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On the Design of Flight-Deck Procedures

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SUMMARY

In complex human-machine systems, operations, training, and standardization depend on a elaborate set of procedures which are specified and mandated by the operational management of the organization. These procedures indicate to the human operator (in this case the pilot) the manner in which operational management intends to have various tasks performed. The intent is to provide guidance to the pilots, to ensure a logical, efficient, safe, and predictable (standardized) means of carrying out the mission objectives.

However, in some operations these procedures can become a hodge-podge, with little coherency in terms of consistency and operational logic. Inconsistent or illogical procedures may lead to deviations from procedures by flight crews, as well as difficulty in transition training for pilots moving from one aircraft to another.

In this report the authors examine the issue of procedure use and design from a broad viewpoint. The authors recommend a process which we call “The Four P's:” philosophy, policies, procedures, and practices. We believe that if an organization commits to this process, it can create a set of procedures that are more internally consistent, less confusing, better respected by the flight crews, and that will lead to greater conformity.

The “Four-P” model, and the guidelines for procedural development in Appendix 1, resulted from cockpit observations, extensive interviews with airline management and pilots, interviews and discussion at one major airframe manufacturer, and an examination of accident and incident reports involving deviation from standard operating procedures (SOPs). Although this report is based on airline operations, we believe that the principles may be applicable to other complex, high-risk systems, such as nuclear power production, manufacturing process control, space flight, law enforcement, military operations, and high-technology medical practice.

1. INTRODUCTION

> When we try to pick out anything by itself,
> we find it hitched to everything else...
>
> -- John Muir

1.1 BACKGROUND

A complex human-machine system is more than merely one or more human operators and a collection of hardware components. In order to operate a complex system successfully, the human-machine system must be supported by an organizational infrastructure of operating concepts, rules, guidelines, and documents. The coherency of such operating concepts, in terms of consistency and logic, is vitally important for the efficiency and safety of any complex system.

In high-risk endeavors such as aircraft operations, space flight, nuclear power production, chemical production, and military operations, it is essential that such support be flawless, as the price of deviations can be high. When operating rules are not adhered to, or the rules are inadequate for the task at hand, not only will the system's goals be thwarted, but there may also be tragic human and material consequences. Even a cursory examination of accident and incident reports from any domain of operations will confirm this.

To ensure safe and predictable operations, support to the pilots often comes in the form of standard operating procedures. These provide the crew with step-by-step guidance for carrying out their operations. SOPs do indeed promote uniformity, but they do so at the risk of reducing the role of human operators to a lower level. Furthermore, an exhaustive set of procedures does not ensure flawless system behavior: deviations from SOP have occurred at organizations that are regarded as highly procedurized.

The system designers and operational management must occupy a middle ground: operations of high-risk systems cannot be left to the whim of the individual. Management likewise must recognize the danger of over-procedurization, which fails to exploit one of the most valuable assets in the system, the intelligent operator who is “on the scene.” The alert system designer and operations manager recognize that there cannot be a procedure for everything, and the time will come in which the operators of a complex system will face a situation for which there is no written procedure. It is at this point that we recognize the reason for keeping humans in the system. Procedures, whether executed by humans or machines, have their place, but so does human cognition.

A dramatic example was provided by an accident at Sioux City. A United Airlines DC-10 suffered a total loss of hydraulic systems, and hence aircraft control, due to a disintegration of the center engine fan disk (National Transportation Safety Board [NTSB], 1990a). When the captain had sized up the situation, he turned to the flight engineer and asked what the procedure was for controlling the aircraft. The reply is worth remembering: “There is none.” Human ingenuity and resource management were required: the crew used unorthodox methods to control the aircraft. This resulted in a crash landing in which well over half of the passengers survived.

This report is a continuation of our previous work on the human factors of aircraft checklists in air carrier operations (Degani and Wiener, 1990, 1993). Our research in this area was undertaken largely as a result of the discovery, during the investigation of the Northwest 255 crash (National Transportation Safety Board [NTSB], 1988) that checklists, for all their importance to safe operation, had somehow escaped the scrutiny of the human factors profession. The same, we later found, can be said of most flight-deck procedures.

1.2 PROCEDURAL DEVIATION: ITS INFLUENCE ON SAFETY

Problems within the human-procedure context usually manifest themselves in the form of procedural deviation. If all goes well, these deviations are not apparent to the operational management, and in most cases are left unresolved. They do become apparent, however, following an incident or an accident. In 1987 Lautman and Gallimore conducted a study of jet-transport aircraft accident reports in order to "better understand accident cause factors." They analyzed 93 hull-loss accidents that occurred between 1977-1984. The leading crew-caused factor in their study was "pilot deviation from basic operational procedures" (Figure 1).

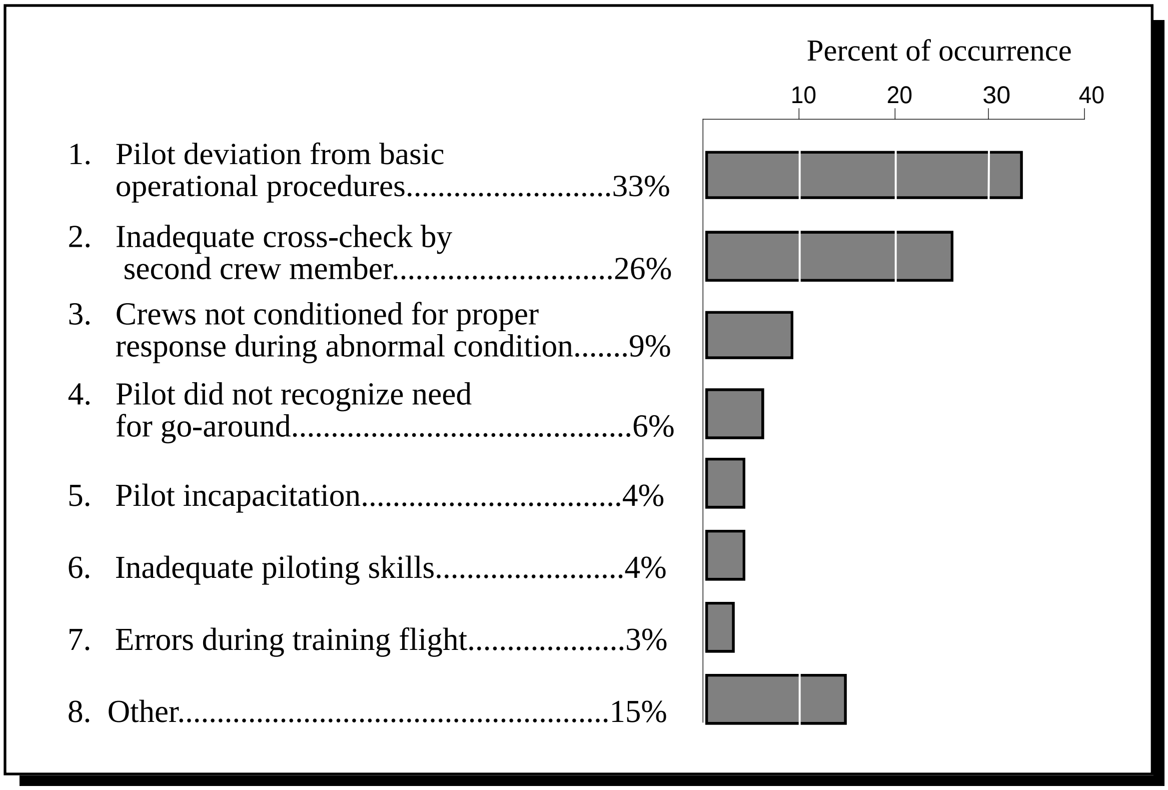

Figure 1. Significant crew-caused factors in 93 hull loss accidents.
Source: Lautman and Gallimore (1987)

Similar results were reported by Duke (1991) in his analysis of 21 turbojet (Part 121) accidents. Lack of procedural behavior accounted for 69 percent of crew errors (more then three times larger than the second ranking category -- decision making)[1]. These findings are clearly supported by three airline accidents that occurred in the last five years. In the first, Northwest Airlines Flight 255, an MD-82, crashed at Detroit Metropolitan Airport following a no-flap/no-slat takeoff (NTSB, 1988). In the second, Delta Air Lines Flight 1141, a B-727, crashed shortly after lifting off from Dallas-Fort Worth International Airport, following a no-flap/no-slat takeoff (NTSB, 1989). In the third, USAir Flight 5050, a B-737, ran off the runway at La Guardia Airport and dropped into adjacent waters, following a mis-set rudder trim and several other problems (NTSB, 1990b).

We submit that the classification of "pilot deviation from basic operational procedures" may be somewhat misleading. One should first ask whether the procedures were compatible with the operating environment. Were they part of a consistent and logical set of procedures? Most important, was there something in the design of the procedures or the manner in which they were taught that led a responsible pilot to deviate from them?

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[1] Similar statistics, showing that procedural deviation is by far the highest ranking category in crew or operator caused accidents, can also be found in the maritime industry (Perrow, 1984, p. 207), and nuclear industry (V. E. Barnes, personal communication, July 1993; Trager, 1988)

Hendrick (1987) states that human factors, or ergonomics, has two levels: micro-ergonomics and macro-ergonomics. Micro-ergonomics is focused at the direct human-machine system, e.g., controls, displays, etc. Macro-ergonomics, by comparison, is focused at the overall human-technology system and is concerned with its impacts on organizational, managerial, and personnel sub-systems. Likewise, we argue that in order to understand how pilots conduct flight-deck procedures, we cannot look only at the micro-ergonomics, i.e. procedures, but we also must also examine macro-ergonomics, i.e., the policies and concepts of operation, that are the basis on which procedures are developed, taught, and used. We submit that both the macro- and micro-ergonomics aspects of any complex human-machine system must be examined in order to improve any human-machine system. The same, we have found, is true for procedural design.

1.3 OBJECTIVES OF THE STUDY

The intent of this work was to conduct a broad examination of design, usage, and compliance of cockpit procedures from both macro- and micro-ergonomics perspectives. The objectives were to:

1. Understand what procedures are.
2. Identify the process by which procedures are presently designed.
3. Understand whether procedures are actually used by line pilots, and why deviations from SOPs exist.
4. Highlight some of the factors that affect procedural design.
5. Provide guidelines for conceptual framework, design, and implementation of flight-deck procedures.

Based on our previous work on checklists (Degani and Wiener, 1990; 1991), we developed a framework, or model, of the link between the goal of operation and conduct of procedures. In addition to the five objectives listed above, we also wanted to test the usefulness of this model for procedural design. The two chapters that follow will detail this theory.

2. THEORY OF THE THREE P'S: PHILOSOPHY, POLICIES, AND PROCEDURES

2.1 PROCEDURE DEVELOPMENT

Procedures do not fall from the sky. Nor are they inherent in the equipment. Procedures must be based on a broad concept of the user's operation. These operating concepts blend into a set of work policies and procedures that specify how to operate the equipment efficiently. There is a link between procedures and the concepts of operations. We call that link “The Three P's of cockpit operations”: philosophy, policies, and procedures. In this chapter we shall explore the nature of these links, and how an orderly, consistent path can be constructed from the company's most basic philosophy of operation to the actual conduct of any given task. The fourth P, “practices,” will be introduced in the next chapter.

2.1.1 *Procedures: What and Why?*

In general, procedures exist in order to specify, *unambiguously*, six things:

1. What the task is.
2. When the task is conducted (time and sequence).
3. By whom it is conducted.
4. How the task is done (actions).
5. What the sequence of actions consists of.
6. What type of feedback is provided (callout, indicator)

The function of a well-designed procedure is to aid flight crews by dictating and specifying a progression of sub-tasks and actions to ensure that the primary task at hand will be carried out in a manner that is efficient, logical, and also error resistant. Another important function of a cockpit procedure is that it should promote coordination between agents in the system, be they cockpit crew, cabin crew, ground crew, or others. A procedure is also a form of quality control by management and regulating agencies (e.g., FAA) over the airlines.

2.1.2 *Standard Operating Procedures*

Standard operating procedures are set of procedures that serve to provide a common ground for two or three individuals (comprising a flight crew) who are usually unfamiliar with each other's experience and technical capabilities. So strong is the airline industry's belief in SOPs, it is believed that in a well standardized operation, a cockpit crew member could be plucked from the cockpit in mid-flight and replaced with another pilot qualified in the seat, and the operation would continue safely and smoothly.

As mergers and acquisitions of airlines create “mega-carriers,” the process of standardization becomes increasingly important, costly, and difficult to achieve. The need to render manuals, procedures, policies, and philosophies that are consistent and unambiguous becomes more difficult. This is because not all flight crews equally share the corporate history and culture that led to a certain concept of operation. Nevertheless, any human operator knows that adherence to SOPs is not the only way that one can operate equipment. There may be several other ways of doing the same task with a reasonable level of safety (Orlady, 1989). For example, most carriers require that crews enter the magnetic course of the runway into the heading select window on the mode control panel (MCP) before takeoff. One company requires that the first published or expected heading will be entered instead. Good reasons exist for both procedures.

2.2 PHILOSOPHY

The cornerstone of our approach to the concepts of cockpit procedures is philosophy of operations. By philosophy we mean that the airline management determines an over-arching view of how they will conduct the business of the airline, including flight operations. A company's philosophy is largely influenced by the individual philosophies of the top decision makers. It is also influenced by the company's culture, a term that has come into favor in recent years to explain broad-scale differences between corporations. The corporate culture permeates the company, and a philosophy of flight operations emerges. For a discussion on the development and implementation of a company-stated philosophy, see Howard (1990).

Although most airline managers, when asked, cannot clearly state their philosophy, such philosophies of operation do indeed exist within airlines. They can be inferred from procedures, policies, training, punitive actions, etc. For example, one company that we surveyed had a flight operation philosophy of granting great discretion (they called it “wide road”) to the individual pilot. Pilots were schooled under the concept that they were both qualified and trained to perform all tasks. Consistent with this philosophy, the company allowed the first officer to call for as well as conduct (when he or she is the pilot flying) the rejected takeoff (RTO) -- a maneuver which is the captain's absolute prerogative at most carriers.

The emergence of flight-deck automation as an operational problem has recently generated an interest in the philosophy of operations, partly due to lack of agreement about how and when automatic features are to be used, and who may make that decision (Wiener, 1989). This has led one carrier, Delta Air Lines, to develop a one-page formal statement of automation philosophy (see Appendix 2). This philosophy is discussed in Wiener, Chidester, Kanki, Palmer, Curry, and Gregorich (1991). To the best of our knowledge, this is the first case where an airline management actually wrote out its philosophy and the consequences of the philosophy on doing business, and distributed copies to its pilots.

2.3 POLICY

The philosophy of operations, in combination with economic factors, public relations campaigns, new generations of aircraft, and major organizational changes, generates policies. Policies are broad specifications of the manner in which management expects things to be done (training, flying, maintenance, exercise of authority, personal conduct, etc.). Procedures, then, should be designed to be as much as possible consistent with the policies (which, in turn, should be consistent with the philosophy). Figure 2 depicts this framework.

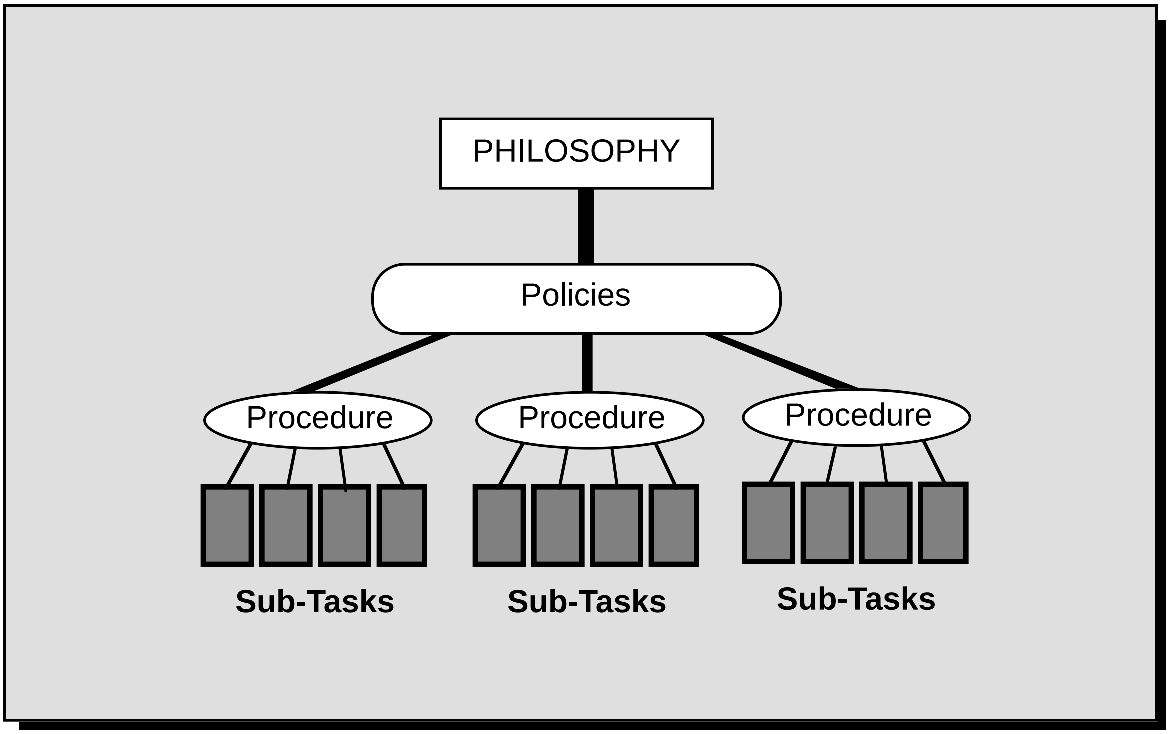

Figure 2. *The Three P's*

The levels in the Three-P framework are not rigid. For some aspects of flight operations there may be several policies, for others there may be only a philosophy. For example, checklist SOP is a mature aspect of flight operation: there can be an overall checklist philosophy, checklist policies for normal, abnormal, and emergency situations. Flight-deck automation is still in an immature stage of development. As the operation matures, policies will be defined and added, and philosophies may change[2].

To illustrate the Three P's, let us assume that the task at hand is the configuration of an advanced technology aircraft for a Category-I ILS approach:

1. Philosophy: Automation is just another tool to help the pilot.
2. Policy: Use or non-use of automatic features (within reason) is at the discretion of the crew.
3. Procedure: On a Category-I approach, the flight crew will first decide what level of automation to use (hand-fly with flight director; autopilot and mode control panel; coupled; etc.), which determines what must be done to configure the cockpit.
4. Sub-tasks (or actions): Follow from procedures (e.g., tune and identify localizer and compass locator, set decision height, select autopilot mode, etc.)

In some cases, policies that are actually remote from flight operations can affect procedures. One carrier's new public relations policy called for more interaction between the cockpit crew and the passengers. It was recommended that at each destination the captain stand at the cockpit door and make farewells to the passengers as they departed the cabin. In particular, the marketing department wanted the pilot to be in place at the cockpit door in time to greet the disembarking first-class passengers. This dictated a procedural change in that most of the SECURE-AIRCRAFT checklist had to be done alone by the first officer. Thus checklist procedures which would normally be run by both pilots, probably as a challenge-and-response, were performed by a single pilot in deference to public relations imperatives.

To conclude, it is our position that procedures should be based on the operational concepts of the organization. We hypothesize that if these operational concepts are specified (in writing) as a philosophy and a set of policies, then (1) a logical and consistent set of cockpit procedures that are in accord with the policies and philosophy can be generated, (2) discrepancies and conflicting procedures will be easily detected, and (3) flight crews will be aware of the logic behind every SOP[3]. We also hypothesize that all of the above will lead to a higher degree of conformity to procedures during line operations. In addition, flight training, transition training, and line and FAA checking will be made easier, and the general quality of flight operations will be enhanced.

To design procedures, even in the manner that we have recommended, does not ensure perfect conformity by line crews. In the next chapter we will explore the actual practices as conducted on the line, and the reasons for non-conformity to standard operating procedures. This discussion extends the development of the model to the fourth "P" - practices. An all- inclusive model, linking the four P's to line operations will be developed, and the role of feedback from line to management will be discussed.

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[2] Rosenbrock (1990), makes a somewhat similar distinction between purpose, policy, and schedule, from a view point of a control theorist.

[3] For a practical example detailing the benefits of specifying policies prior to making technical decisions, see Hammond and Adelman (1976).

3. THE FOURTH P: PRACTICES

3.1. AN EXTENSION OF THE THREE P's

As we began this study we focused on the macro-ergonomics aspects of flight operations: the philosophy, policies, and procedures. As we progressed, it appeared to us that something was missing. We discovered that the macro-ergonomics approach had led us astray from the focal point of any human-machine system -- the human operator. We neglected the ultimate consumer of the procedure -- the flight crew, whose decisions and actions determine the "system outcome."

To correct this, we have added an additional component -- practices. The term "practice" encompasses every activity conducted on the flight deck: correct execution of a procedure, deviation from a procedure, omission of a procedure, the use of a technique, or any other action. While a procedure may be mandatory, it is the pilot who will either conform to it or deviate from it. The procedure is specified by management -- the practice is conducted by the crew. *Ideally procedures and practices should be the sam*e. The high prevalence of the "pilot deviation from SOP" classification mentioned earlier indicates that no one can assume that pilots will always follow any given procedure dictated by management[4].

The goal of flight management is to promote "good" practices by specifying coherent procedures. But we must also recognize that this is not always the case: procedures may be poorly designed. The crew can either conform to a procedure or deviate from it. The deviation may be trivial (e.g., superimposing some non-standard language on a procedural callout), or it may be significant (e.g., not setting the auto-brakes according to the takeoff procedures). The alternatives of conformity versus deviation can be visualized as a switch (Figure 3). This may be somewhat of an over-simplification, but it expresses the choice that the crew member must make: to conform to the company's SOP, or to deviate. For example, we once observed a captain who, in response to the first officer's question regarding the conduct of a *mandatory* taxi procedure, replied "I just don't do that procedure." That captain, unequivocally, placed the switch in the deviate position.

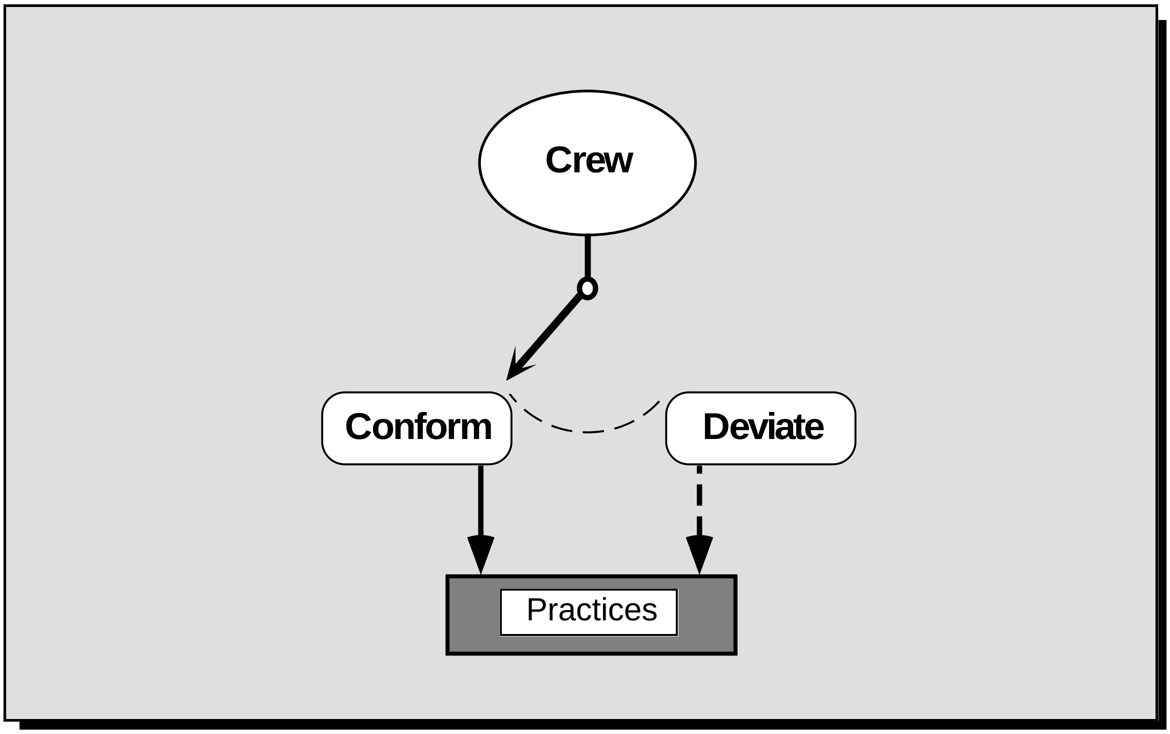

Figure 3. *The deviate versus conform "switch"*

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[4] Assuming, of course, that the procedure is clear to the crew. We recognize, however, that this is not always the case and some SOPs can be ambiguous and lead to deviations by a well meaning pilot.

