can be reasonably be initiated and accomplished any time after the captain begins to taxi.." (NTSB, 1988a p. 57). Almost all companies require that checklists will be completed during the taxi phase, yet

only a few add a phrase or two instructing when to initiate the checklist during taxiing.

> Landing was normal, but due to 15 knots cross-wind component, I was fully occupied with controlling the aircraft. During this period Tower advised "turn left, first taxiway available". The first officer acknowledged and we cleared the active runway. Flight engineer, and first officer began the "AFTER LANDING" checklist. Crossing Runway 4L, I heard a voice (later identified as light aircraft) say "It's okay, aircraft A we'll takeoff over you". Observed a light twin engine aircraft well down the runway and well above us. At this point, first officer looked up and remarked "we were suppose to hold short of runway 4 Left. This was the first time I was aware of this...(ASRS #34026)

Another airline captain who had also taxied without clearance recommends a very sensible time-frame that might have prevented the above incident,

> ...I normally call for the checklist immediately after clearing the runway. However, <after this incident> I now feel that it's best to first ascertain taxi-in clearance before calling for the checklist...After riding jumpseat with various airlines I noticed that there is an unusual habit of calling for the AFTER LANDING checklist too quickly. It's apparent this could be the root of numerous taxi/communication errors. (ASRS #33672)

4.2. CHALLENGE-RESPONSE

This section will detail different checklist usage behaviors, the problems associated with each one and their effects on checklist performance. Most of this information was gathered during the field studies, and some from line pilot interviews.

4.2.1. Memory Guided Checklist

In several instances during night operation, the checklist was drawn out of the slot (above the glare shield), but no light was turned-on to allow reading. The checklist subsequently was done from memory. A quite similar habit was observed in both day and night operation: the pilot would stretch his hand out and touch the checklist situated horizontally on the glare shield (there is almost no ability to read the checklist in such condition), but would not draw the checklist out of the slot. It is interesting to note that the pilot had a habit pattern of associating a motor response with the checklist procedure. Nevertheless, the checklist was not drawn from the slot and the checklist was read completely from memory.

4.2.2. Verification

In some cockpits, the task of verification was left only to the pilot responding to the checklist. The pilot challenging the checklist (PNF) would read the checklist items but not move his eyes away from the list to cross-check his partner. Therefore, the mutual supervision embedded in the checklist procedure was eliminated.

Several Pilots Flying (PF) would answer with the proper response immediately when they heard the challenge call from the PNF, not verifying that the item called was set accordingly. This was clearly evident in high work-load phases of flight, or while the PF was trying to demonstrate

a high level of competency. In this case, the pilot must rely on his short-term memory to judge whether he did or did not set the checklist item a few seconds or minutes ago.

Some of the above pilots who had the habit of not closely watching the item before responding to the challenge have added an additional personalized safeguard. The responding pilot would complete the entire "challenge-and-response" callouts, and only then focus on the items in order to verify that the responses he called before did in fact portray the actual configuration of the airplane. It appears that the pilot did sense the low quality of his checklist process, and thus created for himself this additional safeguard. Quite similarly, several pilots that were interviewed stated that they have their own checklist procedure which they perform from memory just prior to takeoff. Nevertheless, this backup technique has some inherent hazards:

1. It is based on memory, and not on a step by step challenge-and-response
2. It is dependent on the availability of time after the quick completion of the checklist
3. It is vulnerable to distraction such as ATC communication, outside scan, and more

4.2.3. "Short-Cutting" the Checklist

Several pilots deviated from the item-by-item challenge-and-response method to a faster technique. This technique

was to call several challenge items together in one "chunk", while the other pilot would reply with a series of "chunked" responses. This technique of conducting the checklist undermines the concept behind the step by step challenge-and-response procedure. The problem with this type of technique is that it relies on the pilot's short-term and long-term memory as to the order and completion of the checklist, which, in fact, is exactly what the checklist is supposed to prevent. Quite interestingly, Swain and Guttman (1983) found the same checklist technique used by nuclear power plant operators. They defined this behavior as, "performing several steps and then checking them off all at once on the checklist" (p. 16/2).

Performing part of the checklist as a do-list method was another technique of short cutting the checklist. This was mainly observed in the TAXI and DESCENT/APPROACH checklist. When the flight checklist becomes a do-list, the double safeguard embedded in the procedure is lost--making the checklist more prone to errors.

4.3. DISTRACTIONS

This issue is probably one of the most critical factors in checklist failures. Distractions in checklist flow can be divided into two distinct categories:

1. Airborne phase--mainly involving distractions from

other piloting tasks, service/passenger problems, malfunctions, high workload, etc.

2. Ground phase--involving distractions from ground crews, ramp agents, maintenance,, etc.

All of the above entities and tasks can come into play while the checklist is performed or while the PIC/PF plans to initiate a checklist. Most of these can be reduced with good cockpit management, however, some of these distractions cannot be controlled by the flight crews.

Monan (1979) conducted a study of distraction reports sent to the ASRS system in order to determine the causes of distraction in the aviation system. He states that "one of the frequently occurring causes of hazardous events in air carrier operation is the human susceptibility to distractions" (p. 3). He argues that due to distraction, one airman is removed from the operational loop and thereby a vital cross-checking function is eliminated. The operation becomes vulnerable to any error committed during "the one man show".

4.3.1. Airborne Phase

In 1983 a Republic DC-9-82 lost all power from both engines while on cruise at 35,000 feet, 20 miles north of Bryce, Utah. During the emergency descent, the crew performed the emergency checklist and switched-on all of the fuel boost pumps. Upon reaching 12,200 feet, both engines started. The crew and airplane diverted to Las Vegas,

Nevada. The NTSB investigation revealed that the main fuel tank on each wing was empty while the center tank contained all the fuel needed to complete the flight safely.

According to the DC-9-82 CLIMB task-checklist procedure (challenge--and-response by the PNF only), center-tank fuel boost-pumps were to be switched-on shortly after takeoff (see Figure 9). During the takeoff, the autopilot heading-select knob came off, momentarily distracting both pilots, leading the captain to call for the CLIMB checklist "out of normal order". The first officer wrote that,

> at that point and during a turn, Bob <the captain> called for "climb check". Because of our weight and my being new in the plane, I thought he wanted to turn with flaps and slats extended during the turn, so I proceeded with the climb check. I planned to go down the checklist to, but not including the hydraulic pumps, and then wait for the flap/slat retraction command. During the checklist, as I completed the ignition off <item>, Bob called for "flaps and slats retract". I then received a radio call to "change to departure" frequency. After flaps and slats were retracted and the radio frequency change, I continued with the checklist as I had planned. In retrospect, it appears that I may have left the center boost pump switches <u>off</u> (NTSB, 1983).

Figure 9

Republic DC-9-80 checklist

BEFORE START

SEAT BELT . . . . . *ON
PITOT HEAT . . . . . *CAPT
WINDSHIELD HEAT . . . . . .*ON
FUEL PUMPS . . . . . .*MAINS ON
AUX HYD PUMP & PRESS . . . .*ON & CKD
RADIOS-ALT & FLT DIR . . .**CKD & SET
XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
FUEL & OIL . . . (QUANTITIES) & RESET
BRAKES & IGNITION . . . . AS REQ & ON

AFTER START

ANNUNCIATOR . . . . . CKD
IGNITION . . . . . *OFF
ELECTRICAL POWER . . . . . *CKD
APU AIR . . . . . *AS REQ
AIR COND PACKS . . . . . .*AUTO
PNEU X-FEED . . . . . *1 CLOSED
TRANS PUMP & HYD SYS . . . .*ON & CKD

TAXI

FLAPS . . . . . .*15°
TRIM . . . . . .**SET & CKD
EPR & IAS BUGS . . . . .**SET & X-CKD
FLT INSTRUMENTS . . . .**(HDG) & SLVG
ANTI-SKID . . . . . **ARMED
CONTROLS & ELEV PWR . . .**FREE & CKD

DELAYED ENG START

BRAKES & IGNITION . . . . AS REQ & ON

DELAYED AFTER START

ANNUNCIATOR . . . . . .CKD
IGNITION . . . . . *OFF
ELECTRICAL POWER . . . . . *CKD
APU AIR . . . . . .*OFF
AIR COND PACKS . . . . . .*AUTO

ENG ANTI-ICE & FUEL HEAT . . . AS REQ
PNEU X-FEEDS . . . . . .*CLOSED
APU . . . . . .*OFF

REPUBLIC AIRLINES, INC.

DC-9-80

BEFORE TAKEOFF

FLT ATTENDANT SIGNAL . . . . *2 BELLS
TRANSPONDER . . . . . *ON
FLAPS . . . . . *(SETTING) & CKD
ANNUNCIATOR . . . . . CKD
IGNITION . . . . . ON

CLIMB

NO SMOKE . . . . . *OFF
IGNITION . . . . . .*AS REQ
FUEL PUMPS . . . . . *CKD
CABIN PRESSURE . . . . . *CKD
AIR COND AUTO SHUT OFF . . . . .*OVRD
HYDRAULIC PUMPS . . . . . .*OFF & LOW
FLAP T.O. SEL . . . . . *STOWED

IN RANGE

ALTIMETERS . . . ** SETTING) & X-CKD
EPR & IAS BUGS . . . . .**SET & X-CKD
SEAT BELTS . . . . . .*ON
CABIN ALTITUDE . . . . . *CKD
HYDRAULIC PUMPS . . . . . .*ON & HIGH

BEFORE LANDING

NO SMOKE . . . . . .*ON
IGNITION . . . . . .*ON
FUEL SYSTEM . . . . *SET FOR LANDING
AIR COND AUTO SHUT OFF . . . . .*AUTO
GEAR . . . . . *3 GREEN
SPOILERS . . . . . .ARMED
AUTO BRAKES . . . . . *AS REQ

Adopted from NTSB, 1983

In his study, Monan (1979) reviewed 169 air-carrier distraction reports from the ASRS database. The tabulation of these reports indicated that checklist usage created more distraction than any other task (Table-C). The reason for this is that compared to all other tasks detailed, the checklist processes are the most lengthy in time-frame, and they are routinely performed during the high workload phase of flight.

TABLE-C Types of reported distractions

Type	Number
Non-operational activities	
Paperwork	7
PA system	12
Conversation	9
Flight attendant	11
Company radio	16
Operational - Flight workload tasks	
Checklist	22
Malfunctions	19
Traffic watch	16
ATC communication	6
Radar monitoring	12
Studying approach plate	14
Looking for airport	3
New first officer	10
Fatigue	10
Miscellaneous	2
Total	169

(Adopted from Monan, 1979, table 1, p. 5)

4.3.2. Ground phase

During this phase, when the plane is either at the gate or taxiing to the runway, the checklist sometimes needs to be stopped to await a certain condition(s) that is under the responsibility and control of external entities (waiting for fuel, waiting for cargo door to be closed, maintenance, etc.). One ASRS report details such an interruption of checklist sequence,

> ...beset by schedule delay and distracted by a jumpseat rider and a ramp-agent, the ENGINE START checklist was interrupted; the flight was "standing-by for fuel"....inadvertently missed the only reference to fuel on any of our checklist. During taxi, I did glance at the fuel gauges, but since it was not in response to a checklist, I noted only that the gauges looked "about right". The next time I glanced at the gauges we were at cruise....This time they didn't look "about right" and I immediately realized what had happen. (ASRS Callback #115, 1988)

Hold on the checklist. Several companies have a procedure to manage this situation. They require that during an interruption that leads to a stop in the checklist sequence, the pilot should call "hold on <name of checklist item>". Nevertheless, most pilot that interviewed said that in practice only very rarely would they would use this callout. Other companies disregard this condition, and do not state how the pilot should behave upon an interruption or hold in the checklist sequence. When no special provisions are taken to mark the location of the hold, then the only place for retaining the hold point is in the low-capacity short term memory.

Short-term memory highly susceptible to interference from communication (such as flight attendants, ATC, ATIS,, etc.). Wickens (1988) states that,

> the principal cause of forgetting or of loss of information from working memory <short term memory> is interference. That is, information to be stored in working memory becomes confused or replaced either by information that was previously stored or by new information. Unless actively rehearsed, information in working <short-term> memory will generally be forgotten within about 10 to 20 seconds. (Wickens and Flach, 1988, p. 126)

The step-by-step sequence of the checklist procedure, is well known to give inexplicable errors. Some of these errors are due to the fact that position in the sequence must be indexed by some kind of a pointer in the working memory. This pointer, however, is easily displaced by any other form of activity during this sequence (D. E. Broadbent, private communication, March 14, 1989). One solution, mandated by one US carrier (AA), is to start the procedure from the beginning of the task-checklist following a hold. However, it is only reasonable to require this in cases where the appropriate checklist is relatively short. If a ground phase checklist contains 60 items, it will not be operationally sound to require starting the list over again because most pilots will eventually short-cut this requirement.

4.3.3. Holding Line

In several BEFORE START checklists and other task-checklist obtained by the author, the items on the checklist were divided in two groups separated by a dashed line. This

method is used to indicated a usual holding place in the checklist process. This location is termed as "the line". The line usually indicates a time frame for major tasks such as physically starting the engines. Therefore, the checklist is completed to "the line" and so stated in a callout. At this point the pilot can attend to other tasks, and afterwards continue with the items "below the line".

4.3.4. Maintenance

Maintenance personnel, as all other agents that are involved in dispatching the plane, can disrupt the checklist process. However, as opposed to all other agents who can only interfere or distract the pilot while performing the checklist, maintenance personnel have "hands on" access to checklist items.

In many cases, maintenance personnel are under the same schedule pressures as are the pilots for "on-time departure". While working on a malfunction, maintenance personnel sometimes need to alter the configuration of the plane. But, under pressure, they may forget to reset the plane's systems to their proper configurations.

