Chapter 8
Improving the Reliability of Maintenance Checklists

Amy Pearl and Colin G. Drury, Ph.D.
State University of New York at Buffalo

8.1 Introduction

Patel, Prabhu, and Drury (1993) describe a workcard as "the prime source of on-line directive and feedforward information in aircraft inspection. It is the primary document that starts the inspection and serves as a major influencing factor on inspection performance" (p.1). The workcard can also be viewed as a checklist that aids the mechanic in recalling all the numerous tasks to be performed in a check. Once a task or group of tasks is finished, the mechanic or inspector is required to sign it as being satisfactorily completed. As the workers perform these tasks repeatedly, there is a tendency to perform them at least partially from memory, with a block of sign-offs made at a convenient time. This is not how workcards are intended to be used, and such use can result in errors. Since the safety of civil aircraft is highly dependent on reliable inspection, we undertook an analysis of how workcards are presently used and how workcards design affects their use and the subsequent potential for error.

8.1.1 Checklist Objectives

Workcards and other forms of checklists are common throughout the aviation industry. In addition to workcards being used for all inspection and maintenance tasks, flight crews use checklists to prepare the aircraft for each new stage of a flight. Degani and Wiener (1990; 1993) reviewed the role of checklists in the cockpit, the potential effects of their design, and sociotechnical factors affecting their use. Although the content of flight deck checklists differs substantially from those for maintenance and inspection, the checklists' objectives (as Degani and Wiener describe them), as well as many of their design concepts and performance factors, are similar.

Degani and Wiener defined checklist objectives that are pertinent to aircraft maintenance: to assist the user in recalling procedures, to outline a convenient sequence for motor movements and eye fixations, to allow mutual supervision within crews, to distribute tasks among crew members, and to act as a quality control tool for management and government regulators (Degani and Wiener, 1990, p.7). The first objective of a workcard is to remind mechanics or inspectors of items to be checked; any type of job aid shares this goal. By providing information externally, a job aid reduces the information a person must store and process (Swezey, 1987). Listing tasks in an order providing a convenient sequence of motor movements should reduce the time spent accessing the task areas. Workcards also provide written records of tasks to be performed and ease the supervision and distribution of tasks. Finally, sign-offs of tasks on a workcard verify that the work is complete, as dictated by the airline and by FAA regulations. Workcards used in aircraft maintenance and inspection tasks **should** meet these checklist objectives. For this project, we analyzed methods maintenance technicians use to perform different levels of checks to determine if their workcards met these goals. More-detailed B-, C- and D-checks have fewer, larger tasks on each workcard. Lower-level checks (A-checks and below) were the main focus of this study because they typically consist of larger lists (20-100 items) of relatively short tasks. These are what is called "checklists." Although people performing these checks are classified as mechanics, these tasks' functions are associated with inspection, i.e., checking whether specific aircraft features meet pre-defined criteria for safe flight. Our earlier work on inspection is directly relevant to the present study: Patel, et al. (1993) investigated specific design issues relevant to inspection using workcards.

8.1.2 Workcard Design Issues

Patel, et al. (1993) found that usable documentation must embrace the following factors: information readability, information content, information organization, and physical handling and environmental factors. Information readability issues are concerned with the documentation's typographic layout, as well as conventions concerning sentences, words, and letters. Information content involves what information to give, how to give it, and in what order. Documentation must be appropriate, accurate, complete, and easily comprehensible. Information organization deals with the classification and differentiation of directive information and other information such as notes and warnings. The structure of directive information should be broken down into the command verb, the action qualifier, and the object of the action (Inaba, 1991). Patel, et al. (1993), in their study of A- and C-checks, pointed out that tasks should be listed in the natural sequence most inspectors use during a check. Finally, the workcard must be physically suitable for the tasks and the environment. Inspectors should be able to carry workcards with them while they perform tasks, without the workcards hindering task performance. Workcards should be resilient to all types of weather and to dirt and oil because inspections are performed under a variety of adverse conditions.

Patel, et al. (1993, p. 13-16) developed a set of guidelines for designing documentation for aircraft inspection tasks. Using these guidelines to redesign workcards, they found significant improvements in inspectors' and mechanics' ratings of redesigned workcards when compared with old workcards. These researchers also observed that, for A-check workcards, the sequence of tasks did not match the sequence mechanics typically follow to perform checks. There is some variability in the ways mechanics and inspectors sequence their tasks throughout a check, and the number of sign-offs varies across tasks. These findings demonstrate the need for investigation of issues related to workcard task sequence and the optimal number of sign-offs.

8.1.3 Purpose of Project

This project's original aim was to undertake an experimental evaluation of checklist reliability. The factors of interest were the grouping of tasks and the number of sign-offs required. Different workcard formats were to be designed for less-detailed, frequently performed checks such as low-level and A-checks. Possible formats would have included workcards with sign-offs after each step, with sign-offs only after the most salient items, and two-level checklists providing more-detailed information for less-experienced mechanics. The methodology of this project changed from an off-line experiment to a field study at the request of our airline partner and after our observation of mechanics performing these checks.

The task analysis described in the next section shows that present workcards do not provide mechanics and inspectors with the most useful information. Although mechanics and inspectors do read workcards for changes, they do not continually use workcards as they perform the checks. They are highly practiced in their tasks, and the fact that checks are repetitive makes it difficult to ensure that all tasks are performed to the same level each time. Job aids or redesign of workcards may help achieve the reliability required in aircraft inspection. This is why we changed the project's aims to determining how mechanics use workcards, why mechanics do not use workcards continually during some checks, the possible effects of mechanics not using workcards, and how to make workcards meet checklist objectives Degani and Wiener (1990; 1993) defined.

8.2 Study of Workcard Usage

The project's first objective was to determine how mechanics actually use workcards during frequently performed checks. We needed to study workcard usage on the hangar floor to establish the degree that workcards meet Degani and Wiener's checklist objectives. A task analysis of a system is the foundation of any human factors investigation (Drury, Prabhu, and Gramopadhye, 1990).

8.2.1 Task Analysis

Our study of mechanics' current use of workcards during checks consisted of videotaping and observing mechanics performing three levels of checks, as well as interviews and workcard evaluations. We made no videotape without the mechanics' permission. Videotaping is an unintrusive way to gain accurate information on how a mechanic normally performs a check. The specific checks we studied were A-checks and two less-detailed checks: lower-level check 1 (least comprehensive) and lower-level check 2 (more comprehensive, but less than an A-check). Our activity during our first two trips to a hangar consisted of following mechanics as they performed the check. An observer asked questions to gain a basic understanding of each check for various types of equipment. The primary data we gathered from videotapes were the sequence of tasks a mechanic performed, the number of times a mechanic referred to the workcard, and the approximate number of times a mechanic was interrupted. After mechanics finished a check, we interviewed them, often while they viewed the videotape of their inspection activity. We also questioned supervisors and lead mechanics about the workcards' usefulness and asked for their suggestions for change. In order to gain opinions from an adequate number of mechanics, we distributed evaluations on both the workcards and the subsequently developed job aids at one maintenance base. We present results of videotaping, interviews, and workcard evaluations so that readers may develop an understanding of workcards' usefulness for frequently performed, repetitive checks.