We envision a term "Δ" -- delta, or the degree of difference between procedures and practices (Figure 4). This "Δ," not to be taken as a quantitative value by any means, expresses symbolically the amount of deviation from a specified procedure. This term has two components: (1) the magnitude of deviation from the procedure, and (2) the frequency of such deviations during actual line operations. The goal of flight management is to minimize "Δ." When "Δ" is large (flight crews constantly deviate from SOP and/or deviate in a gross manner), there is a problem. This "Δ" may be due to a crew's deviation and/or a problem in using this procedure.

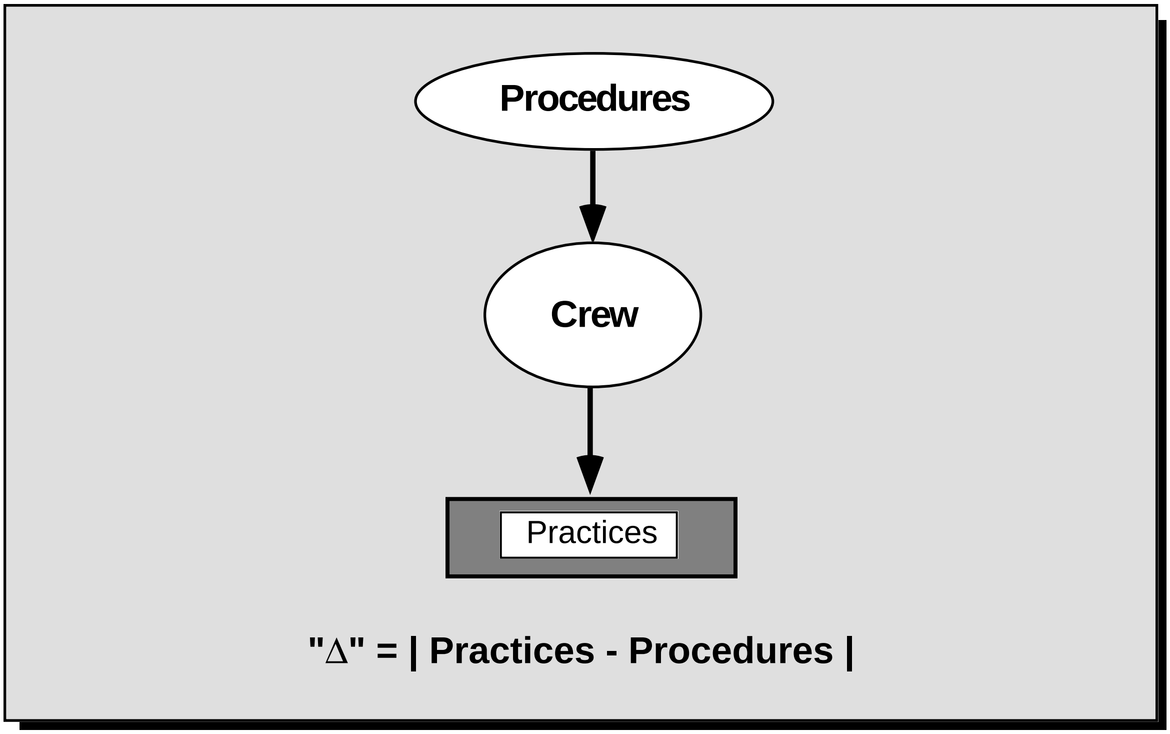

Figure 4. *The quantity "Δ" - deviation from procedures.*

The human operator in this situation is analogous to a filter. From the above, standards and training departments dictate and teach the way procedures should be performed. However, in daily line operations (and not under the watchful eye of a check-airman), the individual pilot may adjust the gauge of the filter. This gauge will determine the degree to which the SOPs actually will be observed, modified, misused, or completely ignored. The purpose of standardization is to bias the filter toward prevention of deviations.

The consequences of the failure to conform to a procedure can be seen in the following report from NASA's Aviation Safety Reporting System (ASRS)[5] :

> Our flight departed late PM local time for the 4:30 plus flight to SFO. F/O was PF. En-route discussed necessity to request lower altitudes with both OAK Center and Bay Approach when approaching SFO due to tendency to be "caught high" on arrival in this aircraft type. Area arrival progressed smoothly and we were cleared for the QUIET BRIDGE visual to 28R. Good speed control and vertical descent planning until vicinity of BRIJJ LOM. When changing radio frequency from approach to tower (head down), F/O selected "open descent" to 400 feet MSL. Autopilot was off, both flight directors were engaged, and autothrust was on. While contacting SFO tower I became aware that we were below the glideslope, that airspeed was decaying, and that we were in an "open descent." Instructed the F/O to engage the "vertical speed" mode in order to stop our descent, restore the speed mode for the autothrust, and continue the approach visually once above the 28R ILS glideslope. Company procedures explicitly prohibit selecting an altitude below 1500 feet AGL for an open descent, since this places the aircraft close to the ground with engines at idle. (ASRS Report No. 149672)

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[5] ASRS reports are quoted here verbatim.

To summarize, the ultimate factor that determines the quality of the system outcome is actual practices. Management's role does not end with the design of the procedure. Management must maintain an active involvement as the procedure moves from management offices to the line, remain concerned with practices, and committed to management of quality through reduction of “Δ.” These goals are generally approached as “standardization,” a form of quality management aimed at ensuring compliance. Standardization is also a check on the quality of the procedures themselves, as well as on the training function. The “Four-P” model allows us to evaluate compliance versus non-compliance with procedures, standardization, and internal consistency of procedures with training.

3.2 FEATURES OF THE “FOUR-P” MODEL

Our “Four-P” model is an extension of the “Three-P” model, taking into account the following: tasks, crews, practices, management, quality assurance, and the system outcome. Figure 5 is a more global depiction of the interrelationship of the elements as we see them. The top of the chart is essentially the same as in Figure 2. But when we get to the “crew” circle, we open the door to *practices* (and “Δ”).

3.2.1 *Deviations from Procedures*

In this section we shall examine several reasons why “Δ” exists, why a well-trained, well-standardized, and presumably well-motivated pilot intentionally deviates from the company's published procedures.

Individualism. “Δ” arises primarily due to the fact that pilots are individuals, and in spite of training, loyalty, and general devotion to safe practices, they will impose their individuality on a procedure. This may or may not adversely affect the system. We also recognize that there is a positive side to individualism: it is one of the differences between humans and computers. Individualism makes life interesting and provides us with an incentive to achieve. Pilots are not “procedure-doing” robots; they are individuals who bring to their job certain biases, prejudices, opinions, experiences, and self-concepts. For example, one of the most unusual practices we have observed was demonstrated by a captain of a B-757. Acting as pilot not flying (PNF), he tuned the arrival ATIS on the VHF radio, listened to it, and then rather than writing it on a pad or a form, he proceeded to encrypt it into the scratch line of the control display unit (CDU). He then read it from the CDU to the pilot flying. This was a captain who obviously wanted to make maximum use of his automated devices. Of course this method of recording the ATIS has its limitations, the most severe being that only one person in the world could decode the ATIS as recorded.

The problem, of course, is the potential conflict between individualism and standardization in high-risk enterprises. On one hand, standardization is the foundation of a structured operation; on the other hand, humans are not machines (Rosenbrock, 1990). Furthermore, humans possess brains that allow great flexibility, and this can become critically important in extreme cases where no procedure is available, e.g., United's previously mentioned Sioux City accident (NTSB, 1990a).

Complacency. It is well established in aviation that a pilot's vigilance may not remain at its highest, or even at an acceptable level at all times. This phenomenon of dropping one's guard is generally labeled “complacency.” Wiener (1981) has questioned whether the term has any real meaning, and whether its use makes any real contribution to understanding safety. Pending an answer to this question, it seems safe to say that complacency, as the term is used, may be responsible for many of the departures from SOP.

It is the very safety and error tolerance of the system that may generate complacency and non-adherence to SOPs. If day after day, year after year, pilots encounter few threats, and few genuine emergency situations, the temptation to ease up and accept less than standard performance is understandable. Recent work by Parasuraman and his collaborators have examined what they call “automation complacency,” the tendency to become overly trustful and over-dependent on various automatic devices in the cockpit (Parasuraman, Molloy, and Singh, 1991).

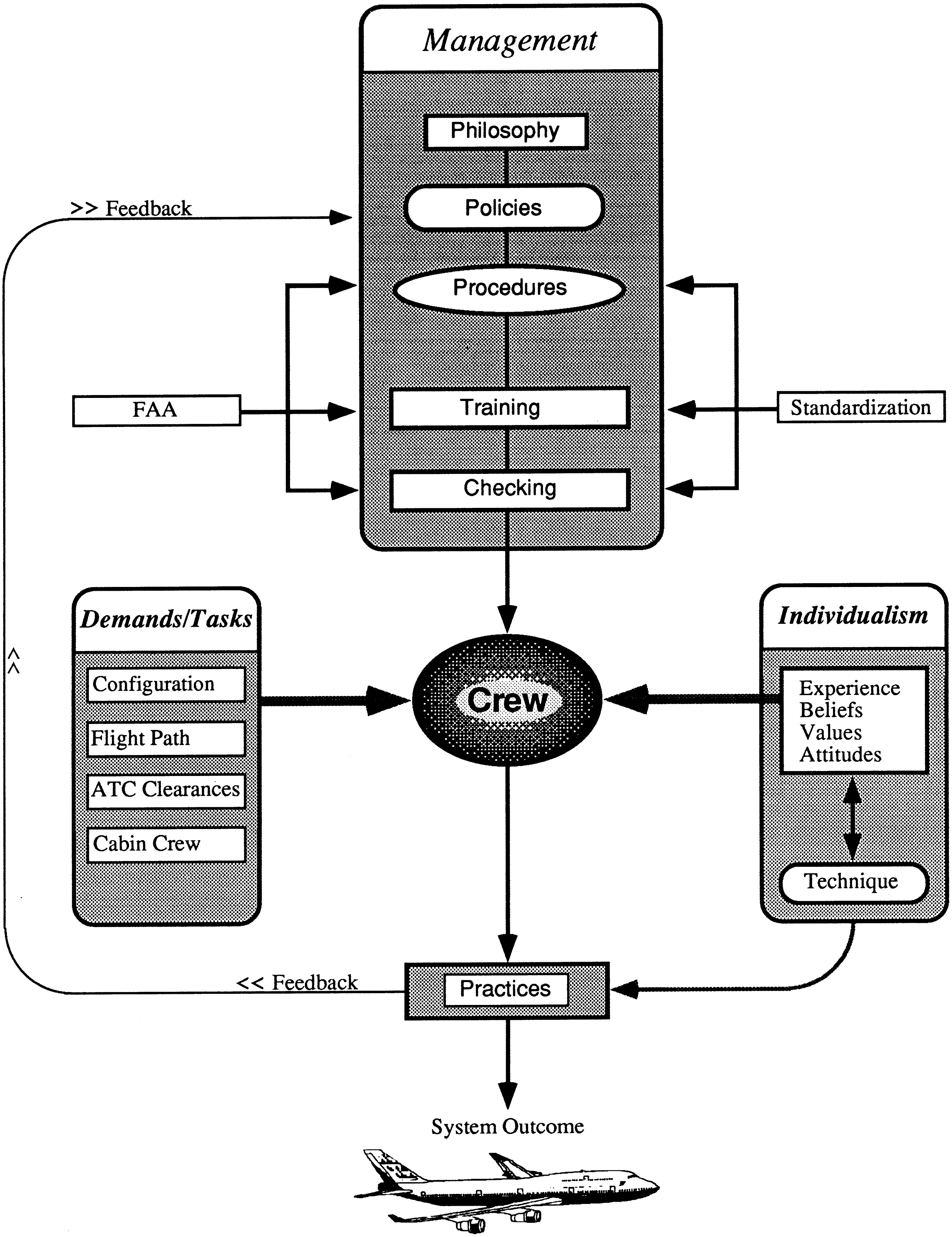

Figure 5. *Schematic linking all "Four-P's."*

Humor. Humor is closely related to individualism, but its consequence may be similar to that which results from complacency. Humor in the cockpit represents the desire to inject some variety and stimulation into an otherwise humorless situation. Humor, like individualism, has its place. It makes life enjoyable, overcomes the tedium of a highly precise job, and establishes a form of communication between crew members. It also carries potential hazards:

> I called for clearance to Saint Louis (STL) as follows: 'clearance delivery, company identification, ATIS information, federal aid to Saint Louis.' Federal aid was meant to mean FAA clearance in a joking fashion. The controller misinterpreted this to mean that we were being hijacked and called the FBI and airport police.... Minutes later police arrived at the aircraft.
>
> It was not my intent to indicate we had a hijacking. I was merely requesting a clearance.... The phrase federal aid to obtain a clearance has been a sarcastic term used for years in the cockpit and I thought [it] could not be mistaken to indicate other problems. I will use absolutely standard phraseology in the future... (ASRS Report No. 248982)

During our cockpit observations, we noted checklist reading behavior when the pilot reads "gasoline" where the checklist requires a challenge of "fuel," or use of the Spanish term *uno mas* instead of a 1000 feet to level-off callout. These departures are inevitable, as they break the monotony of a highly standardized and procedurized situation. The meanings are *assumed* to be clear and the departure from SOP is usually harmless. But that is exactly what cockpit standardization is all about: trying to eliminate the need to make unnecessary *assumptions* or interpretations during high-risk operations. The difficult decision is where to draw the line. Unfortunately, the absolute distinction between what is humor and what is a deviation from SOP usually depends on the outcome. If this non-standard verbiage (e.g., federal aid) caused a breakdown in communication that led to an incident, then it would be labeled "deviation from SOP." If it did not result in an untoward consequence, then it would be humor.

Nonetheless, we take the position that any deviations during critical phases of flight should not be taken lightly: We once observed a takeoff in which the captain was the pilot flying. The first officer was supposed to make standard airspeed calls of V-1, V-r, and V-2. Instead, he combined the first two into a non-standard call of "V-one-r", and at V-2 called, "two of 'em." Apparently, the captain knew what was meant by these strange calls, and while one cannot say that this was a dangerous compromise with safety, it did represent a potentially serious departure from SOPs. Perhaps worse, it established an atmosphere of tolerance on the part of the captain of non-standard (one may say sub-standard) performance, which laid the foundation for more serious SOP departures later in the flight.

We may question what moved the first officer to depart from standard procedures and utter nonsensical callouts. This example could of course be attributed to complacency. The link may be that complacency induces the introduction of "humor" in place of standardization. A critical phase of flight operations, such as takeoff, is probably not an appropriate arena for humor.

Perhaps the appropriateness of humor on the flight deck is an area addressable by cockpit resource management (CRM). It might be a relatively simple matter for the captain, during his initial briefing, to advise the subordinate crew member(s) on how he or she feels about humor in the performance of duties. However, in spite of the fact that CRM training stresses free two-way communication in the cockpit, it might be somewhat more difficult for the other crew persons to do the same for the "humorous" captain.

Frustration. Pilots may feel that they have been driven to non-conformity by frustrating forces beyond their control. An example would be the failure to use the oxygen mask (above FL 250) when one pilot leaves the cockpit in a modern, two-pilot aircraft. We repeatedly observed low conformity to this regulation. First, it is not comfortable to wear any mask; and second, in some modern aircraft, it is difficult to replace the inflatable masks in their receptacles. Pilots find it a frustrating task and avoid it by simply not conforming to the regulation. "Δ", in this case, is equipment-induced.

We observed an interesting technique (or ploy) to overcome the mask while still obeying the regulation. In a two-pilot aircraft with the inflatable mask, the captain left the cockpit briefly while the aircraft was climbing unrestricted to FL 330. At about FL 200 the first officer called ATC and requested level off at FL 250, which he maintained until the captain returned, and then requested continuation of his climb (the mask is only required above FL 250). In this case the pilot conformed to the regulation and procedure, but at some cost to the company (increased fuel usage resulting from sub-optimal climb profile) and possibly some inconvenience to the ATC system.

3.2.2 *Technique*

The term “technique” is defined here as a personal method (practice) for carrying out a task. The use of technique allows the pilot to express individualism and creativity without violating procedural constraints. If the technique is consistent with the procedure and the overlying policy, then the task is conducted with no violation of constraints, and “Δ” is zero.

Techniques have been developed by pilots over their years of experience of flying various aircraft. Every pilot carries with him a virtual catalog of techniques. They are often fine points which pilots have discovered for themselves, experimented with, or learned from other pilots. Consider the following technique:

> The Quiet Bridge visual approach to runway 28R at San Francisco (SFO) requires a profile descent with fixes at 6000 feet 18 DME, 4000 feet 13 DME, and recommended 1900 feet 6 DME from the SFO VOR. We once observed a crew that, in preparation for this approach, built these fixes into the FMC and named them “6000,” “4000,” and “1900” (in an A-320 FMC it is possible to give any name for a “man-made” waypoint, as opposed to “SFO01,” etc. in other FMS aircraft). As they flew this approach using only the autopilot and manual flying, the depiction of these fixes and their associated names (altitudes) on the map display (HSI) provided an “enhanced” situation display.

Why does the procedure writer not include the techniques as part of the procedure? Generally this is not advisable: the techniques are too fine-grained. If SOPs were replaced with the detailed descriptions necessary for one to carry them out, the flight operations manuals would be many times their present size. The company should be happy to specify the procedure and leave it to the individual pilot to apply what he or she considers the best technique.

To the credit of the flying profession, pilots are always looking for better techniques. The motivations are various: professional pride, overcoming boredom, expression of individuality, the comfort of the passengers, and perhaps most salient, a feeling that they can find a better way. Note that some of the motivations are the same as those that led to deviant behavior and “Δ,” but in the case of techniques, they led to a more favorable result. Further discussion of technique, its relation and influence on policies, management, automation usage, and CRM, is provided in Chapter 5.

3.2.3 *Standardization*

Standardization is the palace guard of procedures. It is a management function which begins with the writing of procedures, to ensure that they are consistent with the first two P's (philosophy and policies), are technically correct, and are published in a manner that will be clear to the line pilots. Standardization also extends to the various quality assurance methods that allow flight management to monitor line performance, training performance (of both instructors and trainees), and to guarantee conformity to SOPs (low values of “Δ”). These methods include recurrent training, line oriented flight training (LOFT), line checks, and simulator check-rides. Standardization personnel play a vital part in establishing and maintaining the feedback loop which links the line to flight management. We shall now discuss the feedback process and its role in procedure development.

3.2.4 *Feedback*

Feedback from the line to management is an essential process because some procedures are not perfectly designed. Furthermore, changes in the operational environment constantly lead to procedural modifications. As we have noted earlier, another reason why pilots deviate from accepted procedures (create “Δ”) is that they think that they know a better way. In some cases they may be right.

One way of promoting conformity to procedures is by providing a formalized feedback between the operational world and flight management. Some may argue that this is not necessary and that flight management *is* part of the operational world. On the other hand, the performance of line pilots is the ultimate measure of the adequacy of procedures because of their daily interaction with the operating environment. When written procedures are incompatible with the operational environment, have technical deficiencies, induce workload, create conflicts in time management, or produce other problems, flight crews may react by resisting and deviating from SOP.

We have used the word “formal” to describe the desired feedback path. Bland statements from management such as “my door is always open,” or “you can always go to your chief pilot” do not constitute a sufficient feedback path. Likewise, offhand comments given while passing in the corridors and in coffee shops do not qualify as effective feedback mechanisms. The line pilot must feel that his or her input is desired, and will be taken seriously. Ideally, feedback should be in written form. We recommend that all written communications from line to management result in a written reply. The frustration of a crew member who felt that management was unresponsive to feedback from the line can be seen in the following ASRS report.

> I am very concerned about the safety of the company's new checklist policy. The climb checklist has three different segments and it not completed until about of 18,000 feet. The approach checklist has a descent check that precedes it. The landing check has four segments. The “landing check" is called after the approach flap settings. The "landing gear" call stands alone, and the final segments are completed after the final flaps are set. The last segment requires both pilots to watch the flaps come down, no matter how busy an approach [we are flying]. We have had several major checklist changes over the last two years. This latest one is the most radical. Having flown with 20-30 F/Os using it, I find that about 30 to 40 percent of the time we are able to do all the checklists correctly. Since it takes so long to complete all the segments of the list, something usually gets left out. Many times it's the "gear down" check, since it no longer is "gear down/landing check" as we have all done since day-one in our careers. Also much of the check is done with a flow that does not match the checklist. After time off you have to re-memorize the flow since it's so different from the list. I note that when a situation is tight we are all, at times, reverting back to some of the calls from the previous procedures. Even the new hires who never used another checklist are not able to remember all the steps. The company imposed the procedures without input from the line, and is not interested in our input. Please help us convince the company that these procedures are not user friendly before someone makes a serious mistake. (ASRS Report No. 155183)

Discussing the feedback path from line to management forces us to consider briefly labor-management relations at airlines. To be successful, the feedback process must involve the participation of the appropriate pilots' representative group. The feedback path then would consist of a communication from the line to the pilots' representative group, and thence to management. This may have some advantages over direct pilot-to-management communication, in that the pilot may wish, for various reasons, to be insulated from his or her managers. Also, by working through a committee, patterns can be observed by the committee members.

For this system to be effective, it is essential that a cooperative, non-adversarial relationship exist between management and the representative group. This is sometimes difficult when contract negotiations are underway, or when for whatever reason tensions exist between pilots and management (e.g., a furlough has been announced). The feedback process can be effective only if management makes it clear that they are eager to receive input from the pilots' representative group on a non-adversarial basis, and the pilots' group in turn must resolve to stick to its safety mandate, and not be tempted to use safety as a smoke screen for contractual matters. It is a measure of the maturity of the management of both the company and the union if both sides can transcend “politics as usual” for the sake of promoting safety.

> *Guideline #1*: A feedback loop from line pilots to flight management and procedure designers should be established. This feedback loop should be a formal process, as opposed to an informal process. It must be maintained as a non-punitive, reactive system, with mandatory feedback from management to the initiating line pilot about the progress of his report and/or suggestion.

Having built a foundation for procedure development, and explored the reasons for non-conformity to procedures, we attempted to verify the model by a field study of actual airline management and line practices. This is described briefly in Chapter 4.

4. FIELD STUDY

4.1 RATIONALE

The previous sections detailed our framework, or model, of what we felt was the rational process. We wished to test this framework in the real world of airline operations and to modify it depending on what we might discover. For this reason we sought and obtained the cooperation of three major U.S. airlines in hosting a field study. In a sense our approach was "anthropological": we went into the field and observed both management and flight crews doing their jobs.

There are two entities that design procedures: the operators of aircraft and the airframe manufacturers (or alternatively component manufacturers, such as avionics firms). Despite their common interest in establishing procedures which will promote flight safety, their approach and objectives are quite different. Our field study focused on the operators, and only briefly surveyed the second. The main body of this report is based on the operators' approach to procedures and not that of the manufacturers.

4.2 METHOD

4.2.1 *Activities at Participating Airlines*

Three major U.S. airlines agreed to participate in this research study. These airlines had previously expressed an interest in evaluating the way they design procedures, and wished to cooperate with this project. We visited each of the three airlines, conducted interviews with flight management and line pilots, and attended procedural design meetings. We focused our research on procedures for automated cockpits (e.g., B-757/767, A-320, B-737-300).

In addition, we wanted to see how procedures are actually conducted on the line (i.e. practices). We therefore conducted observations and informal discussions with line pilots while occupying the jumpseat with all three carriers. All companies and individuals were promised anonymity. No companies or individuals would be identified in connection with any particular statements, events, or findings.

Interviews with flight management and line pilots. Prior to conducting the interviews, we presented our initial concepts to personnel in flight management. Since the "Four-P" model encompassed both high level management and line pilots, we decided to interview both. The underlying rationale was that if we wanted to examine how the organization directs flight operations, we must first have a clear understanding of how flight operation concepts are perceived at each level within the organization. The questions for top management were aimed at philosophies and policies (see Appendix 3). As we descended the organizational ladder, the questions moved toward procedures and ultimately, toward practices.

At each of the participating carriers, we started with the vice-president for flight operations, and worked our way down the ranks of flight management. The following personnel in each flight department were interviewed:

1. The head of the flight operation department (usually vice-president for flight operations)
2. The senior aid to the head of the flight department
3. Manager responsible for flight standards
4. Manager responsible for flight training
5. Manager responsible for checking (check-airman program)
6. Fleet manager of an advanced technology aircraft

In cooperation with the pilot representative group, we conducted interviews with line pilots who were currently flying FMS equipped aircraft. We interviewed three or four pilots in each session. The sample at each airline ranged from nine to twelve pilots. We asked the flight crews the same questions that we asked flight management personnel (see Appendix 4). We wanted to test whether the concepts of operations and the philosophy of the airline are truly shared by management and line pilots, and how line pilots perceive their company's concept of operations.

Procedure design meetings. We also wanted a view-port into the process itself. That is, how flight management actually designs or modifies procedures. We attended meetings in which procedural changes were addressed.

Jumpseat observations. Mindful of the last P of our "Four-P" model (practices), we wanted to observe how procedures are actually used in daily line operations. We also wished to informally discuss procedural concepts with line crews in their operational habitat: the cockpit. Appendix 5 contains the informal questionnaire used during line observations. This proved to be a very useful methodology. Flight crews discussed and pointed to procedural problems as they occurred. We flew a total of more then 200 legs and some 400 hours with the three cooperating airlines.