> Arrived in ORD on a turnaround back to EWR...Noted after landing the #3 thrust reversers lever was not quite flush with #1 and #2...Maintenance began investigating. Maintenance worked on it until 15 minutes prior to our departure, determined it requested a part and placed the item on the open item list. The crew did the through-stop portion of the checklist, than the before start prior to pushback....During the start I must have been distracted...As my scan returned to the instruments, I expected to see approximately 20% N2 and some N1....What I saw when I first looked at N2 was approximately 35% and accelerating. I looked down and saw the start lever in

> idle, then saw EGT peak at or slightly below the maximum allowable temperature for engine start on the ground....My first thought was that the first officer had raised the start lever as I was looking left without saying anything. I then noted that all 3 start levers were in the idle detent and it became clear that maintenance had placed them in that position during their work....The full receiving checklist calls for checking the start levers in the cut-off position, which we did in when we received the plane in EWR....Through stop checklist does not call for us to check the start levers in cut off. Not expecting them to be in a different position from where we left them after the parking-checklist, all 3 crew members and obviously maintenance before us failed to catch that they were in idle. (ASRS #90128)

It appears that cockpit management requires the captain to consider the work done by outside agents and asses the likelihood that this may have an affect on the proper configuration of the plane. He then can decide whether he wishes to conduct the "through stop" checklist or conduct the lengthy preflight checklist even though the plane is in a through-stop station.

4.3.5. Indexing the checklist

Swain and Guttman (1983), in their study of human reliability, analyzed Human Error Probabilities (HEP) for various tasks in nuclear power plant operations. Operators in these facilities also use checklists for various tasks such as maintenance, normal and abnormal operations. They have recognized that a checklist without a check-off provision "is more susceptible to errors of omission than a procedure with a check-off provisions that is used properly" (p. 15/13). They reported that the estimated probability of

error (per-item) for a checklist with no check-off provision is 0.01, while the probability of human error for a checklist with check-off provision is 0.003 (see Table D).

TABLE-D. Estimated Human Error Probabilities (HEP) probabilities of errors of omissions per item of instructions when use of written procedures is specified

Omission of item:	HEP
1. When procedures with check-off provisions are used:	
a). Short list, < 10 items	0.001
b). Long list, > 10 items	0.003
2. When procedures without check-off provision are used, or when check-off provision are incorrectly used:	
a). Short list, < 10 items	0.003
b). Long list, > 10 items	0.01
3. When written procedures are available and should be used, but they are not used (for very frequently used procedures, "second nature")	0.01

(Adopted from Swain and Guttman, 1983, table 16-1, p. 16/5)

There are few personalized techniques which pilots use to safeguard themselves from omitting an item. The most common one seen by the author was the habit of moving the left-hand thumb along the left-justified checklist items. This habit allows the use of the thumb as an index for the current item as well as a indicator once the checklist is interrupted.

However, there are some problems with this technique:

1) In most checklists, the vertical spacing between the lines is too small to precisely identify the location of the thumb to a particular line.
2) If the checklist is interrupted for a length of time, it requires the pilot to hold his hand and thumb in an awkward hand and wrist position throughout this period.
3) If the checklist is organized in two columns on a single sheet of paper, this technique will only be sufficient for the left-most column.

Some pilots use a grease marker to mark the location of a hold in the checklist and to "tick off" accomplished items. However, this technique becomes quite cumbersome in the cockpit operational environment. Other pilots write the item on which the checklist was interrupted on a pad, and use this note while returning back to complete the checklist.

In sum, checklist interruptions might lead the following consequences.

1. Elimination of the vital cross-checking of the other crew member.
2. Disruption of the sequential flow of the checklist.
3. Committing to memory the location of the interruption or hold in the checklist sequence.

The presentation and layout of the paper checklist does not allow visual indication of the point where a checklist

was interrupted or denote any differentiation between accomplished and non-accomplished items. Therefore, the step-by-step sequence of conducting a checklist is the only available measure to control this procedure. However, as the above incidents show, ATC communication, ground personnel, and many other entities or distractions can easily break the delicate sequence of the checklist and leave the pilots with no safeguards against checklist omissions.

4.4. COMPLETION

The lack of indication that a task-checklist is fully completed is another handicap of the paper checklist. The only safeguard here is a completion call, such as "The BEFORE START checklist is complete" which is made by the challenging pilot as he completes the checklist, indicating to all crew members that the checklist is fully completed.

> ...The aircraft had arrived late at the gate in Chicago, crew change and this resulted in minimum turn-around time. We had not completed the BEFORE START checklist when the mechanic called for pushback. I first became aware of the oversight when the mechanic called, after the engines were started, that he was having difficulty disconnecting the tow-bar and he asked if the "A" hydraulic system was pressurized. Fortunately he was not injured....In order to preclude this from happening again, my personal procedure is to place the checklist in a obviously different position--on top (not front) of the radar screen....until BEFORE START checklist is complete. (ASRS #47488)

Some companies write the completion call as the last item in each task-checklist, making the call the final item. Some choose not to list this call in the checklist, but still

require the pilots to make the completion call. A few other airlines disregard this call completely.

The field study showed many cases where pilots (using a checklist without a written completion item) chose not to make this callout, or made a very faint (mumble) callout that probably was not heard by the other pilot. In these cases, it appears that the gesture of returning the checklist card to its place on top of the glare shield was the only notification of completion. The author believes this is because (1) the completion callout is not a result of a motor or perceptual process as opposed to many checklist items, and (2) the callout is redundant--in most cases the addressee of this callout (PIC, PF) has already participated in completing the checklist.

Nonetheless, this call is a very important one, because one time or another, due to interruption or distraction, it is the only indication to the "out of the loop" member that the checklist was completed, and that the crew can securely move to another task-checklist.

4.4.1. Uncompleted Checklist

Here, much like the indexing methods, pilots found their own personalized techniques for protecting themselves against the deficiencies embedded in the design of the paper checklist. To indicate an unfinished checklist, the challenging pilot would pull the checklist card half way out of the slot. The checklist would hang over the instrument

panel indicating an uncompleted task-checklist. Although this technique appeared to work quite satisfactorily in the observed cockpits, it has some limitations:

1. The visual cue as to how much the card is drawn-out can be subjectively interpreted by the various pilots.
2. The technique still relies on the pilot's short-term memory to indicate which item was not completed.

Other techniques used were to locate the checklist card over the engine instruments situated between the two pilots (see ASRS #47488), or, to pull down the magnetic compass located above the window to indicate an uncompleted checklist. Two B-737 pilots that the author interviewed said they always associate the lowering of the magnetic compass with fuel. They would use this technique to indicate that the plane was waiting for fuel at the gate, as well while the engines were being cross-fed during flight.

In sum, the completion call, is a redundant action. In most cases crew members know that the checklist is completed, and neither the PNF and PF pay much attention to the call itself. However, this is the only feedback available to indicate a completed checklist. Furthermore, the statement that a specific checklist is complete provides a "cap", or a closure, to the checklist process. This statement enables all crew members to mentally move from the checklist to other areas of the operation with assurance that the checklist has been completed.

Chapter 5

5.1. PSYCHOLOGICAL EFFECTS

Several checklist incidents occurred when pilots stated that they thought they had set a control properly, but actually they had not. This issue is a common denominator in many checklist incidents and accidents. Some of the psychological influencing this effect will be discussed below.

5.1.1. Perception

To perceive something is to be conscious of it and to pay attention to it (Foley and Moray, 1987). Perception is a dynamic process. It changes constantly depending on (1) the physical stimuli, and (2) the way in which the brain processes this physical information. The first stage of the process is termed "bottom-up" processing, meaning that stimuli is sensed by receptors (ears, eyes, etc.) and sent to the brain. The second stage of the process is termed "top-down", meaning that information from the memory adjusts, and in extreme cases even overrides the physical information obtained through the receptors. Therefore, the mere existence of a physical stimuli obtained by a receptor (eyes) is inadequate to predict what the pilot will perceive regarding a checklist item. (Moray and Foley, 1987).

5.1.2. Mental Models. When a certain task is performed over and over again in the same manner, the operators become experienced with the task. In a sense, they actually create a mental model of the task. This model is not very different from the concept of any mathematical model--it describes a set of conditions and formulates an outcome.

Pilots and experienced operators, have "mental models" for each task they perform regularly. As experience accumulates, the shape of the mental model becomes more and more rigid in its allowing of the top-bottom processing to adjust the bottom-up processing. In most cases it is an advantage, resulting in faster information processing, flexibility, reduction in workload, stress, etc. In return, this "mental model" may adjust the perception of physical stimuli coming from the receptors and mislead the brain ("seeing what one is used to seeing"). One ASRS report details this effect,

> Pushed back, taxied, and takeoff with seat belts switch sign off. We did do the BEFORE STARTING ENGINE checklist which should have stated this item. Apparently I (captain) responded to the checklist item, but either did not look at the switch or looked and "saw" what I was accustomed to see (ASRS #34250).

In most cases experience and expectations work to the pilot's advantage; for example, the ability to understand part of a distorted ATC instruction by filling in the gaps of missed information. Wickens (1984) states that top-bottom processing is,

a kind of a guessing assistance that is used to

> compensate for poor data quality. The context reduces the number of possible alternatives for the degraded and ambiguous stimulus, and so there is a greater likelihood that the degraded features will uniquely match one of the remaining alternatives (p. 129).

However, in extreme cases, expectancy, or top-down processing, can override and contradict the physical evidence. All pilots that were interviewed as well as many that the author had discussed this topic with, have stated that at one time or another they had seen a checklist item in the <u>improper</u> status, yet they perceived it was in the correct status and replayed accordingly. For example, the flap handle is at the 0 degree slot (physical stimulus), but the pilot perceives its location on the 15 degree slot because he expects it to be there. This is based on numerous similar checks in which the flap handle was always in the proper setting while performing this task-checklist (TAXI). These cases are rare, and when they do occur, they are usually coupled with adverse psychological and physical conditions such as time pressure, disruption, divided attention, fatigue, noise, etc. Nevertheless, the result is human failure.

<u>Pattern Analysis.</u> Most drivers have had the experience of driving along familiar route and suddenly realizing that they have traveled some distance without being aware of actually operating the car. The driver ceases to continuously perceive information for a significant length of time because the skill of driving in a <u>familiar</u>

environment is controlled by the output of the brain pattern-analyzing-mechanism. Indeed, a very highly practiced task (such as verifying checklist items) can be partially performed without conscious attention. Some of the incoming physical information is used to produce a response, but it is not continuously perceived by the operator.

There was almost a consensus among the pilots interviewed that many times checklist procedure becomes an automatic routine ("sing-song" as some called it). The pilot would "run" the checklist, but the reply would be done from memory, and not based on the actual state of the item. The author believes that this phenomena is the outcome of the pattern-analyzing-mechanism that actually adjusts and controls the checklist procedure. The danger here, of course, is that the actual physical stimulus is lost.

> Preflight planning out of ABE showed we were right up to maximum weight for the 95 degrees day....Further analysis showed that only a flap 5 departure could be made, and not flap 1 as normally done. Both pilots acknowledged this, but then both set flap 1 speeds on their airspeed bugs, set flap 1 on the flaps indicator and flaps 1 was acknowledged on the takeoff checklist. Halfway down the takeoff roll, I realized that the flaps were not set right, called out "flaps coming to 5" and moved the flaps handle....Both captain and myself had been on the aircraft 6 months and the captain had only made one 5 flap takeoff...The routine which developed turned into a very tough habit to brake... (ASRS #55121)

Reversion to Older Habit. This phenomena is quite common in aviation and usually occurs following a pilot's transition from one plane to another. Rolfe (1972) calls the phenomena as "the misleading influence of past experience",

and states that this happens "when he <pilot> acts in a way which follows expected pattern of behavior rather than actually demanded responses" (Rolfe, 1972, p.79)

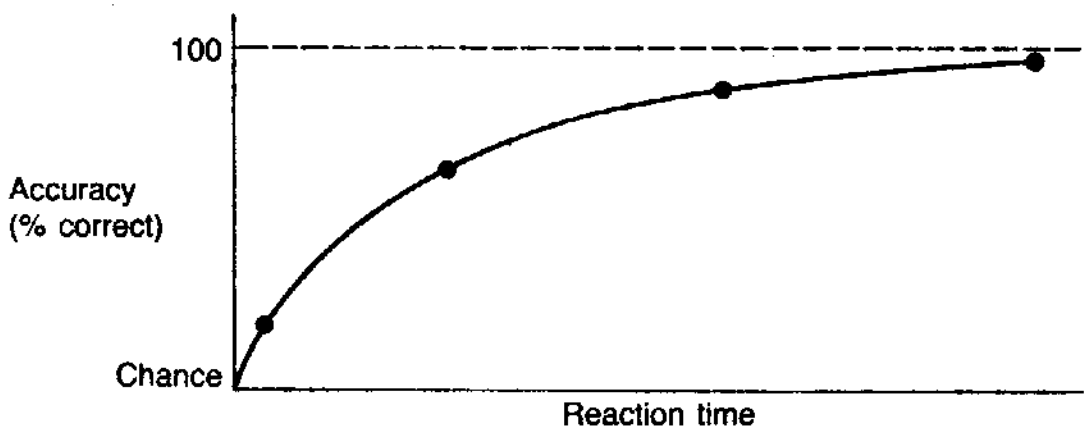
This phenomena is also found in checklist usage. Such problems were cited by the Safety Board in the recent accident of the Air New Orleans BAc J-31. The plane crashed immediately after takeoff because the flight crew did not advance the RPM lever to 100% as per operating procedure and checklist. The captain and first officer had limited amount of time on the aircraft (47 and 15 hours respectively), and both had considerable experience in a Beechcraft BE-99. The BE-99 operating procedure and checklist required that the RPM levers be set to takeoff position just before the airplane leaves the parking position. The BAc J-31 procedure requires that the RPM levers be set before takeoff. Therefore, the item was the last on the BEFORE TAKEOFF checklist. Under urgency and stress imposed by the controller, "...they may have reverted back to recent habit patterns and began the takeoff believing that the RPM levers already had been properly positioned" (NTSB, 1988b, p. 21).