8.2.1.1 Mechanics' Attitudes Towards the Workcards

Responses to interviews and workcard evaluations we distributed to mechanics provided many interesting insights. Perhaps the most important finding is that mechanics use individual methods and skills to complete checks. Lock and Strutt (1985), in their study of the reliability of inspections in British aviation, had similar findings. The implication of this finding is that it is difficult to establish reliability of checks because mechanics do not value the standard workcard.

Workcard evaluation results are presented in Appendix 8-A. Question 5 in Section II showed that some mechanics do not usually refer to a workcard during a check. About half responded that they perform a particular check in the same sequence each time they perform the check. Most indicated that they sequence tasks based on locations on the airplane; they start with the nose and work around the aircraft to check for discrepancies. If a check is assigned to two people, tasks are typically divided logically, e.g., into exterior and interior tasks. The exterior is usually checked before the interior. Some mechanics sequence tasks by difficulty and/or the probability of finding a discrepancy that must be fixed. If they need assistance, they request a "floater" to help them. Appendix 8-B shows mechanics' ratings of task difficulty and the probability of finding a discrepancy for B-737 lower-level 2 checks. Tires and brakes generate the most concern because of the time required to change them when a discrepancy is identified.

Although workcard evaluation results indicate that mechanics find workcards useful, interviews with and observations of mechanics performing checks indicate that workcards are not always used as intended. Many mechanics view workcards as guides only for inexperienced workers who may refer to it during a check: checks become routine and easily memorized. Also, mechanics typically check more items than the workcard requires because of their conscientious natures. Most mechanics feel that they only need to refer to a workcard for interim changes before performing a check. When mechanics find a discrepancy during a check, most state that they make a note to fix the discrepancy after they finish the check. However, the observer rarely saw notetaking, with the exception of one mechanic. This could be because some mechanics do not carry workcards continuously while performing a check. After completing a check, mechanics return to the workcard to sign-off the tasks. The question remaining is, if mechanics do not use the workcard to sequence tasks for a check, what are the reasons for this and how do they sequence the required tasks?

8.2.1.2 Content of the Check

One reason mechanics rarely use the workcard while performing these checks is that the lower-level and A-checks are repetitive and frequent. Most of these mechanics perform fifteen lower-level 2 checks and five A-checks every month. They have done these checks at this maintenance base for an average of 9 years (this result came from the workcard evaluations shown as Appendix 8-F). Furthermore, checks for various kinds of equipment are similar, with only a few, possibly important, differences. Mechanics easily memorize the checks and believe they do not need workcards as portable job aids.

8.2.1.3 Task and Environmental Factors

Lower-level and A-checks are mobile: their tasks are located throughout an airplane's exterior and interior. Mechanics walk around a plane to check for defects, bending, kneeling, or reaching into an access panel. These movements are not conducive for carrying an 8.5 X 11 inch workcard that a mechanic can refer to, make notes on, and sign-off tasks. In addition, many line checks are performed outside in a variety of weather conditions such as wind, cold, rain, and/or snow. Carrying a paper workcard and writing on it is even less practical in these circumstances.

8.2.1.4 Sequence of Tasks

Patel, et al. (1993) found that mechanics' ordering of tasks for an A-check did not match the workcard's order. In the current study, mechanics also rarely performed tasks in the order listed on the workcard. In a second workcard evaluation, mechanics were asked to order tasks of a B-737 lower-level 2 check in the sequence they normally complete the check. Appendix 8-C presents results of this workcard evaluation. No mechanic provided the sequence given in the workcard. Subjects 1 and 2 have an additional column in their tables since they were videotaped. In addition to sequence data from workcard evaluations, transcript analyses from videotapes of subjects performing checks show that mechanics do not use workcards to sequence their tasks. Tasks that are difficult to observe directly are indicated by asterisks in Appendix 8-C. This does not indicate that tasks were not performed, only that the observer could not see them on the videotape.

Workcard evaluations and videotapes indicate that mechanics tend to sequence tasks by spatial cues on the airplane, associating a specific area on the aircraft with all checks for that area. For example, at the right main landing gear, a mechanic checks tires for serviceability, checks the tire pressure, checks the tie bolts, cleans the strut piston, cleans the downlock viewer and indicator, and checks the brakes. All these tasks are performed at the right main landing gear before the mechanic moves to another area. The workcard's functional organization, however, asks a mechanic to check all tires for serviceability before moving to another sign-off task. This would require a mechanic to walk around the nose landing gear, the right main landing gear, and the left main landing gear and then to revisit the same locations to check the tire pressures. The workcard sequence does not reflect the way most people work. Tasks such as "Check fuselage, empennage, and wings for obvious damage or irregularities as viewed from the ground" demonstrate this point even more dramatically. A mechanic does not check the entire fuselage for discrepancies at once; instead, he or she checks the fuselage while working around the aircraft performing other checks. This is demonstrated by the numerous times mechanics being videotaped checked the fuselage; they often cover the same area more than once and re-visit the same task numerous times (see Appendix 8-C).

Mechanics organize tasks by spatial cues, not by workcards' functional order, because areas to be inspected are very large. Humans optimize their use of time by minimizing the distance to be travelled. By checking everything in a particular aircraft area before moving to an adjacent area, a mechanic saves significant time and energy compared with that necessary to walk around the airplane as many times as would be necessary to check everything by functions. Using spatial cues, instead of functional locations, reduces the number of things a mechanic must remember, hence reducing his or her mental workload.

There is a mismatch between the tool provided for the job (workcard) and mechanics' natural way of working. Such a mismatch can be addressed either by altering the tool or by altering the way of working. The alteration chosen depends ultimately upon what system reliability is obtainable.

8.2.2 Non-Compliance in Using Workcards

Our observations from other airlines during previous projects confirm this project's findings. For rarely performed tasks, such as most C- and D-checks, inspectors use workcards to perform the check. Mechanics do not use workcards for frequently performed checks, i.e., A-checks and below. They have memorized these checks, "gaining a feel for items to check" through frequent repetition. One of the problems with this is that mechanics may not receive feedback on the accuracy of their judgments since problems rarely occur. Also, since workcards are not physically compatible with the environment and the tasks, even inexperienced mechanics who want to use workcards have difficulty doing so. Finally, the functional sequence of tasks on workcards does not match the way people sequence tasks distributed over large areas. Tasks with only one sign-off for a particular function are often distributed over large areas of an aircraft, e.g., check the tire pressure of the main landing gear tires, and are performed as a mechanic reaches the area. Since mechanics tend to sign-off all tasks when the entire check is complete, tasks that are not completed sequentially should have separate sign-offs. We conclude that present workcards do not provide useful information for mechanics and, consequently, do not meet the checklist objectives Degani and Wiener (1990; 1993) defined.