4.2.2 *Meeting at One Airframe Manufacturer*

The airframe manufacturer is the first to design procedures for a new aircraft. After the manufacturer completes the certification process (FAR Part 25), the customer operating under Federal Aviation Regulation Part 121, is responsible for certifying the procedures for the type of operation that the customer conducts. It is no secret that airline and manufacturer procedures do not resemble each other -- their perspectives are very different. When we asked airline flight managers why they did not simply accept the procedures from the airframe manufacturer, their answer was always the same: "they design and build airplanes, we fly passengers."

This provides some friction between airline procedure designers and the manufacturers' representatives, who would prefer that their customers stay with the original procedures provided with the airplanes. An exception to the above, however, are some abnormal and emergency procedures. In this case most carriers adopt the manufacturer's procedures, with the exception of callouts and allocation of tasks among crew members.

We surveyed one airframe manufacturer in order to understand its concepts for designing procedures. We presented our framework and conducted discussions with a group of managers and engineers responsible for procedure design. Our main objectives were (1) to understand how the manufacturer specifies procedures for a new aircraft, (2) to understand their view of the reasons why carriers take the manufacturer's procedure and modify it.

4.2.3 *Accident and Incident Databases*

In order to gain insight into the influence of procedures in the "real world" of line operations, we conducted searches of two databases: (1) the incident database of NASA's Aviation Safety Reporting System (ASRS), and (2) the accident database of the National Transportation Safety Board (NTSB).

The chapters that follow are based on our work with the three U.S. airlines that participated in the study. We have tracked the flow of procedure development from the airframe manufacturer, its subsequent tailoring to fit the individual airline's operation, its use by the line pilot, and the never-ending process of modification. We will discuss the factors that affect procedure development, issues in procedure design, and provide guidelines for the designer.

5. FACTORS THAT BEAR ON PROCEDURE DESIGN

In Chapters 1, 2, and 3 we formulated our generic approach to procedure development, modification, and management. This approach provides the user with a theoretical framework that is independent of any particular aircraft model, airline, or nation. In the following chapters we will show how the Four P's, as constructed in the first three chapters, can be applied to procedure development.

In Chapter Five, we discuss those factors, both internal to and external to the cockpit, that affect operating procedures. In addition, we will confront the issue of pilot technique, and how it fits into, and is compatible with, the Four P's formulation. In Chapters 6 and 7 we detail some of the issues involved in designing and using procedures. Obviously we could not plunge into the details of every procedure. Nevertheless, we believe that the procedure designer will be able to identify themes and concepts in our formulation, and apply them[6].

5.1. PROCEDURAL DEVELOPMENT BY AIRFRAME MANUFACTURER

In the past, airlines have criticized the airframe manufacturers for designing new procedures for new aircraft without sufficient consideration of the unique operational environment in which airlines “live.” In developing a new aircraft, one airframe manufacturer has taken steps to bridge this gap. The airframe manufacturer stated that it tries to target its procedure more toward Part 121 operators, while acknowledging the differences in operational environment between airlines that may affect procedural design and flow. For example, different carriers provide manifest, gross weight, zero fuel weight, and trim information at different times in the ground phase of the flight. This has considerable bearing on designing the procedures for this phase, as many tasks are dependent on this information. The manufacturer has to take these differences into account in designing the flow of tasks in the cockpit.

As a conceptual framework for designing procedures for its new aircraft, the airframe manufacturer now attempts to design the new procedures based on its previous glass cockpits designs. In developing the procedures, the design team included instructors from the manufacturer's customer training department. This was designed to achieve a significant level of procedural standardization between the previous aircraft and the new aircraft in order to facilitate positive transfer. Another goal was to standardize terminology. For example, the MCP button that engages the power setting for takeoff and climb has different names depending on the type of engines used (N1 for CFM engines and EPR for Pratt and Whitney). In the new aircraft, the design team decided to call the button according to its function -- Climb Power. Although the engineers who designed the system labeled the button “Thrust,” the instructors felt that line pilots would find the label “Climb Power” more appropriate for the task. In essence, the instructors on the design team performed a valuable transformation process between engineers who design the systems and the target population -- line pilots, who must use these systems.

5.2 WHAT PROMPTS A PROCEDURE CHANGE?

Before considering the process of procedural changes by the airlines, we had to explore just what events, internal or external to the cockpit, might prompt a carrier to make changes in procedures. We were astonished at the great variety of events or conditions that could trigger procedure changes. These event include changes in procedures due to straight forward triggers such as new equipment, new maintenance data, new routes, and many more. In addition, these events included changes that at first seem remote from the cockpit, such as labor relations, marketing influence, new cabin regulations, etc. Seventeen of these categories, each with a brief example, are listed in Appendix 6.

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[6] The authors must point out that the Four P's formulation, the concepts, and the guidelines presented in this report were not the result of an experiment. They were based on interviews, observations, examination of incidents and accidents, and our analysis of the problem. The reader should understand that we have not "proven" the case for our approach.

5.3 MERGERS AND ACQUISITIONS

Mergers and acquisitions between airlines have been occurring at a dizzying pace since the enactment of the Airline Deregulation Act of 1978, and similar legislation in European countries. Today there are few “pure” airlines - all have mixed parentage, some of which is so complex that a given airline's tributaries can best be communicated by drawing a family tree. For example, the present Northwest Airlines acquired Republic in 1986. Republic in turn was the product of a three-way merger in the early 1980's of North Central, Southern, and Hughes Airwest. Furthermore, Airwest itself was the product of the merger of a number of smaller airlines. One could probably not find (or create) three more diverse cultures.

Mergers and acquisitions produced three effects that interest us here:

1. The corporate culture, which we shall discuss in Section 5.4, and other influences attributable to the history of the acquiring companies, are highly diluted. Although the acquiring company's culture has tended to prevail, due partly to geographic influences, the resulting companies no longer have a strong, unalloyed corporate culture.
2. The acquiring company suddenly finds itself with mixed fleets of aircraft; various cockpit configurations of aircraft they already had; and aircraft that they did not previously operate. When Northwest acquired Republic in 1986, it became heir to the world's largest fleet of DC-9s. In so doing, it also acquired a vast fund of experience in two-pilot operations. Prior to that, with the exception of a small number of B-757s acquired just before the merger, Northwest had had no two-pilot aircraft in over two decades.
3. With the mergers and acquisitions come mixtures of not only fleets of aircraft, but pilot groups, procedures, checklists, and other documentation. An immense standardization, training, and rewriting job results. The new standardized procedures are, of course, based on the philosophy of the acquiring company, which is sometimes very different than the philosophy of the acquired company (Degani and Wiener, 1990)

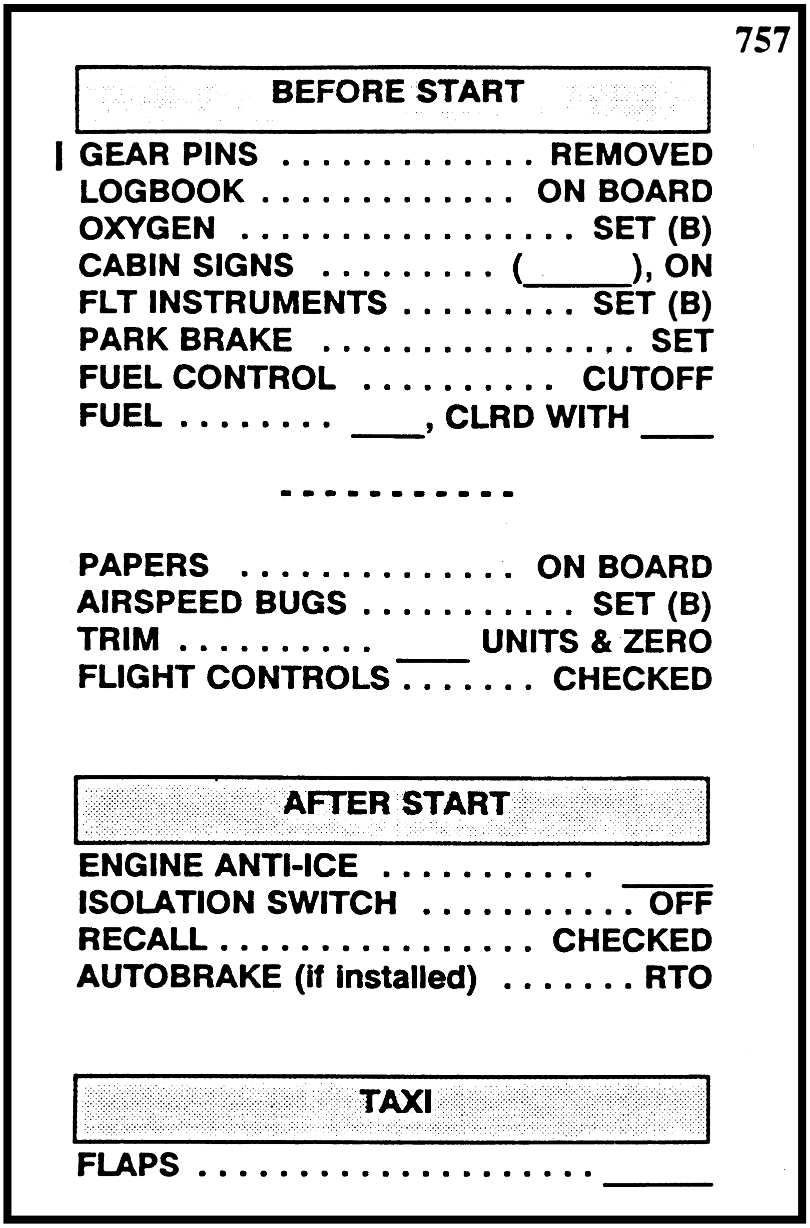
The acquiring company typically hastens to make what revisions are necessary to operate the acquired fleet. In the case of aircraft that are new to the acquiring company, it is a vast, sprawling task to impose its philosophy, policies, procedures, methods, and documents on the new fleet and crews. Often the process antagonizes the pilots from the acquired fleet, who feel, perhaps with some justification, that their former company is the best authority on how to operate their aircraft. Nonetheless, standardization must take place; a company cannot efficiently operate under two sets of operations philosophies and procedures. A firm stand must be taken, or the operation will constantly “weave and curve” its operating philosophy in order to provide some floating compromise. This will result in constant changes in procedures that will not only confuse pilots from both acquired and existing airline, but will also alienate them. Wolff (1991, pp. 22-23) describes the takeover by Delta of the Pan American shuttle: “Within a few days, we pilots received a 135-page addendum to our operating manual that described the aircraft differences... Some of these differences required changes and additions to Delta's normal procedures, so we also received about 100 pages of those to put into our manual after removing the original pages.”

In summary, mergers and acquisitions impose upon the acquiring carrier the immense task of melding the two (or more) carriers into one. As we have noted, the acquiring carrier is confident that its way of operating is superior, and in the interest of standardization, imposes its procedures upon the acquired carrier(s). However, we might comment that it is probably the wise management at the acquiring company that looks carefully at the procedures and documentation of the acquired fleet to see if there is something to be learned.

Finally, we take note of the fact that the next series of mergers and acquisitions are likely to involve international carriers. The first steps in this direction have already been made. If such mergers occur, this will superimpose upon the usual problems of melding two (or more) carriers and their cultures new problems (and opportunities) international in character. For a discussion of cultural differences between carriers, see Johnston (1993) and Yamamori and Mito (1993).

5.4 DIFFERENCES AMONG CARRIERS

At first glance, it is amazing to note the breadth of differences in operating procedures between carriers (Degani and Wiener, 1990). For example, Figure 6 present a B-757 checklist used by one airline and Figure 7 presents a B-757 checklist used by another airline. It can instantly be seen that these two checklists are quite different. During our field study we were also surprised to find that some critical procedures such as a rejected takeoff or in-flight engine failure are also executed differently at the various carriers. It may seem logical, from a pure "engineering" stand point, that for the same equipment the operating procedures must be the same. However, each airline has its own concepts of how its employees should normally operate the equipment. This difference in operating philosophy is usually reflected in normal and not in abnormal/emergency procedures. This is probably due to the fact that unlike normal procedures and routine tasks, emergency procedures tend to address only aircraft specific systems, and not the operational environment surrounding the aircraft (company, gate agents, paperwork, passenger handling, airport-specific procedures, etc.).



757

BEFORE START

GEAR PINS .... REMOVED
LOGBOOK .... ON BOARD
OXYGEN .... SET (B)
CABIN SIGNS .... (______), ON
FLT INSTRUMENTS .... SET (B)
PARK BRAKE .... SET
FUEL CONTROL .... CUTOFF
FUEL .... ____, CLRD WITH ____

\- - - - - - - - - - -

PAPERS .... ON BOARD
AIRSPEED BUGS .... SET (B)
TRIM .... ____ UNITS & ZERO
FLIGHT CONTROLS .... CHECKED

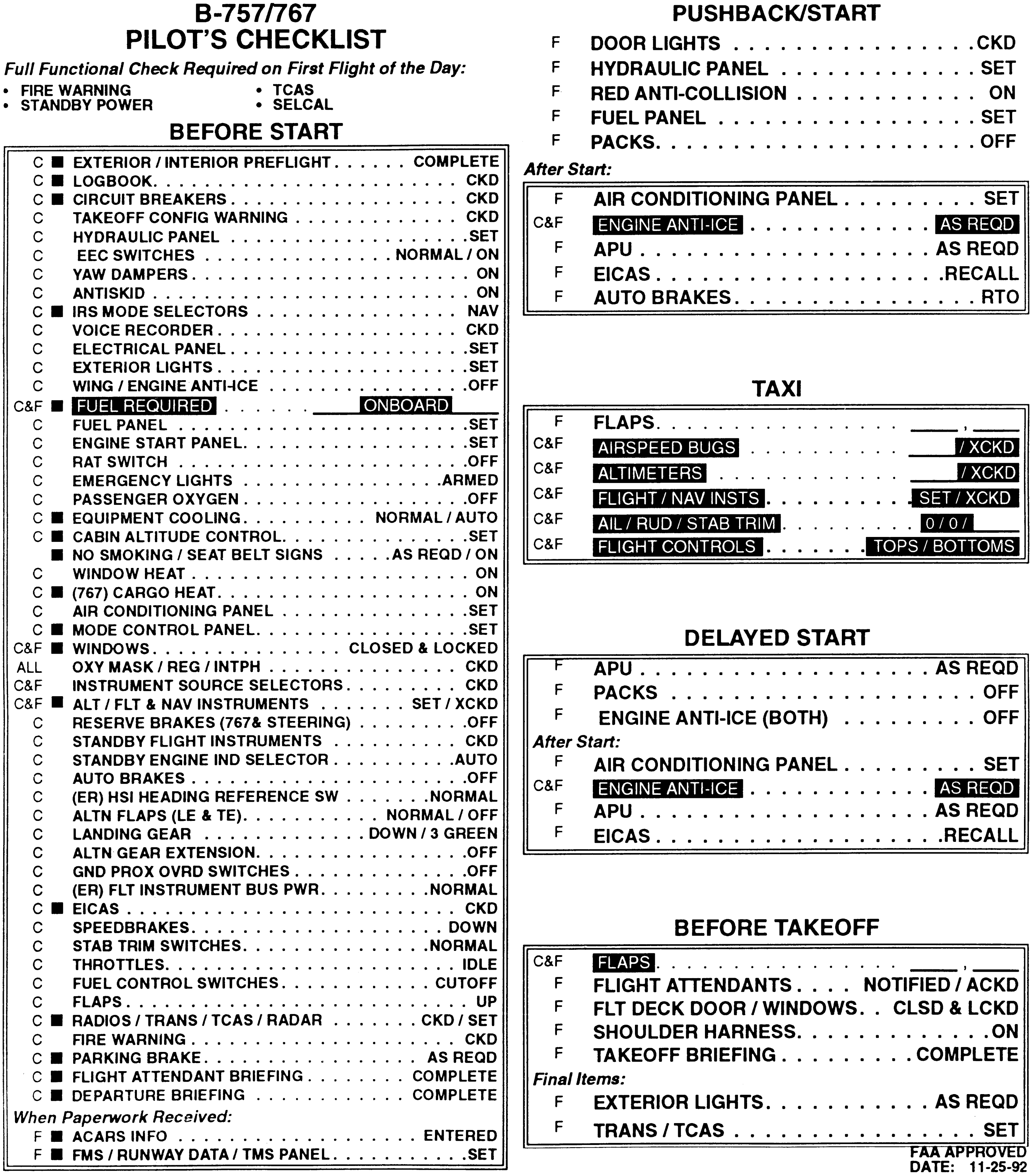
AFTER START

ENGINE ANTI-ICE .... _____
ISOLATION SWITCH .... OFF
RECALL .... CHECKED
AUTOBRAKE (if installed) .... RTO

TAXI

FLAPS .... ______

Figure 6. *A Boeing B-757 checklist used by one airline.*



B-757/767
PILOT'S CHECKLIST

Full Functional Check Required on First Flight of the Day:

- FIRE WARNING
- STANDBY POWER
- TCAS
- SELCAL

BEFORE START

C	■	EXTERIOR / INTERIOR PREFLIGHT	COMPLETE
C	■	LOGBOOK	CKD
C	■	CIRCUIT BREAKERS	CKD
C		TAKEOFF CONFIG WARNING	CKD
C		HYDRAULIC PANEL	SET
C		EEC SWITCHES	NORMAL / ON
C		YAW DAMPERS	ON
C		ANTISKID	ON
C	■	IRS MODE SELECTORS	NAV
C		VOICE RECORDER	CKD
C		ELECTRICAL PANEL	SET
C		EXTERIOR LIGHTS	SET
C		WING / ENGINE ANTI-ICE	OFF
C&F	■	FUEL REQUIRED	ONBOARD ____
C		FUEL PANEL	SET
C		ENGINE START PANEL	SET
C		RAT SWITCH	OFF
C		EMERGENCY LIGHTS	ARMED
C		PASSENGER OXYGEN	OFF
C	■	EQUIPMENT COOLING	NORMAL / AUTO
C	■	CABIN ALTITUDE CONTROL	SET
	■	NO SMOKING / SEAT BELT SIGNS	AS REQD / ON
C		WINDOW HEAT	ON
C	■	(767) CARGO HEAT	ON
C		AIR CONDITIONING PANEL	SET
C	■	MODE CONTROL PANEL	SET
C&F	■	WINDOWS	CLOSED & LOCKED
ALL		OXY MASK / REG / INTPH	CKD
C&F		INSTRUMENT SOURCE SELECTORS	CKD
C&F	■	ALT / FLT & NAV INSTRUMENTS	SET / XCKD
C		RESERVE BRAKES (767& STEERING)	OFF
C		STANDBY FLIGHT INSTRUMENTS	CKD
C		STANDBY ENGINE IND SELECTOR	AUTO
C		AUTO BRAKES	OFF
C		(ER) HSI HEADING REFERENCE SW	NORMAL
C		ALTN FLAPS (LE & TE)	NORMAL / OFF
C		LANDING GEAR	DOWN / 3 GREEN
C		ALTN GEAR EXTENSION	OFF
C		GND PROX OVRD SWITCHES	OFF
C		(ER) FLT INSTRUMENT BUS PWR	NORMAL
C	■	EICAS	CKD
C		SPEEDBRAKES	DOWN
C		STAB TRIM SWITCHES	NORMAL
C		THROTTLES	IDLE
C		FUEL CONTROL SWITCHES	CUTOFF
C		FLAPS	UP
C	■	RADIOS / TRANS / TCAS / RADAR	CKD / SET
C		FIRE WARNING	CKD
C	■	PARKING BRAKE	AS REQD
C	■	FLIGHT ATTENDANT BRIEFING	COMPLETE
C	■	DEPARTURE BRIEFING	COMPLETE

When Paperwork Received:

F	■	ACARS INFO	ENTERED
F	■	FMS / RUNWAY DATA / TMS PANEL	SET

PUSHBACK/START

F	DOOR LIGHTS	CKD
F	HYDRAULIC PANEL	SET
F	RED ANTI-COLLISION	ON
F	FUEL PANEL	SET
F	PACKS	OFF

After Start:

F	AIR CONDITIONING PANEL	SET
C&F	ENGINE ANTI-ICE	AS REQD
F	APU	AS REQD
F	EICAS	RECALL
F	AUTO BRAKES	RTO

TAXI

F	FLAPS	____ , ____
C&F	AIRSPEED BUGS	____ / XCKD
C&F	ALTIMETERS	____ / XCKD
C&F	FLIGHT / NAV INSTS	SET / XCKD
C&F	AIL / RUD / STAB TRIM	0 / 0 / ____
C&F	FLIGHT CONTROLS	TOPS / BOTTOMS

DELAYED START

F	APU	AS REQD
F	PACKS	OFF
F	ENGINE ANTI-ICE (BOTH)	OFF

After Start:

F	AIR CONDITIONING PANEL	SET
C&F	ENGINE ANTI-ICE	AS REQD
F	APU	AS REQD
F	EICAS	RECALL

BEFORE TAKEOFF

C&F	FLAPS	____ , ____
F	FLIGHT ATTENDANTS	NOTIFIED / ACKD
F	FLT DECK DOOR / WINDOWS	CLSD & LCKD
F	SHOULDER HARNESS	ON
F	TAKEOFF BRIEFING	COMPLETE

Final Items:

F	EXTERIOR LIGHTS	AS REQD
F	TRANS / TCAS	SET

FAA APPROVED
DATE: 11-25-92

Figure 7. *A Boeing B-757 checklist used by another airline.*

Thus, not only the hardware affects procedures -- the company culture and the structure of the operational environment also bear on procedural development. In the following sub-section we have listed some of these social factors. This is not an exhaustive list.

5.4.1 *The Nature of the Carrier's Operations*

The operational character of the airline may dictate certain procedures. For example, a short-haul operator flying many legs per aircraft per day may wish to minimize ground time. At intermediate stops, the pilots may remain in the cockpit and keep certain equipment powered in order to facilitate a rapid turn-around at the station. A carrier operating identical equipment over fewer, longer legs would call for a complete shutdown at intermediate stations, and the pilots would probably depart the cockpit. Two different types of checklists would have to be designed to support the different type of operations. A checklist insensitive to the differences would result in a sub-optimal operation, and probably a high rate of procedural deviations.

5.4.2 *Influence of a Strong Leader*

Some procedures stem from the biases and personalities of the managers and executives. Legend has it that Captain Eddie Rickenbacker insisted that Eastern Airlines use a QFE altimeter on approaches, in addition to the QNH altimeter, following an altitude-related accident[7]. QFE altimetry existed at Eastern Airlines until about three years before its demise[8]. Note that the decision to use QFE altimetry on approach and takeoff invokes a host of procedures peculiar to that airline.

5.4.3 *Influence of Corporate Culture*

The term “corporate culture” is a somewhat vague and elusive concept in the sociology of organizations. *Culture* refers to the underlying values, beliefs, and principals that serve as the foundation for an organizational management system as well as a set of management practices and behaviors that exemplify and reinforce those principals (Deal and Kennedy, 1983). As difficult as corporate culture is to define, it does exist and does exert an influence on philosophy and policies of operation. Certainly corporations do have a culture, stemming largely from the nature of their business, their geographic location, the background of their founders and present management. Strong cultural influence is portrayed when values and actions are consistent. This consistency serves to improve performance and efficiency. For example, one airline that we surveyed has a culture that places a high value on discipline, order, and devotion to duty. This, we believe, leads to an operating concept that is rigidly procedurized and highly standardized. The flight crews “religiously” adhere to their “SOPA” (SOP Amplified), which is the “bible” by which the airline is operated. It is a meticulously detailed description of procedures and tasks. An example of the extent of this company’s procedures can be seen in their system for altitude callouts prior to target altitude. Unlike most airlines which require a callout 1000 feet prior to the target altitude, the SOPA mandates two altitude callouts, the first at 2000 feet, then a second one at 1000 feet.

5.5 ECONOMICALLY-DRIVEN INFLUENCES

The cockpit is not oblivious to market and economic pressures (Monan and Cheaney, 1990). But the extent to which economic forces may have penetrated the flight deck and affected cockpit procedures may not be obvious. For convenience, we will divide these forces into two parts: market, or public relations procedures; and resource conservation procedures.

5.5.1 *Public Relations Procedures*

Most companies require the cockpit crew to make periodic public address (PA) announcements to the passengers in the interest of public relations. Although PA’s are always at the captain's discretion, we are aware of at least one airline that specifies an altitude (on descent) at which the PA announcement is to

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[7] QFE altimeter displays aircraft altitude in reference to airport elevation. QNH altimeter displays aircraft altitude in reference to mean sea level.

[8] To our knowledge, only one U.S. carrier (American Airlines) still uses the QFE altimeter in domestic operations.

be made. Consider, also, the following example: One company, providing mostly short-haul flights with fast turn-around, required all its pilots to avoid hard braking and fast turns in an attempt to make the nearest high-speed turnoff. Passengers' complaints to the company public relations office could not be ignored. Efficiency of operations yielded to passenger comfort.