5.1.3. Speed Accuracy Trade Off

Another psychological factor that has an affect on checklist performance is the relationship between the speed of performing the checklist and the quality (accuracy) of the action's outcome. Laboratory research has shown that there is a very definable relationship between response-time

Figure 10

Speed Accuracy Trade Off (SATO)



(Adopted from Wickens, 1984, p. 395)

and error-rate (Figure 10) (Wickens 1984). Therefore, the faster the observer will scan the appropriate panel and its controls/display the less accurate his perception will be. Observers or operators behave is if they "collect" information about which to make a judgement and from which to construct perception (Foley and Moray, 1984).

5.1.4. Realization of Checklist Importance

The relationship between the task and its expected outcome is another way in which the mental model is shaped. Without the crew witnessing its apparent effectiveness ("lets do the never-ending list") the redundancy of the checklist as a backup system can sometimes lead to a reduction in the realization of how important this task is. This reduction is based on the relationship between the task of using the checklist to the expected outcome. This is somewhat analogous to the use of seat belts in a car: although most experienced drivers are aware of the consequences of not wearing a seat belt, the individual's experience about the likelihood of an injury whilst not wearing seat-belt is relatively low. That is one of the reasons why some of us who are less self-disciplined opt in some cases not to use the seat belt. The same applies to pilots and checklist use.

In sum, the combined effect of expectations, experience, and the pattern-analyzing-mechanism is a double edge sword. On the one hand, this ability makes the user flexible and

faster in responding to multiple conditions. On the other hand, it can lead the operator to make a disastrous mistake just because part of the information which was collected quickly or without much attention matched an existing expectation.

5.2. CHECKLIST PHRASEOLOGY

Although the wording used in the checklist process is quite rigidly defined on the checklist card itself, it is evident that there are several problems associated with phraseology that have lead many to err and created confusion for other crew members.

5.2.1. Standard Phraseology

Standard communications in aviation are rooted in the early days of aviation when radio communication was hampered by static and the level of noise inside the cockpit which restricted regular communication. Communication between two different entities will never be perfect. Distortion, misunderstanding, interruptions, hearing loss and confusion will always tend to reduce the quality of the physical stimulus. Operators will usually compensate by increasing stimulus expectancy,

> ...taxiing out for takeoff (runway 23L) ground control told our flight to switch to tower frequency and also stated "taxi short of taxiway Lima" - but due to background noise and cockpit workload (manifest check and checklists) - clearance was only interpreted as "taxi via taxiway Lima)... Comments: ...we were evidently running a checklist or talking when ground control called....more

> than usual background noise in our radio and the frequency was busy with messages to everybody...(ASRS #29080)

To reduce the potential danger of communication expectancy, several design guidelines are available:

1. Restricting vocabulary size, and use of phonetically balanced words (Kryter, 1972).
2. Increasing sequential constraints between pairs of items
3. Employing frequently used words. (Wickens, 1984; Hawkins, 1987).

Therefore, it is beneficial to restrict checklist challenge-and-response calls to standard words only. The same should be applied to initiation and completion calls.

5.2.2. Non Standard Phraseology

Non-standard phraseology in task-oriented communications is an integral part of any system which sets a goal to standardize communication. Billings and Cheaney (1981) state that "non-standard or ad hoc procedures or phraseology is one of the behavior attributes frequently found in association with information transfer problems" (p. 86).

Most companies require standard phraseology for checklist callouts and communication. However, the author's field studies and interviews indicated that some pilots change this phraseology as a reflection of the role structure within the cockpit and for their own convenient. Some of the reasons pilots deviate from checklist phraseology are:

1. The pilot thinks the standard checklist phraseology is too cumbersome.
2. The pilot thinks that standard phraseology is not adequate, and therefore uses his own phraseology.
3. The pilot wishes to be unique.
4. The pilot wishes to show high level of competency

The first two of these subpoints are mainly the outcome of improper discipline, and/or may portray management reluctance to obtain feed-back from the line pilots. The third is quite common among many professional operators. Many operators that are required to use standardized communication tend to presume they lose their individuality while using standard phraseology, and the only way to restore this significance is to perform communications in a unique way--by demonstrating a personal style. Another factor is the level of knowledge of the other crew member's behavior. When the checklist is constantly read to the same crew member, it is tempting to believe that he will comprehend any non-standard phraseology.

Although the checklist in most cases requires short and precise communication, departure from standard phraseology was observed throughout the field study. It was noted in the initiation calls "lets do it"; in the challenge-and-responses calls, "fuel.....We are OK"; and use of hand signals (thumb up) to indicate completion of task-checklists and items. Use of hand signals for completion of checklist

were also cited by the press regarding the Safety Board hearing on the case of Delta Airlines Flight 1141 (Herald Wire Services, 1988b). By not calling the standard phraseology, the following may occur:

1. The other crew member might not detect a checklist error.
2. The other crew member might not be able to follow the sequence of checklist procedure.
3. The other crew member might confuse the checklist callout with other intra-cockpit communication.

5.2.3. Checklist Ambiguity

It is fascinating to note how many ambiguous terms can be found in the checklist. The ASRS data base has numerous reports where checklist responses were improperly performed because of such ambiguity. Many checklists obtained by the author employ the ambiguous responses "set", "check", and/or "completed" to indicate that an item is accomplished. The author argues that when ever possible, the response should always portray the actual status or the value of the item being checked (levers, lights, fuel quantities, speed bugs, etc.). One ASRS report details the problems with this ambiguity and also provides the solution,

> During taxi phase, the first officer normally set V2 in the autopilot for proper display and auto-throttle operation. Being tired, rushed, and late at night, Vref+10 (landing speed) was left in the window. The Vref white bug (marker) was still left as is....when EPR and AIRSPEED were called on the checklist, we looked, saw out bugs in a normal set up and I replied "checked and set". It wasn't till the takeoff roll we noticed the incorrect

> setting (our approach setting). I strongly feel, with complacency being so easy to fall into with advanced cockpits, that we need to back the response portion of our checklist with "what you see" responses not just "checked and set", etc. For example "Altimeters 30.10" and not "checked"; airspeed/EPR 125/2.00. It takes as much time to say it like it is as to say "checked and set". The problem is checked and set can be said too easily without any sound verification. (ASRS #76798)

5.2.4. Display/Control Ambiguity

A unique phraseology and standardization problem encountered while operating aircraft that were manufactured by different airframe manufacturers is display/control names. It is surprising to note how many different names can be assigned to the same control, and how prevalent this non-standard wording is in the industry. For example, the engine master switch used in starting the engine can be also termed master-lever, start-lever, or engine-switch. All names correspond to the same control. A similar wording problem found with throttles, thrust-levers, power-levers, engine-power-control, etc. To reduce this variability, one company has undergone a program to standardize nomenclature of documentation (checklist, flight manuals, etc.) between different models from various manufacturers in order to reduce this variability among pilots transitioning from and to different planes.

5.3. USE OF PROCEDURES

Humans, as opposed to machines, are very flexible in adapting to changing conditions. However, this flexibility is purchased at a cost. Human performance is variable--it fluctuates (regression to the mean), and therefore can produce errors when performance is at the minima of the curve. In addition, humans "become creative in changing their responses while it is not optimal to do so" (Wickens, 1984, p. 7). Standardization of any procedure, in our case the checklist procedure, is intended to reduce this ever-existing variance in human behavior (Wiener, private communication 1988). Procedures, when applied in a disciplinary and standard manner, are intended to support the human operator by providing him with a firm foundation for the upon task which he can depend during these lows in performance (NTSB, 1988a).

Standard procedures are also very important in large air carriers where bidding processes can pair two individuals that have never met before (Foushee and Manos, 1981) and therefore have no knowledge of each others skills and deficiencies (NTSB 1988d). Following a brief acquaintance, these individuals are asked to operate a highly complicated system (aircraft) in a hostile environment (air) where success of the flight is dependent upon correct and prompt crew performance. That is why standardized procedures are so vital in air transport.

One of the oldest and most generic problem in aviation is the failure of pilots to follow standard rules and procedures (Orlady, 1989). Therefore, some attention must be devoted to the question of why some highly-trained and educated professionals consciously deviate from the checklist procedures which are intended to safeguard them against committing an error.

In Chapter 2 we discussed human error and differentiated between mistakes (judgement) and slips (actions). Reason (1988) argues that these forms of human-error are limited to the way in which the individual internally processes information (perception, cognition), and do not account for the external factors that contribute to failure. The above framework, he argues, neglects the social organization in which errors are made. He defines the missing factor as violations--"deviations from those practices deemed necessary (by designers, managers and regulatory agencies) to maintain the safe operations of a hazardous system" (Reason, 1988 p. 3). Violations have two extremes: intentional ones fall into the definition of sabotage, and unintentional ones fall into the much detailed definition of human error. However, of a greater interest for this report, are those occupying the middle ground: violations having some degree of intentionally, but not involving the goal of

system damage. Some of these middle ground violations transform to checklist misuse, and in extremes--checklist non-use.

Orlady (1989) states that "willful deviators" are particularly susceptible to peer group pressure, and misuse procedure in order to reinforce their ego. In addition, Orlady lists other factors that cause deviations:

1. The pilot thinks that the established procedure is wrong.
2. The pilot thinks that the established procedure is correct for the "average" pilot, but he is different, and therefore he can short-cut the procedure/system.
3. The pilot thinks his procedure is either just as good or better then the established one.
4. The pilot thinks that the procedure is not important or not necessary--"not worth the bother".

The above explain some of the reasons why number of pilots consciously deviate from performing the checklist procedure. The solution for this type of problem, however, requires much attention from operational management as well as training departments to cater to the unique characteristics of this population.

5.4. COCKPIT MANAGEMENT AND CHECKLIST USAGE

Cockpit Resource Management (CRM) has been a topic of much inquiry in last decade, with concern being focused on

the coordination, and social processes and combined performance of a multi-pilot flight crew. This approach gained more support when it became apparent that human error plays "a progressively more important role in accident causation as aircraft equipment has become more reliable" (Nagel, 1988, p. 266).

Wiener (1989) writes that the term Cockpit Resource Management as used today refers to,

> The manner in which individual crew members support each other, the roles played by the captain as pilot in command (PIC), and the role of the first officer and flight engineer. It is an encompassing term which includes crew coordination, communication, the use of human and inanimate resources of information both within and without the cockpit, role definition, the exercise of authority by the captain, and assertiveness by the other crew member(s). (p. 119)

Checklist procedures are accomplished by coordinated actions and communication between the captain and other pilot(s). In addition, the checklist procedure is designed in such a way as to assign very distinct role definition and it also requires assertiveness from subordinates when the checklist is not initiated properly. These interactions between the CRM, and the process of checklist usage makes CRM a valid area of interest in understanding checklist problems.

5.4.1. Crew Concept

The main theme in CRM training and in the "crew concept" is that "flying a highly sophisticated multi-pilot transport is a highly structured group performance situation where a

number of interpersonal factors are relevant to crew effectiveness" (Foushee and Helmreich, 1988, p. 192). In addition, the cockpit crew (and in some phases also the cabin crew) must act as a team, as opposed to two/three-highly trained individuals who are assigned to the same cockpit.

5.4.2. The Method

The challenge-and-response method which is used by most airlines in the U.S. is a highly structured and coordinated task. It requires full coordination between the pilot reading the checklist and the other crew member hearing the challenge, checking its status and then responding. It is clear that a low quality of coordination between the crew members will result in a low quality checklist.

Distribution of workload between crew members is also part of the checklist method. In the Northwest MD-80 procedures, the flap extension task (initial configuration task) did not require the captain to be either notified or to approve repositioning of the flaps and slats. Therefore, unless he observed the control or the display (dial and light indicator), he would have not known whether the task had been accomplished (NTSB, 1988a).

During taxiing, the captain is involved with the actual steering of the airplane as well as following instructions from the tower and avoiding traffic. He has less time for a casual scan of the panel, in particular the flap control and

displays which are located on the first officer's side of the panel. Similar problems in the distribution of work and supervision were cited by the press in the recent accident of Delta flight 1141 B-727. In this type of plane, operated by a three-pilot crew, the majority of checklist items are performed between the first-officer and the flight engineer. Delta Airline procedures "do not require the captain himself to verify the flap setting" (Newsweek, 1988, p. 10). It should not be inferred from the above that all flight tasks should be called for by the captain (and therefore overload him completely); rather, it seems logical that the very few critical tasks should.

Checklist Management

In 1979, H. P. Ruffell Smith conducted a full Line Oriented Flight Training (LOFT) experiment to study error, vigilance, and decision making capabilities in flight crews. His study gave empirical confirmation to many CRM issues. One of the issues was "the <captain's> failure to anticipate the overloading of a crew member by a certain combination of circumstances" (p. 28).

These problems of checklist management, work distribution, and crew interactions are described in the following reports to the ASRS,

> We taxied to runway 22-Right for takeoff with engine number 2 shutdown <due to fuel conservation>. When we were second in line for takeoff, the captain ordered the flight engineer to start engine number 2. At that time the tower cleared the first aircraft in line for takeoff (a light twin), and also cleared us into 'position and

> hold'. The captain picked up the public address (PA) handset to make a cabin announcement <to the passengers>, and started to taxi to the toward the runway end. Because an engine takes about 60 seconds to start, the flight engineer has general panel steps to accomplish and it takes another 60 seconds or so to complete the BEFORE TAKEOFF checklist. It was obvious to me that we were not ready for takeoff and so advised the tower while the captain was talking on the PA. By this time the flight engineer was starting to read the BEFORE TAKEOFF checklist and the tower instructed us to "hold your position" <in order to complete the pre-takeoff duties>. I interrupted the checklist to advise the captain we were not cleared on the runway (he had not heard the "hold in your position" while he was giving the PA announcement). But he continued to the runway and insisted that we where ready to go. I so advised the tower and we were cleared for takeoff with another aircraft on the final approach. By the time we lined up on the runway the flight engineer and myself were only about halfway finished with the checklist. It was my takeoff but the captain said "Let's go" and partially advanced the throttles. The flight engineer rushed the last remaining checklist items while hesitating to set takeoff thrust (ASRS #35968).