8.2.3 Relationship Between Workcard and Checklist Objectives

To review, the objectives of a checklist are to aid the user in recalling procedures, to outline a convenient sequence for motor movements and eye fixations, to allow mutual supervision within a crew, to distribute tasks among crew members, and to function as a quality control tool for management and government regulators (Degani and Wiener, 1990;1993). Since present workcards do not provide a convenient sequence for motor movements and eye fixations, they are not used continuously during checks. The workcards do not aid the user to recall procedures. The present workcards cannot be used conveniently to distribute tasks among mechanics because many sign-offs are not separated. The practice of signing off tasks at the end of the checks diminishes the workcards' ability to serve as a quality control tool. A job aid needs to be designed that meets checklist objectives listed above and that accommodates mechanics' different work methods. Mechanics working for many different airlines would use such a job aid.

8.3 National Data on the Effects of not Meeting Workcard Goals

That the present system appears to be working is demonstrated by high reliability, i.e., accidents are extremely rare. However, mechanics' workcard use is reduced because the job aids do not match their needs and individual work methods. The danger of not using workcards during a check is that a mechanic must then rely solely on his or her memory. If a mechanic were to become distracted, he or she could forget to perform a check, yet automatically sign it off because he or she has performed the check so many times correctly. A mechanic's confusion with similar checks and other aircraft may result in him or her substituting a required task with a task appropriate for another check or aircraft.

Our observations from other airlines indicate that similar patterns in workcard usage exist throughout the industry. It is worthwhile to place our findings in a broader context by analyzing similar errors reported elsewhere. The following examples of errors relating to these issues are taken from NASA's Aviation Safety Reporting System (ASRS). These voluntary reports are subject to reporting biases, and no airline is named in these reports.

The following excerpts from ASRS' reports illustrate the importance of workcards meeting checklist goals. They also illustrate other problems, such as the speed-accuracy tradeoff and poor training, but all have a common contributing cause of mechanics' not following procedures specified on the workcard.

* I had just completed an outside service inspection...when an FAA inspector pointed out that I had failed to check for water in the fuel tanks and had missed a couple of unreadable placards but had signed off blocks saying I had checked these items. Both were inadvertent oversights, were not deliberate, and did not cause any significant unsafe conditions. The problem arose because I was in a hurry to get the job done. Also, in the 2 years that I have worked on these aircraft, I have never heard of any mechanics finding water in the fuel tanks. I have corrected the situation by slowing down and paying attention to the checklist and my actions.

* While performing an A check,...one of my coworkers, Y, pencil-whipped the aircraft landing gear and flap lube. I had been working the engines all night and know that the flaps had not been extended for lubing.

* I did not perform a pitot static leak check on the altimeter system after altimeter replacement....I was at fault because I was unaware that the maintenance manual had been revised to reflect this change.

* Due to an oversight, not having the sign-off document immediately available, I did not document the company form that I had complied with XXXX, a visual inspection of the cargo door prior to takeoff.

* I feel my actions may well be the cause of the gear failure due to improper reassembly of the uplock activator, and failure to follow proper procedures. In addition, I made several mistakes in following the proper procedures, as called for by company maintenance manuals. I failed to enter a discrepancy on a mechanic's discrepancy list. I did not use proper maintenance manual reviews. I did not perform a gear retraction following reassembly of the activator.

These reports all illustrate errors that could be attributed to not using or not complying with workcards or maintenance manuals. The first two reports provide examples of workers signing-off tasks they did not perform. The example of a mechanic not performing a fuel tank sump check demonstrates one of the effects of experience. Since the mechanic does not expect to find a problem, the check is not taken seriously. The report of an inspector or mechanic being unaware of a maintenance manual revision is an example of a failure to read interim changes. The fourth account states that the reporter did not have the workcard immediately available, probably because the workcard was incompatible with the task and environment. The last report provides another example of a mechanic not complying with proper procedures. This could be attributed to numerous factors such as training, the mechanic's attitudes, time constraints, and environmental factors that make using the maintenance manual either difficult or inconvenient.

* After servicing #1 engine and while servicing #3 I was distracted by another crew member standing below my servicing buggy. He wanted me to check something else on the aircraft and after doing so I returned to my servicing buggy, still thinking that I had finished #3 engine. I moved on to another aircraft. This aircraft took off and during the first part of the flight the crew noted the #3 engine oil level falling and then stabilizing at an acceptable level. Upon landing the crew called maintenance, who found the #3 engine oil service door missing, along with the oil cap.

* During the reassembly procedure the screws were not installed in the panel. I was called away by a co-worker and foreman to help on another problem on the aircraft. Then a push to get the aircraft on line occurred...The aircraft was stopped at its next destination; the panel was found missing.

* On the aircraft's right wing tail light assembly, I removed the light assembly to change the top bulb. Note: On removal of the unit, I had laid the 8 securing screws on top of the wing. Before I secured the unit into the wing tip, I wanted to be sure it worked. I went into the cockpit and activated the lights. I went out to the wing tip to find them working properly and returned to cockpit to shut them off, as the lights would be blinding while securing the unit. After shutting lights off from cockpit, I stopped for 3-4 minutes to talk to a mechanic who was doing aircraft interior work. After leaving the interior of the aircraft, I was thinking I wanted to finish all exterior work quickly, as it was 18 degrees F with the wind chill factor. A ladder I had out on the left engine caught my eye as I was coming down the stairs. I was running through my mind items I had to complete to get inside out of the weather. With the wing tip light fixed, all I had to do was put the ladder away [without securing the screws].

These errors demonstrate potential negative effects of inattention and distractions. Although the mechanics we interviewed all strongly stated that if they were distracted they would not need to make a note to remember which tasks to complete, most research in human error suggests otherwise. Reason (1990) developed a human error model that particularly considers the effects of inattention.

8.3.1 Applicable Human Error Research

Rasmussen (1982) models human performance and its interactions with a possibly unaccommodating environment, categorizing it on the basis of human information processing. At the skill-based (SB) performance level, people perform familiar, routine tasks requiring little attention. Rule-based (RB) activities involve using established rules to make familiar decisions or to solve common problems. Knowledge-based (KB) performance is employed when no known rules are available for the situation and a person must resort to reasoning, to mental models, and to high-order cognitive processes to appraise the available information, to assign goals, and to develop methods for achieving them.

Reason (1990) describes two cognitive modes for differentiating between the sequential reasoning used for KB tasks and the automatic control used for SB and RB tasks. The attentional mode for knowledge-based activities requires high cognitive effort and is characteristic of the decision-maker's low level of experience with the problem or situation. During SB and RB performance, the schematic mode involves semi-automatic actions with few or no attentional checks. A person's intentions or matching conditions in the environment activate strongly associated groups of actions called "schemata."

Reason writes, "When cognitive operations are underspecified, they tend to default to contextually appropriate, high-frequency responses, or, the more often a cognitive routine achieves a successful outcome in relation to a particular context, the more likely it is to reappear in conditions of incomplete specification" (1990, p. 97). In other words, when a person cannot define all aspects of a situation, he or she resorts to habitual actions. Incomplete specification of a situation can be attributed to a combination of situational factors and/or a person's lack of attention. Errors result from activation of the wrong schemata or from activating the right schemata either in the wrong order or at the wrong time. As a person becomes practiced with a habitual task, the chances of activating a common, yet inappropriate, schemata increase.