5.5.2 *Resource Conservation Procedures*

Fuel conservation is a major consideration in development of airline procedures. Because the "multipliers" in airline operations over the fleets over time are so great, a procedural change yielding, on any given leg, a seemingly small saving can result in a very considerable dollar savings annually. This has brought about a host of fuel conservation procedures: single engine taxiing, delayed engine start, delayed lowering of landing gear and flaps, reduced use of the APU, and recalculation of fuel requirements. All have important procedural implications.

Fuel is not the only consideration. Wear on equipment may lead to procedures such as derated takeoffs to reduce engine wear, lower flap extension speeds to reduce wear, and use of autobrakes for landing to reduce brake and tire wear. An example of the impact of equipment conservation on procedures is reduction of APU starts. One airline has the following procedure: on taxi-in, if the taxi time is estimated (by the crew) to be less than nine minutes on a B-757, they taxi on both engines and do not start the APU (two engines provide two generators)[9].

5.6 AUTOMATION

Our observations suggest that increased automation reduces the number of procedures on the fight deck. It appears that as systems become more autonomous (engaged in higher levels of automation) there is less need for procedures. It is not that the procedure evaporates as soon as the system is automated -- the point is that the procedure is simply written in software, and therefore the machine takes over some aspects of the procedure execution. For example, consider the task of rolling out of a turn. When hand flying an aircraft, a useful rule of thumb (or procedure), is to start leveling the wings several degrees prior to the assigned heading. The time-honored rule of thumb is to lead the rollout heading by the number of degrees equal to half of the angle of bank (e.g., for a bank angle of 10 degrees to turn right to a heading of 090, rollout will be initiated at 085). On the other hand, when the autopilot is engaged, the flight crew will dial 090 in the heading window and the plane will turn and level off by itself. Again, it is not that the procedure has vanished, but it is simply concealed in the autopilot computer code (in a more precise control algorithm, of course). In a previous paper (Degani and Wiener, 1991), we described procedures as a bridge between the crew and the machine. With increased automation, duties and procedures that were previously assigned to the human are now usurped by the machine.

Conversely, when there is a need for a reduction in level of automation, a procedure must be instituted. For example, consider the following situation. When a glass cockpit aircraft is intercepting the glide slope and localizer while HEADING SELECT mode is engaged, and subsequently selecting APPROACH mode before the "localizer" and "glide slope" are captured, there is a possibility for a false capture: The "glide slope" will capture and the plane will start to descend while maintaining the heading displayed in the HEADING SELECT window (and *not* the LOCALIZER course). The concern is obvious -- the aircraft will descend, but not to the runway. The only feedback available to the flight crews is on the ADI: the LOCALIZER symbol will be armed (white), as opposed to being engaged (green)[10]. To counter this, one company's SOP states: "to prevent a false capture, do not arm the APPROACH mode until the localizer and glide slope pointers have appeared on the ADI."

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[9] This is due, in part, to the fact that the APU uses more fuel to start than running an engine. Another benefit of this procedure is the reduction in the number of APU start sequences.

[10] This information can not be obtained from the mode control panel (MCP) -- because according to the MCP logic, once APPROACH mode is armed, the button is lit (regardless of whether the "localizer" has been captured or not).

The above example shows how automation and procedures are inversely related. To "fix" a problem with automation, one must go one step down in the level of automation. Subsequently, this requires an increase in procedurization -- the pilots of this company may only engage the APPROACH mode after seeing the "localizer" and "glide slope" pointers on the ADI.

It appears that increased level of automation eliminates the need for some procedures. Also, automation makes it more difficult to mandate a large set of stringent procedures. We believe several factors lead to this.

1. Some tasks that were previously assigned to the pilot have been *completely* automated. For example, the engine start sequence of an Airbus A-320 has been automated. This has resulted in one less engine control (the "fuel control" switch), reduction in task requirement (positioning the "fuel control" switch to "run"), and elimination of associated procedures ("Aborted Engine Starts or Excessive EGT on Ground"), as the system provides all limit protection as well as automatic engine crank after start abort.
2. Since most modern automation is controlled by some type of digital processor, the interface between human and machine is usually some form of computer input device. The most common form is a keyboard. Using the CDU, simple tasks, such as position initialization, can be performed as a set of procedures. Nevertheless, tasks that must be conducted in real time, require far more complex interaction with the computer, and hence are not amenable to simple procedurization. For instance, many crews build approaches that are not available in the FMC. The FMC routing and STARs will guide them to a certain point short of the airport. If they wish FMC guidance the rest of the way, they have to build it, and this is too complex to be reduced to step-by-step procedures and sub-tasks.
3. Many aircraft systems, such as the autoflight system, operate in a dynamic and sometimes unpredictable environment and therefore cannot be completely pre-programmed. In these cases, the autoflight system provides the pilot with several semi-automatic modes to choose from. An example is the various modes available to perform a level change: there are at least five different methods to conduct this task. Therefore, any attempts to completely procedurize such tasks by mandating one method, would usually fail (and lead to non-compliance). One major U.S. company attempted to procedurize the descent profile of its B-737-EFIS fleet. The result was non-compliance. The project was quietly abandoned.

To conclude, we argue that automation requires a new dimension in the design of flight deck procedures. As we have noted previously, a procedure that is ponderous and is perceived as increasing workload and/or interrupting smooth cockpit flow will probably be ignored on the line. Even worse, there could be a spreading of this effect, since a rejected procedure may lead to a more general distrust of procedures, resulting in non-conformity in other areas.

> *Guideline #2*: When designing procedures for automated cockpits, the designer should recognize that many tasks that involve the use of automation are too complex and interactive to allow a stringent set of SOPs to be mandated.

5.6.1 *Lack of Automation Philosophy*

Most airlines that fly glass cockpit aircraft have attempted to develop an operational doctrine for operating these aircraft. Those that have failed to articulate a clear philosophy (and hence policies) have probably done so because they jumped immediately into policies, and in some cases straight into procedures without a governing philosophy.

One of the problems with not developing and publishing a philosophy of operations is that policies, decisions, and ultimately procedures are put into place without an explanatory basis. The philosophy behind these decisions is not articulated nor understood. What is more, philosophies change from time to time. Because these changes in philosophy are not made public, they can lead to confusion and to a compliance problem. For example, one airline's early automation doctrine was to fly an automated aircraft, to the extent possible, as if it were a B-727, and thereby minimizing the use of advanced features. Then, following a change in management, it switched to a philosophy of "use the automation as much as possible" (in order to save fuel, wear, etc.). Recently, as indicated by the vice president of flight operations, the philosophy moved to a more “liberal” approach to automation, stating that “there are many 'detents' between 'fully automated' and 'manual.'” Although this new doctrine has been conveyed to some crews, it was not done in a formal way. Some check airman are still rating check rides according to the management philosophy that pilots describe as “we bought it, you use it.”

Not surprisingly, many flight crews complained during our interviews that they are using semi-automatic modes during descent on a regular basis, but when a check airman arrives they try to use L/VNAV as much as possible. One captain explained, “why argue and get into long discussions. If that's what he is looking for, I'll give it to him.” Note that the Delta automation philosophy statement (Appendix 2) leaves no doubt about where the company stands regarding use of levels of automation. The crews are expected to be proficient in employing the automation at every level, but the choice of automation versus manual modes remains in the cockpit.

> *Guideline #3*: It is essential that management develop a philosophy of its operations. This is particularly important for operating automated cockpits.

5.6.2 *Automation and Procedures*

Introducing any new technology into the cockpit, or any other domain, requires the procedure designer to (1) reevaluate all of the existing concepts and policies in light of the new technology, and (2) support the new technology via new procedures. For example, traditional cockpit procedures specify that the pilot-not-flying (PNF) sets the altitude in the altitude window/alerter. Recently, however, several glass cockpit fleets have changed their policies and procedures so that the pilot-flying (PF) is responsible for *all* flight path control actions while an autopilot is engaged. The new procedure indicates that the PF (and not the PNF) is responsible for setting the altitude when the autopilot is used. The reason for this is explained by the logic of the autoflight system: when the autopilot is engaged, the aircraft flight path can be controlled via the MCP altitude window (the autopilot will not cross the altitude set in the MCP window). The policy and procedure developers argue that flight path control should not be split between the PF and PNF.

> *Guideline #4*: When introducing new technology into the cockpit, the procedure designer should reevaluate all of the existing procedures and policies in light of the new technology and support the new technology via new procedures.

5.7 USING TECHNIQUE

The role of pilot technique must be recognized for two reasons. First, the procedure developer cannot and should not try to write “a procedure for everything.” It would be both futile and uneconomical to develop a forest of minute details and huge procedures books (and the pilot would not conform to all these anyhow). Second, each individual pilot harbors a large program of techniques for carrying out procedures. They represent his or her “personal style” of flying, a highly individualized way of getting the job done.

5.7.1 *Technique and Automation*

The introduction of cockpit automation has brought a plethora of techniques, largely consisting of ways in which the pilots choose to employ the automatic devices and modes to achieve a desired result. These techniques are the result of the great variety of ways that a task can be accomplished in a high-technology aircraft, due to its many modes and options. For example, there are at least three different methods in which plane position information can be transferred into the Inertial Reference System of a glass cockpit aircraft.

Another example is the automatic level-off maneuver. Many pilots feel that left to its own, the auto-leveling produces flight maneuvers that are safe and satisfactory, but could be smoother and more comfortable for the passengers. Pilots also believe that in the auto-level-off maneuver the autothrottles are too aggressive. As a result of this, many have developed techniques to smooth these actions; most of these techniques involve switching autopilot modes during the level-off. We emphasize that these are *techniques* and not procedures. As stated earlier, they represent the superimposition of the pilot's own way of doing things upon a standard procedure. Some pilot technique is actually accommodated by modern flight guidance systems. The bank angle limiter, for example, invites the crew to express their preference for maximum bank angles and rates of turn, consistent with the demands of ATC, the comfort of their passengers, and the crew's preferences.

Other techniques have been developed to “trick the computer.” For example, the pilot of a glass cockpit aircraft, wishing to start a descent on VNAV path earlier than the displayed top of descent (TOD) point, can either enter a fictitious tail-wind into the flight guidance computer, or can enter an altitude for turning on thermal anti-ice protection (which he has no intention of actually doing). Both methods will result in a re-computation of the TOD and VNAV path, with an earlier descent. Why would the pilots do this? Because experience has taught them that the correctly computed VNAV path often results in speeds that require the use of spoilers, which pilots consider unprofessional, as well as creating vibration that will discomfit the passengers (Wiener, 1989).

5.7.2 *Techniques and Procedures*

Techniques are usually superimposed on procedures. The procedure specifies tasks, while the technique is the pilot's way of adding his or her own methods on top of the tasks. Techniques are usually found in tasks that are more loosely procedurized (e.g., level-off task). Techniques are rarely found in tasks that are tightly procedurized (in which every action is detailed in the procedure, e.g., engine shut down). For example, one altitude setup procedure for hand flying states that the “PNF sets the MCP/altitude alerter altitude and points to the MCP/altitude alerter. The PF points at the new altitude and verbally acknowledges it.” One captain stated that in addition to the above procedure, he (as PNF), first sets the altitude in the MCP/altitude alerter, and only then reads back to ATC whatever he has entered into the MCP/altitude alerter. While the task takes somewhat longer when performed this way, it attempts to eliminate the possible transformation error between what is held in the pilot’s short term memory and what is actually entered to the machine. This technique does not violate the procedure, but rather imposes an additional action to reduce the likelihood of a readback error.

The framework of how the above readback technique fits in with the higher level task and procedure can be seen in Figure 8.

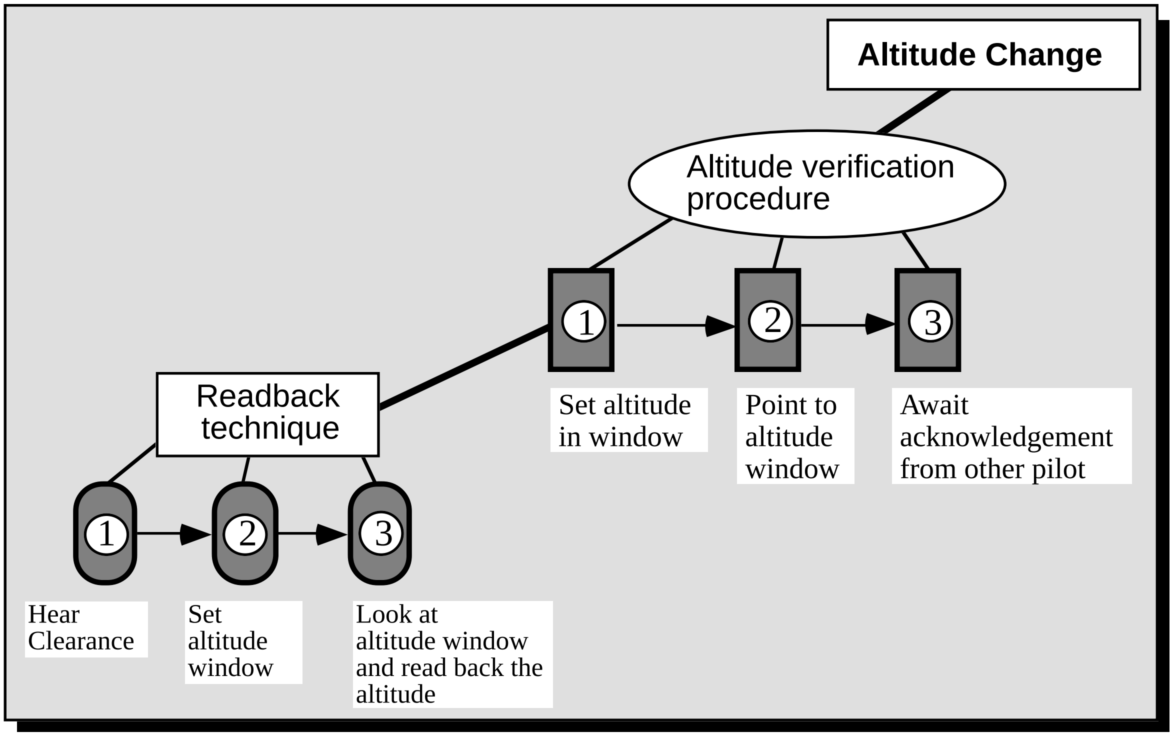

Figure 8. *Framework of a technique and procedure*

5.7.3 *Technique and Policies*

Any given technique may indeed conform to the written procedure, and thus not add to "Δ," but could still entail an unnecessary risk or inefficiency. Consider the example mentioned earlier (Section 3.2.1) of leveling off at FL 250 during a climb to a higher cruise altitude for the sake of avoiding the use of the oxygen mask. If this technique is evaluated from a procedural stand point, there is no "Δ." The technique is in full conformity with the FAR and company procedures. Yet, if the company policy/philosophy includes a statement about efficiency of operations, then it is non-conformity. Therefore, it is not enough for the technique to conform to the procedure; it must also be consistent with the policies.

In some cases there is no procedure for a given task and related procedures do not help in solving the problem. At this point policies are the only guidance to the crew on how they may use a technique. It is here where the structure of policies and philosophy pays off. Figure 9 depicts this relationship between the technique and the policy.

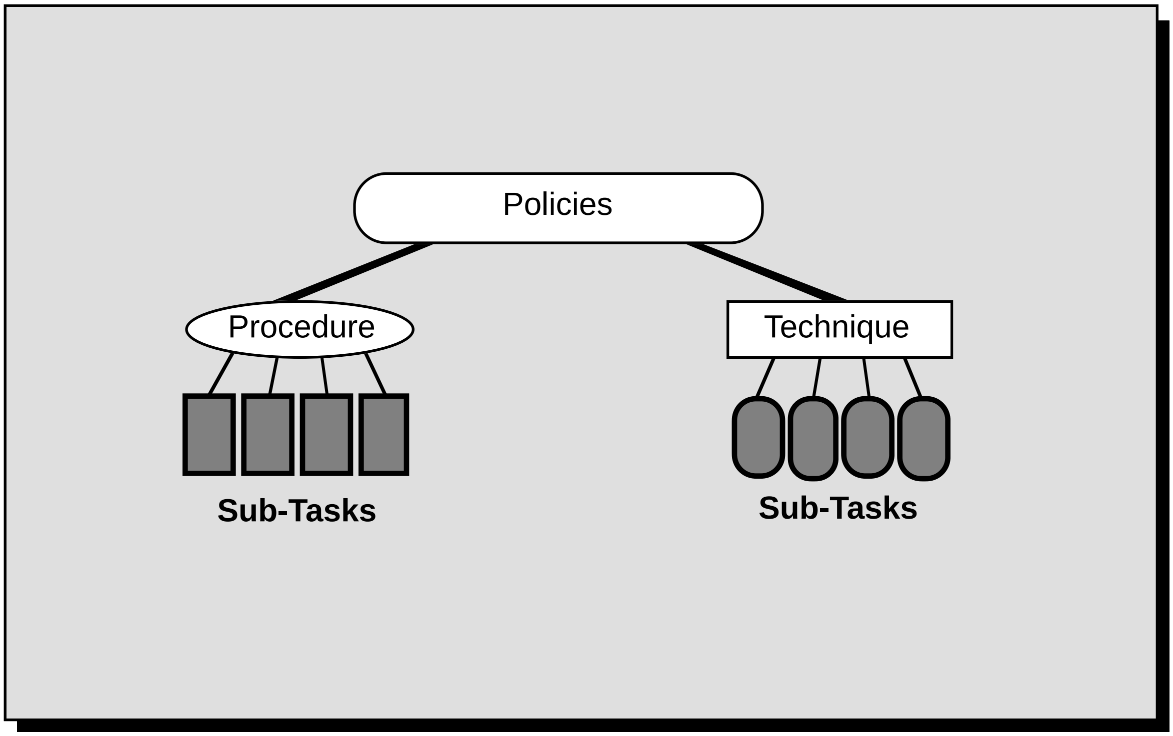

Figure 9. *Framework of technique and policy.*

For example, one of the many auto-leveloff techniques we observed involved placing a 300-knot airspeed in the autothrottle while climbing in vertical speed mode below 10,000 feet. The purpose was to provide a smoother acceleration to an intermediate speed when leveling at or above 10,000 feet. During the leveloff the pilot would switch to airspeed mode and the aircraft would smoothly accelerate as it leveled. The potential hazard is that it would not be difficult to switch inadvertently to airspeed mode below 10,000 feet and thus violate the speed restriction.

Properly applied, the technique should work well, provide a smoother flight for the passengers, and remain in conformity with the 250 knots restriction. And although "Δ" is not increased, time after time when the technique is employed, the seeds of a latent error may have been planted. The following ASRS report illustrates a similar technique for the same task and the potential for an error:

> Our departure clearance of out Atlanta included instructions to maintain 10,000 feet. On this flight the captain decided to delete the 250 knots restriction from the FMS climb page in order to eliminate the throttle burst associated with leveling off at 10,000. He planned to follow the flight director pitch bar up to 300 AGL [during takeoff] and then decrease pitch to allow the aircraft to accelerate to 250 knots Once at 250 knots his plan was

> to maintain this speed up to 10,000 by adjusting pitch and ignoring the flight director pitch bar. This technique had proven to give a much smoother level off and acceleration to climb speed.
>
> Our takeoff had been behind an aircraft and slightly after takeoff we had experienced a little turbulence which we assumed was from the proceeding wide body. The captain decreased pitch to stay out of his wake while we both were looking outside of the aircraft in an effort to see the wide-body. Unable to acquire the aircraft, the captain's scan returned to his ADI and he began to follow the pitch bar, which led him to accelerate beyond 250 knots Aircraft speed was noted and reduction begun. Aircraft accelerated to approximately 320 knots (ASRS Report No. 155390).

For the sake of explaining how policies affect technique, let us assume that the airline had a policy of backing up critical tasks with other modes or aids. Examples of procedures that stem from such policy would be a requirement that visual approaches should be backed-up by the ILS and/or ADF, and a procedure specifying that pilots of automated cockpits track LNAV heading by appropriately updating the MCP heading display whenever the aircraft changes heading. If such a policy is specified, then one can argue that both of the auto-leveloff techniques that we have detailed above violate this policy. Such a policy provides that a failure of a certain system component does not leave the crew empty handed. The intent is that the crew choose their primary mode, but also configure other modes to which they or the system can default to. The same policy can be applied for automation, i.e., configure all the appropriate automation modes so that if one fails, the pilot or the system can easily default to another. As can be seen in the ASRS report above, the 300-knots technique does not comply with this policy.

Similar policies of backup as related to use of automation can be seen in the following altitude procedure: “Do not set expected altitudes in the MCP/altitude alerter. Set the most restrictive altitudes as opposed to the top/bottom altitudes.” The concept here is if the automation (VNAV) fails, then the autopilot will not cross the hard altitude set in the MCP window. At other airlines this is done differently: during the step-down descent the altitude window is set for the lowest restriction. The reader should note that both procedures stem from a different operating policy of the autoflight system.

Let us examine another technique from a policy standpoint:

> After takeoff the aircraft accelerated to 250 knots and flaps were retracted. While in a tight (30 degree bank) turn, ATC requested: “slow to 230 knots.” The captain (PF) disengaged the autothrottles, reduced power and pitch, and maintained 230. After being cleared back to 250 knots he re-engaged them. At cruise, we asked him why disengaged the autothrottles. He replied that the clean (no flaps) maneuvering speed was 245, therefore, had he dialed 230 knots in the speed window, the alpha protection logic of the autothrottles would have maintained a speed of 245. Since he did not want to “dirty” the aircraft by extending slats, he choose to disengage the autothrottles (and with it, the alpha floor protection), reduce bank angle, and maintain 230. He stated that this was not per SOP. Nevertheless, he felt that other built-in protection of the aircraft would have prevented him from reaching buffet speed.

To answer the question of whether or not this example represents an acceptable technique, one must compare it with the company's stated policies. If this technique is compared to the policy, discussed above, of backups and defaults for using automation, then, of course, it is not acceptable.

To summarize, our position is that a technique not only must conform to the procedure -- it must also conform with the company policy. The fact that a technique does not violate a written procedure (produces no “Δ”) does not necessarily make it acceptable. The technique may still entail an unessential risk and inefficiency. Every technique must therefore conform to both procedures and policies (and possibly philosophies).

5.7.4 *Technique and Management*

What view should management take of pilots developing their own techniques? Does the superimposition of “personal” technique on SOPs represent a compromise with standardization? Once again the answer is to be found in the “Four-P” model. Management must develop a philosophy that governs the freedom of the pilot to improvise, and from this philosophy will flow company policies that will state exactly what the company expects of the line. Our own view, of course, is to return to the definition of “Δ.” If the techniques employed on the line lead to practices that are consistent with the published procedure and policies, then “Δ” is zero and management should not interfere.

For example, one company constantly changed its procedure for setting of the bank angle limiter of a B-757. It was perceived by the line pilots that every time there was a staff change in flight management, a new procedure would appear. Finally, this procedure was eliminated and the setting was left to pilot discretion (or in our terms, assigned to "technique"). Likewise, if the same procedure constantly changes because of changing environmental conditions or because there is never an agreement in flight management on how to implement it -- it may be downgraded to the level of a technique (considering, of course, all the other issues such as criticality, CRM, etc.).

If, however, management discovers through standardization and quality management techniques, or through the feedback loop, that certain techniques may have potential for procedural deviation, then this can be dealt with through the normal quality assurance processes. It is entirely possible that the opposite can occur, that the quality management or feedback processes can discover superior techniques that should become procedures. Check airmen play a vital role here. While their job is generally quality assurance and standardization, they should be watchful for line-generated techniques that could and should be incorporated into the company's SOPs.

> *Guideline #5*: Management, through the feedback loop and the line check airman program, should be watchful of techniques that are used on the line. Techniques that conform to procedures and policies should not be interfered with. Techniques that have a potential for policy and procedure deviation should be addressed through the normal quality assurance processes. Techniques that yield better and safer ways of doing a task may be considered for SOP.

5.7.5 *Technique and CRM*

Our discussion of technique has centered on the means of executing company-generated cockpit procedures. The same principles apply to the vast and ill-defined area known as cockpit resource management (Wiener, Kanki, and Helmreich, 1993). Pilots develop communication, team-building, stress management, and other mechanisms for getting the job done effectively. These can also be viewed as techniques, personalized ways of carrying out procedures.

CRM training programs attempt to teach principles of communication; specific CRM techniques are discovered later. As with cockpit techniques, CRM techniques are developed largely by trial and error, as well as observations of others. We have all seen examples of good and bad communications techniques in the cockpit and elsewhere. We can again apply the definition of "Δ." If one's personal CRM techniques lead to congruence between procedures and practices, they should be considered adaptive. If not, they generate "Δ" and must be dealt with through the same quality management mechanisms that are invoked by unsatisfactory piloting. Our comments of the last section apply to CRM as well: check airmen should be vigilant in observing adaptive and maladaptive CRM techniques on the line and in training.

The hazards of poor crew coordination with regards to using a technique, can be seen in the following ASRS report.