The initiation of the checklist must be carefully evaluated by the captain before making this call. The captain's considerations should include the following:

1) Are the other pilot(s) overloaded with other task?
2) What are the consequences of having the other pilot(s) running the checklist and, therefore, not participating in the current task?
3) What is the outcome of delaying the checklist because of the above considerations?

5.4.3. Management of Information

There are numerous sources of information in the modern cockpit. However, not every piece of information is available to all pilots instantly. Checklists, as stated

earlier, are performed in the high workload portions of the flight. During these periods the PF is occupied with piloting and must depend on the other pilot to aid him in obtaining or directing to the displayed information that relates to the configuration of the plane.

Obtaining configuration information is even more critical in modern two-pilot cockpits. Compared to three-pilot cockpits it is physically difficult in a modern two-pilot cockpit for one pilot to observe what the other pilot has done mainly because displays of many flight functions have shifted from the panels to cathode ray tubes (CRT) driven by onboard computers such as the EICAS. In older technology airplanes, one scan on the appropriate panel would have given the pilot the information required. In modern aircraft, this requires some page manipulations on computer's display unit. This certainly requires more crew coordination and better information transfer in cockpits of modern airplanes (Wiener, 1989)

5.4.4. Role Structure

The role structure in the airline cockpit is one of the most unique structures in any organization mainly because of the time critical operation, the hostile environment in which the system operates and the catastrophic potentials. The airline captain serves as a hands-on operator and also holds absolute authority in the plane. Therefore, he is prone to operator error and management mistakes.

This very stringently defined structure and its associated discipline and behavior has been the foundation for operation in this high risk system. However, increased automation and use of computers in the flight deck ".. tend to induce a breakdown of the traditional and clearly defined role of the pilot flying versus the pilot not flying (PNF), and a less clear demarcation of 'who does what' than in traditional cockpits" (Wiener, 1989, p.178). The same phenomena can be observed in the marine industry. As vessels become more and more automated and dependent on the use of computers, the captains rely more and more on their electronics officers for daily operations; as a direct result there is an immediate decentralization of authority (Perrow, 1984).

Role structure problems were cited by the Safety Board as some of the components that led to the omission of the flaps/slat setting in the Northwest Flight 255 accident (NTSB, 1988a):

1. Northwest procedures required that during ground operations the captain is to initiate each checklist by calling for it by name; if the captain does not call for the checklist, the first officer is required to ask the captain if he is ready to run the checklist. Except for the BEFORE START checklist, the captain of flight 255 did not call for the AFTER START, TAXI, or BEFORE TAKEOFF checklist, nor did the

first officer ask the captain if he was ready to perform any of these before he started reading the items.

2. Checklist items that required actions and responses from the captain were only performed by the first officer alone.

The fundamental and well-defined role structure in the cockpit was broken down by the captain who apparently yielded authority to his subordinate, and by the first officer who assumed that authority. In regards to checklist initiation and checklist use, the first officer assumed the role of the leader, in addition to his defined role as an operator. Consequently, the first officer was overloaded by a combination of his own duties and some of the captain's. But at that point there was none to back him up. This breakdown in role structure and coordination "rendered the crew more susceptible to distractions and memory lapses" (NTSB, 1988a).

A similar, yet reversed, breakdown of crew role structure and coordination was cited by the Safety Board in the accident of the Air New Orleans commuter plane accident. In this accident, the crew failed to comply with the BEFORE TAKEOFF checklist by not properly advancing the RPM levers to the high RPM position. The captain (PF at that leg) stated that "...he had personally advanced the RPM levers rather than the first officer, even though the company

procedures required the non-flying pilot to advance the RPM levers" (NTSB 1988b).

Quite similar to how the first officer of Northwest Flight 255 overloaded himself with his captain's duties, the captain of the commuter plane overloaded himself with his first officer's duties. Therefore, he was left with no backup for his actions. The captain used his authority to "short-cut" a structured procedure, broke an element of crew coordination, and may have somewhat shifted his subordinate first officer away from "the loop".

In sum, checklist procedures require effective coordination and strict adherence to role structures and duties in the flight deck. A departure from these concepts, well intentioned or not, can lead to a breakdown of crew coordination and omission of checklist items.

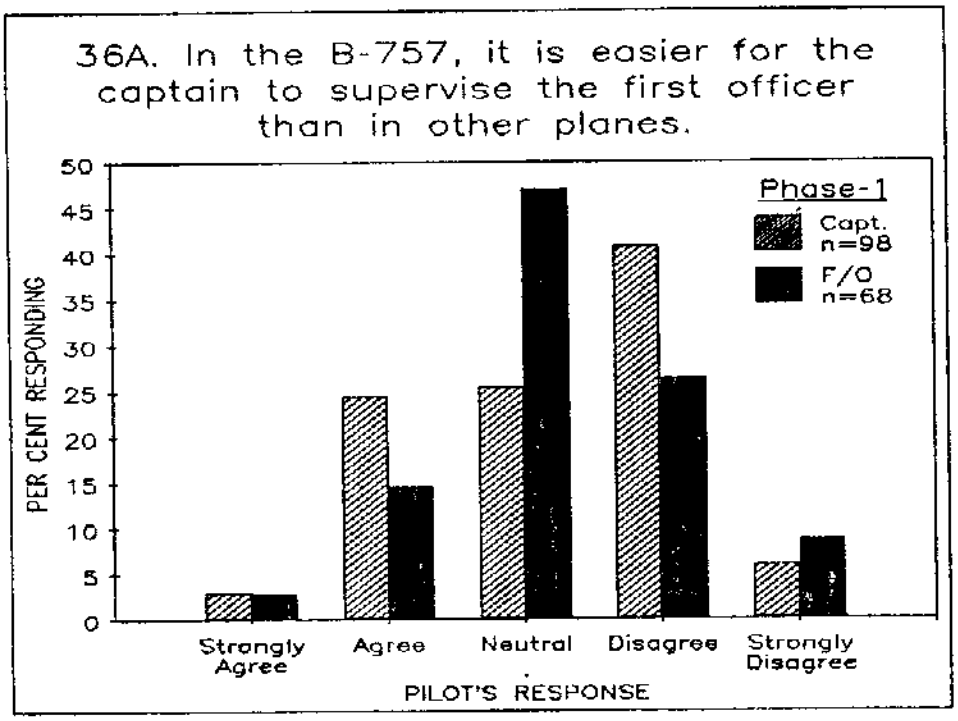
5.4.5. Mutual Supervision

Supervising the other pilot during checklist procedure is the basis for the mutual redundancy embedded in the checklist procedure. When this element is diminished, the quality of checklist performance is reduced.

Supervision of the other crew member becomes somewhat harder in modern aircraft. Wiener (1989) posed this issue (among others) in a questionnaire sent to a sample of 166 B-757 pilots. Figure 11 shows that the captains leaned more towards the view that supervision of first officers is more difficult. The first officers chose the neutral opinion

Figure 11

Probe 36A



(Adopted from Wiener, 1989, Figure 36A, p. 122)

(probably because the question related to captains) and somewhat leaned toward supervision been more difficult.

Another problem in mutual supervision within the cockpit is over-cohesiveness of crew members. Although it might seem somewhat contradictory to many examples of CRM accidents/incidents in which the captain was over-governing the rest of the crew, the opposite extreme can also create problems. The crew, by being too cohesive, may produce errors due to number of reasons (Foushee and Helmreich, 1988). First is the fear of upsetting the group which has already decided to "short cut" a checklist or not to use it at all. Second, the individual is less "on guard" because the rest of the group is (supposedly) "on guard" too. Third, because the individual is too familiar with the past performance of the other crew member,

> First Officer forgot to read flap setting on pre-takeoff checklist and made takeoff with flaps up....First officer said he was distracted by tower call. The PIC says they were behind schedule...and <u>with this highly competent</u> first officer he had become a little complacent (ASRS #58147).

<u>5.4.6. The Captain as the Pilot Not Flying (PNF)</u>

Most airlines require that during a flight segment without foreseeable adverse conditions (such as weather or a difficult departure/approach) the captain and the first officer should alternate the Pilot Flying (PF) and Pilot Not Flying (PNF) duties. This of course, does not relieve the captain of his duties as pilot in command, but rather it

adds an additional supervisory task to his usual role. This role change does not come without some inherent problems. There are some airline companies that believe that captains do not always do the monitoring functions well when the first officer is flying, and therefore these airlines put training emphasis on this point (Lautman and Gallimore, 1988).

From the author's field studies, it was evident that some of these problems are also apparent in checklist use. In several extreme cases the checklists were not done at all. Out of six crews that the author observed flying the B-757, two did not perform the flight phase checklist during one leg. This was clearly observed as the checklist card did not leave the glare-shield slot throughout the flight phase (Taxi to Landing), nor was the yoke mounted checklist ever used (it was covered with the approach plate). There were several common factors to these occurrences:

1) The captain was the pilot not flying.
2) The leg was a very short one following a long leg.
3) The type of plane used was a B-757.

It was interesting to note that the captain--the highest authority on the plane--took the liberty to overrule a burdening and redundant procedure. The first officers never made any comment, assertive or non-assertive, to the disregard of this procedure. The author believes that the short length of the leg (compared to the previous long leg)

and the fact that the flight was the final one for the day, also played a part in causing this negligent checklist behavior. In addition, the minimal size (number of items) of the B-757 checklist used by this company made it attractive to commit the checklist items to memory.

5.4.7. Intra-cockpit Communications

The importance of intra-cockpit communication is well-documented in aviation research (Foushee and Manos, 1981; Foushee, Lauber, Baetge, and Acomb, 1986). This can be only amplified when discussing checklist use since the checklist procedure requires significant amount of communication between crew members. The previously mentioned studies have shown that task-oriented "..cockpit communication patterns are related to flight crew performance" (Foushee and Manos, 1981).

It was strikingly evident from the author's field observations that there was a close association between task-oriented cockpit communication and the correct use of the checklist. Crews that communicated well regarding flight status (use of autopilot, auto-throttles, takeoff and lading briefing etc.) were also the crews that adhered completely to checklist procedures. Conversely, crews that did not communicate well evidently did not use the checklist properly. This subjective observation can be coupled with the reported association between task-oriented communication and flight crew performance. In a testimony before the NTSB

public hearing in the Northwest accident, H. C. Foushee stated that evidence from his own study suggested that "..the way the checklists were used were directly related to the number of errors made by the flight-crews. The flight-crews that performed their checklist by the book, challenge and response methodology....tend to perform more efficiently" (NTSB 1988a, p. 45).

In sum, checklist performance is affected by the way the individuals perform it as a crew. Poor crew coordination and diminished role structures can lead to omissions and mistakes. And when these omissions interact with component failure, this may result in an incident or an accident.

Chapter 6

The following discussion will detail the considerations in designing a checklist. The use of a challenge response method for conducting the checklist and a hand-held, traditional paper checklist, is assumed.

6.1. TASK ANALYSIS

In the chapters 2 and 3, we determined that the use of checklist in Part 121 and 135 operators is a task by itself and not just a device for memory enhancement. Therefore it seems logical to analyze this task by using a formal human factors method that is regularly used in analyzing and designing any human-machine interfaces, instructions, manuals, etc. This methodology is the task analysis. Drury, Paramore, Van Cott, Grey, and Corlett (1987) state that task analysis is a method "...which describes and analyzes the performance demands made on the human element of a system. By concentrating on the human element in the system, it can compare these task demands with the known human capabilities" (p. 371).

In general, the process of analyzing a human assignment in a system is based on three different, yet interrelated analyses. The first is the hardware/software operating

process which is the foundation for the entire task analysis. This stage entails the functional analysis and the operational sequence of the hardware/software components of the system. The second stage is the task classification and description which details the human task requirements and provides the information needed to perform the job. The third is the actual analysis, interpretation, evaluation, and transformation of the task demands based on the knowledge of human capabilities (Drury et al., 1987).

6.1.1. Task Description

While the process of system operations is quite straightforward to analyze, the second analysis--the task-definition--is somewhat arbitrary and subject to different interpretations.

Drury et al. (1987) state several considerations in defining the tasks. Similar considerations apply for the checklist analysis.

1. Task actions are related not only by their objectives but also by their occurrences in time. One of the concerns of task analysis is to establish and evaluate the time distribution of actions within and across tasks. Task actions include overt actions such as control task, motor task and also covert actions such as perceptions and cognitive actions.
2. Each task has a starting point that can be identified as a stimulus or cue for task initiation.

3. Each task has a completion point that occurs when information or feedback is received and the objective of the task has been accomplished.

6.1.2. Defining the Task-Checklist

The entire flight checklist is made up of several task-checklists that follow the sequence of the flight (PREFLIGHT through SECURING THE PLANE). There are many ways one can divide and categorize the flight into separate task-checklists. For example, the ground phase can be divided into several task-checklists: BEFORE ENGINE START, AFTER ENGINE START, BEFORE TAXI, TAXI, BEFORE TAKEOFF. Another approach is to divide the same phase into only two task-checklists: BEFORE ENGINE START, and BEFORE TAKE OFF.

The categorization of the checklist is governed by several considerations:

1) The type of checks needed.
2) The operational function of different systems in the plane.
3) The operational logic of the plane in its environment (fuel conservation procedures, ACARS procedures, etc.).

Checklist of older technology airplanes such as the L-1011, DC-9 series, and DC-10 usually have a long list of items on the BEFORE ENGINE START. Some have as many as 76 items on the checklist of the first flight of the day, and 37 check items for the pilots to check in intermediate

stations. Many pilots who were interviewed stated that following an interruption or a hold in the checklist sequence, it is difficult to remember at what point the checklist procedure should resume. This problem is more intensified if a long task-checklist is employed.

Swain and Guttman (1983) have "recognized the fact that as the list of items grows, there may be a higher probability of overlooking any given item" (p. 15/13). They have tested the above in terms of human error probabilities by arbitrarily defining a short checklist as one with less than 10 items, and a long checklist as one with more than 10 items. Their probabilities of error (per item) seems to indicate that a short list is less prone to error than a long one (Table-D).