Errors often occur in "strong-but-wrong" form, i.e., behavior is appropriate to past circumstances because of lack of attention to changed circumstances. Skill-based performance errors occur because actions at this level are directed by schemata most active when an attentional check is omitted or mistimed. Rule-based performance errors are usually attributed to inappropriate associations between contextual cues and previously applicable rules. Knowledge-based performance errors are unpredictable since the person does not have the knowledge to deal with the unfamiliar situation. These errors are due to "bounded rationality" and incomplete or inaccurate mental models (Reason, 1990).

The potential skill-based errors is particularly important for repetitive lower-level and A-checks. Experienced mechanics quite familiar with the tasks operate at the skill-based level when they move between tasks within a check. When an attentional check is omitted, the mechanic does not specifically note where he or she is in the task sequence. The mechanic then can easily be "captured" by a schema or another task that he or she frequently would perform in that situation, even if the mechanic's intentions call for a different action. For example, an attentional check can be omitted because of an external interruption such as another crew member asking the mechanic to check something. The distraction could be internal, e.g., the mechanic worrying about other tasks, the weather, even time pressure.

Mechanics may use rules to determine if an indication is a discrepancy. One objective of workcards and maintenance manuals is to externalize rules so the mechanic does not need to remember them. For example, the workcard gives the acceptable range of tire pressure. If the mechanic does not use the workcard, the potential for rule-based errors rises since the mechanic is forced to rely on memory. Rules often differ among tasks which are otherwise similar, e.g., different tire pressures are acceptable for different aircraft.

Knowledge-based errors are not relevant to the checks under study in this project. As mentioned, lower-level and A-checks are repetitive and familiar for these mechanics. Knowledge-based reasoning rarely occurs; when it does, a workcard is likely to be of little assistance. In knowledge-based situations, maintenance manuals and a mechanic's experience and knowledge are the best resources. The goals of checklists are to assist skill-based and rule-based performance and to compel mechanics to make more attentional checks while they work in the schematic mode. The errors listed in the next section are associated with workcards' failure to meet objectives for checklists.

8.3.2 Potential Errors Related to Workcards

We derived the following potential errors after considering Reason's theories of human error and from our study of workcard usage. We made our predictions of potential types of errors related to workcards knowing that mechanics rarely use workcards, that they sign-off all tasks at the end of the check, and that the potential for distractions and interruptions is high as they perform these checks. The first three kinds of errors are omissions related to skill-based performance. The last category is related to rule-based errors. There are other kinds of potential errors, but the following are most relevant to findings of our study of workcard usage.

8.3.2.1 Omissions Related to Interruptions

Reason's (1990) theories predict that distractions and interruptions occurring while workers perform highly skilled, familiar tasks, such as lower-level and A-checks, are particularly critical. When the mechanic directs attention back to the check, he or she may not finish a task or fail to perform a task. Since checks are performed in the schematic mode, task completion within a check is fairly automatic. A mechanic recovers from most interruptions by making a conscious effort to ensure continuity. Unless the mechanic makes an effort to recall what he or she was doing when interrupted or distracted, the mechanic can continue the check after being interrupted as in the most frequently occurring circumstances. Since the mechanic has previously completed the task numerous times, he or she may honestly believe the task to have been completed. As the ASRS' examples illustrate, the mechanic may never direct attention back to the task, particularly if there is time pressure to complete the check. After an interruption, the mechanic may start on a new set of tasks and never return to his or her original mental task list. Possible remedies for these types of errors include the following:

a) Workcards should be designed to be easy for workers to make notes on or to sign off complete tasks

b) Mechanics should be informed of effects of interruptions and distractions, as well as the importance of making notes about incomplete tasks.

We need to consider ways to combat all errors frequent enough to be captured by ASRS.

8.3.2.2 Omissions Related to Workcard Sequence

Workcards sequence tasks by functions. If mechanics actually followed workcards' sequences, the probability of distraction would increase as they constantly moved around the aircraft to complete functional checks. In turn, this would increase the likelihood of an omission associated with an interruption or distraction. Sign-offs for some tasks are not separated, although the tasks are spatially separated. For example, there is a single sign-off for serviceability of both right and left main landing tires. However, tires are checked separately. This workcard sequence of tasks may increase the probability of a mechanic signing-off the task after checking one side of the main landing tires, but before checking both sides.

8.3.2.3 Omissions Related to Workcard Non-Compliance

Task analysis of mechanics performing checks revealed that workcards' functional sequence of tasks rarely matches the spatial sequence mechanics use. The task analysis also predicted and revealed that mechanics rarely use workcards, partly because they do not match work habits and partly because they are physically incompatible with the tasks and environment. Mechanics disregarding the task sequence on a workcard rely on memory and are thus more likely to omit a task, particularly one they perceive as unlikely to reveal a discrepancy. Since mechanics assigned to frequent checks generally perform them on a number of different aircraft, they may unknowingly confuse checks, e.g., substitute a task from a different check or aircraft. Workcards help them recall tasks to be performed. Most mechanics decrease the chances of this type of error by performing substantially more checks than the workcard requires. For example, a mechanic may treat part of a lower-level check as the equivalent part of an A-check.

A lack of a rigidly performed sequence is likely to induce omission(s) when the task sequence is not habitual and requires more attention. A number of mechanics indicated that they do not follow the same task sequence each time they perform a check. Also, mechanics' practice of signing-off all tasks at a convenient break, even at the end of a check, instead of immediately after completing a task, increases the likelihood of an omission when a mechanic frequently performs the checks. If an omission is possible due to a distraction, time pressure, or some other reason, the mechanic signing-off tasks must pay careful attention to each one he or she signs-off, and must actually recall performing that task at that time. Since sign-offs are highly repetitive and require very little attention, a mechanic could easily assume that a task was completed because it previously was always completed.

8.3.2.4 Rule-Based Errors

One of the objectives of a checklist is to aid users to recall procedures (Degani and Wiener, 1990; 1993). Workcards mainly outline tasks to be performed; they also remind mechanics of some specification limits, such as those for tire pressures. Other specification limits are not given on the workcards, so one recommendation for improvement is to include all limits on the workcard. If a mechanic does not regularly use a workcard throughout a check, he or she may confuse specification limits among airplanes.

More likely causes of rule-based errors relate to the nature of a check and the high experience levels of mechanics performing them. Because mechanics are familiar with the checks, they may not readily recognize unusual circumstances, as Reason predicts. Although experience normally assists mechanics by directing their attention to likely locations of defects, it may hinder them when circumstances substantially differ from their expectations. As Lock and Strutt write, "There is a danger that too much familiarity with a particular item could lead an experienced inspector to miss a significant defect, if it does not conform to the expected pattern (condition) or expected locations which are fixed in the inspector's mental model of the aircraft and its pattern of deterioration" (1985, p. 6.5). Paradoxically, mechanics' high level of experience and expertise is one of the greatest challenges we face in developing a job aid for the checks.

8.3.3 The Challenge of Developing a Job Aid

Task analyses performed with existing workcards revealed potential causes of error as checks are currently performed. A job aid needs to be designed that reduces the potential for errors associated with workcards incompatible with mechanics' work habits and for errors related to mechanics' failure to use workcards throughout a check. These errors all stem from the fact that the present workcard is frankly not useful for mechanics. The design difficulty is compounded by the fact that highly skilled, well-trained, and experienced mechanics view workcards as guides for inexperienced mechanics and as quality control tools.