> We were cleared to cross 40 NM west of LINDEN VOR to maintain FL 270. The captain and I began discussing the best method to program the CDU to allow the performance management system to descend the aircraft. We had a difference of opinion on how best to accomplish this task (since we are trained to use all possible on-board performance systems). We wanted to use the aircraft's capabilities to its fullest. As a result, a late descent was started using conventional autopilot capabilities (vertical speed, maximum indicated mach/airspeed and speed brakes). Near the end of the descent, the aircraft was descending at 340 knots and 6000 fpm. The aircraft crossed the fix approx. 250-500' high.... This possible altitude excursion resulted because of the following reasons.
>
> First, the captain and F/O had differences of opinion on how to program the [FMC for] descent. Both thought their method was best: the captain's of programming (fooling) the computer to believe that anti-ice would be used during descent, which starts the descent earlier. The F/O's of subtracting 5 miles from the navigation fix and programming the computer to cross 5 miles prior to LINDEN at FL 270. Second, Minor personality clash between captain and F/O brought about by differences of opinion on general flying duties, techniques of flying, and checklist discipline. Three, time wasted by both captain and F/O (especially F/O) in incorrectly programming CDU and FMS for descent, which obviously wasted time at level flight, which should have been used for descent. (ASRS Report No. 122778).

In summary, we see that there is room for flexibility and blossoming of individualism even within rigid procedurization and standardization. Yet this requires a coherent structure of procedures and policies. If a given technique is not consistent with published procedure and stated policy, calling it a “technique” accomplishes little -- it is a deviation from SOP, nothing more and nothing less.

Having explored the various factors that influence the design of cockpit procedures, we shall next discuss the various issues in procedure design. Chapter 6 is largely an exploration of the many factors that must be considered in order to construct the appropriate guidelines. This chapter should illustrate to the reader the great complexity of procedure design, and the number of factors that the designer must take into account. In Section 6.2, we introduce the role of cockpit resource management (CRM) to emphasize that those who write procedures must keep in mind that many aircraft operations are conducted by several individuals (e.g., pilots, ground crew, etc.) working as a team. The procedures should support this approach, by building in teamwork, communication, division of labor, and clear specifications of "who does what."

6. ISSUES IN PROCEDURE DESIGN

6.1 COMPATIBILITY OF PROCEDURES

Philosophies, policies, and procedures must not be developed and designed without consideration of the operational environment in which they will be used. Commercial aviation procedures, in this regard, are complex because of the ever-changing environment (weather, other traffic in vicinity, airport limitations, etc.). In addition, the necessity to coordinate so many different agents and entities, which are all involved in dispatching and maintaining control over the aircraft during flight, requires compatibility with the operational environment. When elements of the system, in this case the procedures, tasks, devices, equipment, are compatible, the process of conducting the task is more efficient -- the pilots have to exert less mental and physical effort. We define compatibility here as the orderly and efficient integration with other elements in the system. We will now attempt to describe the basic structure of airline operations that may cause an incompatibility of procedures.

6.1.1 *Environment and Procedures*

Many cockpit procedures are dependent on the activities of external agents such as flight attendants, gate agents, fuelers, and others. When designing a procedure, the influence of these entities on procedure design, implementation, and task completion must be considered (Degani and Wiener, 1990).

For example, one company's SOP requires a check of log books for open maintenance items prior to activating any controls or switches in the aircraft. The logic is that this check will prevent a flight crew member from activating a system that may be inoperative, thereby causing more damage (e.g., attempting to start an inoperative APU). At most stations, the aircraft log books are in the cockpit when the flight crews come on board. However, at some remote stations, due to maintenance procedures the log book is brought to the aircraft five minutes before push-back. Therefore the procedure cannot be accomplished in those remote stations. A change in the procedure, so that this information can be obtained from another source, or a change in maintenance procedure is required to defeat this incompatibility.

Let us examine another example. One company was considering a change in their SOP so that flaps extension would be performed as soon as the aircraft leaves the gate. Pilots raised the concern of hitting a truck or other obstacles under the wing (as the crew cannot see the wing from the cockpit). Although the ground crew's salute is an indication that all is clear, there was still a concern that this gesture is not dependable. The argument was made that when a widebody leaves the gate, there are many ground personnel around the aircraft. When a salute is given, the flight crew is assured that the area below the wing is clean. In contrast, when a medium size twin-jet is departing from a remote station, where the company has only a part-time ground crew who may be less experienced, flight crews are less certain that a salute is truly an indication that all is clear. In one incident, a cargo cart reached the aircraft *after* the salute, and the ground crew opened a cargo door. The only way the cockpit was aware of the intrusion was that the cargo bay light illuminated on the panel.

These are two examples of what we call “system procedures.” The system in these cases involves not only the cockpit crew and the aircraft, but also ground crew, their management, and ATC (handling ramp congestion and taxi clearances). Such *system procedures* must be developed using a systems approach -- developing a common definition of the task and involving all the components of the system in the design of the procedures and policies. If *system procedures* are designed piecemeal, then the product may be an inefficient procedure, unbalanced set of responsibilities, and complicated dependencies -- all are the foundations of a potential system breakdown.

Compatibility between components in the system is not restricted to matching cockpit procedures to the operating environment; it can also be the other way around. For example, we once observed a flight in which the ground controller cleared the aircraft (a narrow body twin-jet) toward a runway intersection. The controller tried to schedule the taxi clearances so that the approach-end of the runway would be utilized by heavy jets, with smaller jets making intersection takeoffs. After the aircraft taxied to the intersection, the controller communicated to the flight to expect an intersection takeoff. The crew, however, insisted that they use full runway. The reason: the company's policy prohibited the flight crews from making intersection takeoffs. The controller, unaware of the company procedure, felt that the crew was unwilling to cooperate with him. The result was frustration on both sides, a long delay, and an inefficient taxi (back track on the active runway).

In this case, the intentions of the controller were incompatible with the policies of the airline. One may argue that possibly ATC should be made aware of a company's policies and resulting procedures that affect the efficient control of the aircraft by ATC. Likewise, one could argue for better communication on part of the captain -- explaining to the controller why he could not accept an intersection takeoff.

Since there always be problems in matching procedures with the operating environment, we believe that over-procedurization will have an adverse effect on the practices, and consequently on the system outcome. A highly procedurized operation, as compelling as it may be, has disadvantages. It may provide a false sense of security, both to pilots and to flight management. Having too many procedures leads to an inflexible system, and generally results in some procedure being violated. It may lead to a creation of “classes” of procedures: some that are regarded important by flight crew and some that are not. An example of a procedure usually regarded as unimportant by the crews is the requirement for the remaining pilot to wear his or her oxygen mask when one pilot leaves the cockpit above FL 250.

> *Guideline #6*: Care must be taken that not only the principal participants of a system (e.g., flight crews in this case), but also others that are affected (e.g., controllers, ground crews, cabin attendants) be involved and informed in the design and modifications of a system procedure.

6.1.2 *Type of Operation*

A somewhat different example of incompatible procedures, usually caused by the lack of a proper policy, is the effect of long- and short-haul operation on procedure usage. Pilots who fly short flight segments perform the normal flight checklists as much as 3-8 times per day and as many as 12-32 times on a typical trip. Pilots who fly long-haul flights perform their checklists significantly less. In addition, when foreign operations are involved, factors such as fatigue, lack of standardization of the ATC environment between countries, complicated navigation and communication systems, accented English on the radio, various transition altitudes, and mixtures of metric and English scales, result in checklists and procedures that are highly detailed.

A requirement to conduct a very long and meticulous checklist procedure for short-haul operations may lead to compliance problems. For example, we observed the first officer of a twin jet who did not use the checklist the entire flight (a short leg of about 50 minutes). The only instance in which he used the checklist was after engine start. The twin jet checklist included many items that are there for sake of standardization with the widebody fleets of that carrier. While such a checklist may be efficient for heavy jets flying internationally and assist a dead-tired crew after a 10-hour flight, it is not compatible with the operation of a two-person twin-jet aircraft flying short legs. The result is that some crews do not use it at all.

> *Guideline #7*: Procedures must be tailored to the particularities of the type of operation. Ignoring these particularities can foster low compliance with procedures on the line.

6.1.3 *Interface and Procedures*

Procedures are an integral part of the interfaces in the cockpit -- specifying and dictating the actions by which the pilot is expected to interact with the machine. Procedures, therefore, must be compatible with the interface. For example, the procedure which dictates the sequence of items to be checked on a panel in the cockpit (e.g., overhead panel) must be compatible with the layout of that panel (Degani and Wiener, 1990). In employing automation, it is particularly important that the task and procedure match the device.

An example would be intercepting a radial outbound from a VOR. Ironically, it is a more difficult procedure in a glass cockpit than in a traditional model aircraft. Occasionally, aircraft departing Miami International for East Coast cities via Orlando VOR are given a clearance to intercept the 347 degree radial of Fort Lauderdale (FLL) outbound. There is no easy way to do this employing LNAV. The solution involves “anchoring” a “man-made” waypoint at an arbitrary distance (100 miles typically) on a bearing of 347 degrees from FL[11]. [12]

> Guideline #8: The procedures designer must be mindful of the limitations and capabilities of the device he or she is designing a procedure for. Devices that are well designed for the human user require minimal procedurization. Less robust devices will require more thought on the part of the designer, and will probably require more complex and lengthy procedures.

Electronic checklist displays are highly demanding of compatibility between the procedure and display. The first generation of electronic checklists is currently installed in three air transport aircraft (A-310, A-320, and MD-11). With respect to procedural modifications, these systems are inflexible because the customer cannot easily modify the items which will appear on the electronic checklist display, or even their order of appearance. For example, one of the procedures in the electrical checklist system is quite cumbersome when performed at a low altitude. To combat this, one airline devised a procedure called the “mini checklist.”

> If engine failure occurs at low altitude and landing is imminent, the ECAM procedure, if sequentially followed, results in turning off various equipment, reactivating the hydraulic system, and then turning ON much of the same equipment that was just turned OFF. To preclude this, and streamline the procedure, a good technique is to turn ON the green electronic pumps and the appropriate PTU shortly after engine failure in order to reactivate the affected hydraulic system and eliminate much of the ECAM procedure. It is also a good technique to start the APU to provide electrical backup. Commonly used terminology is to call for the “mini-checklist” which consists only of restoring the hydraulic system and starting the APU as noted above. (If an engine fails during takeoff, do not call for the “mini-checklist” until after calling for flaps up).

The mini-checklist is a paper checklist which is kept in the cockpit. It lists several items for restoring the hydraulic system and starting the APU. The “mini-checklist,” therefore, is a form of adaptation in human-machine systems. A task is “tailored,” or modified, by the human operator to accommodate a constraints imposed by inflexible devices (Woods and Cook, 1991). This adaptation is required because the modified procedure cannot be supported by the existing electronic checklist. The consequences of such inflexibility are that the pilot is required to conduct a procedure (mini checklist) on top of another procedure (ECAM), in order to execute the task. Note that both procedures discussed are performed in a highly critical and workload-intensive situation -- restoring an essential system after an engine failure at low altitude.

6.1.4 *Aircraft Systems and Procedures*

A procedure that details how to operate a particular sub-system must be compatible (or correct) in terms of its procedural steps, actions, and flow. The following examples will show how much the procedural designer must be attuned to the engineering aspect of the device (or sub-system). One company’s split-flap procedure had to be re-written when it was found to be wrong. The problem was traced to the fact that system components that were powered by the standby power unit were different from the standard configuration for this model aircraft. The airline apparently did not keep a good record of its own electrical system specifications. Such problems, however, are not unique only to airlines. During Space Shuttle Mission 49, the crew of the orbiter *Endeavor* tried to deploy a rescued satellite (Intelsat). The primary and backup deployment circuits would not send power to the cradle holding the satellite. “Investigation showed that the checklists used in Mission Control and on *Endeavor* were identical to those on the other three NASA orbiters. But the problem occurred when circuitry for *Endeavor's* wiring was engineered differently and the checklists were not changed to conform with the new orbiter's design.” The problem was finally overcome with the help of engineers in Ground Control (*Aviation Week and Space Technology*, 1992a, p.79).

Likewise, there may be wide differences in aircraft configurations within a given fleet. This sets the stage for the possibility of using an inappropriate procedure in some models. This is particularly true if

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[11] One captain that we interviewed remarked that the 757 (and other glass aircraft equally so) is “a good 'to' airplane, but a poor 'from' airplane.”

[12] A similar incompatibility that requires a cumbersome procedure is the task of intercepting a jet airway in a 757/767 FMS. The procedure requires some 6 steps and two mode changes.

there are a small number of “odd ball” aircraft within the fleet. In designing procedures for such a mixed fleet, special caution must be taken regarding sub-systems that are invisible to the pilots (e.g., electrical bus configuration).

> *Guideline #9*: Management must guarantee that any procedure is compatible with the engineering of the aircraft or any sub-system. Care must be taken when there are subtle differences between aircraft (especially if these differences are invisible or difficult to detect). Incompatibility can be resolved either by re-engineering or procedure.

6.1.5 *Cockpit Layout and Procedures*

We have noted instances of incompatibility of procedures with the ergonomic layout of the flight deck. Consider the flap/slat and gear levers, for example. Traditionally, gear and flap/slat levers were mounted in the first officer's area (right side of the cockpit). They were not within easy reach for the captain in the cockpit of a widebody airplane. In most U.S. airlines the captain and the first officer rotate the duties of pilot flying (PF) and pilot not flying (PNF) during a trip. If the first officer is the PF, the SOP usually dictates that the captain raise the gear and flaps/slats after takeoff. To do this, the captain must lean to the right of the throttle quadrant to grasp the gear or flap/slat lever(s). In several aircraft cockpits, specially widebodies, the captain cannot see the flap/slat detents very well and he or she can also accidentally push the throttles rearward. The same error may occur when the first officer, as the PF, wants to use the speed-brakes located to the left of the throttle quadrant. Note that this incompatibility is due to the operational philosophy of most U.S. airlines that encourages rotation of pilot flying duties. In contrast, in some foreign airlines PF duties are not rotated every leg. For those airlines, this incompatibility does not exist.

There are two approaches for solving this incompatibility: (1) procedural, and (2) hardware.

1. Some have argued that since the cockpit layout cannot be changed (within reasonable boundaries of cost efficiency), the procedure should be changed so that when the first officer is the PF, he or she will retract/extend the gear.
2. In contrast with the Douglas DC-10, the designers of the MD-11 located the landing gear lever in the middle of the forward panel. It is within equal reach-distance for both the captain and the first officer. Likewise, the designers of the Airbus A-320 eliminated a portion of this incompatibility by placing the speed brakes and flap levers on the pedestal between the two pilots.

Note that both the MD-11 and A-320 aircraft were designed during a different social era than their predecessors. Social culture has affected the airlines’ philosophies of operation (a flatter cross-cockpit authority and role gradient), the airlines’ policies (rotation of PF duties) and has thereby affected associated procedures (gear extension by PNF). To accommodate these philosophy, policy, and procedural changes, the cockpits were designed differently. Not surprisingly, there is greater involvement of airlines nowadays in the design phase of new aircraft (*Aviation Week and Space Technology*, 1992b).

> *Guideline #10*: Airframe manufacturers and component suppliers (such as avionics firms) must be attuned to general airline procedures. Knowledge of such procedures may influence ergonomic considerations.

6.1.6 *Paperwork and Procedures*

Documents, manuals, checklists, and many other paper forms are used in the cockpit. The compatibility between the procedures and their associated devices (manuals, checklist cards, etc.) exerts an effect on procedural execution. Ruffell Smith (1979) reported that excluding aircraft flight manuals, the amount of paperwork needed for a flight from Washington D.C. via New York to London, had a single side area of 200 square feet. Interestingly, the 15 years since Ruffell Smith's study have not yielded any reduction in cockpit paperwork. On the contrary, the problem has only intensified (as evident from recent ASRS reports).

On August 19, 1980, a Saudi Arabian Lockheed L-1011 was returning to Riyadh Airport (Saudi Arabia), after warnings in the cockpit indicated smoke in the aft cargo compartment. The crew was searching for the appropriate emergency procedure in their flight documentation. The accident report stated:

> About 3 minutes were spent by the crew looking for the aft cargo smoke warning procedure. Evidence indicated this difficulty was due to a split of the Emergency and Abnormal procedures into Emergencies, Abnormal, and Additional [sections]. The crew apparently believed that the procedure was in the Abnormal section when it was actually in the Emergency section. (*Flight Safety Focus*, 1985, May)

This, and several other factors led to a horrific accident in which 287 passengers and 14 crew members died of fire and toxic smoke inhalation. During one cockpit observation, we noticed a similar problem in locating the proper procedure:

> While the aircraft was taxiing to the runway, the "Hydraulic RAT Failure" warning appeared on the aircraft's system monitoring display. The concern was whether the ram air turbine (RAT) was unlocked and hanging down from the bottom of the aircraft. The crew, aware of a known problem with a sensor, anticipated that this could be a false warning, and expected that the warning would disappear during taxi (and it did). As the aircraft started the takeoff roll the warning appeared again. The captain decided to abort the takeoff and work on the problem. However, he could not find the written procedure that specified how to verify this condition.
>
> There were *five* places where such procedure could be listed: (1) the Flight Operational Manual, (2) the Supplemental section in the flight manual, (3) Operations Bulletin, (4) the aircraft newsletter, and (5) on the dispatch paperwork. The procedure could not be found in any of these. An attempt to find it using an index failed -- there was no index in the manual. The captain called the local station and asked them to read it to him on the radio. They could not find it either. After waiting for several minutes, he decided to conduct the procedure from memory -- a violation of a company policy that requires that procedures must be conducted from the book and not by memory[13].

Clearly, the standardization of books and manuals is important for fast retrieval of information, procedural execution, training, as well as compliance. We believe that a consistent criterion for which procedure goes into what book, and where, is essential. For example, one company's push-back procedure was listed in a manual that included personal appearance policies (“haircuts and shoe shines,” as they are known by the pilots).

As stated earlier, one of the beneficial “side effects” of standardization is that it may aid in transition training. A well defined and logical organization of manuals and books can yield such a dividend. Kyllonen and Alluisi further noted, “The hierarchy characteristic of memory organization is a feature that can be exploited in designing learning materials. It has long been known that humans find it considerably easier to remember materials that have a built in organization structure, and easier yet if that structure is made quite apparent” (1987, p. 126). For example, one company has invested a considerable amount of resources in a standardization of its procedures and manuals. The concept was to provide an aircraft publication policy manual, in essence -- a “style book,” that specifies the outline, format, general rules, checklist names, and standard text to be used in all the company's aircraft publications. This would include the cockpit operating manual, aircraft operating manual, performance manual, weight manual, quick reference manual, and all takeoff/approach data cards. The company also attempted to standardize, using the same process, all the procedures used by the airline. Although this huge project is far from complete, it has already yielded fruit: many flight crews stated that flight-deck documentation is now well standardized. Moreover, they felt that by launching the procedure standardization project, the company was making an effort to support them in their daily task. As the project continued, the pilots' perception of the SOP as a useful and well thought-out tool became more entrenched.

> *Guideline #11*: The entire documentation supplied to the cockpit (and elsewhere) should be regarded as a system, and designed accordingly as a system, not a collection of independent documents. A clear and logical (from the user’s view) structure for this system and a criterion for the location of different procedures is important. An effective index in each manual would go a long way toward aiding pilots in finding materials they seek, especially when it is an unfamiliar, obscure, or seldom accessed procedure.

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[13] These deficiencies have since been corrected by the airline.

6.1.7 *Computerwork and Procedures*

Procedures dictate tasks, and often these tasks involve some form of transformation (e.g., converting altitude reported in meters to setting the altimeter in feet). A complex transformation between input and output may increase workload, create possible confusion, require procedural aiding, and worst of all, invite error. The following example illustrates the effect of a complicated transformation.

> The crew of a B-757, preparing to fly from Miami to Washington National, was dispatched with a computer-generated flight plan with the following route: "radar vectors, AR-1 CLB ILM J-40 RIC..." When the crew attempted to enter the flight plan into the Route page of the CDU, they got no further than CLB, which continually resulted in an error message of "not in database." They repeatedly tried to enter the flight plan and continued to receive the same message after entering CLB. What was the problem? CLB (Carolina Beach) is a non-directional beacon, not a VOR as the three-letter designator on the flight plan implied. The flight plan, to be correct and compatible with the "expectations" of the CDU should have read "CLBNB." It was not until the crew took out their paper charts and traced the route that the error in the flight plan was apparent (Wiener, 1989).

If the same computer-generated flight plan had been issued to a non-FMS aircraft, there would be no such incompatibility. But that is exactly the point -- documents must be compatible with the equipment they support. If an efficient operation is desired, the transformation between the input task and the output task should be kept simple. In this case, there should have been a direct mapping between the data entry task (CLB from the flight plan) and the output (entering the NDB into the CDU).

> *Guideline #12*: Paperwork should be designed carefully to be compatible with the device for which it is intended. Particular care should be exercised in preparing materials for computer-based systems. It may be necessary to provide differently formatted documents for different cockpit configurations.

6.2 CRM AND PROCEDURES

Effective execution of procedures in a multi-person crew depends on effective crew coordination and resource management (Wiener, Kanki, and Helmreich, 1993). Although the term CRM is widely used to describe many aspects of human-human interactions, including team-building, social interaction, leadership, etc., the discussion here is limited only to the crew coordination aspects of performing a specified task.

6.2.1 *Crew Coordination*

One of the objectives of any procedure is to promote better coordination among crews. The term crew is expanded here to include all agents that are involved in performing a task (e.g., the push-back of an aircraft from the gate requires that the ground crew and the pilots work together). For that duration, all of the agents involved in performing a task (e.g., ground crew, ground controller, cockpit crew, gate agent) are considered here as a crew. These system procedures, accordingly, are shared and conducted by all the agents involved.

There are several attributes of a procedure that can be utilized by the designer in order to promote crew coordination:

Reduced variance. Procedures trigger a predetermined and expected set of actions. There are several benefits resulting from this:

1. SOPs allow "freshly formed" crews, often comprised of individuals who have never previously met, to effectively and efficiently discharge important operational tasks with minimal need for formal co-coordination and superfluous communication" (Johnston, 1991; Hackman, 1993).
2. Clear expectations of the in-process or in-coming tasks allow for easier monitoring on part of the other agent(s) in the crew.

3. The procedures allow the other agent(s) to plan and schedule their own actions/tasks in parallel to the procedure(s).
4. They set a defined standard of performance that allows all crew members to continually compare targets (inputs) with actual performance, thereby providing all crew members with a baseline for questioning and correcting substandard performance on part of other crew members.

Feedback. SOPs specify expected feedback to other crew members (e.g., callouts). This feedback can detail (1) the current, and/or expected system state; (2) the actions that are currently being conducted; (3) the system outcome; and (4) an indication of task completion.

There are several ways in which this feedback is provided: (1) verbally (callouts, callback, etc.); (2) non-verbally (gestures, manual operation -- such as pulling down the gear lever); (3) via the interface (when the configuration of the system is significantly changed, e.g., all CRT's are momentarily blank when power is switched from APU to engine-driven generators, this provides clear feedback to the other pilot); and (4) via the operating environment (when slats/flaps are extended during approach, there is a clear aerodynamic feedback -- pitch change).

Information transfer. Procedures convey, or transfer, information from one agent to others. In designing tasks, procedures, and callouts, the designer must make sure that no information is lost and that no *noise*[14] is added into information channel. Care must be taken with specifying non-verbal (para-linguistic) communication, as this form is usually less precise, difficult to standardize, and subject to misinterpretation (Wiener, 1993). Noise can be added when an ATC call, or a flight attendant, interrupts intra-cockpit communication during high workload periods. One system goal is that the same amount of information that is sent by one agent will be received by the other agent. When procedural requirements are violated by the agent transmitting the information, e.g., the example of the first officer's takeoff callouts of "V one- r, two of 'em" (Section 3.2.1), one can say that another form of unwanted noise (a deviant callout) has entered into the system.

Why are these attributes important? Because the designer may want to consider them while designing a procedure for a certain task. The procedure designer should design the feedback and information transfer aspects of the procedure in a way that will accommodate the requirements of the task. For example, if the designer decides that a procedure is critical (e.g., CAT II approach), he or she may decide to employ all possible forms of feedback into the design in order to safeguard crew coordination.

As for information transfer, understanding how information can become distorted allows the designer to provide safeguards to reduce their likelihood of occurrence. The procedure and the other tasks conducted at the same time should be designed so as to minimize noise and losses. For example, information can be lost when a completion call, such as *"the after takeoff checklist is complete,"* is mumbled by the PNF. In our previous study we recommended that the completion call of the checklist should be made an item in the checklist (Degani and Wiener, 1990).

Each of the above forms of noise, when introduced into the system independently, would probably not lead to a sub-optimal performance. But as it usually happens in a system accidents, the interaction between several of such sources of noise (e.g., a not-per-SOP rotation callout and an interrupting ATC call) and possibly other active failures (e.g., engine failure during rotation) may lead to sub-optimal performance (Perrow, 1986; Reason, 1990). The designer cannot foresee each possible combination of distraction and unwanted interaction. The designer has no choice but to laboriously contain each source of noise independently. When the source is internal to the aircraft and company, containment is not difficult (e.g., sterile cockpit rule), but if it is external (e.g., ATC), it is far more difficult to control.