In long term memory, the human stores factual information by linking this to that which already exists in this memory (Sanders and McCormick, 1987). Information is stored hierarchically, making it considerably easy for humans to use and learn material if it is presented and built into the memory according to a definable structure. For example, if it is made noticeable that some items are components of system A and the rest are sets of components of system B, it is easier to remember these components than if we think of them as a series of independent entities (Kyllonen and Alluisi, 1987 pp. 126-127).

Therefore, it appears advantageous to divide a very long task-checklist, such as the 76-item one, into two or three smaller task-checklists and thereby reduce the amount of items per list. This will make the list easier to learn by associating some systems (hydraulics, electrical, air conditioning) with a task-checklist.

This does not imply that every task-checklist should be divided into smaller lists. However, having one task-checklist with 76 items may be somewhat absurd.

6.1.3. Chuncking Items of the Task-Checklist

Once the task-checklists have been defined and hierarchically arranged, the next step is to arrange the individual items within the task-checklist. This process should be well thought out and well-coordinated in order to enhance the logic and sequencing of the items on the task-checklists.

The limited capacity of working memory (short term memory) is one of the most severe constraints on human performance (Card, Moran, and Newell, 1983; Sanders and McCormick, 1987). Yet in many tasks, such as checklist use, place unrealistic demands on the operator's working memory (Swain and Guttman, 1983). Nevertheless, certain techniques in aiding human abilities under these limitations are documented in the literature. Miller (1956) has formulated the 7 ± 2 rule as the normal capacity of items that can be stored in the working memory. In addition, he has also

recognized that people can chunk (cluster) information into defined units regardless of the length or size of the unit. The chunk is created when two or more items share a common factor that aids in "gluing" these items together. A simple example of chunking is remembering a telephone number. Space is inserted between unrelated digits to create several chunks that aid the user's memory and recall of the number. A string of telephone numbers such as 18005551212 can be more easily remembered when it is divided into chunks of numbers: 1-800-555-1212.

Wickens (1987) states the following about the use of chunks:

> When printed information is read, stored and used (as in instructions, procedures, and recipes), the retention process can be aided by determining the logical chunks that are grouped together in memory because of their common associations, and by physically separating these chunks from others (p. 82).

Chunks can also be used in designing the sequence of the items in a task-checklist by grouping the items according to the "geographical" location of the systems and units in the cockpit. By doing so, the following advantages are obtained:

1. It will be easier to index and follow the order of the items while conducting the checklist, since the sequence of movement will be within and between chunks.
2. If interruption occurs, it will be easier for the pilot to remember in which chunk the interruption took

place (7 $\pm$ 2 rule of working memory), as opposed to remembering the location of an independent item as one part of the entire task-checklist.

6.2. SEQUENCING OF CHECKLIST ITEMS

In the traditional paper checklist, the sequencing of the checklist is the only indicator as to the operator's point of progress in the checklist ("where are we on the checklist"). Therefore, the sequence of the checklist is a structural key to reducing the potential for failure.

When sequencing the items in a task-checklist, the following must be considered,

1. The systems sequence.
2. The patterns of the pilot's motor and eye movements.
3. The operational logic of the entire system (plane, pilots, ATC, ground crews, gate agent, etc.).

6.2.1. System Operation Sequence

When operating a complex system like an airplane, it is clear that operations must be sequenced according to the activation and operation of units and system. For example, it would not be appropriate to check hydraulic pressure prior to activation of hydraulic pumps. This type of sequencing is most stringent in the process of starting the engines, and in activating related system such as air conditioning, hydraulics, and electrical. Other checks such as checking altimeters, setting speed bugs, speed brakes,

etc., are not so stringently coupled with prior activities, and in such cases, the designer has flexibility to allocate the items in a sequence that will be most advantageous for his design.

6.2.2. Patterns of Motor and Eye Movements

As discussed in earlier sections, the challenge-and-response method of conducting a checklist requires that items be initially performed by the pilots and only afterwards backed-up by use of the checklist. The initial configuration tasks include critical as well as many uncritical items that must be performed. Most training departments require that the initial configuration of the plane be conducted in a particular pattern called a "flow-pattern".

6.2.3. Flow Pattern

In the cockpit of an airplane, the instruments, units and system panels are arranged in certain geographical locations depending on frequency of use, type of feedback, relation to other units, and many other human factors and engineering considerations. In order to facilitate a logical flow of operating the systems, training departments teach a certain path or flow pattern of moving eye fixations and hands from one system panel to the other. This initial configuration "flow pattern" is performed directly long term memory. The objective here is to provide a standardized method of

configuring the plane, and thereby minimize the probability of error and omission.

The use of flow patterns for enhancing frequently recalled information is based on the spatial organization of the systems and controls in the cockpit. Many of us use the same technique while dialing familiar numbers on a touch-tone telephone. We remember the spatial sequence of pressing the buttons. This learned spatial pattern is performed faster and more accurately than by using a string of unrelated numbers.

6.2.4. Geographical Arrangement

A common guideline for any design is that stimuli which need to be processed together or in sequence should be arranged close in geographical location on the panels in the cockpit. When designing a new or revised checklist for an existing aircraft, the reverse logic of this guideline is applied: since the location of the components is already allocated by the airframe manufacturer, the order of the checklist items and chunks should follow the spatial arrangement of the cockpit.

Additional enhancement of the procedure can be achieved if the sequence of accomplishing the items and chunks follows a logical order. For example, one can conduct the BEFORE ENGINE START checklist from the aft (upper) portion of the overhead panel, moving with the checks toward the lower part of this panel. By using a top-to-bottom order of

checking panels and items, the design can accommodate population stereotype of order and sequence (top-to bottom is a common arrangement), as well as some biomechanical considerations (it is less fatiguing to move the arms and the head from above to below than vice-versa).

The use of flow patterns in conducting the checklist procedure can aid the process in the following ways:

1. Standardizing of the checklist.
2. Making the checklist sequence of use parallel to the initial configuration flow patterns, and thereby simplifying the learning process and the daily use of the procedures.
3. Making the checklist actions logical, and consistent (as opposed to intermittent) in the motor movement of the head, arms and hands.

There are many advantages to using two perceptual channels (print/verbal--challenge-and-response, spatial--flow patterns) for conducting a step-by-step hierarchial procedure as the checklist. Booher (1977) used several combinations of spatial (pictorial) and print formats for procedural instruction in operating a control panel. He reported that action-response type information is more efficiently presented in print instructions, while spatial presentation is better for "organizing a perceptual-motor routine in an optimum manner" (Booher, 1977). When using pictures, operators are getting advanced information about

the sequence of the task which in turn helps them to create a perceptual blueprint of the task.

Booher (1977) found that only one unique combination that takes into consideration dual processing abilities will yield better performance and accuracy of comprehension from the operator. He states that the,

> Human processing system is most efficient in comprehension of instruction when the pictorial mode is used to aid in selection and organization of a range of perceptual-motor actions and the verbal material is available to confirm specific tasks <action-response> within the range. (p. 276)

From the above it is apparent that, by using a combination of spatial flow pattern and a verbal challenge-and-response, the designer can maximize the efficiency of the checklist procedure.

The flow pattern aids in the selection and organization of the different cockpit panels, while the printed checklist will confirm the items within the chunk (fuel, circuit-barkers, hydraulics, etc.). Additional benefits to using a multiple processing channels is that such redundancy will increase the reliability of a system, and this design will tend to "accommodate the strength of different ability groups in the population (e.g. users of high spatial versus high verbal ability)..." (Wickens 1987, pp.76-77).

The author believes that multiple channel redundancy can also aid the checklist procedure in instances where this highly sequential procedure is interrupted. The use of

spatial organization will provide an additional pointer as to the location of the interruption on the geographical layout of the cockpit.

In addition to visual verification of the check item, motor movement such as touching the displays or the controls is also an effective enhancement for the verification process. The use of the hand to guide the eye while using the flow pattern can substantially aid this technique by committing part of the mental sequencing process to motor actions. In addition, the use of the hand and finger to direct the eye to a control or an alphanumeric display can aid in fixating the eye on the item and prevent the eye from wandering away from the display.

6.2.5. Operational Logic

Certain tasks that are part of the checklist are dependent on other internal and external entities such as flight attendants, gate agents, refueling agents, etc. When considering the order and sequence of the checklist, the affect of these uncontrollable entities must be considered. For example, it will be inappropriate to require pilots to check the weight-and-balance sheets at the beginning of the checklist, when, due to operational constraints, these papers are handed to the cockpit-crew just prior to closing the passenger door. The same logic also applies for the closing of cargo doors (waiting for the ground crew to load the cargo), waiting for fuel, and many other tasks.

A task-checklist that includes items that do not run parallel to the activities occurring around the plane can have an inherent disadvantage. Omission of checklist items sometimes occurs when an item that could not be completed at the proper point within a sequence (due to the above limitations) is deferred by the crew only to be accomplished later on. However, the traditional paper checklist has no means of prompting the pilot about such unaccomplished items. Therefore, in most cases, a deferred item is stored in the pilot's short term memory. Due to the limitations of short term memory, coupled with time constraints, the likelihood of this item being omitted is relatively high.

The following report to the ASRS explains the importance of operational logic,

> Prior to departure from Denver, as the pre-flight checklists were being accomplished, it was noted that the plane was not fueled yet. The crew <u>continued</u> <differed the item for later completion> in accomplishing the rest of the checklist and related pre-flight duties. Approximately ten minutes after takeoff the second officer noted that the plane was not fueled. The flight returned to Denver for additional fuel....At company Denver facilities, experience dictates that dispatch fuel is not on board prior to completion of the pre-flight checklist in approximately 75% of departures...." (ASRS #28551)

6.2.6. Sequencing of Most Critical Items

One of the important rules of the PIC or PF in checklist management is to call for the task-checklist at the appropriate time. This issue is amplified in the taxiing and airborne phase where time is a critical factor and the crew

is engaged in many tasks simultaneously. In most cases, the captain will call for the task-checklist when the workload and the probability for interruption are low. For example, the captain will call for the TAXI checklist after the plane is clear of all obstacles in the ramp, all systems are working, instructions for taxiing are known, etc. At this instant, the probability of successfully accomplishing the first item on the TAXI checklist is the highest. This probability of successfully accomplishing the item slowly diminishes as time elapses, allowing more time for interruption to occur and workload to increase. Therefore, the most critical checks should be completed first, and not as the last item on the task checklist. Nevertheless, in many checklists obtained by the author, critical items such as flaps/slats, trim, power levers, etc. were placed as the last items on the BEFORE TAKEOFF checklist.

6.2.7. Duplication of Checklist Items

Several carriers have opted to use duplications of items to ensure that the pilots will not skip item(s) on the checklists. Ironically, this is very common in companies that use detailed checklist. Although this additional redundancy in the checklist might prevent an item from being missed, overemphasis of items can have the same side effect as a long and meticulous checklist, and thereby diminish the crew's realization of the importance of the check. It is interesting to note that some duplicated items (mainly in

fuel management) can be traced to past incidents and accidents that occurred during a company's history.

Nevertheless, duplication of items can be also be highly beneficial. For example, item such as flaps and slats settings are calculated according to several variables such as the length of the runway, temperature and wind components. Flight crews are usually briefed (by ATC) prior to taxi to expect a certain runway, and calculate the above settings accordingly. Sometimes, due to weather changes, takeoff from a taxiway intersection (to avoid a long line), and/or change of assigned runway, these setting may require recalculations very close to takeoff. In this case, duplication of an item can provide additional safeguards within the checklist.

In the Northwest flight 255 accident, the Safety Board could not determine conclusively why the first officer did not extend the flaps/slats. One of their speculations was that "...perhaps anticipating a different flap setting due to the runway change.." the first office might have elected to delay the deployment of the flaps until a specific runway would be assigned. To prevent such delay of task completion due to anticipating changes, the author believes that duplication of very critical checklist items can be beneficial. This will ensure that critical items will be at least initially performed.

In sum, there are certain steps that one has to follow in designing the checklist:

1. Task-checklist are defined and analyzed
2. Task-checklists are divided into relatively small routines according to the systems and the operational logic.
3. Task-checklists are subdivided into chunks of items according to the geographic location of the panel.
4. The chunks and items are arranged in a logical flow pattern that resemble flow patterns already used for initial configuration.

Chapter 7

The way in which checklist are designed, taught and used can be examined by employing several concepts that are used in system analysis. In addition this chapter will also discuss the unique contributions of human error to incidents and accidents in high risk systems.

7.1. SYSTEMS

Systems are found everywhere we look. They range from agencies, firms, universities, etc. to more complex systems such as nuclear plants, chemical plants, aircraft, etc. Systems, as any manmade structure, are found to fail from time to time. However, when nuclear plants and aircraft fail, the results can become catastrophic. Therefore, these systems can be defined as high risk systems.

The list of failure of high risk systems is long: the double B-747 accident at Tenrife; the nuclear accident at the Three Mile Island power plant and in Chernobyl, Russia; the accident in the chemical plant in Bohpal, India; the Herald of Free Enterprise, and the Exxon Valdez to mention a few recent cases. Failures, no doubt, are an inherent property of any system.

Leading to any system failure is a component (unit/part) failure. One source of system failure very common in high risk systems is the unpredictable interaction of several components failures. Each one by itself is not critical enough to create a whole system failure, but the timely combination of these individual failures may lead to the failure of the entire system.

An example of such a combination is the Northwest Flight 255 accident. The misuse of the checklist alone, <u>or</u> the failure of the CAWS system alone, would not have created a system accident. But, the timely interaction between the breakdown of crew coordination, non-use of the TAXI checklist, and the failure of the takeoff alert unit (CAWS), all combined to strip the system of its defenses. Perrow (1984, 1986) argues that since designers expect everything to be subject to failure, they guard against each singular failure with one or more safety devices. What system designers cannot anticipate is that "...multiple failures will interact so as to defeat, bypass, or disable the safety devices" (Perrow, 1984, p. 116). These unexpected and incomprehensible interactions of small failures are termed by Perrow as "system accidents" arising from certain characteristics of the system that permits such interaction and failures. These accidents, he argues, are rare yet <u>normal</u> for the systems that host them. Therefore, in a sense, they are "normal accidents" (Perrow, 1984).