This project's challenge was to help increase the reliability of an already reliable system. Mechanics' work is extremely reliable without workcards. Even when mechanics make an error, they rarely receive feedback. Due to the redundancy and frequency of checks, airplanes normally fly without incident. However, there remains a slight possibility that not using workcards during the check, or using workcards that do not match work methods, could result in an error with adverse consequences. Adding to the challenge is the fact that as mechanics' experience increases, the probability they use a workcard as intended decreases. It is worthwhile to explore developing a job aid that reduces the small probability of error because it is compatible with mechanics' work habits and meets Degani and Wiener's checklist objectives. Any increase in reliability is worth the effort in an industry affecting public safety as directly as airlines.

8.4 The Job Aid

The proposed job aid must meet individual mechanic's work methods, must be physically compatible with their environment and tasks, and must meet guidelines for workcard design Patel, Prabhu, and Drury (1992) developed. Mechanics are more likely to use a job aid with these characteristics.

8.4.1 The Development of the Job Aid

Observations and videotapes of checks revealed that the task sequence differs among mechanics. Even the same mechanic performs tasks for the same check in a different sequence on different nights. These findings suggest that the job aid must be flexible in task sequencing and adaptable to different circumstances.

Most mechanics order tasks by using spatial locations on an airplane. Appendix 8-D lists grouped tasks of a B-737 lower-level 2 check commonly occurring sequentially within a check. We developed this list after analyzing the videotaped checks. We organized tasks in a FROM/TO chart that showed the number of times two tasks were performed sequentially. We follow each task in Appendix 8-D with a list of tasks performed sequentially to the first task for a group. Groups largely mirror the spatial layout of tasks on the aircraft. Workcard tasks could be divided into the spatial areas in which mechanics perform a group of checks, as revealed by sequential analysis.

The proposed job aid organizes tasks spatially by listing all tasks for a particular area of the aircraft on one pocket-sized card. The cards are laminated and placed on a ring so that a mechanic easily can change the order of cards. Figure 8.1 shows the front page of the cards. Dividing tasks by area into small cards allows a mechanic to sequence areas according to his or her individual work habits. Tasks are organized with the spatial layout most mechanics prefer. A mechanic can use a grease pencil to note discrepancies, interrupted tasks, or sign-off tasks completed. Notes can then be copied onto reports or wiped off the job aid when the check is complete. The job aid cards are designed to have a bar code on each card so that a future scanning system could check which cards had been completed or to match cards with bar codes located on the aircraft. This feature was removed after initial design and is not used in the current evaluation.

Job aids were designed for both lower-level checks and for A-checks on three fleets of aircraft. The workcards' design follows Patel, et al.'s (1992) guidelines for information readability, information content, information organization, and physical handling and environmental factors. Some guidelines were particularly important for this job aid.

The guidelines for information content recommend that "information provided should be supportive of the inspector's personal goal to read quickly and also understand the information, to ensure its usage and eliminate personal biases" (Patel, et al., 1992, p.14). We accomplished this in the job aid's design by meeting other guidelines such as the following:

> Resort to use of primary typographic spatial cues like vertical spacing, lateral positioning, paragraphing and heading positioning as far as possible; if space usage is premium, then resort to use of secondary cueings, e.g., boldfacing, italics, underlining, color coding and capital cueing in a decreasing order of preference

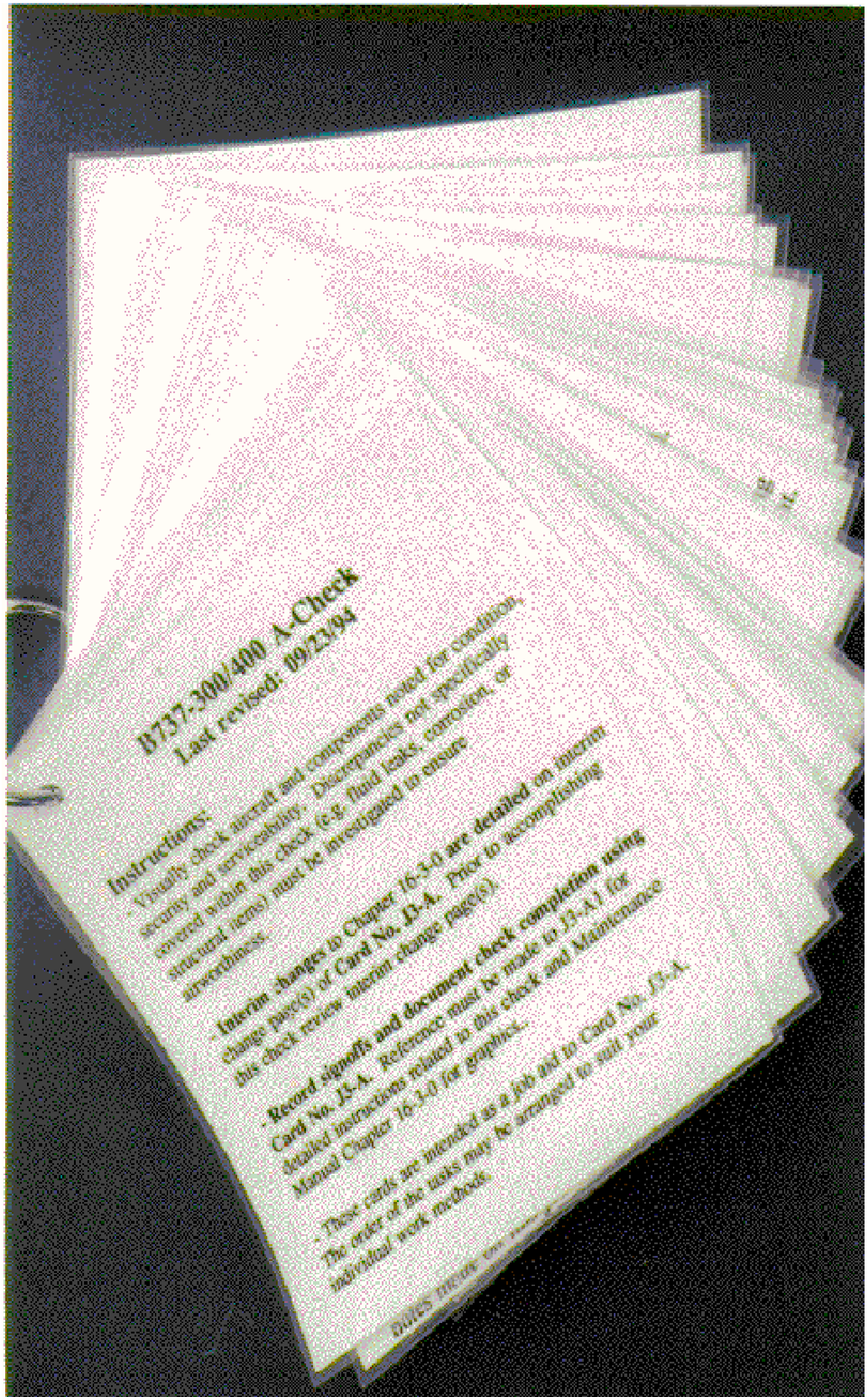
B737-300/400 A-Check
Last revised: 09/23/94
Instructions:

Figure 8.1 Top Card of the Job Aid for a B737-300/400 A-Check

Distinguish between directive information, reference information, warnings, cautions, notes, procedures and methods

Directive information should be broken into the command verb (e.g., check), the objects (e.g., valves, hydraulic lines) and the action qualifiers (e.g., for wear, frays). Use a consistent typographic layout throughout the document

[The content] should have certain consistent and common elements to foster generalizations across contexts (Patel, et al., 1992, pp. 13-15).