The issues of reducing variance and enhancing feedback and information transfer allows us to analyze the interaction between critical tasks and technique via the eyes of CRM. When the aircraft is in a critical phase of flight, such as during approach or takeoff, there is no time to be creative with individualistic technique. At that point it must be strictly procedural -- not even a slight ambiguity among the crew how the task is conducted. Procedures minimize variance in pilot performance and therefore allow the other

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[14] Note that in this section we are using the term *noise* in the electrical engineering sense -- meaning anything that distorts or degrades the signal or information.

pilot a much easier monitoring task. Technique, with all its value, does introduce a form of variability to crew coordination (in both feedback and information transfer). Nevertheless, techniques can be positively introduced during all other phases or tasks.

> *Guideline #13*: Procedure design includes intra-cockpit communication. The expected communication should be specified, trained, and subject to standardization like any other procedure.

6.2.2 *Sharing of Information*

Ideally, all information is shared and known to all crew members (Orasanu, 1993). Nevertheless, this is not always practical. Not all information can be shared via SOP, as the amount of information can be enormous. In defining the task and the procedure, the crew coordination attributes must be also defined. The designer should determine the level of awareness required of other crew members about the task by asking:

1. Must the other crew member(s) know all the details of the task (fly heading 280, intercept the 050 radial of XYZ VOR)?
2. Should the other crew member(s) know in general that the system is configured according to SOP (pressurization is set)?
3. Should the other crew member(s) just be aware that the task is being taken care of (or under control), but not necessarily its exact state (walk-around)?
4. Is there is a need for the other crew member(s) to know about the task when it is part of some else's SOP (that all flight attendants are “buckled in” prior to takeoff)?

Another form of information sharing is a briefing. For example, during a landing briefing, the crew is briefed on the published procedure, landing category that will be used, limitations, etc. as well as situation-dependent information that may affect the approach/landing task (weather, captain's minimums, gross weight, NOTAMs, etc.). Briefing, from a procedure development point of view, can therefore be described as a task that assembles and coordinates a set of procedures in order to “ground” the procedures within constraints of the forthcoming situation. Briefing is provided prior to the task in order to facilitate transfer of information, to increase expectation, and to allow for better feedback.

As discussed in Section 5.6, automated cockpits cannot be procedurized as completely or easily as their predecessors. General operating policies, recommended techniques, and individual techniques, substitute for this. However, all lack the “reduction of variance” attributes of a procedure. In managing flight path in automated cockpits, briefing becomes an critical crew coordination tool -- not so much to reduce variance, but rather to reduce the level of ambiguity in the minds of the other crew members by clarifying expectations. The more one allows for technique, the more one has to stress briefing.

During our cockpit observations there were many instances in which in response to the challenge “briefing,” the person responsible for that task (usually the PF) would merely respond with the term “standard.” The meaning of this was that there was nothing to brief about as the forthcoming task was “as usual.” Based on the above discussion, we argue here that in a critical phase of flight such as takeoff or landing, there is no such thing as standard, and that a briefing (possibly very short, but still of intentions, concerns, procedures, etc.), is always required. The use of “standard” in place of a proper briefing, may be regarded as a form of complacency.

> *Guideline #14*: In managing automated cockpits, briefing becomes an critical crew coordination tool -- not so much to reduce variance, but rather to reduce the level of ambiguity of other agents (e.g., PNF or F/O) by increasing expectations. The more one allows for technique, the more one has to stress briefing.

6.2.3 *Reduction of Ambiguity*

As our definition of procedure implies, a procedure should never be vague. Generality is a desirable attribute of a policy or a philosophy, but not a procedure. Procedures must be “bullet-proof” against vagueness, as vagueness violates one of the most important by-products of cockpit procedures:

coordination of tasks between agents. If the same SOP, used in different situations, yields a significantly different outcome, then this should raise a warning flag to the procedure designer. The following example illustrates such ambiguity.

> The SOP for starting engines of a twin-jet for one U.S. carrier is for the ground-crewmember to call the cockpit and say, "Cleared to start engines." During line operations, however, most experienced ground-crewmembers will give this clearance per a specific engine, i.e., "cleared to start No. 1," or "cleared to start No. 2." It is preferred to start the No.1 (left engine) first, because the bags/cargo are loaded from the right side of the aircraft. Another reason for this sequence is that the tow-bar pin is extracted from the right side. Therefore, it is recommended not to have the right engine operating while the ground crew is disconnecting the tow bar.

In one reported incident a ground-crew trainee called the cockpit and told the captain "cleared to start engines" (exactly as SOP dictates). What he should have said was "cleared to start No. 1," as other ground crews were loading bags on the right side of the aircraft. The captain later stated that the callout "just did not sound right." He *did not* start the engine and called the ground crewmen to verify if he was cleared to start any engine, or just one of them.

The procedure, apparently, led to an ambiguous situation. As our definition of procedure in Section 2.1.1 stated, the outcome of a procedure must be a product which is unambiguous to all agents involved. If the same procedure can yield significantly different outcomes, then the procedure must be modified or changed (e.g., "Cleared to start engine number [one, or two]").

Likewise, in spite of the best efforts of standardization departments, flight crews can also make a procedure or callout ambiguous by taking shortcuts. We observed a captain who, upon being given a heading, altitude, and airspeed to make good while descending for a landing at San Diego, replied to ATC, "We'll do it all." Note that by not repeating the information, he short-circuited the checking process, denying both ATC and his fellow crew persons the opportunity to be sure that he operating on correct information.

> *Guideline #15*: If the same procedure can yield significantly different outcomes, then the procedure must be modified in order to eliminate its embedded ambiguity. In brief, a procedure should lead to a totally predictable outcome.

6.2.4 *Resources and Demands*

If the procedure places an unrealistic demand on the crew, then some pilots will very quickly develop creative "tricks" to bypass these procedural restrictions. These creative "tricks" may be even more dangerous than the situation which the procedure attempted to regulate. For example, ACARS push back time is sensed automatically when the captain releases the brakes. This information is then used to determine on-time performance. To bypass this, some crews have developed a technique in which they release the brakes and then set them again before they are ready to go, so that the push back signal will enter into the ACARS. Besides the fact that the crew is deliberately falsifying data, if this practice is not well coordinated with the ground crew, it can result in an injury.

In summary, all the above design issues cannot be extracted from the system by management only. The awareness and cooperation of flight crews is required in order to point to an existing problem. A formal feedback loop, such as previously advocated in Section 3.2.4, should be in place to obtain, collect, analyze, and rectify problems encountered on the line.

6.3 CALLOUTS

Callouts are aids in maintaining awareness of the crew as to the status of given tasks. They are extremely important in aiding situational awareness of a dynamic task, such as flight-path changes, engine starts, etc. There are several advantages and disadvantages to this form of status reporting. It allows the controlling entity to have full information on the status of each system component. Likewise, each component in the system also knows the state of other components. This, however, is purchased at a price -- constant chatter. But even repetitious chatter is not always a disadvantage, as the experienced human operator may detect departure from the monotonous sing-song as an indication of a problem starting to develop (Rochlin, La Porte, and Roberts. 1987).

Sing-song reporting methods are not cost-free: they place a burden on the pilot. His workload increases and his attention may be reduced. Nevertheless, they make the system dynamics appear more discrete and therefore more manageable and comprehensible. An example of SOP sing-song is engine start callouts. Most companies specify a sequence of callouts that help the crew monitor the process of engine start and detect abnormalities. Apparently, the level of detail in some companies' engine-start procedure for a two-pilot cockpit was borrowed from a three-pilot aircraft in which the F/E calls out information that is not easily accessible to the F/O and captain (e.g., "start valve open"). Some have argued that the amount of detail in this procedure can be reduced, as both pilots are monitoring the engine instruments in front of them.

Another method for status reporting is called "by exception." Using this method the pilot makes a callout only if the system has deviated from the assigned parameters. Its weakness is analogous to problems with remote sensors. In the absence of an alert, one of the two conditions can exist: (1) the system is within limits or (2), the sensor failed (and the system may be out of limits).

When specifying the method, the script, frequency, and sequence of callouts, the designer should consider the following:

1. If the task duration is long, a sing-song method may not be appropriate, as it will overload the pilot. In this case a "by exception" method may be more efficient.
2. If the system is highly dynamic and unstable, a sing-song method is preferred. If the system is temporal and predictable, exception reporting may be preferred.
3. If the task requires a high level of monitoring while other tasks must be accomplished, a sing-song may be preferred. However, this must also be designed with economy of information processing involved. We have seen one company's callouts on low visibility approaches which are so demanding that the PNF almost never stops talking for the last 1000 feet above ground.
4. If the state of the primary task is in front of the entire crew, as opposed to being hidden from them, exception reporting should be considered.

Proper sequencing of callouts is also an important design aspect. One concern in control of dynamic systems is that status reports will overlap in time, overloading the reporting channel and leading to a situation referred to by some operators as "control chaos." To avoid this, military organizations spend considerable effort to sequence these reports properly -- especially when the system is in an abnormal/crisis situation.

One airline has recently changed its non-precision altitude callout sequence because of this problem. The SOP stated that the crew make a 500 foot AGL callout. In addition, SOP stated that a MDA callout should also be made. Since many MDA's are around 480 feet AGL, this created a sequencing problem. As a result, the requirement for the 500' AGL was removed[15].

We believe that callouts should be examined like any other procedure. They should be economical, unambiguous, and should convey only the information needed by the other crew member(s). Quantitative calls should be used if necessary ("1000 feet, sink 5"). Qualitative calls ("on profile") are economical of both the sender and receiver and can be used for normal conditions where precise quantitative information is not needed. Callouts by exception can be useful in their place (e.g., no call if on localizer and glideslope).

Finally, the designer should resist the temptation to create a "cattle auction" which may allow the PNF to drown the PF in callout information (especially a sea of numbers). This may also reduce the PNF situational awareness and his ability to backup the PF. Complex callouts may sound precise and give the impression of being professional, but actually convey little usable information. In fact they may obscure vital information. For example, one carrier required callouts at various altitudes on final approach to include altitude, rate of descent, and deviation from selected (bug) speed (e.g., "500 feet, sink ten, plus fifteen"). The PNF never stopped talking throughout the approach.

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[15] Note that the MDA callout is more critical than the 500 foot AGL callout, as the MDA callout is associated with a control action (level off at the MDA and proceed inbound). See Sections 7.1 and 7.2. for a discussion on this issue.

Similarly, it has been a common practice (yet not a mandated procedure) in another carrier for the PNF to call out heights above touch down as the aircraft approaches the runway. The concern was that by making these frequent callouts (100, 50, 40, 30, 20, 10, feet above the runway) the PNF must focus entirely on the radio altimeters (heads down), and not on his primary task -- backing up the PF during the landing.

> *Guideline #16*: Particular attention should be paid in order to safeguard information transfer during critical and high workload phases of flight. Callouts should be economical, unambiguous, and should convey only the information needed by the other crew member(s). They should not distract the crew member from his primary task(s). Finally, we urge frequent review of callout procedures: as other procedures change, callouts should be reexamined.

6.4 PROCEDURAL DEVIATION DURING AN ABNORMAL SITUATION

The discussion up to this point has focused on procedure deviation during normal operations. There are procedure deviations during emergencies too. The topic of procedures, in general, always brings about the question of when is it *permissible* to deviate from them. Is it permissible to deviate from a low priority procedure (e.g., after takeoff checklist) when, due to high workload induced by an abnormal condition (electrical failure and a IFR missed approach), it cannot be performed (Wiener et al. 1991)? The answer is clearly "yes:" procedures were designed remotely from the situation at hand, and occasionally it is necessary to deviate from a procedure. As we have said before, procedures are in place to aid pilots, not to enslave them.

It is the nature of any goal-oriented system that the *system goal*, e.g., making a safe landing/evacuation following a malfunction, is always highlighted, not the process by which it is achieved. We assume that if the process is valid, then the result will be too. But that assumption is not *always* true. If a pilot deviates from procedures, training, policies, or even regulations, but saves the day, he or she is a hero, and there is a lot of talk about the flexibility of the human. On the other hand, if the pilot fails, he or she can be charged for deviation from basic operating procedures and discredited, or worse.

This paradox will always exist in any goal-oriented system, particularly if it operates in a dynamic and tightly coupled environment. Therefore it is important that management make a stand on this paradox via policies and philosophy. We have previously stated that one goal of management is to minimize deviations from procedures. In an emergency, such deviations must be accepted. The following ASRS report speaks to that issue and summarizes, via an example, the discussion of this chapter.

> While cruising at FL280, the left engine flamed out. Two unsuccessful attempts were made to restart the engine. Aircraft was landed at Cedar Rapids Airport 13,000 pounds over weight (143,000 pounds gross weight). The time elapsed from engine failure to landing was almost 30 minutes. During that time, the workload on a 2-person cockpit is tremendous. Communication with ATC, flight attendants, passengers, and each other, leaves little time for through analysis of aircraft problem itself. Our checklists are more directed to engine failure at takeoff, or shortly thereafter, with almost no guidance on priorities at altitude. So many books to check for single engine altitude, drift down speed, failure checklist, maximum over weight, landing weight for runway available, restart checklist, and normal checklists. Although I had *my own written* [italics added] rough guide for this situation, I found it necessary to revise many items in light of my experience. (ASRS report no. 216283).

We pass now from principles of procedure design, and factors that must be considered, to a discussion about the task of designing procedures. Chapter 7 lays out an orderly, comprehensive method for the actual construction of the procedures, and in Section 7.4 the implementation of procedures, something we have not emphasized in previous chapters. The difficult question of standardization, both within and across fleets, is attacked is this chapter. Numerous examples from database searches and from our own experience in the jumpseat illustrate the points.

7. DESIGNING PROCEDURES

7.1 OBJECTIVES AND STRUCTURE OF PROCEDURES

In general, execution of tasks can be viewed as the transition between *current* state (e.g., before engine start checklist is complete) and *target* state (engines have been started) in order to achieve the objective. To support the crews in performing the task, flight management must determine what is expected from the crew in terms of task performance. A set of different "methods," (e.g., mandatory procedure, recommended technique, and policies, etc.), are then introduced to aid the pilots in making the transition from current to target state.

7.1.1 *Objectives of procedures*

The designer must identify and list all the procedure objective(s) before plunging into the details of procedure development. He or she must determine, exactly, what the procedure is trying to establish. For example, are checklist procedures designed as an aid for a "dead tired" crew which flies an international route? Or, are checklist procedures developed as only a minimal "killer items" list? Although the apparent objective of the checklist is the same (to configure the aircraft properly), the interaction with either of the two objectives will yield dramatically different checklists.

Consider also the following example: Most airline SOPs require that a callout should be made 1000 feet before the assigned altitude. The purpose of this callout is to increase crew awareness prior to an event (level-off), that if not conducted properly, may have an adverse effect (altitude deviation). The most common practice is to call out "one thousand to go." This callout, however, fails to transfer critical pieces of information which bound the level-off task: the target altitude, the current altitude, and the direction (climb/descent). The real objective of the task is not just the *level-off* maneuver, it is also to *level-off at the assigned altitude*. The procedure and callout should therefore include both[16]. One airline, in an attempt to curtail altitude violations, dictated the following procedure "PF will verbalize leaving the altitude 1,000 feet prior to an assigned altitude. Not 'one to go'; rather 'six thousand for seven thousand' or 'flight level three zero zero for two niner zero."

7.1.2 *Who is the Target Population?*

At first, the answer to the above question may seem trivial -- the pilots. But a closer examination will reveal that there are several sub-populations within a company's pilot population. Are the procedures designed for the line pilot who has been flying the same aircraft for 15 years? For the pilot who just transitioned from a traditional cockpit to a glass cockpit aircraft? For a new hire who occupies the right seat in a DC-9? Or are they designed according to the capabilities of the seasoned chief-pilot who designed them?

For example, one airline's current rejected takeoff (RTO) procedure allows the first officer, when acting as PNF, to call for and, when he or she is PF, to conduct the maneuver. This procedure, however, is currently being revised. The future RTO procedure for this airline will allow *only* the captain to perform this maneuver. There were several factors that led the airline to change this procedure. One was the belief that a new first officer of a widebody is not experienced enough either to perform or call-for this complicated and extremely hazardous maneuver. In this case the company has made a decision to change the procedure so that it will accommodate the perceived abilities of the lowest proficiency level in the line pilot population.

To summarize, the definition of the target population must be developed, tested, and agreed upon prior to designing the details of a procedure. Once this component of the operating philosophy has been determined it must be communicated to all pilots in the company.

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[16] Note that the "thousand to go" callout is also an example of a too general and somewhat ambiguous SOP -- the same procedure yields significantly different outcomes (see Section 6.2.3).

7.1.3 *Structure of Procedures*

As mentioned earlier, it is common in all high-risk systems that critical tasks that affect the goals of the system are always accompanied with a set of procedures. Procedures, in turn, specify a set of sub-tasks or actions to be completed. That is, each procedure can be shown to lie between a higher level task and a lower level sub-tasks. Figure 10 shows this structure.

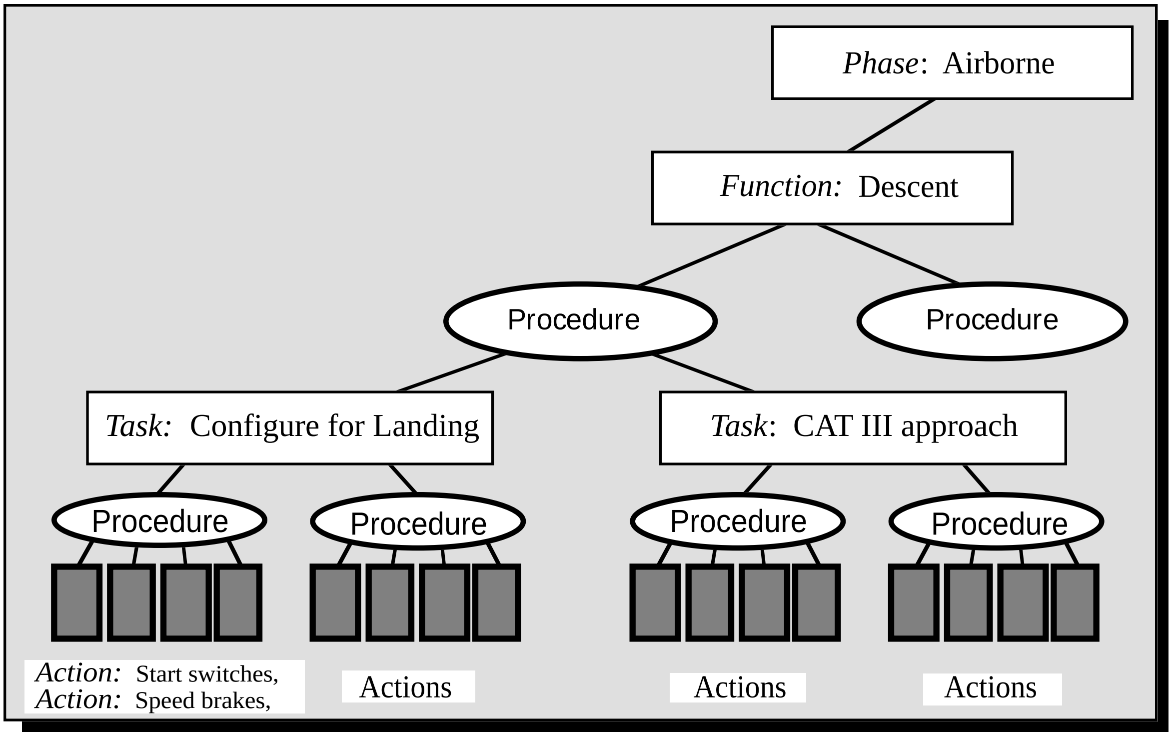


Figure 10. *The task-procedure structure.*

The normal tasks and procedures that are required to fly a passenger aircraft can be arranged in such a hierarchical manner: possibly starting with a high level *goal* of flying passengers from point A to B, and then branching out to *phases* such as ground phase at departing airport, airborne phase, and ground phase at destination. This is followed by a third level, that includes *functions* such as preflight, boarding passengers, engine start and push back, before taxi, etc. The fourth level includes *tasks* such as starting engines, configuration of various systems, etc. The fifth level includes the various *actions* such as setting switches, tuning radios, monitoring a gauge, etc., that are necessary to perform the task.

The task-procedure hierarchy allows the designer to structure the procedures in the context of the overlying tasks, functions, and the phases of flight. Such decomposition is a proven way to manage the complexity involved in human machine systems (Miller, 1985; Mitchell and Miller, 1986; Rasmussen and Lind, 1981). By using such decomposition methodology, one can better design the procedure so that it will meet the demands.

For each function (e.g., engine start and push back) the objectives are determined and listed. Once the objectives are specified, the tasks required to meet them are listed. Then, the actions required to execute each task are listed. Finally, the procedure is designed. The procedure, of course, is composed of all the previously listed actions necessary to perform the task. For example, let us assume that the function is “engine start and push back.” In this case the objectives may be to:

1. Start all engines safely and economically
2. Involve all crew members (both cockpit and ground) in the engine start process
3. Disconnect and push back safely

4. Get ready for the next phase (taxi)

The tasks and actions are:

1. Brief the crew (cockpit and ground) regarding engine start sequence: when to start, which engine is started first, etc.
2. Check for completion of all pre-start conditions: clearance, configuration, cabin doors locked, safety of ground crew, etc.
3. Perform the engine start sequence: ignition selector, open start valve, open spar fuel valve, etc.
4. Closely monitor start process: oil pressure, N2, N1, EGT, starter cutout, etc.
5. Configure systems after engine start.
6. Advise ground crew and check for completion of post-start conditions: disconnect external power, air, etc.
7. Obtain push-back clearance from ATC
8. Coordinate and monitor push-back and disconnect from the ground crew

The procedures are:

1. Before start checklist
2. Engine start process and callouts
3. After engine start configuration flow
4. SOP tasks and callout for coordination with ground crew

It is at this point that the adequacy and the compatibility between the SOP and the tasks begin to be revealed. If the design and sequence of the SOP associated with engine start and push back do not support all the tasks, then the SOP must be changed. Likewise, if the SOP does not allow for the fulfillment of *all* objectives, then either the tasks or objectives must be changed. For an example in which the procedure did not support all the objectives, see the example in Section 6.2.3 regarding ambiguity in engine start sequence.

7.2 SCHEDULING OF TASKS AND PROCEDURES

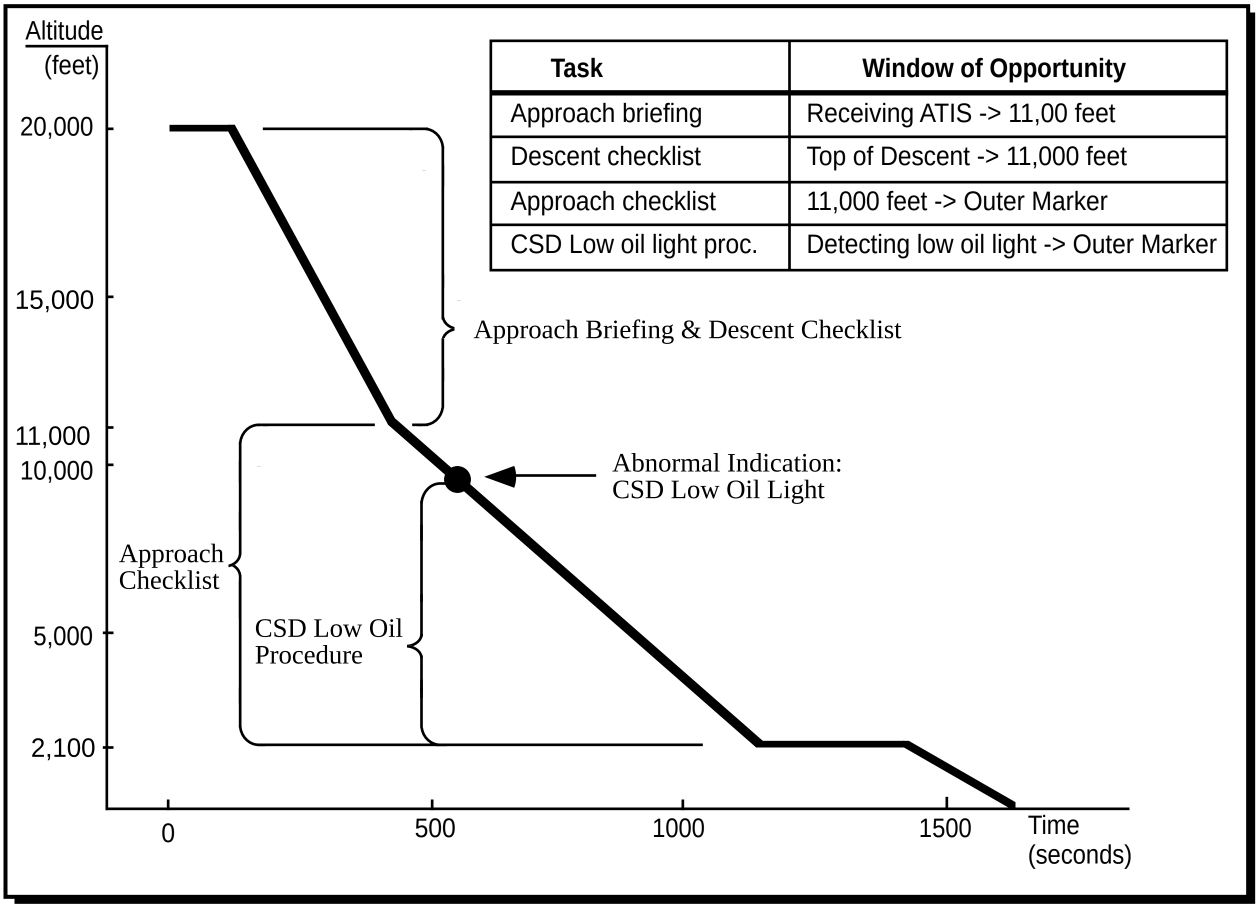
Two factors affect the flow of procedures in the cockpit. First is the sequencing of tasks and procedures, which is specified by the designer of the SOPs and checklists. Second, is the actual scheduling of tasks and procedures, which is conducted by the cockpit crew. The goal is to optimize the sequencing in the design process and to promote efficient scheduling by the crews.