Perrow (1984) defines two major characteristics of any system--the type of interactions between system components, and the level of dependency (coupling) between components within the system.

Interactiveness. As systems grow in size and diversity, they tend to get more complex. Systems experience more and more interactions that were not formulated by the system designers. These unexpected interactions manifest themselves in many incidents and rarely in a system accident.

On the other hand, some systems incorporate more linear interactions. Components are arranged in a simple sequence, and the interaction of components is expected and obvious. A good example is an assembly line. If production station (milling machine for example) fails, it is quite clear what will happen to the parts "downstream" and also "upstream" of that station, because the system is linear and has no complex interactions.

Dependency (coupling). This term relates to the amount of slack or buffers between system components, and in most cases this factor is dependent upon time. Consider the above example of the assembly line. When the milling machine fails, the line can be stopped until a suitable solution is found. This implies a "loose coupled" system. In loose coupled systems, delays are possible, and partially finished products will not change while waiting.

In tightly coupled systems, there is only a small slack

or buffer between system components. A good example is a chemical processing plant. Time is a critical factor: units of the system cannot stand by or wait until attended to; instead they must be processed precisely and sequentially. Piloting an airplane is another example of a tightly coupled system, and takeoffs and approach/landing phases make the system even more tightly coupled.

7.1.1. The Checklist as a System

The same characteristics of a large system apply for a smaller system (subsystem) such as a checklist that operates within the structure of a larger system (aircraft, air traffic control, airline). From the above definitions, it appears that the checklist is a linear system. It requires verifying configuration items in a linear manner. There are almost no interactions between checklist items; most items are independent of each other.

As for the second concept, coupling, one may argue that the checklist is a loosely coupled subsystem. The checklist process can be stopped or interfered with as there is almost no critical time dependency between items (as opposed to a chemical transformation process). However, in daily line operations the reality is sometimes very different and the checklist can easily be made into a tightly coupled system. This transformation can be caused by (1) operators, (2) designers, and (3) management.

7.1.2 Operators

The cockpit crew, and in particular the PF or PIC, can tightly couple the checklist procedure to other flight tasks such as takeoffs, landing, starting engines, etc., by calling for the checklist at the improper time, or, not allowing enough time for checklist completion. When a checklist is tightly coupled with other system tasks, the buffers embedded in the system (redundancies and backups) are bypassed, and the ability of the pilots to recover from a failure is small. This point is amplified in an earlier discussion about checklist and CRM.

7.1.3. Checklist Design

The same concept of tightly coupling the checklist to other systems is sometimes carelessly "designed" into the checklist procedure by the designer. Some companies require that a TAKEOFF checklist be accomplished on the active runway, while another requires it to be done just prior to the plane entry onto the active runway. In this case, the BEFORE TAKEOFF checklist is tightly coupled with other takeoff tasks that are very critical. On the active runway, the pilot is concerned with ATC instructions, other planes on final approach and/or those just taking off, and with the complex mental preparation for takeoff (V speeds, wind, takeoff cutbacks, etc.). By adding to this high workload phase another task such as the checklist, all these tasks are tightly coupled and this may result in errors.

Similar tightening of coupling is caused by checklist designers and operators during the taxiing phase, whether it is taxiing to the active runway or taxiing to the gate. The ASRS database contains numerous incidents where conducting the taxi checklist interfered with the actual taxiing task as well as the ability of the first officer to backup the captain while the latter was taxiing the plane,

> Taxiing for takeoff while performing the pre-takeoff checklist. We were on the perpendicular taxiway approaching the parallel taxiway and the active Runway 8R. Both the copilot and I were busy checking items on the checklist and I kept looking out to see where we were. I thought we were approaching the parallel taxiway when in fact we were nearing the active runway. I looked to my right, preparing to start a turn into what I thought was the taxiway and instead saw an aircraft turn on its lights and start its takeoff roll. I slammed on the brakes and stopped just short of the active runway. Some moments later, the aircraft roared past our nose on its takeoff roll. The tower than cleared us for a 180 degrees turn... Even though we were following SOP's, I think it's bad practice to be doing a checklist while taxiing.. (ASRS #60045).

Another pilot experienced a similar incident makes the following remark,

> ...When taxi times are minimal, there are runways to cross prior to the takeoff runway, and the copilot is starting engines, running checklists, and making radio calls, he fails to adequately monitor the captain's taxi progress...(ASRS #40429).

The author believes that TAXI checklists should be completed as closely as possible to the gate and as far away as possible from the active runways and adjacent taxiway. Taxiways are areas of tightly coupled operations, and they become more tightly coupled closer to active runways. It

seems logical that flight crews should try to conduct their checklist at the ramp while the airplane is not moving, and only when finished leave the ramp and taxi toward the taxiways and runways.

7.1.4. Management

One of the characteristics of any tightly coupled system is that it is very efficient (Perrow, 1984). Such systems are efficient on energy (fuel), schedules are tightly governed in order to utilize the system to its maximum capability (fast turnarounds), thus making the system very efficient in operating costs. However, this efficiency is purchased at a cost: a tightly coupled and extremely efficient system is more prone to failure (Perrow, 1986).

The Deregulation Act of 1978 has brought many companies to the extreme edge of efficiency, otherwise the chances of survival for a company in such highly competitive industry is very slim. There are two main factors related to the competition within the industry that affect checklist usage--fuel conservation, and production pressure ("making schedules").

Fuel conservation. Jet fuel is a major cost for the airlines. Much has been done in order to conserve fuel during all flight phases (taxi, climb, cruise, approach/descent taxi). A sound example of such an effort during cruise is the ECON speed found on most Flight Management Computers (FMC) which calculates the best speed

for optimal fuel efficiency at the assigned altitude.

Another way of conserving fuel is taxiing only on one or two engine(s), and starting the rest prior to takeoff. This technique is sometimes the only way to cope with long takeoff waiting lines. Otherwise, flights might have to come back to the ramp for refueling, only to taxi back to a still long waiting line.

Starting one or two engines on the taxiway complicates the engine start and makes the process more prone to errors. Yet, in most cases the checklist can be coordinated and planned in advance by the flight crew while also designating time for scan, and allowing time for recovery. In some reported cases, captains would delay starting the engine(s) to the last possible minute (for sake of conserving more fuel), only to find that engine starts, checklist procedures, ATC instructions, and the actual takeoff tasks, were at that point tightly coupled with one another.

During the field study, one captain had repeatedly delayed engine start even in situations where there was ample fuel onboard and almost no waiting line on the taxiway. The prime objective was to save fuel. However, by starting the engine on the taxiway while taxiing toward the runway he created some other problems. The quality of monitoring engine start (checking the gauges for proper N's, temperatures, fuel flow, roll back) was low. The captain was preoccupied with steering the plane, looking for landing

traffic, and at the same time starting the engine. Here the system was deliberately tightly coupled with almost no substantial economical gain.

Production Pressures. Management pressure for "on time performance" is another factor that leads to high operating-efficiency. Planes fly in and out of a hub-and-spoke system with fast turnarounds. One long delay at one station, or an accumulation of several short delays that snowball from station to station, can lead to angry passengers, damaged reputation, and most critical--loss of revenues. Meanwhile, the Department of Transportation (DOT) monitors flight schedules in order to publish the highest and lowest ranking airlines in "on time performance" and thereby place another public relations (PR) burden on management.

On-time performance pressures, or production pressures, find their way into the cockpit and consequently affect cockpit management. They significantly affect the quality of cockpit operations and invite operating errors (the SATO effect).

> On a very short turnaround, and behind schedule departure, the captain rushed the crew, and I (F/E) missed several checklist items and inadvertently took off with the APU running and several generators not on the bus--this was abnormal but not unsafe. More emphasis needs to be made not to rush. Especially before takeoff. (ASRS #48505)

Checklists, as safety devices that are initiated and then conducted by the flight crew, are highly susceptible to production pressures. Under production pressures, checklist

are sometimes "renegaded to second place status in order to save time" (Majikas, 1989, p. 14). In addition, production pressures, much like fuel conservation procedures, tightly couple the system to its maximum capabilities and thereby minimize the time for recovery from human errors.

Here production pressures lead to error-induced operations. They "set the ground work" for errors by yielding substandard performance (SATO affect) and later on strip the system of its own defenses (checklists).

The marine industry, for example, holds one of the poorest safety records out of all the high risk industries. Some statistics show that at least one ship is lost every day somewhere around the world! Captains are evaluated and financially taxed or given bonuses for their ability to make schedules. The example given in the introduction of this report regarding the "Herald of Free Enterprise" is indicative of such production pressures and their potentially disastrous results. Because of delays at Dover (England), there was great pressure on the vessel's crews to sail early. A memo from an operations manager stated "put pressure on your first officer if he is not moving fast enough... sailing late out of Zeeburgee isn't on. It's 15 minutes early for us" (Reason, 1988). Similar production pressures for rapid turnarounds had already led to several prior incidents in which company's ships sailed to sea with their bow or stern doors open.

The same type of production pressures also exist in the aviation industry,

> ...After making our approach and landing at XYZ <de-identified airport>, we were running approximately 53 minutes late. While on the ground, the first officer read the BEFORE START checklist and when fuel was mentioned my response was "to go". We both saw a fuel truck go by, and the agent entered the cockpit to give us the papers. As we checked them they were correct in showing 20,000 lbs of fuel. Everyone was running around trying to get us out as we were running very late due to weather. I was given the signal to start the engines and by that time I had forgotten to check the fuel gauges. We were not fueled at XYZ...(ASRS #27237)

In sum, flying is a tightly coupled and complex system by nature. Nevertheless, some subsystems within the system can be designed to reduce the probability of failure. Redundancy, in particular engineering safety devices, are not always the ultimate solution. Complex interactions tend to defeat engineered safety devices and bypass them, producing failures that are both unexpected and completely unforseen. However, if subsystems--checklists in this case--are forcibly tightly coupled by designers, operators, and management, then at one time or another this may result in a checklist accident--a normal accident.

7.2. SYSTEM PATHOGENS

In considering the human contribution to incidents and accidents in high risk systems, a distinction can be made on the basis of the period of time required for human failure to manifest itself within the system. The distinction is

between active and latent failures (Reason, 1988).

Active failures. These immediate failures (wrong stabilizer trim setting, forgetting to close cargo doors, wrong balance/trim data) are associated with the "first line" operators (pilots, maintenance, dispatcher, etc.). The errors of these individuals are the actions that bring direct response (failures) from system components.

Latent failures. "These failures are ones whose adverse consequences may lie dormant within the system for a long time, only becoming evident when they combine with other factors to breach the system's defenses. Their defining feature is that they were present within the socio-technical system well before the onset of an accident sequence" (Reasons, 1988).

7.2.1. Latent Failures in High Risk Systems

Analysis of many accidents, show that latent failures provided the "fuel" for many interactions that ultimately led to accidents in high risk systems. In most cases, accident investigators focus primarily upon active operator error ("pilot error") and hardware failures. Although it might have been possible for the operators to recover from the incident if this....and if that..., many of the root causes of the failure were present within the system long before these active errors were committed.

The history of high risk systems is full of just such interactions of active and latent failures that have led to

catastrophe. In the nuclear accident at the Three Mile Island plant, maintenance failures coupled with poor human factors considerations in the design of the control room were latent in the system. The defective design of the Challenger's solid booster rocket "O"-ring had resided in the system for nine years. The Herald of Free Enterprise and other ferry ships owned by the company were sailing many years with no indication on the bridge as to the condition (close/open) of the bow or stern doors. And the list goes on and on.

The aviation industry also provides a wide variety of similar examples:

In 1979, a New Zealand Airways DC-10 struck the slopes of Mount Erebus in Antarctica. The initial inquiry blamed one of the 257 victims--the captain. The cause: pilot error. A later investigation, prompted by the pilot union revealed that incorrect data was entered into a ground base computer which supplied the flight-plan for the Inertial Navigation System (INS). Although the pilots had a restriction of 16,000 feet, they were expected to fly low since the airline advertised that low flights were made to improve sightseeing (Hawkins, 1987; Perrow 1984).

Another relevant example was the design of the CAWS fail-light on the Northwest flight 255 MD-80, which did not allow visual presentation of loss of power to the unit. Therefore, hiding from the flight crew the fact that the CAWS was

inoperative (NTSB, 1988a, p. 55).

A broader example is the current state of traffic conditions at John Wayne Orange County Airport, California. The airport is largely used by General Aviation aircraft. The ever increasing airline and commuter flight, mainly due to the relatively wealthy and growing population of the area. The noise abatement procedures (a wealthy neighborhood is located on one side of the airport) that require complicated and margin-less takeoffs. In addition, there is a very dense military activity is present around the airport due to the proximity of several military bases.

Reason (1988) calls these conditions "resident pathogen" because they reside within a system in the same way biological pathogen resides within a living body, only to manifest themselves at an unique set of unexpected conditions. Engineering defenses offer little or no protection against the interaction of these pathogens with active failures. Quite commonly, most of these resident pathogens are socio-technical in nature, leaving even less hope for the success of engineered safeguards.

And so is the checklist.

Chapter 8

8.1. CONCLUSIONS

The author concludes that the traditional flight deck checklist is a resident pathogen that lies within this system. The list of accidents and incidents to which checklists have contributed is very long. The NTSB, ICAO, and ASRS data bases hold hundreds of such incidents and accidents. The reader may ask why has this pathogen resided in the system for so long, and why does it remain uncontrolled even today? Perrow (1986) points to one of the reasons,

> Formal accidents investigations usually start with an assumption that the operator must have failed, and if this attribution can be made, that is the end of serious inquiry. Finding that faulty designs were responsible would entail shutdown and retrofiring costs; finding that management was responsible would threaten those in charge; but finding that operators were responsible preserves the system, with some soporific injunctions about better training. (p. 115)

We have discussed throughout this report the design weakness of the checklist device: the lack of pointer and retrieval system, and the limitations of human monitoring abilities that must interact with this device. In addition, other aviation systems also closely interact with use of the checklist use. These interaction, if not properly designed

and controlled, only combine to reduce the efficiency of the checklist procedure.