Each workcard's heading refers to a spatial location on the aircraft combined with a functional description, e.g., right main landing tires, right forward fuselage, flight deck, right CSD oil. We capitalized the headings and centered them on the top of each workcard. Each heading's color indicates where the group of tasks listed on the workcard is located on the aircraft, e.g., green indicates radome and forward fuselage. Color-coding makes sorting cards by aircraft areas easier: mechanics can arrange cards in their preferred sequence quickly. Tasks to be performed are left-justified. Cautions are indented and bold. Notes are indented from the cautions and presented in a smaller font (see Figure 8.2). Each task is numbered on the workcard and separated from other tasks with blank lines. This arrangement makes it easier for mechanics to distinguish among tasks and to mark completed tasks with a grease pencil. The command verb immediately follows the number; it is followed by the object and the action qualifiers, as in the following example:

1) Check: forward lavatory for general appearance and condition.

The command verb and the object are bold because mechanics already know the action qualifier and simply need a reminder of the task to be performed. Some mechanics suggested listing only the object to be checked on the workcards. We could not investigate this idea in this project because regulations do not allow workcards' content to be changed. The typographic layout and general content is consistent throughout workcards for all checks, ensuring consistency for mechanics.

The following are the organizational issues and physical handling/environment factors we considered pertinent to the design of the job aid:

Task information should be ordered/sequenced in the natural order most inspectors would perform the tasks

The page should act as a naturally occurring information module

The workcard's pages should be a handy size

If use of a workcard demands exposure to environmental agents like wind, rain, snow or even harsh and oily floor conditions, we should take adequate precautions to avoid excessive degradation" (Patel, et al., 1992, p. 16).

One of the primary goals of our job aid is to meet the guideline concerning the order of task information. Patel, et al. (1992) ordered tasks in an A-check by finding the most common sequence among mechanics they surveyed. For our study, we took an approach based upon groups of tasks that mechanics perform sequentially. We then listed each group of tasks on one card (for an example, see Figure 8.3) so that workcards act as naturally occurring information modules. Since mechanics can arrange the groups of tasks in any order they choose; our job aid provides a natural sequence to **all** mechanics, not to **most** mechanics.

Further, the pocket-sized cards leave mechanics' hands free, when necessary. The cards are laminated to protect them against environmental agents and to provide a better writing surface than paper (see Figure 8.4).

Although we encourage mechanics to make notes on the job aids and to check tasks completed, the job aid does not replace workcards' sign-off sheets. The first card of the job aid explains what the job aid is and instructs the mechanic to read interim changes included in the workcard and to sign-off tasks on the workcard. The second card shows the headings' colors and associates colors with areas of the aircraft. These features help meet the checklist objectives and, consequently, reduce the potential for error.