Tasks require time, attention, cognitive resources, and therefore they contribute to workload. The designer's goal is not merely to minimize workload, but also to distribute it throughout the phase(s) of flight in order to avoid periods of very high or very low workload. While this is important for any routine operation, it appears to be extremely important in today’s automated two-person cockpit.

7.2.1 *“Window of Opportunity”*

For every task on the flight deck, there is a time boundary. This period is sometimes referred to as the *window of opportunity*, indicating the time period in which a task can take place. For example, the window of opportunity for the DESCENT checklist can be defined as the time period between top of descent and 10,000 feet. This time period (i.e., from time at top of descent to time at 10,000 feet) depends on cruise altitude, rate of descent, ATC vectors and restrictions, and therefore may vary.

Although a given task can be effectively accomplished at any time within the window, it appears that there is an advantage in conducting the task early. Laudeman and Palmer (in preparation) conducted a study to evaluate task-scheduling strategies of airline pilots flying DC-9 and MD-88 aircraft in a full mission simulation (see Wiener et al., 1991). They reported that crews who scheduled their task early within the window tended to be rated as high performing crews. Conversely, crews who scheduled their tasks late within the window tended to be rated as low performing crews. Laudeman and Palmer concluded that “scheduling of a task early in the window of opportunity is the optimal task scheduling strategy” (p. 20). Figure 11 is a graphical depiction of several windows of opportunity in the Laudeman and Palmer study.



Task	Window of Opportunity
Approach briefing	Receiving ATIS -> 11,00 feet
Descent checklist	Top of Descent -> 11,000 feet
Approach checklist	11,000 feet -> Outer Marker
CSD Low oil light proc.	Detecting low oil light -> Outer Marker

Figure 11. *Windows of opportunity during the descent to Columbia, SC.*

The above findings are applicable in light of a recent airline accident (NTSB, 1991):

> In 1990 a MarkAir B-737 crashed about 7.5 miles short of runway 14, Unalakleet, Alaska. The captain (who was the PF) incorrectly deduced the location of the FAF to be 10 DME from the localizer, rather than 5 DME. He therefore prematurely descended to 500 feet MSL, 5 miles prior to the FAF and consequently hit the ground (meteorological information was: ceiling, 500 feet overcast; visibility 1.5 miles with fog). The first officer (who was new on the aircraft) did not notice, or did not make the captain aware of, the departure from the approach procedure. The Safety Board, however, “believes it is more likely that the first officer was not monitoring the approach closely because he was preoccupied with his other duties.”

In addition to the regular tasks of the PNF, the first officer had two other tasks to perform: (1) reconfiguring the engine bleeds to aid in avoiding foreign object damage, and (2) starting the APU. The manufacturer of the aircraft (Boeing), recommends that the bleeds be reconfigured below 10,000 feet; the MarkAir written procedure specifies doing this below 5,000 feet; a MarkAir management pilot stated “we try to keep them reconfigured as low as possible...usually down around couple thousand feet...” (p. 9); the captain briefed the first officer to reconfigure the bleeds “when we roll in on final...” (p. 59).

During the actual approach the captain instructed the first officer to reconfigure the bleeds as the aircraft was in a turn and descending through 1,700. The Safety Board stated that “reconfiguring the bleed switches around 1,700 feet prevented a rapid pressurization change within the cabin, but was not reason enough to risk pilot distraction at a critical point in the flight (NTSB, 1991 p. 32). The Safety Board concluded with a recommendation to the FAA to “revise the MarkAir flight checklist and training program to ensure that bleed switch deactivation for gravel runway landing is accomplished at sufficient altitude so as not to be a distraction during critical phases of flight” (p. 36).

The following is the MarkAir B-737 procedure for bleed switch configuration (NTSB, 1991):

> If landing on a gravel or contaminated runway, start APU, and when below 5,000 ft. MSL, configure pressurization system for engine bleeds off landing:
>
> Right pack switch - ON
> Isolation valve - CLOSED
> Left pack switch - ON
> No. 1 engine bleed switch - OFF
> APU bleed switch - ON
> No. 2 engine bleed switch - OFF

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

7.2.2 *Sequencing in the Window*

Some will argue that completing some tasks early within the window of opportunity is sometimes inefficient because there may be a change or a new constraint “down the road.” Here are some examples: (1) obtaining ATIS early -- there may be change in runway, weather, NOTAMs, etc.; (2) conducting the approach briefing -- there may be a runway change; (3) positioning flaps or stabilizer setting for takeoff -- there may be a change in load manifest, runway assignment.

Nevertheless, in many discrete cockpit tasks, such as performing checklist items, briefing, mandatory company calls, PA calls, configuration, etc., early completion within the window of opportunity may have advantages.

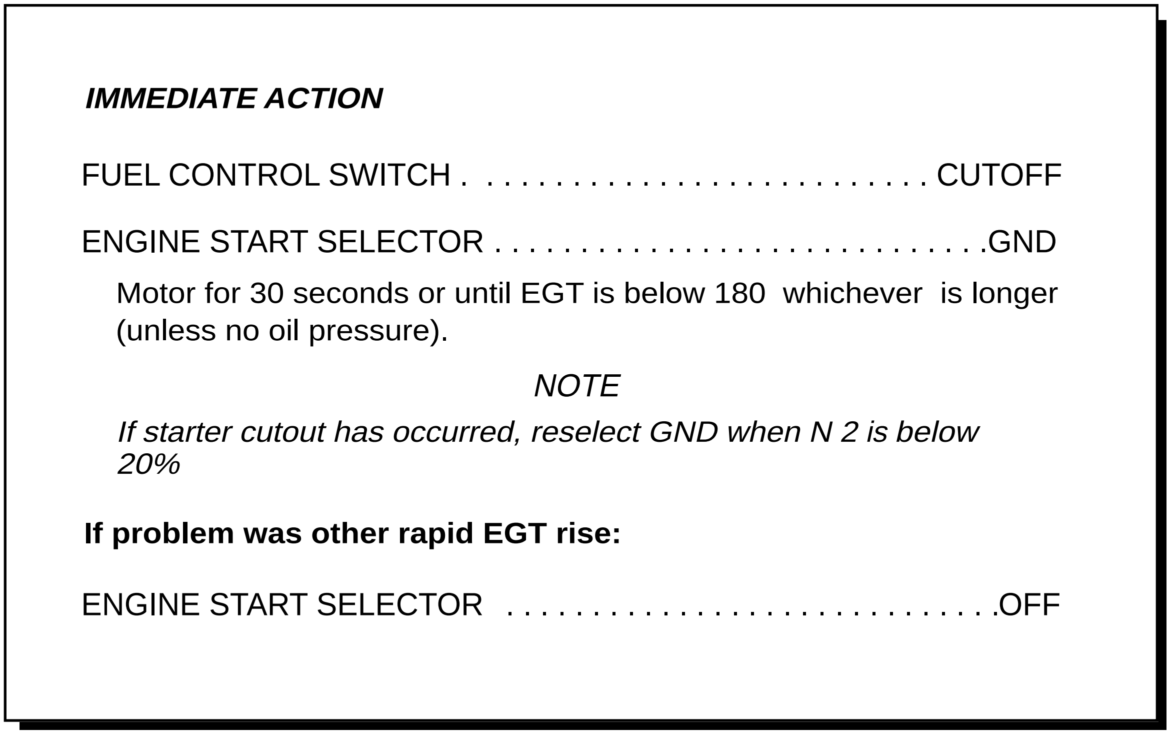
1. The task (e.g., briefing), is done and removed from the queue early on. This reduces memory load and cognitive scheduling effort from the pilot (“I have to find a good time between ATC calls, configuration tasks, and prior to reaching 5,000 feet to do the approach briefing”). Decisions, options, and discussion can be formulated early, when the workload is still relatively low.
2. If an unanticipated event (e.g., generator failure) occurs, the diagnostic process and the reconfiguration process will not interfere with the task (e.g., approach briefing), as it was already done early in the window of opportunity. Changes pertaining to the failure can be amended during the approach briefing later on.
3. Conducting some aspect of the task, even if it may change later, guards against completely forgetting it in unique cases where the procedure is vulnerable to human error. For example, positioning the flaps to a takeoff setting before starting to taxi (even though the crew expects a future change in flap setting) may guard against totally forgetting to set flaps for takeoff (NTSB, 1988; Degani and Wiener, 1990).

An example of taking advantage of the early completion of tasks within the window of opportunity can be seen in one company's policy of minimizing non-configuration tasks below 18,000 feet. Accordingly, we noticed that some flight crews turn the sterile cockpit light on prior to reaching 18,000 (although the FAR mandates sterile cockpit below 10,000 feet). One may argue that this is sub-optimal, sterilizing the cockpit before it is required and thereby discourage necessary cabin-cockpit communications (Chute and Wiener, in preparation). On the other hand, flight crews that we observed felt that this is an efficient technique: the task is completed early in the descent and the possibility of distractions by flight attendants during the descent are eliminated. In short, the crew found it advantageous to be more “sterile” than the law requires.

7.2.3 *Sequencing of Actions Within a Procedure*

Sequencing is the internal mechanism that drives many cockpit procedures -- especially critical and time dependent procedures. Sometimes the only reason for a procedure is the absolute necessity of a correct sequencing of actions (e.g., engine start procedure, engine fire procedure, generator fail procedure, etc.). In a previous study (Degani and Wiener, 1990), we discussed sequential deficiencies in the *normal checklists* of several U.S. carriers, in which the procedural flow becomes intermittent (as opposed to consistent) in the motor movement of eyes and hands along the panels in the cockpit. While conducting the research for this study, we found similar deficiencies in *abnormal/emergency* procedures. With respect to emergency procedures, these deficiencies are very critical because of the time limitation, workload, and level of stress involved in dealing with an emergency. In addition, failure checklists are mostly performed as “action lists,” i.e., an item is read (or recalled from memory) and immediately performed. In this case a sequential mistake can lead a crew member to take an irreversible action.

For example, consider the immediate action procedure for an IRREGULAR START for a medium-range aircraft (Figure 12):



IMMEDIATE ACTION

FUEL CONTROL SWITCH . . . . CUTOFF

ENGINE START SELECTOR . . . . .GND

Motor for 30 seconds or until EGT is below 180 whichever is longer (unless no oil pressure).

NOTE

If starter cutout has occurred, reselect GND when N 2 is below 20%

If problem was other rapid EGT rise:

ENGINE START SELECTOR . . . . .OFF

Figure 12. *IRREGULAR START procedure*

If the procedure is carried out in the sequence listed, then the flight crew may overlook the restriction and select “ground” (GND) when N2 is above 20%. A simple solution used by some pilots is to write the restriction on the checklist before the word GND. We note that, while one's intention may be the best, writing on, and thereby modifying, the checklist card is a violation of FAR 121.315, although it is not an uncommon practice. The dangers of using such “custom built” procedures are quite obvious.

To conclude, the designer of flight-deck procedures should strive to eliminate any sequential problems, especially in emergency procedures. That is not an easy job, yet the feedback loop from line pilots discussed in Section 3.2.4, can be used to identify these problems.

> *Guideline #17*: Procedure designers should always bear in mind the contribution which any procedure makes to total workload of the crew at any given time. They should be especially sensitive to procedures that may require crew attention in times of high workload, and should strive to “manage” workload by moving tasks that are not time-critical to periods of low workload.

7.3 DECOUPLING OF TASKS

Tight coupling is a mechanical term which is used here to denote a phase, or a task, that is made up of several actions that are interrelated, performed simultaneously, and are time dependent. The problem with tight coupling is that when unexpected events occur, the time dependency and the interrelation between components make it difficult for pilots to intervene quickly and efficiently in order to contain the unexpected situation. A takeoff is an example of a tightly coupled task. Complexity and tight coupling are inherent characteristics in dynamic systems such as driving or flying. The designer's challenge is to design the sequence of tasks in a way that tight coupling is minimized, or more realistically, managed.

We are suggesting here the term *decoupling*. We use this term to denote the process in which the designer is trying to “break away” some of the tight coupling inherent in a phase or a task. In decoupling an activity the level of criticality is an important factor. Not all cockpit tasks conducted during the same phase of flight are equivalent in terms of criticality. Some may be more critical (e.g., monitoring the final approach), some may be less (e.g., cabin announcements).

In most cases, the primary tasks are continuous (taxiing the aircraft, looking for taxiway, etc.), while the secondary tasks are discrete tasks (entry of manifest changes into CDU, calling company to report push-back time, configuring bleeds). Critical primary objectives should be well “guarded.” This can be done by decoupling secondary or tertiary tasks that may interfere with performing the primary task. For example, if it is decided that the primary objectives of the PNF from the FAF to touch down is to backup the PF, then secondary tasks, such as configuration of bleeds, should be decoupled. Another example of procedures that decouple the primary task from the rest is the following altitude change procedure: “both pilots should *refrain* [italics added] from other duties during the last 1,000 feet of climb and descent to an assigned altitude.” Finally, a classical case of decoupling of a task is the stabilized approach maneuver. This maneuver requires that the aircraft be configured for landing, descending on glide-slope, tracking the localizer at a appropriate speed during the last 1000 feet of the approach[17].

> *Guideline #18*: The designer of flight-deck documentation should search for situations where procedures are tightly coupled, and exploit the opportunity to decouple them.

7.3.1 *Methods for Decoupling*

The following is a list of several methods to achieve decoupling. This list is certainly not exhaustive.

1. *Reassigning the secondary tasks to a different phase*. Some carriers opt to perform a takeoff checklist while on the active runway. Some airlines, attempting to decouple this checklist task from the more critical takeoff duties (e.g., listening to ATC, looking for traffic, mental preparation for takeoff, etc.), have mandated that the takeoff checklist will be conducted prior to entry into the active runway.
2. *Reassigning the task to another crew member*. Some airlines require the flight crew to make a PA call to the passengers before taking off. Others have elected to reassign this task to the senior flight attendant. Likewise, some airlines are considering installing an ACARS control display unit in the cabin to allow the flight attendants to interact with company regarding passenger comfort items (requesting wheel chairs, information about connecting flights, etc.).
3. *Minimizing the time and resources to perform an SOP*. Secondary SOP's can be shortened or relaxed, thereby freeing resources. For example, one airline which operates only two-pilot aircraft, allows the PNF to perform the AFTER TAKEOFF checklist without a formal challenge-

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[17] The details of this procedure vary among airlines -- the concept does not.

response. The PF, therefore, can concentrate on the climb-out and not be bothered with the AFTER TAKEOFF checklist.

4. *Eliminating secondary tasks*. There are two methods to achieve this. One is by “assigning” the task to a machine. For example, in an earlier Section (6.3) we discussed one company’s concern about PNF being occupied by making radio altimeter callouts and not monitoring the landing. The solution, currently under implementation, is to use a feature of the GPWS that will sound these calls automatically.

Another method is to eliminate the task completely. For example, some airlines have a sterile-cockpit light switch to indicate this state to the cabin crew members. Pilots would switch it “on” or “off” crossing 10,000 feet. Other carriers do not have such a light, thereby eliminating this task and the associated procedures.

7.4 IMPLEMENTING PROCEDURES

One should not assume that management's duties are over once a procedure is designed and implemented. The practices of the users and the outcome of the procedure are also within the responsibility of management.

A common complaint of many flight crews is that procedures are being changed in a rate far greater than would seem required by such external factors such as new FAR or ATC procedures, new equipment, etc. Many believe that flight managers sometimes change procedures for the sake of making a political statement or to justify a project that they are responsible for. The situation can be alleviated by management seeking to minimize non-essential procedure and checklist changes, and by, wherever possible, explaining the reasons for the changes. Some of the counter-measures that management can take in attempting to avoid minimize non-essential procedural changes are listed below.

> *Guideline #19*: Frequent procedure and checklist changes lead flight crews to conclude that the system is unstable. This may diminish the importance they attribute to new and modified procedure. Therefore, management should minimize frequent procedures or checklist changes. It is probably better to bunch them together and make larger, less frequent “bundles” of changes if the items are not time-critical.

7.4.1 *Experimentation*

We recommend that important flight-deck procedures should be validated experimentally by testing them against the *behavior* of line pilots, and not the judgment of others. The experimentation should take place in the appropriate flight simulator using a true sample of the target population, i.e., *line* pilots, as opposed to management pilots. The dependent variables such as flow, time, correctness, subjective ratings, workload ratings, etc., should be analyzed to determine the optimum results. Evaluation in a full mission simulation environment, although expensive and time-consuming, can go a long way toward demonstrating potential “pitfalls” of procedures under evaluation (Mosier, Palmer, and Degani, 1992). A simulator test will uncover possible problems that would not be apparent to persons writing procedures and checklists “around the table.”

As stated in Section 6.2.3, the outcome of a procedure should always be the same, i.e., independent of the constraints in the operational environment. To achieve this, procedures must be tested throughout the possible constraints, or scenarios, prior to implementation. This will reduce the likelihood of modifications to the procedure down the road. A proper procedure must work well in any ATC environment, under any reasonable workload level, weather, terrain, or geographical location. Particular scrutiny should be applied to trans-oceanic operating procedures, due to their special sensitivity to error.

7.4.2 *Documenting Procedures*

It is extremely important that the operational logic that leads to the construct of a procedure be documented and maintained. Documentation is essential in order to provide for the efficient and cost effective development, modifications, and maintenance, as well as for understanding the concepts behind a complicated set of procedures (Sheppard, 1987).

While observing several procedure-design sessions, we noted that flight management personnel who were responsible for designing procedure could not recall the operational logic and the constraints that prompted an existing procedural sequence. This is understandable, specially in light of constant change in personal in flight management departments. However, the result is inefficiency -- much time is spent in trying to recall or understand the logic and constraints that led to the construct of the procedure. Critical constraints may be forgotten, and what is even worse, constraints that may no longer exist, are being "carried along."

Such documentation can be tied into the "Four-P" model, showing the logical links between the procedures, policies, and philosophies. They can be also extremely helpful when questions arise while flight crews learn new procedures during transition training.

> *Guideline #20*: The SOP documentation should not only explain the mechanics of the procedure, but also state the logic behind it. A detailed account of the operational logic, system constraints, and the link to the "Four-P" model should be part of the documentation.

7.4.3 *"Selling" Procedures*

Once the decision to change a procedure is approved by flight management and the FAA's principal operations inspector, the change must be communicated to the line pilots. This may seem the most trivial part of procedure modification -- but it is not. Pilots will usually, in some form or another, resist changes in procedures, particularly the ones that may seem as "change for the sake of change." Management must be able to persuade itself and the line pilots that the procedure change is truly necessary and beneficial. Flight crews, therefore, have to know the *why* behind a procedure change and not just *what* and *how*. The "Four-P" model could be used in this regard, as the logical progression from philosophies, policies, to procedures can be shown.

Flight management can be creative in making this "sell." For example, one airline sent a video tape to all pilots in the fleet, explaining and presenting the new upcoming changes. If procedure changes are just sent out as a revision to the manual and not properly communicated, then the likelihood of proper implementation is low.

7.5 IMPLEMENTING STANDARDIZATION

Perrow (1986) contrasts the complex human-machine systems of nuclear power plants with aircraft operations: "In the aircraft and the ATC system, we let more of the operating environment in -- it complicates the situation" (p. 229). This factor, the complexity associated with the interaction with the ever changing operational environment, is critical in any attempt at standardization. If one could better control the environment, then a greater level standardization could be achieved (Landau and Stout, 1979). Unfortunately, that is almost impossible.

When a company is relatively small, standardization is sometimes achieved by default[18]. Pilots traditionally had a clear career path, i.e., they transition through the different seats in a consistent sequential manner. Nevertheless, in today's mega-carriers, this clear career path does not exist because of the sheer size of the organization, the number of bases, and the variety of aircraft in a company's fleet. This is why standardization has become such an important issue. There are several components to the efficient standardization of procedures, which we shall now discuss.

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[18] Note that we have used the term "standardization" in two ways in this report. In the sense of the present discussion, it refers to commonalty of cockpit hardware and procedures within and across fleets. In previous discussions (see Section 3.2.3), the term referred to management's function in quality control of pilot performance in adherence to procedures and regulations. In the first sense, it is hardware and supporting documentation and devices that are standardized, in the second it is the crew members' behavior.

7.5.1 *Cross-fleet Standardization*

Cross-fleet standardization is an economic (and sometimes emotional) topic that involves complex trade-offs, and often has no easy solution. If done properly, cross-fleet standardization provides for smooth transition from one aircraft to another, and a solid framework for training, checking, and line flying.

During our visits to the airlines, we attended such standardization meetings. In one meeting, the agenda items was the cross-fleet consistency of the DESCENT, APPROACH, and LANDING checklist with respect to the altimeters check.

> The problem was that in Europe, the transition altitude varies from nation to nation and can be as low as FL 40. Likewise, in some parts of the Caribbean (where U.S.-operated domestic narrow body aircraft also fly), the transition altitude is lower then in the U.S. The procedural dilemma was how to implement a procedure that checks that altimeters are set to QNH during descent into the terminal area.
>
> The first alternative was to have all aircraft check altimeters at 18,000 feet (note, however, that this is an unnecessary check when the transition altitude is below 18,000 feet). The second was to have all aircraft check altimeters with the APPROACH checklist (which is conducted below 18,000 feet) to “cover” those aircraft that fly to the Orient were transition altitude may be somewhere between FL 140 and FL 80. This would add a “nuisance” checklist items to the domestic narrow body aircraft). The third was to have *all* aircraft check altimeters with the LANDING check to cover all those aircraft that are landing in Europe. The effect of this standardization would be to add two “nuisance” checklist items to the domestic narrow body fleets.
>
> The final solution was to list altimeters checks in the DESCENT and APPROACH checklist only. The *altimeters check* was to be written as the last item on the APPROACH checklist, and a *to go* item was to be allowed. When the APPROACH checklist is performed above the transition altitude, the PNF will say “altimeters to go” and wait until the transition altitude is reached in order to complete the APPROACH checklist.

The benefits of cross fleet standardization are quite obvious. And there are vast areas in cockpit operations where this can be done properly (mainly in the non-aircraft specific procedures, e.g., precision/non-precision profile callouts, and many more). Nevertheless, it is not always possible. If done improperly, it may lead to sub-optimal procedures by superimposing procedures that are suitable for one type of cockpit operation on another. This kind of cross-fleet standardization may turn out to be a very expensive will-of-the-wisp.

> Part of the altitude verification procedure described in Section 5.7.2 is also illustrative of a trade-off in designing cross-fleet procedures. This procedure specifies the duties, with respect to manipulation of controls between the PF and PNF, as a function of the level of automation used: hand flying (PNF manipulates the MCP controls) or autopilot operation (PF does so). This procedure was generic to the extent that it could be used across all fleets, with exception, however, of the DC-9 fleet.
>
> In the DC-9 cockpit, the location of the altitude alerter is adjacent to the F/O's left knee. It is difficult for the captain to access, set, or read its numeric display. Therefore the procedure for the DC-9 fleet is different from other fleets: the F/O always sets the altitude alerter, regardless of whether he or she is the PF or PNF. An entire cross-fleet standardization could be not be achieved -- the price was just too high.

Inappropriate standardization may therefore interfere with the intelligent exercise of piloting tasks (Johnston, 1991). In such cases, the flight crews are the ones who have to bear the consequences of this incompatibility. We therefore argue that the airline must develop a philosophy for cross-fleet standardization. Such a philosophy can help draw the line between reasonable and unreasonable cross-fleet standardization efforts. This will allow the designer a frame of reference with regards to such procedures. Once communicated to all, the standardization philosophy may allow other persons (such as instructors, IOE and line check airman, FAA inspectors, and line pilots) to better understand, critique, and check such procedures.

An additional measure for improving standardization efforts is creating a formal cross-fleet forum (such as one company’s fleet captains’ board). This forum, which includes the lead captain from every fleet in the airline, meets regularly and is the only entity that approves such procedural changes. The fact that any procedure change must be approved by all fleet captains, enhances coordination and minimizes the likelihood of improper cross-fleet standardization procedures. Likewise, involving the entities that teach, use, and check procedures (ground training, flight training, line pilots, check-airman, etc.) in procedural design can provide benefits in the long run. Both measures can go a long way to improve cross-fleet standardization.