Nevertheless, the author strongly believes that merely improving the engineering design of this task will not eliminate the problem. The human is still the center of this task, regardless of its design. Accommodating the human strengths and limitations should be the heart of this design.

Checklist designers should be aware of the behavioral consequences of their designs. Flight crews should be taught about the psychological and behavioral factors that can lead to checklist failures. Management, meanwhile, should be vigilant for symptoms of incorrect checklist behavior that might appear during routine operations.

The unique interaction of checklist, humans, machines, and the systems in which they operate makes the checklist problem a true human factors issue. The author hopes that this report will aid those individuals in the air transport industry who will attempt to extract this resident pathogen from their systems.

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APPENDIX A

A.1 PROPOSED GUIDELINES

In this Appendix the author proposes several guidelines for designing and using flight deck checklists. These considerations are not specifications. Rather, each one should be carefully evaluated to coincide with the operational constraints and philosophy of use of the checklist in the specific airline.

(1). The challenge-response method conducted by more than one individual (mutual redundancy), appears to be superior to the do-list method in redundancy and flexibility (3.1.4.).

(2). Training departments should be made aware of the potential hazards of not "recalling" configuration items that reside within the onboard computers of modern air transport (2.2.7.).

(3). Every effort should be made to avoid using the checklist as a "site" to resolve disciplinary problems (3.2.3.).

(4). Standardization of checklist between fleets should be done carefully to prevent enforcing checklist procedures that belong to one aircraft on the checklist procedures of another aircraft (3.3).

(5). The completion call of a task checklist should be

written as the last item on the checklist, to allow all crew members to mental move from the checklist to other areas of operation with assurance that the checklist is completed.

(6). Checklist responses should portray the actual status or the value of the item being considered (5.2.3.).

(7). Training departments should attempt to standardize the names assigned to controls and displays among different fleets (5.2.4).

(8). Captains should be aware that checklist procedures might overload other crew members and thereby reduce the overall efficiency of the check as well as other tasks performed by this crew member during this time frame (5.4.2).

(9). Very long task checklist should be divided to smaller task checklists that can be associated with systems and panels in the cockpit (6.1.2).

(10). Training departments should design flow patterns for checklist use, and provide a pictorial scheme of this flow (6.2.2).

(11). Sequencing of checklist items should follow the "geographical" organization of the items in the cockpit, and be performed in a logical order according to population stereotypes and biomechanical considerations. The use of hands and finger to touch appropriate controls, switches, and displays while conducting the checklist is highly recommended (6.2.4.).

(12). Checklist items should "run" parallel to internal and external activities that require input from outer-cockpit agents such as cabin crew, ground crew, fuel agents, and gate agents. (6.2.5).

(13). The most critical items on the task checklist should be completed as close as possible to the initiation of the task checklist, in order to increase the likelihood of completing the task before interruptions occur (6.2.6).

(14). Critical checklist items such as flaps/slats that might be reset due to new information should be duplicated between task checklists (6.2.7.).

(15). Checklist should be designed in such a way that they will not be tightly coupled with other tasks. Every effort should be made to provide buffers for recovery from failure (7.1.3.)

(16). The TAXI checklist should be completed as close as possible to the gate and as far away as possible from the active runway(s) and adjacent taxiways. It is recommended that TAXI checklist will be completed while the plane is not moving (7.1.3.).

(17). Flight crews should be made aware that the checklist procedure is highly susceptible to production pressures. These pressures "set the ground work" for errors by yielding substandard performance, and later on strip the system from its defenses (7.1.4.).

APPENDIX B

B.1. COVER LETTER FOR PILOT INTERVIEWS

UNIVERSITY OF Miami

20 January 1989

TO: Participants in human factors study of checklists

FROM: Earl L. Wiener, Project Director

SUBJ: Confidentiality

We appreciate very much your volunteering to be a source of information for this study. Recent events have made the study of human factors in the design and philosophy of checklists a very vital subject.

Any information provided in this study will be useful to us. We will use the information, but will not reveal the source. NASA has had years of experience in working with airline pilots in human factors studies, including the operation of the Aviation Safety Reporting System, and a basic rule of our work is respecting the confidentiality of pilots that Mr. Degani interviews.

Again, our thanks for your cooperation. We will send you a copy of our report.

B.2. CHECKLIST INTERVIEWS QUESTIONNAIRE[3]

1. What are the advantages/disadvantages in checklist in general?
2. What is the method of running a checklist are you currently using? Who is challenging and who is responding? What are the types of responses?
3. What do you think should be the role of the manufacturer, FAA, and the company, in the process of designing a checklist?
4. Which items should be included in the checklist and which items should not be included? As for items which are not included, how should they be performed?
5. What should be the criteria for sub-grouping of checklist items? How sub grouping can aid the safe use of checklists.
6. What are your thoughts about standardization of checklist among different series of aircraft, and between different aircraft in the company?
7. Verification of checked items. How should it be coordinated and preformed? What is the role of Captain's responsibility in this process?

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3. Approved by the Air Line Pilot Association.

8. What is the role of PNF and PF, and of seat, in running the checklist? Should this distinction be indicated on the checklist?
9. How should through-flight items, and plane receiving items should be handled and displayed on the checklist?
10. What in your opinion are the key elements graphical design of the checklist.
11. What type of checklist documentation your company uses? Is it adequate for use? Where is it held indifferent stages of flight, is this location adequate?
12. What is the role of the checklist in the awareness of the pilot, as to the type of plane and plane series he is flying?
13. What can you say about the method of running a checklist, and its safe guards against disturbances (ATC, cabin crew, maintenance crew, etc.)? How do you handle items which are not preformed in sequence?
14. What is the affect of work-load, discipline and fatigue on the correct use of checklist?
15. What is the affect of physical and physiological factors on the correct use of checklist:

    Luminance level

    Motion sickness

    Vibration

APPENDIX C

C.1. GRAPHIC DESIGN OF A PAPER CHECKLIST

Documents, manuals, checklists and considerable amount of paper forms are in use in the cockpit. The human factors quality of these forms of documentation, their proper use, as well as the hygienic reading condition in the cockpit have a significant affect on the efficiency of the operation, and therefore, in extreme cases, on flight safety.

In 1980, a Saudi Arabian Lockheed L-1011 was approaching Riyadh Airport (Saudi Arabia), when warnings in the cockpit indicated smoke in the aft cargo area. The crew was searching for the appropriate procedure in their flight documentation. The Saudi Arabian investigation reported that about three valuable minutes were lost while the crew searched for this procedure in inadequately designed operating procedures. In the meantime, all 301 passengers died from inhalation of toxic smoke and fire (Saudi Arabian accident report as cited in Hawkins, 1987).

The NTSB in its accident report on the Air New Orleans commuter accident plane had stated that "although there was no evidence that checklist legibility was a factor in this accident, the safety board believes that under other operational circumstances, this deficiency could compromise

the intended purpose of this device" (NTSB, 1988b, p. 22). Furthermore, the NTSB states in the conclusions section of the report that"...the design of the air New Orleans J-31 checklist did not conform to accepted human engineering design criteria for legibility.."(NTSB 1988b, p. 24). Figure 12 is a copy of this documentation showing the almost "legal document" size of the text.

The graphic technicalities of designing a flight deck checklist are mainly concerned with the correct layout and typography. These considerations should include the following:

1. The unique physical condition of the cockpit (illumination, layout, etc.).
2. The special method of using and running the checklist as indicated in the companies operational rules.
3. The limitation and capabilities of the end user--the pilot.

This section highlights and briefly discusses several typographical and environmental factors that effect the ability of the pilot to read, comprehend, and use flight deck checklist, a task normally preformed under non-optimal reading and operating conditions. For more detailed information regarding document presentation and use in the cockpit see Degani, 1988a and Degani, 1988b.

Figure 12

Air New Orleans BAc 31 Flight crew checklist
(7th Edition)

BAE-31 NORMAL PROCEDURES CHECKLIST — **Seventh Revision**

BEFORE STARTING (* - First Flight of the day)

1. Prop Start Locks/Fuel Caps/Inlet Covers - CHECKED L/R
2. Circuit Breakers - CHECKED
3. Gear Handle - DOWN
4. Battery Master - AS REQUIRED/VOLTAGE CHECKED
5. Parking Brake - 700 PSI/SET
*6. Left/Right Skirt Panels - CHECKED/TESTED
7. Fans/Freon/Gnd Heat - OFF
*8 Fire extinguishers/Hyd Pump Handle - CHECKED/ON BOARD
*9. Emergency Hyd Selector - NORMAL
10. Trims - SET (3)
*11. Feather levers - TEST/OPEN
12. Power/RPM Levers - GROUND START/TAXI/FULL & FREE
13. Pressurization/Temps Panel - SET
*14. Battery Temps - TEST/CHECK
15. EGT - LESS THAN 200°
16. Fuel Quantity - CHECKED
17. Cap Panel - CHECKED/TEST
*18. L.P. Cocks - TEST/OPEN
19. SBL/TTL - ON
*20. Fuel Crossfeed - TEST/NORMAL
21. Boost Pumps - ON
22. Generators - OFF EXTERNAL PWR/ON INTERNAL PWR
23. Avionics Master - OFF
24. Emergency Lights - TEST/NORMAL
25. External Lights - AS REQUIRED

BEFORE TAXI

1. Generators - ON
2. Battery Master - INTERNAL
3. Amp/Volt Meters - CHECK LOADS/SHARING
4. Ground Power - REMOVED AND CLEAR
5. Chocks - REMOVED
6. Avionics Master - ON
7. Windshield Heat - WARM
8. Fans/Freon - AS REQUIRED
9. Flow Selectors - ON
10. Hyd Pressures - CHECKED (4 at 2000 PSI)
11. Start Locks - REMOVED
12. Taxi/External Lights - AS REQUIRED

ONE INCH

BEFORE TAKEOFF

1. Passenger Briefing - COMPLETE
2. Cabin Signs - ON
3. Air/Gnd Switches - AIR
4. Oil Cooler Flaps - AS REQUIRED
5. Radar - STANDBY

CR6. Brakes/RWS - CHECKED WITH TAXI
CR7. Flight Instruments/Stby Horizon - CHECKED/SET
CR8. Oxygen - NORMAL/PRESSURE
CR9. D V Window - SECURED L/R
CR10. Engine Instruments - NORMAL
CR11. Fuel Quantity - TOTAL IN HOURS
CR12. Avionics - SET/CLEARANCE BRIEFING
CR13. Seat Belts/Harness - SECURED L/R
CR14. Airframe/Eng. Prop De-ice - CHECKED & TESTED
CR15. Flaps - SET/TESTED
CR16. Gust Locks - REMOVED
CR17. Flight Controls - FREE/CORRECT
CR18. Stall Protection - TESTED/ON
CR19. Cap Panel - SBL/BETA
CR20. APR - TESTED/ARM AS REQUIRED
*CR21. TTL - TESTED
CR22. V Speeds/Captain's Briefing - COMPLETE

BEFORE TAKEOFF (FINAL ITEMS)

1. Windshield Heat - ON
2. Pilot Heat - ON
3. Transponder - ON
4. Oil Cooler Flaps - CLOSED/TEMPS NORMAL
5. Lights - AS REQUIRED

CR6. Ice Protection - AS REQUIRED
CR7. Flow Selectors - OFF
CR8. Speed Levers - SET/ WHEN CLEARED

TAKE-OFF SPEEDS

TAKE-OFF

WEIGHT LB	V1 KT	V2 KT
15212	111	114
[illegible]	110	113
14040	109	112
14000	108	111
14300	107	110
14110	106	109
13870	105	108
13630	104	107
13380	103	106
<13300	102	105

C.1.1. Layout and Organization of the checklist on the card

The layout of the paper checklist is an important factor in the design of the checklist. Most checklists are too long to fit on one form, and thus require some organizational manipulation on part of the designer.

As discussed above, there are no guidelines for checklist presentation. Some carriers use 8.5 x 11 laminated cards. Others use much smaller cards or tapes of paper. The Northwest MD-80 checklist was printed on a 6.75 x 11 inch card divided into thirds by dashed lines (see Figure 3). Each section included different task-checklists:

Section 1	BEFORE START, AFTER START
Section 2	TAXI, DELAYED ENGINE START, BEFORE TAKEOFF, CLIMB IN RANGE
Section 3	BEFORE LANDING, AFTER LANDING, PARKING, TERMINATING

From the above it is clear that the organization of the task-checklist on the checklist card itself is also a factor in the design of the checklist. It appears logical that the task-checklists be organized on the card in a certain sequence that will coincide with the sequence of operation, and with the cues which are employed by the flight crews.

There are two approaches in checklist design and organization concerning the pre-flight checklist. Usually, prior to the first flight of the day, certain additional items such as checking oxygen gear, arming the emergency

exit light, etc. must be done. One approach is to list these items on a separate checklist sometimes termed the PREFLIGHT checklist. Another approach is to list these items as part of the BEFORE START checklist and to differentiate between these items and the regular BEFORE START items. In cases where the pre-flight checklist consists of more than a few items, the author believes that the first approach is better. Cluttering of the BEFORE START checklist with items that must be skipped may lead someone to skipping a required item (see Figure 13).

Another factor to be considered is the graphical pleasingness and appearance of the checklist. A checklist that is not graphically sound might deter the users. Hawkins (1987) states that "the visual impression created by a document is most important....in any case where it is desired to motivate the reader to take an interest in the document" (p. 207). This concept is widely understood by advertising and PR departments, yet is much neglected by airline training departments.