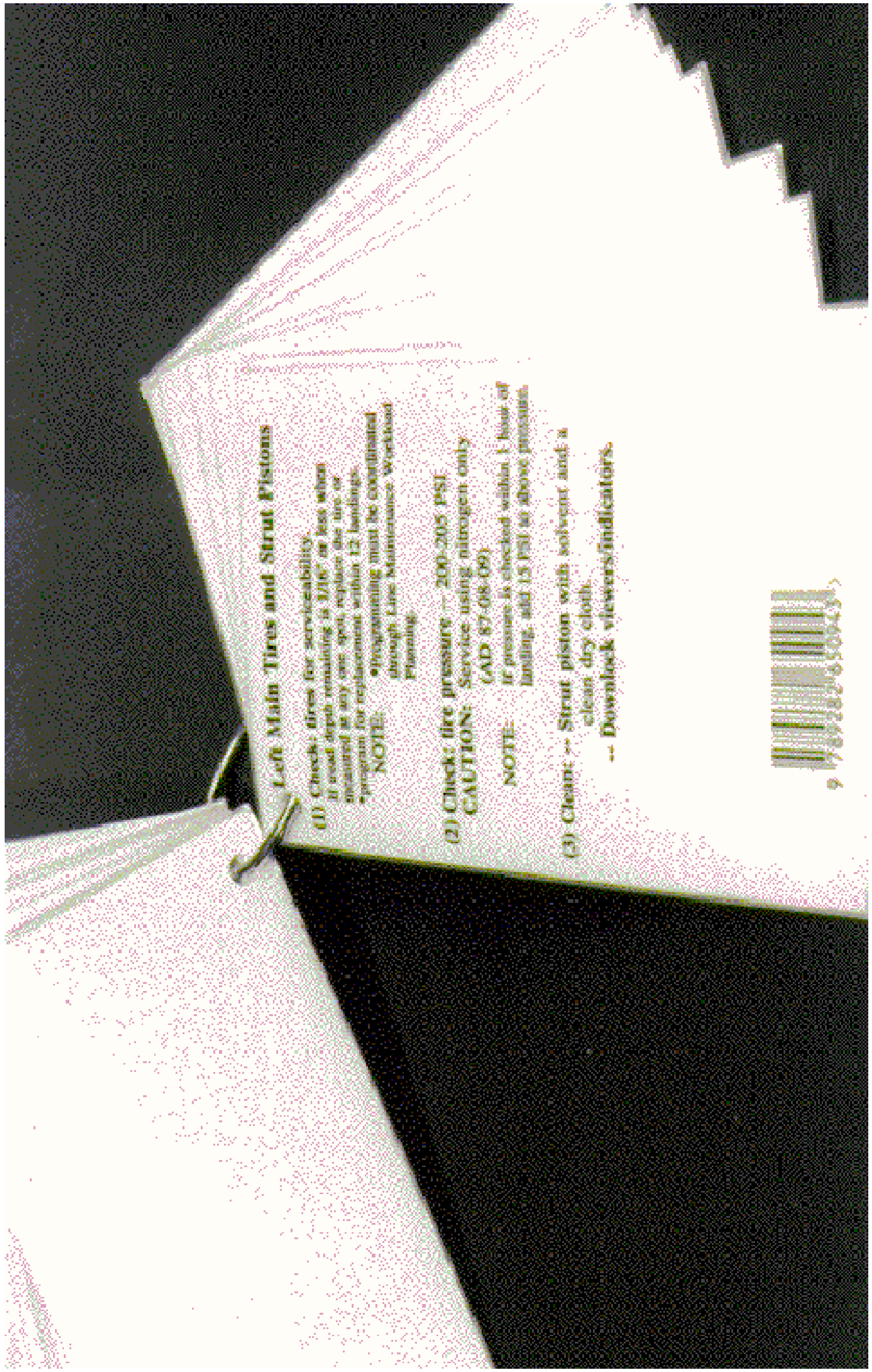

Figure 8.2 Example of Job Aid Layout, with Barcode

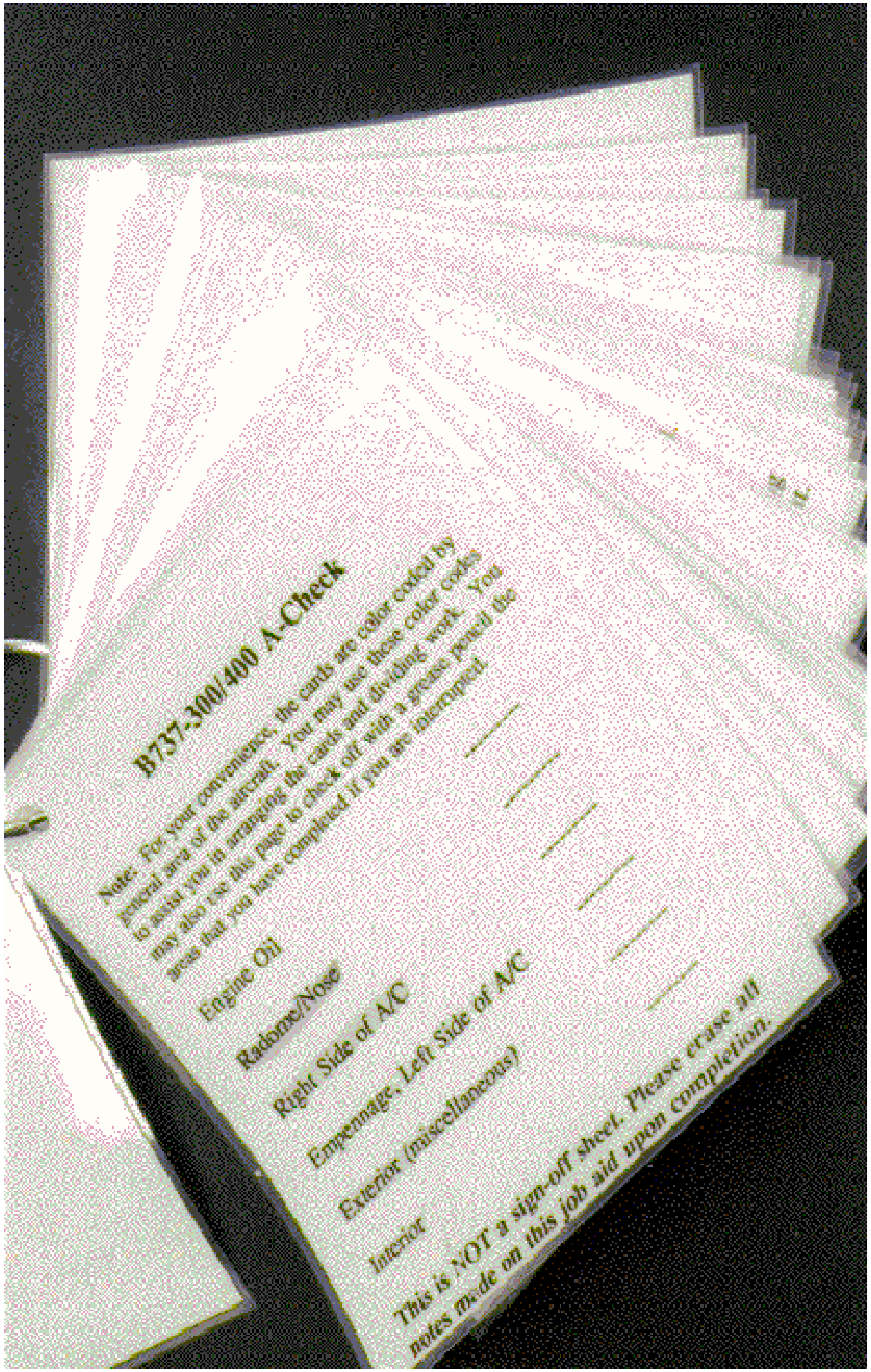

Figure 8.3 Spatial Layout Grouping for Work Card Items in Job Aid

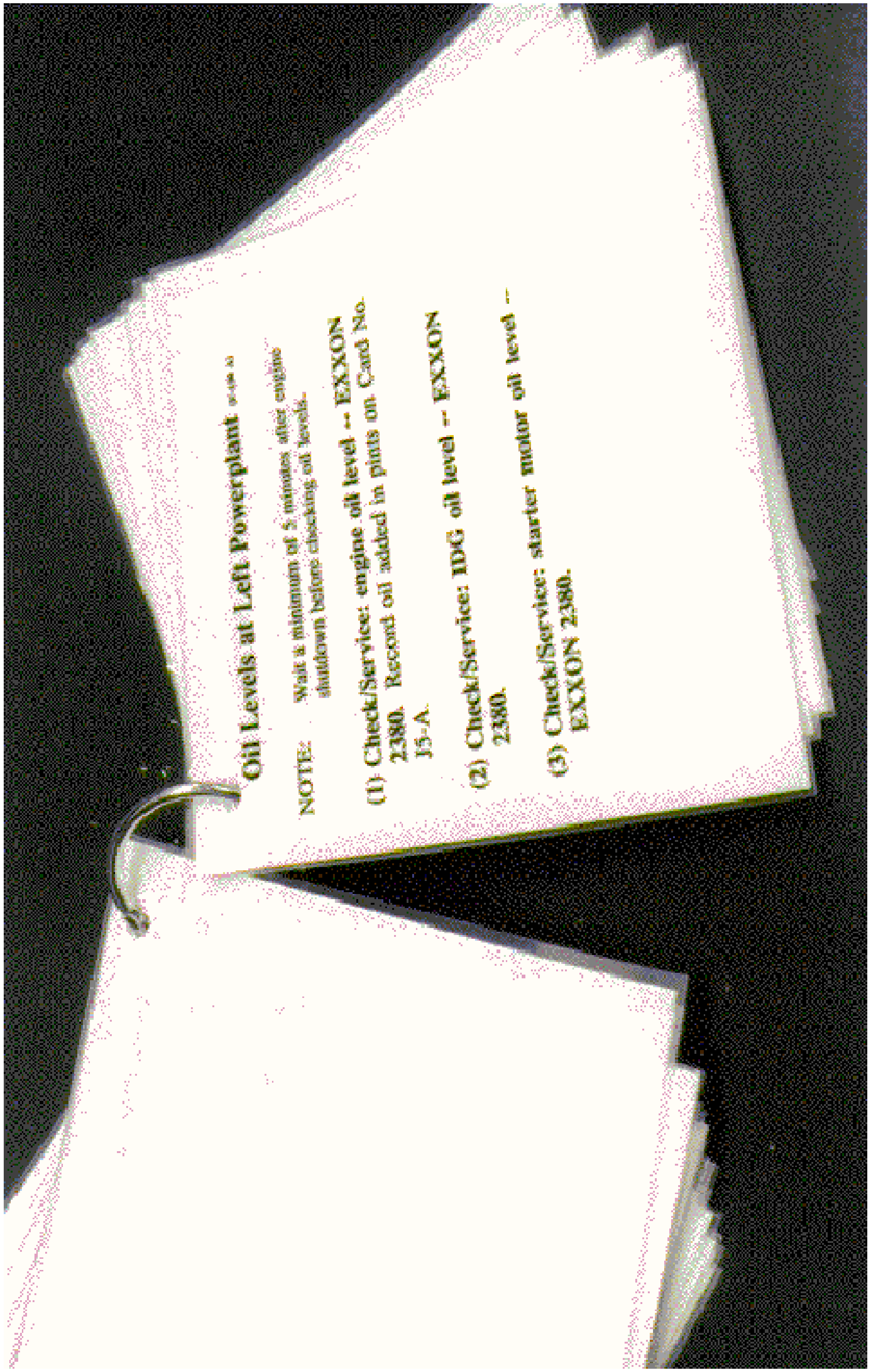

Figure 8.4 Typical Page Layout and Lamination of Job Aid

8.4.2 Does The Job Aid Meet Checklist Objectives?

To review, the objectives of a checklist are to aid the user in recalling procedures, to outline a convenient sequence for motor movements and eye fixations, to allow mutual supervision in a crew, to distribute tasks among crew members, and to function as a quality control tool for management and government regulators (Degani and Wiener, 1990; 1993). Dividing tasks spatially in small cards affords a mechanic the flexibility to sequence areas according to his or her individual work habits while also organizing the tasks spatially. The job aid provides a convenient sequence for motor movements **within** an area while allowing a mechanic to determine the most convenient sequence **between** areas. In addition, dividing tasks into cards that can be separated allows for easier task distribution among crew members, allowing mutual supervision in a crew. Features of our job aid such as allowing mechanics to sequence and distribute tasks, the convenient size and surface of the cards, and, possibly, increased ease of reading the workcards (in compliance with the Patel, et al.'s (1992) guidelines) should promote mechanics' use of the job aid, in turn aiding users in recalling procedures. Although our job aid will not replace a sign-off sheet as a quality control tool, it should reduce sign-off errors since mechanics no longer have to rely on memory to know which tasks are complete. Since tasks are separated logically into cards, mechanics can check cards as they complete the tasks.

Since our job aid meets these objectives, it should reduce errors associated with workcards, as the task analysis predicts. Omissions related to workcards not matching mechanics' individual work habits should be reduced since the job aid allows flexibility in the sequence of task areas. Omissions related to interruptions should also decrease. Tasks are separated into small, logical groups so that a mechanic can quickly scan the card he or she was working with before being interrupted. The workcards' easier writing surface should encourage mechanics to take notes about tasks interrupted, tasks completed, and of discrepancies found. Omissions and rule-based errors arising from mechanics not using the workcard should be reduced since the job aid was designed in a way that encourages its use. To determine whether these predictions are valid, we obtained feedback from mechanics and observed them using our job aid while performing checks.

8.5 Evaluation of the Job Aid

Our evaluation of the job aid consisted of the same methodology we used for task analysis. We observed mechanics performing the check using the job aid, had interviews with selected mechanics, and distributed workcard evaluations to evaluate and further refine the job aid.

8.5.1 Direct Observation

We videotaped a mechanic performing a lower-level 2 check while using the job aid. He rearranged the cards to reflect his preferred sequence for the check and followed the cards almost exactly during the check. The mechanic frequently referred to the cards to ensure he had completed all tasks in sequence. After he thought he had completed the exterior checks and referred to the cards, he found that he did not check the fuel tank sump. In the aircraft's interior, the mechanic noted blown lights on a piece of paper because the job aid he used was a prototype made of cardstock and not laminated. The mechanic's sequencing of tasks demonstrated the expected spatial sequence; he performed tasks while walking clockwise around the aircraft. General observation indicated that this mechanic followed our job aid's task sequence significantly more than the workcard's task sequence.

8.5.2 First Workcard Evaluation