> *Guideline #21*: While benefits of cross fleet standardization are quite obvious, there are certain situations where this type of standardization is just inappropriate. It may lead to sub-optimal procedures by superimposing procedures that are suitable for one type of cockpit operation on another.

> *Guideline #22*: We recommend a three-way approach for a cross-fleet standardization. (1) Development of a cross-fleet philosophy, (2) creating a cross-fleet standardization forum, and (3) obtaining input for procedural design from personnel that design, certify, teach, use, and check procedures.

7.5.2 *Within-fleet Standardization*

Another form of standardization, sometimes neglected, is between different procedures used on the same model aircraft. For example, in one narrow body aircraft fleet, the CAT I and CAT II callouts were very different from non-precision callouts . The lack of standardization between the various approach procedures was so severe that flight crews found it necessary to brief, prior to each approach, the callouts that should be made and when. The reason for this was twofold: (1) the approach callouts were remarkably different (even in cases where they could be the same) and (2) they changed frequently. This, we believe, is a breakdown of the foundation of SOP; procedures that are designed to be the common baseline no longer serve that function. We again remind the reader of our view that all cockpit documentation and procedures should be in place to *support* the crew, not to make their job more difficult[19].

7.5.3 *The Model for Standardization*

The concepts of operation of a three-pilot cockpit is very different from that of a two-pilot cockpit, primarily in distribution of workload between crew members. In addition, glass cockpits also require a very different philosophy of operations than their predecessors (Wiener, 1988, 1989).

Out of necessity, carriers are gradually moving away from having a three-pilot cockpit aircraft such as the B-727 or B-747 as the model, or flagship, for standardization of procedures. This transition, however, does not solve the problem of standardization-compatibility between glass cockpit aircraft and three pilot cockpit -- it simply changes the aircraft employed to set the standards.

There are two approaches to this standardization issue. One approach is to standardize the fleets according to two distinct standards (i.e., glass cockpit fleets and traditional cockpit fleets). There are many advantages for this approach as the autoflight system of most glass cockpit aircraft are basically the same. Many autoflight related procedures such as PF/PNF duties in various modes, initial climb procedure, precision and non-precision procedures, and many more, can be standardized efficiently. Although some flight managers have stated that there was an attempt to standardize among glass-cockpit fleets, a review of their procedure does not support that. Another approach is to attempt to standardize across glass and traditional cockpits, using one model as a benchmark. There is no golden solution to this issue -- difficulties arise in either approach.

7.5.4 *Standardization in Checking*

Because training and checking are part of the process of transporting the procedures from flight standards to the line, it is another source that generates deviations from mandated procedures. In most airlines there are four entities that are part of this process:

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[19] Somewhere between cross-fleet and within-fleet standardization is the complicated issue of common/same type rating. This puts a greater burden on procedure designer as flight crews are rated on aircraft that may be different in aircraft systems, cockpit layout, and procedures (Braune, 1989; Lyall, 1990)

1. Training department (for both pilot training and proficiency checks)
2. Check airman program
3. FAA inspection
4. Line operations

Because each one of these entities has different perspectives and objectives with regards to procedural execution, there may be differences in how pilots are required to perform. Flight management should attempt to minimize, to the degree possible, the differences in pilot performance between these “worlds.” The all-too-classical statement, “I don't care what they taught you in ground school, this is how we do it out here on the line” portrays a genuine standardization problem. Indeed, several flight crews that we interviewed complained that this was the rule. In their view, the training department had a different concept of flying then flight standards, line operation had different concepts of operation than training and IOE, and even worse, the FAA inspectors expected something still different. It is important to note here that those differences in concept of flying mainly centered on usage of the autoflight system of glass cockpit aircraft. The most common differences in philosophy were (1) cockpit set-up for different phases of flight and (2) engagement of autoflight modes.

We believe that the “Four-P” model detailed in this report, in conjunction with some organizational counter-measures, may be helpful in minimizing such differences. When philosophies and policies of operation are stated and communicated, this sets a single unequivocal baseline to all entities involved. Performance can therefore be judged or justified against this baseline.

> Guideline #23: The flow of any procedure through design, training, checking, implementation, and finally feedback, must be supported by the organizational structure. When a new procedure, or a modified procedure is established, it should be closely monitored (by standardization and check airmen, and LOFT instructors) for compliance.

To summarize, any procedure, even the best one, can never be “bullet proof.” Since the environment around the plane is dynamic, the procedures and policies can only provide a *baseline*. This, we believe, is the true meaning of standardized procedures. The role of flight management is to provide the best possible baseline for the flight crews. “In any operational situation, seek to identify the non-standard or idiosyncratic item of operational significance with is relevant to the task. In other words, avoid reducing flying to an almost mindless ritual in which the normal or standard is unthinkingly accepted” (Johnston, 1991). Procedures should be designed to represent a standardized baseline, but not substitute for an intelligent pilot.

8. SUMMARY AND CONCLUSIONS

Flight deck procedures are the backbone of cockpit operations. They are the structure by which pilots operate aircraft and interact with other agents in the system. Procedures are probably one of the most important factors in maintaining flight safety -- during both normal and abnormal conditions.

It was traditionally believed that procedures are only hardware/software dependent -- that they are inherent in the device. We have tried to show throughout this report to that this is not the case. We argue that they are also dependent on the operational environment, the type of people who operate them and the culture of the company they work for, and the nature of the company's operations. Procedures are not inherent in, or predicable from any single entity.

We have emphasized four factors: compatibility, consistency, quality management, and feedback. Compatibility assures that the procedure is logical and appropriate in the scope of the larger system in which it is operated. Consistency provides the structure of procedures, assuring the line pilot that there is a reason for any given procedure, and that this reason is pervasive within a particular aircraft, between fleets, and throughout the company. Quality management is the sentinel that provides standardization and guards against non-compliance. Feedback provides a final check, the assurance that the cold light of the real world is the final test of the goodness of any individual procedure or policy.

We have attempted to demonstrate, that even in this highly procedurized system, there is room for individualism and that individualism can, and should be designed into these human-machine systems. We have also tried to show that there is no set of procedures that can substitute for the intelligent human operator. And therefore the constraints of the human operator and the unique environment in which he or she is to operate must be thoroughly considered in the process of designing procedures.

We believe that there is no “royal road” to procedure development. There is no such thing as an optimal set of procedures. No manager will ever be able to “open up the box,” install the device, and install “good” procedures along with it. Nor do we anticipate that any computer technology can make this easier. Pilots are trained to fly by procedures. Aircraft are built to operate by procedures. Government regulations are based on procedures. It is a long, tedious, costly, exhausting process. We do not know of any shortcuts.

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APPENDICES

APPENDIX 1 - GUIDELINES FOR PROCEDURE DEVELOPMENT

The following is a list of guidelines that were introduced in this report: Section numbers, where these guidelines are discussed, are in parenthesis.

1. A feedback loop from line pilots to flight management and procedure designers should be established. This feedback loop should be a formal process, as opposed to an informal process. It must be maintained as a non-punitive, reactive system, with mandatory feedback from management to the initiating line pilot about the progress of his report and/or suggestion. (Section 3.2.4)
2. When designing procedures for automated cockpits, the designer should recognize that many tasks that involve the use of automation are too complex and interactive to allow a stringent set of SOPs to be mandated. (Section 5.6)
3. It is essential that management develop a philosophy of its operations. This is particularly important for operating automated cockpits. (Section 5.6.1)
4. When introducing new technology into the cockpit, the procedure designer should reevaluate all of the existing procedures and policies in light of the new technology and support the new technology via new procedures. (Section 5.6.2)
5. Management, through the feedback loop and the line check airman program, should be watchful of techniques that are used on the line. Techniques that conform to procedures and policies should not be interfered with. Techniques that have a potential for policy and procedure deviation should be addressed through the normal quality assurance processes. Techniques that yield better and safer ways of doing a task may be considered for SOP. (Section 5.7.4)
6. Care must be taken that not only the principal participants of a system (e.g., flight crews in this case), but also others that are affected (e.g., controllers, ground crews, cabin attendants) be involved and informed in the design and modifications of a system procedure. (Section 6.1.1)
7. Procedures must be tailored to the particularities of the type of operation. Ignoring these particularities can foster low compliance with procedures on the line. (Section 6.1.2)
8. The procedures designer must be mindful of the limitations and capabilities of the device he or she is designing a procedure for. Devices that are well designed for the human user require minimal procedurization. Less robust devices will require more thought on the part of the designer, and will probably require more complex and lengthy procedures. (Section 6.1.3)
9. Management must guarantee that any procedure is compatible with the engineering of the aircraft or any sub-system. Care must be taken when there are subtle differences between aircraft (especially if these differences are invisible or difficult to detect). Incompatibility can be resolved either by re-engineering or procedure. (Section 6.1.4)
10. Airframe manufacturers and component suppliers (such as avionics firms) must be attuned to general airline procedures. Knowledge of such procedures may influence ergonomic considerations. (Section 6.1.5)
11. The entire documentation supplied to the cockpit (and elsewhere) should be regarded as a system, and designed accordingly as a system, not a collection of independent documents. A clear and logical (from the user's view) structure for this system and a criterion for the location of different procedures is important. An effective index in each manual would go a long way toward aiding pilots in finding materials they seek, especially when it is an unfamiliar, obscure, or seldom accessed procedure. (Section 6.1.6)
12. Paperwork should be designed carefully to be compatible with the device for which it is intended. Particular care should be exercised in preparing materials for computer-based systems. It may be necessary to provide differently formatted documents for different cockpit configurations. (Section 6.1.7)
13. Procedure design includes intra-cockpit communication. The expected communication should be specified, trained, and subject to standardization like any other procedure. (Section 6.2.1)

14. In managing automated cockpits, briefing becomes an critical crew coordination tool -- not so much to reduce variance, but rather to reduce the level of ambiguity of other agents (e.g., PNF or F/O) by increasing expectations. The more one allows for technique, the more one has to stress briefing. (Section 6.2.2)
15. If the same procedure can yield significantly different outcomes, then the procedure must be modified in order to eliminate its embedded ambiguity. In brief, a procedure should lead to a totally predictable outcome. (Section 6.2.3)
16. Particular attention should be paid in order to safeguard information transfer during critical and high workload phases of flight. Callouts should be economical, unambiguous, and should convey only the information needed by the other crew member(s). They should not distract the crew member from his primary task(s). Finally, we urge frequent review of callout procedures: as other procedures change, callouts should be reexamined. (Section 6.3)
17. Procedure designers should always bear in mind the contribution which any procedure makes to total workload of the crew at any given time. They should be especially sensitive to procedures that may require crew attention in times of high workload, and should strive to “manage” workload by moving tasks that are not time-critical to periods of low workload. (Section 7.2.3)
18. The designer of flight-deck documentation should search for situations where procedures are tightly coupled, and exploit the opportunity to decouple them. (Section 7.3)
19. Frequent procedure and checklist changes lead flight crews to conclude that the system is unstable. This may diminish the importance they attribute to new and modified procedure. Therefore, management should minimize frequent procedures or checklist changes. It is probably better to bunch them together and make larger, less frequent “bundles” of changes if the items are not time-critical. (Section 7.4)
20. The SOP documentation should not only explain the mechanics of the procedure, but also state the logic behind it. A detailed account of the operational logic, system constraints, and the link to the “Four-P” model should be part of the documentation. (Section 7.4.2)
21. While benefits of cross fleet standardization are quite obvious, there are certain situations where this type of standardization is just inappropriate. It may lead to sub-optimal procedures by superimposing procedures that are suitable for one type of cockpit operation on another. (Section 7.5.1)
22. We recommend a three-way approach for a cross-fleet standardization. (1) Development of a cross-fleet philosophy, (2) creating a cross-fleet standardization forum, and (3) obtaining input for procedural design from personnel that design, certify, teach, use, and check procedures. (Section 7.5.1)
23. The flow of any procedure through design, training, checking, implementation, and finally feedback, must be supported by the organizational structure. When a new procedure, or a modified procedure is established, it should be closely monitored (by standardization and check airmen, and LOFT instructors) for compliance. (Section 7.5.4)

APPENDIX 2 - DELTA AIR LINES AUTOMATION PHILOSOPHY

The word “Automation,” where it appears in this statement, shall mean the replacement of human function, either manual or cognitive, with a machine function. This definition applies to all levels of automation in all airplanes flown by this airline. The purpose of automation is to aid the pilot is doing his or her job.

The pilot is the most complex, capable and flexible component of the air transport system, and as such is best suited to determine the optimal use of resources in any given situation.

Pilots must be proficient in operating their airplanes in all levels of automation. They must be knowledgeable in the selection of the appropriate degree of automation, and must have the skills needed to move from one level of automation to another.

Automation should be used at the level most appropriate to enhance the priorities of Safety, Passenger Comfort, Public Relations, Schedule, and Economy, as stated in the Flight Operations Policy Manual.

In order to achieve the above priorities, all Delta Air Lines training programs, training devices, procedures, checklists, aircraft and equipment acquisitions, manuals, quality control programs, standardization, supporting documents, and the day-to-day operations of Delta aircraft shall be in accordance with this statement of philosophy.

(Reprinted from Wiener, Chidester, Kanki, Palmer, Curry, and Gregorich, 1991)

APPENDIX 3 - QUESTIONS ASKED OF FLIGHT MANAGEMENT

The following is a list of questions that were asked during our meetings with flight management personnel at each of the participating airlines:

1. Is there an overall philosophy that makes this airline different from other airlines?
2. Suppose you had the same job at another airline. In what way would the concept of operations differ?
3. Where does philosophy influence policies?
4. How are the policies of flight department affected by highest level of management?
5. How do top-level management policies become formed and move down the ranks?
6. Why do you take a Boeing procedure and change it?
7. We recognize that the bottom line affects everything in the industry since deregulation. How is this incorporated into the flight department policies (fuel, on-time departures, maintenance)?
8. What influence do the pilot representatives committee have on policies?
    a. What is your relationship with pilot representatives committees?
    b. Do you feel that your relation to pilot representatives committees is adversarial or cooperative?
9. What are your policies with regards to automation and its use?
10. What is currently the process for feedback from the “line” about procedures, does this reach your desk?
11. What is the lowest level of detail that you get involved in regarding flight deck procedures?
12. What is the biggest challenge in your job?
13. What can we do to help your company?

APPENDIX 4 - QUESTIONS ASKED OF LINE PILOTS

The following is a list of questions that were asked during our formal meetings and discussion with groups of line pilots:

1. Is there an overall philosophy that makes this airline different from other airlines?
2. Where does philosophy influence policies?
3. How do top-level management policies move down the ranks?
4. Can line pilots affect the design and modification of procedures? If so, how is this done? What is your relationship with pilot representatives committees?
5. What are your company's policies with regards to automation and its use? What is your own view of this?
6. Are there any cumbersome procedures in your SOP? Which ones? Have you developed an effective “personalized procedure” (technique) to combat them? What makes a procedure smooth?
7. What is the interaction between procedures and automation? Do you see fewer or more procedures in an automated aircraft? In what way have procedures changed between the Boeing B-727 and the new glass cockpits aircraft? (has the philosophy, spirit, or mind-set changed, who's responsible for what)
8. What affects the successful design as well as execution of procedures?
9. Are there any differences between procedures you are taught in the training center and those you perform on the line?
10. What is the biggest challenge in your job?

APPENDIX 5 - QUESTIONS ASKED DURING JUMPSEAT OBSERVATIONS

The following is a list of questions that were used during our informal discussion with line pilots while conducting jumpseat observations:

1. Are there any cumbersome procedures in your SOP? Which ones? Have you developed an effective “personalized procedure” to combat them? What is a smooth procedure?
2. What is the interaction between procedures and automation? Do you see fewer procedures or more in an automated aircraft? In what way have procedures changed between the Boeing B-727 and the new glass cockpit aircraft? (has the philosophy, spirit, or mind-set changed, or who is responsible for what?)
3. What affects the successful design as well as execution of procedures?
4. Are there any differences between procedures you are taught in the training center and those you perform on the line?

APPENDIX 6 - CATEGORIES OF FACTORS THAT TRIGGER PROCEDURE CHANGE

The following is a list of seventeen categories of events that prompted procedure changes:

1. *New equipment. Example: TCAS.*

The introduction of TCAS required the development of procedures for the configuration of the equipment, exercise of options (e.g., TA-only vs. TA/RA mode for takeoff), and then in-flight procedures in the event of TAs and RAs. Since TCAS was an entirely new development, procedure writers had to "start from scratch," as there was no history nor precedent for airborne collision warning devices.

2. *New regulation. Example: No-smoking rule in the cabin.*

Although the no-smoking rule (first for flights under two hours, later extended to flights under six hours) was aimed at behavior in the passenger cabin, it impacted the cockpit in that the no-smoking light had previously been used for various cockpit signals to the cabin personnel. With the enactment of the smoking regulations, the no-smoking sign was left "on," and other signals had to be devised.

3. *Unfavorable experience. Example: High rate of altitude deviation violations.*

In 1990, USAir was experiencing a high rate of altitude deviations (four FAA-reported cases per month). A thorough study resulted in a procedural intervention whereby the pilot not flying entered the command altitude in the alerter, repeated the altitude orally, and keep his or her finger on the knob until the pilot flying repeated the altitude and also touched the alerter. If there was any difference in their callout, the PNF had to resolve it by calling ATC. In the months following the intervention, FAA-reported cases dropped to less than one per month (Glines, 1992).

4. *New routes. Example: Extended two-engine operations (ETOPS).*

The use of two-engine transports such as the B-767 and A-310 on long over-water flights demanded the development of a series of special procedures, even above those required for international flight of three- and four-engine aircraft. For example, after takeoff, at a certain time into the flight, the aircraft would have to be re-released when it reached the "ETOPS entry point." Special procedures were also needed for selection of alternates. (Hughes, 1992; Steenblik, 1991).

5. *New management. Example: Mergers and acquisitions.*

In the event of a merger or acquisition (see Section 5.3), the acquiring company typically standardizes the acquired fleets against their own, by imposing its procedures on the combined fleet. This usually results in considerable retraining for the acquired pilots. Where a new aircraft model is acquired in a merger or acquisition, considerable procedure writing is necessary to bring its procedures into conformity with those of the acquiring carrier. (Degani and Wiener, 1990, pp. 27-28).

6. *New ATC procedure. Example: Procedure for LDA approach at San Francisco International (SFO).*

The current LDA approach to Runway 28R at SFO requires an entire page of explanation (11-3A) in the Jeppesen manual to detail all of the procedures. Pilots have asked, "What if I'm set up for something else and I get shifted to the LDA? Am I supposed to take the time to read this page?"

7. *Labor relations. Example: Power back from gates.*

In the 1980's airlines began the practice of powering back from the gate. This called for the development of a set of cockpit and cockpit-ground communication procedures. The motivation for power-back was largely to sidestep labor contracts which required that mechanics be used to push the aircraft back.

8. *Change in operational environment. Example: Mountainous terrain.*

With mergers and acquisitions came new routes and new environments. For example, when Delta acquired Western, it acquired routes into a large number of airports, some more adequate than others, in the western U.S. This required a reexamination of Delta's procedures for approaches and departures to and from airports with high surrounding terrain.

9. *Cross-fleet standardization. Example: Shift to lower power radar sets.*

In a previous paper (Degani and Wiener, 1990) we discussed an airline which had a large fleet of DC-9s, and a small number of MD-80s (at that time DC-9-80). The -80 carried a radar set requiring much less electrical energy than the DC-9s. At that time pilots were allowed to fly both aircraft. Because of the lower energy set, the -80 radar could be turned on in ground operations without hazard to ground personnel; the DC-9 sets could not be. Fearing that pilots flying both models might inadvertently turn on a DC-9 set on the ground, the standards group decided to adopt a conservative procedure, and the MD-80 radar was operated in the same manner as the DC-9. The somewhat sub-optimal procedure for the use of the -80 radar was a minor consequence.

10. *Marketing influences. Example: Better service for first-class passengers.*

The following example illustrates the extent to which marketing considerations can influence cockpit procedures. In-flight service has advised flight management that better service can be provided to first class passengers if 2L (second door on left side of the aircraft) rather than 1L, is used for boarding and disembarking passengers. This way the tourist-class passengers do not have to walk through the first-class section. The procedure instructs the B-757 flight crews to “start the APU after landing in order to shutdown the left engine as soon as possible after gate arrival[20].” The procedure also addresses safety implications of having the jetway so close to the left engine -- “pay particular attention to the position of jetway. If you think you are being told to taxi too far past the jetway and are concerned about the left engine [hitting the jetway], don’t hesitate to stop and asked to be towed in or talked in.”

11. *New company policy. Example: Required use of flight directors.*

Airlines have had to strike a balance between requiring the use of certain automation features, and leaving this choice to the discretion of the crew (see Appendix 1). This is one of the more difficult policy issues in procedure writing today. On one hand management may feel that it has the prerogative to set policy for the use of automation. On the other hand, flight crews generally feels that such decisions should remain in the cockpit (see Wiener and Curry, 1980, Guideline No. 5, p. 1009).

One example would be a policy for the use of the flight director on takeoff. We have found a variety of procedures among the airlines on this issue. Many pilots prefer not to use it (presumably to de-clutter the ADI display); some companies now require its use, principally for its availability for pitch guidance in windshear encounters. One company specifies that the flight director not be used on takeoff until reaching 3000 feet unless the aircraft is equipped with a windshear guidance program.

12. *New company philosophy. Example: “A captain's airline”*

Delta Airlines had once prided itself on being “a captain's airline.” There is no precise definition of what this means, but in general it reflects a view consistent with military discipline, namely that the captain is supreme in the cockpit, and the junior officers are there to carry out his commands. Following a series of serious incidents (fortunately no accidents) during the summer of 1987, Delta reconsidered this philosophy, and instituted a CRM course that stressed crew coordination and cross-checking (Byrnes

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[20] The reason that the APU should be started before shutting down the left engine also involves passenger comfort. If the left engine is shut down (and with it the left hydraulic pump) a power transfer unit (PTU), supplying hydraulic power to the left hydraulic system, is automatically activated. However, the PTU is rather noisy and annoys passengers sitting in the back of the aircraft. To prevent the PTU from being automatically activated, the APU is started.

and Black, 1993). This in turn brought new procedures, including an increased emphasis on pre-takeoff briefings.

13. *Noise abatement. Example: Santa Ana, California.*

Locally imposed noise abatement procedures find their way into the cockpit. These may involve low-altitude turns away from populated areas, and low altitude power reductions on takeoff. One of the local requirements most onerous to the pilots is found at John Wayne Airport at Santa Ana, California, which requires a power reduction at 1000 feet. There is a certain amount of "game playing" at some airports - pilots have in their Jeppesen manuals ground plots showing the location of the sound measuring microphones, and attempt to avoid these.

14. *Change in recommended maneuver. Example: Windshear detection and avoidance.*

As new data on windshear occurrences become available, procedures are fine-tuned for avoidance and escape maneuvers. There has been a dramatic change in procedure in the last five years. At one time it was recommended that the crew apply maximum power and pitch up until actuating the stick shaker, trading airspeed for altitude in order to obtain maximum distance above terrain. The current recommended procedures specify that the crew not flirt with a stall, but pitch up to a level computed by on-board automation and displayed by the flight director, at an angle of attack that would stop short of shaker actuation.

15. *Maintenance data. Example: Anti-skid.*

The engineering/maintenance department of one carrier discovered that the tire replacement rate of one aircraft fleet was above the rates recorded at other carriers. It was found that skidding while taxiing led to the high rate of tire change. The procedure was changed so that anti-skid was always activated. Subsequently, the rate of tire replacement dropped.

16. *New natural hazards. Example: Volcanic plumes.*

The eruption of volcanoes in the northwestern U.S., and in the Philippines in recent years has provided a new awareness of the hazard to navigation. New procedures for avoidance and management of the hazard for both the cockpit and ATC have recently been implemented.

17. *New man-made hazards (intentional and otherwise). Example: Terrorism.*

Persons external to the crew, intentionally or otherwise, often provide hazards to flight safety and security. The appearance of terrorism directed toward commercial aircraft is an unfortunate example of willing introduction of hazards. Cockpit procedures and training are continually being revised as new forms of terrorism appear. An example of *unintended*, human-induced hazards would be the unsafe packaging and handling of hazardous cargo. This too impacts cockpit procedures.

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In complex human-machine systems, operations, training, and standardization depend on a elaborate set of procedures which are specified and mandated by the operational management of the organization. The intent is to provide guidance to the pilots, to ensure a logical, efficient, safe, and predictable means of carrying out the mission objectives.

In this report the authors examine the issue of procedure use and design from a broad viewpoint. The authors recommend a process which we call "The Four P's:" philosophy, policies, procedures, and practices. We believe that if an organization commits to this process, it can create a set of procedures that are more internally consistent, less confusing, better respected by the flight crews, and that will lead to greater conformity.

The "Four-P" model, and the guidelines for procedural development in Appendix 1, resulted from cockpit observations, extensive interviews with airline management and pilots, interviews and discussion at one major airframe manufacturer, and an examination of accident and incident reports. Although this report is based on airline operations, we believe that the principles may be applicable to other complex, high-risk systems, such as nuclear power production, manufacturing process control, space flight, and military operations.

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