C.1.2. Typography

Typography is defined by the Webster dictionary as "the arrangement, style, or general appearance of matter printed from type" (Webster Dictionary). In order to select and use the appropriate typographical methods and layout

Figure 13

B-737-300 BEFORE START task checklist

737-300 NORMAL CHECKLIST

BEFORE START

COCKPIT PREPARATION.....COMPLETED
LIGHT TEST.....CHECKED
OXYGEN & INTERPHONE.....CHECKED
* YAW DAMPER.....ON
* FUEL....._____KGS & PUMPS ON
GALLEY POWER.....ON
EMERGENCY EXIT LIGHTS.....ARMED
* NO SMOKING & FASTEN BELTS.....AUTO
* WINDOW HEAT.....ON
* HYDRAULICS.....NORMAL
* AIR COND &
PRESS.....1 PACK, BLEEDS ON, SET
* HSI SWITCHES (Non-EFIS
Airplanes).....AS REQUIRED
AUTOPILOTS.....DISENGAGED
* INSTRUMENTS.....X-CHECKED
ANTISKID.....ON
* AUTOBRAKE.....RTO
* RADIOS, RADAR &
TRANSPONDER.....SET & STANDBY
* SPEEDBRAKE.....DOWN DETENT
* PARKING BRAKE.....SET
STABILIZER TRIM
CUTOUT SWITCHES.....NORMAL
WHEEL WELL FIRE WARNING.....CHECKED
* RUDDER & AILERON TRIM.....ZERO
* PAPERS.....ABOARD
* FMC/CDU.....SET
* N1 & IAS BUGS.....SET

----------CLEARED FOR START----------

* AIR CONDITIONING PACK.....OFF
* START PRESSURE....._____PSI
* ANTICOLLISION LIGHT.....ON

arrangements, there are certain human factors criteria with which printed matter or checklist must confirm.

1. Visibility of print: The quality of the alphanumeric that makes it separately visible from its surrounding. For example, the letter "B" has three horizontal strokes and two spaces between, a total of five elements in height.
2. Legibility of Print: The characteristic of the alphanumeric which enables the observer to positively and quickly identify it from all other letters and characters. This depends on stroke width, form of characters, illumination and contrast.
3. Readability: The quality of the word or text that allows rapid recognition of a single word, word-groups, abbreviations, and symbols. This depends on the spacing of individual characters, spacing of words, spacing of lines, and the ratio of characters' area to background area (Sanders and McCormick, 1987, p. 85; Heglin, 1973)

The above criteria, which must be addressed for every printed matter, is more critical in the design of a critically printed matter such as a checklist. In addition, other typographical and layout techniques need to be employed to meet some of the following characteristics of a paper checklist:

1. Non-optimal viewing condition - such as in the cockpit

of an airplane during night operation, dim lighting (sunset, sunrise), direct sun-light, and IMC conditions.

2. Fast and frequent changes of accommodation - between far sight and near sight.
3. A pilot population of several age groups with different viewing abilities are present (bifocal, regular).

Typeface (font). Typeface refers to the style of the alphanumeric used in printing. There are over 2300 types of typefaces available today. Typefaces are divided into three major sub-groups:

1. Roman.
2. Script.
3. Sans-serif.

Roman is well known since it used daily in newspapers, journals and books (This text, for example, is written in Roman typeface). Script is a typeface that simulates modern handwriting. San-serif is a contemporary typeface that includes the little stroke that projects from the top and or bottom of a main stroke.

Several researchers in the field of typography have reported that when other typographical factors are controlled, san-serif typefaces are more legible than others. The argument behind this claim is that lack of serifs provides a simpler and cleaner typeface, thus

improving the legibility of the print (Cheetham and Grimbly 1964; Poulton, 1965; Heglin, 1973).

Among the sans-serif family of typefaces, there are two typefaces that appear most suitable for checklist use. The first is a typeface called Gill Sans, which was found significantly better than several other typefaces in comprehensibility as well as in character visibility (Poulton, 1965). The second is Bell Centennial, the typeface used in telephone directories (M. Carter, private communication, 31 January 1988).

Lower case vs. upper case. There is almost a universal indication from the literature that lower-case characters are more legible than upper-case (Tinker, 1963; Poulton, 1967; Phillips 1979, Hartley, 1981). It appears that lower case letters can be read more quickly and are ranked higher than upper case letters in legibility and pleasingness.

There are several explanations for the increased legibility of lower-case words over upper-case words.

1. Most printed material we read in everyday life is set in lower-case.
2. Although characters in upper case are perceived at a greater distance than lower case, the total word form is more important while perceiving a word in lower-case (Tinker, 1963, p. 59).

3. Upper case words are perceived in a character by character order, reducing readability and speed of reading of the printed matter.
4. Lower-case words consist of characters that have ascenders (the vertical stroke of "d", "h") 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". Opposingly, the upper-case word appears like a rectangular box with no distinguishable contours (see Figure 14).
5. The combination of a capital letter and lower-case character (Fuel Pumps; Takeoff Warning) gives additional significance to the shape of the word and therefore improves readability.

Tinker suggests that the spatial pattern of a familiar word is stored in the human memory, and while reading text a matching sequence occurs between the observed word and the memory patterns stored in the brain. The more unique the pattern or shape of the word, the easier it is to perform the matching routine (Tinker, 1965, p. 136).

Height of a typeface. If all factors such as legibility, illuminance, subject, age, etc., are kept under control, large letters are more visible than small letters (Woodson,1981). To meet the qualifications of the above statement, the stroke width has to change with proportion to the height of alphanumeric character.

Figure 14

Lower case items and Upper case items.

Landing gear	LANDING GEAR
Recall	RECALL
Flaps	FLAPS

Many graphs are available in the literature that indicate the relationship between character height, viewing distance, and illumination level (Degani, 1988a). These factors can change between cockpits (illumination level) and do not always match pilots' habitual expectations (location of the checklist--yoke, side window, hand). One should be cautious in using the data from these graphs since no information regarding the age of the sample group, as well as other information concerning the controls of the experiment, are given.

In sum, there is no available literature on character height that can be applied directly and safely for the design of a checklist. Rather, the designer will have to make an initial trial assumption from the literature, and validate his findings later in the simulator using company's procedures and pilots.

Stroke width and height-to-width ratio. The stroke width of the letters is another factor in the visibility of characters. Stroke width has an effect on the ability of the eye to differentiate between the stroke of the character and the space inside the character ("E" "F"). The width of a stroke is a function of height of the character and vice versa. While designing a checklist display (such as a mechanical checklist), a different height to width ratio should be considered because fixed displays are viewed from an unfavorable viewing angle which artificially reduces the

apparent width of the character (Heglin, 1973). Some checklists obtained by the author were so badly printed that the height-width ratio was distorted by the printing machine.

Vertical spacing. The vertical as well as horizontal spacing between characters has a significant affect on the legibility of the checklist. The appropriate vertical space between lines increases the chance of optical bridging between adjacent lines--a very critical phenomenon to avoid in the design of checklist. Eye fixations, especially under the influence of fatigue, stress, and time pressure can wander between the lines of the checklist and result in the skipping of an item.

Line length. The length of the line is an important factor in the checklist layout where the number of words on each line is relatively small and a tendency to reduce the size of the document always exists. Tinker (1965) presents several tables on the effect of varied line length on the legibility of print for different heights of typefaces. Although the data is based on experiments which employed Roman typeface, they can be used to obtain preliminary information (Tinker,1963, pp. 77-87).

Most checklist layouts are very similar to index lists or table of contents. A common problem with these types of layouts is the large spatial gap between the entry and its corresponding information across the page (challenge.....response). The wider the gap between the corresponding items, the greater the chance that the reader will mistakenly make a perceptual misalignment (Wright, 1981).

Emphasis. Several experiments in the literature discussed the effect of different emphasis indicators on legibility. These experiments showed that there is a reduction in legibility while employing emphasis and that most subjects judged them as annoying. One last comment while employing **faces** for **contrast** and emphasis is that using too many **attention-seeking** faces can be **CONFUSING** and can **dramatically** reduce the speed, legibility, and readability of the printed matter (Hartley, 1981 p. 18). However, many checklist obtained by the author have many emphasis typefaces to indicate condition such as dual or signal response, intermediate station, different engines, different models, etc.

Contrast and color coding. A character and its background may differ in the amount of light they reflect, their color, or both. This is one of the most important factors in the hygiene of reading. Howett (1983) explains that when the character and it's background are viewed from a short

distance, more visual differences can be contributed by large luminance differences than by even the largest chromatic (color) differences. Thus, contrast is more important than difference between the colors in determining the visibility of characters than the difference between the colors (p. 27).

Black characters over a yellow background and black character over a white background are probably the best choices of color contrast for the checklist (Tinker, 1965). Tinker (1963) also tested the perception of different colored numerals at a glance (a short exposure). The results showed that black characters over yellow background are the most effective of all other combinations--a finding that is very applicable to checklist condition.

In giving an eye movement test, the combination of black over yellow yielded the best rankings. Tinker gives the following recommendations for the use of dark characters over colored backgrounds:

1. The reflection percentage of the background should be at least 70%.
2. The luminance ratio between the character and the background should be 1:8.
3. The typesize should be 0.10" or greater.

One must be cautious in using colors for checklists because human peripheral vision is limited in color sensitivity. Heglin (1973) shows that some colors are

recognized at a greater angle from the Line Of Sight (LOS) than others. At 50 degrees from LOS a yellow object is perceived colorless. This obviously poses some limitations on the use of yellow in extreme conditions.

In creating a colored checklist that will be used during night operations the designer must be aware that certain colors of ambient lighting (usually red or green) will effect the color of the print or background (Kubakawa, 1969). Color also has a psychological affect on human beings, mainly in that humans associate color with past experiences. Using black characters over a yellow background has produced some unique association in pilot groups. It is associated the use of diagonal yellow and black stripes in many military-aviation displays to indicate adverse conditions.

The cumulative effect of non optimal reading conditions. It is clear that the combination of two or more non-optimal or marginal conditions should have a greater affect on the overall legibility. Several experiments were conducted by Tinker (1963) to understand this phenomena, which is rather common in the cockpit. Tinker has found a progressive loss of legibility due to non-optimal conditions such as decrease in typesize, increase in line length, decrease in amount of vertical spacing and changes in font (Tinker, 1963, p. 162-165).

The results showed that the "combined affect of non-optimal conditions is additive but cannot be described as strictly commutative" (Tinker, 1965). In other words, the non-optimal factors combine to yield greater reduction in legibility, but the combined affect cannot be predicted from merely adding the separate affect of each non-optimal condition.

C.1.3. Reading Hygiene

Glare. Several checklists used by commercial companies and some military checklists, are laminated to protect them from wear. Others are inserted into a plastic casing and thusly used until a revision is made. In choosing the plastic cover or lamination type, an anti-glare plastic that diffuses light is preferred; otherwise, some rays from the light source will be reflecting to the pilot eyes (see AA DC-9 checklist). Research has shown that high surface reflection resulted in significant reduction in reading speed (Tinker, 1963).

Other types of glare are common during night operations. When the printed matter is lighted by the pilot's overhead light, the pilot's eyes shift between the checklist and the outside view and must constantly re-adapt to different levels of luminance. Severe differences in luminance between the paper (in the critical vision area) and the surrounding (peripheral vision) cause reduction in visual discrimination, reading speed, and can create ocular

discomfort. Conversely, during day operations, any strong light source that enters the field of vision will cause a disabling glare for the pilot using the checklist. The effect of glare disability on visual efficiency becomes greater as the source of the glare gets close to the LOS (Sanders et al. 1987, cited from Luckiesh et al. 1932).

Slope and angular alignment for reading. The optimum reading configuration is achieved when the printed copy is held flat with the plane of the copy perpendicular to the line of sight. In this condition, the printed alphanumeric are seen in their exact form. As the printed copy is tipped downward and away from the 90° alignment, the geometric form of the alphanumeric is distorted (width-height ratio). Research has shown a reduction of 10 percent in reading speed when the printed copy was tilted 135 degrees from the horizontal (Tinker, 1963 cited from an unpublished report by Skordhal, 1958; Tinker, 1963)

Similar effects occur when the checklist card is rotated away from the vertical. In this condition, the eyes are forced to move obliquely from one fixation pause to another along the line of text, thus straining additional eye muscles and making the act of reading far more complex and difficult for the eye (Tinker, 1965).

Some pilots have the tendency to place the checklist on the glare shield slots (B-737). During checklist use, they partially move the card tilting it toward their eyes. In

this condition, the card's angular alignment far exceeds the optimum 90 degrees.

Quality of print. The visual impression of the printed matter plays a significant role in the attraction and motivation of the user to read the printed matter. One factor is the quality of the actual print that comes from the print shop. The print should be clear; the boundaries between strokes and spaces should be sharp and distinguishable. Otherwise, vertical spacing between characters is reduced. Strokes and space discrimination are lost, and characters lose their visibility.

The effect of age. There is 50% less retinal illumination at the age of 50 than at the age of 20. This reduced level of retinal illuminance also plays a role in slowing the rate and level of the eye's dark adaptation. An increased thickness of the lens is the major cause of farsightedness among the elderly. As the lens thickens, it becomes yellow and reduces the transmission of blue light through it. Thus, elderly people have more difficulty in differentiating between colors. This effect is mainly seen in the blue-green and red regions of the hue. (Sanders and McCormick, 1987; Tinker, 1965). These effects were evident in ordinary reading, and must be corrected in reading a checklist in the cockpit under adverse environmental conditions.

In sum, the lack of literature on the technicalities of designing a checklist is a clear gauge for the lack of importance given to this device. It is sometimes very puzzling to note the lack of attention given to the design of checklists and flight-documentation by many airlines. It appears that these cockpit displays (we believe they are so) are much neglected by airframe manufactures as well as training departments. The reason is unknown to us.

Most of the material cited above was collected from experiments performed to investigate the quality of reading and the hygiene of reading. Therefore they cannot be used unanimously for the task of designing a checklist. However, they can definitely give the designer an initial direction in the process of trial and error that he will have to go through while designing a checklist.

VITA

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