Appendix 8-C shows results of a preliminary workcard evaluation we used for feedback after developing our first job aid. The placemarker page received a "useful" rating. This page is a colored instruction card intended be placed on top of the card stack. As a mechanic turned each card over, the placemarker page separated completed cards from those yet to be performed. Our observations and interviews revealed that mechanics were reluctant to move the placemarker page after they completed tasks on a card. We removed the placemarker feature since it might be more confusing than helpful. Mechanics, instead, can use a grease pencil to track completed tasks.

General results from the first workcard evaluation and those from subsequent interviews with mechanics and an inspector suggested that they found the division of tasks into small cards useful, that they would rearrange the cards into their own preferred order, and that they would find a grease pencil useful. In addition to preferring the job aid to the workcard, they indicated that they would be more likely to perform tasks in the job aid's order they arranged than with the workcard's dictated order. They generally liked the card system and found it useful. Two suggestions we used to design the revised job aid were to make the cards smaller and to color-code cards by spatial areas of the aircraft so that it would be easier to order the cards. Due to time constraints, only three mechanics filled out the preliminary workcard evaluation. After revising job aid, we distributed another workcard evaluation.

8.5.3 Second Workcard Evaluation

Seventeen mechanics completed the second workcard evaluation after they viewed a demonstration of the job aid. The results, presented in Appendix 8-F, reveal little difference between the present workcard and the proposed job aid. The only factor revealing a difference between the workcard and the job aid was the mechanics' opinion that they would perform the check in the order given. They indicated that they seldom perform tasks in the workcard's order but would-sometimes to usually-perform tasks in the order they arranged while using the job aid. This result is encouraging given that the job aid's main goal is to provide a task order mechanics will follow so they use the workcard and do not rely on memory. Mechanics found color coding of cards (3.65), division of tasks into the smaller cards (3.82), and the grease pencil (3.88) slightly less than useful (which would be a 4.0 rating). These findings are somewhat surprising since many mechanics make notes and a mechanic recommended color-coding. One mechanic suggested that the entire card be color-coded. Our question regarding the usefulness of dividing tasks into smaller cards was probably inappropriate since tasks were divided so that mechanics could arrange the sequence (which received a favorable response).

One potential reason for the "neutral to slightly above" evaluation of the job aid versus the workcard is that many respondents did not use the job aid to perform a check, but only saw a demonstration. Had they used the job aid, many mechanics may have been more convinced about its usability. Also, mechanics who had been trained to use workcards were reluctant to accept a change. They seemed concerned about issues of tracking interim changes and the ease of updating cards for new information. If lamination becomes too costly, there is an alternate possibility of printing cards on card stock, which is more resilient to environmental factors than ordinary paper. Such cards could be used once and be updated as easily as the workcards. The job aids printed on card stock that were used for the DC-9 lower-level 2 check we videotaped and reported in 8.5.1 appeared to work well.

Another possible reason for mechanics' neutral responses reflects their belief about the reliability of their work. As we previously discussed, these mechanics are experienced and extremely familiar with tasks performed in a check. They typically receive little, if any, feedback about the danger of interruptions and of failing to use the workcard of to follow its task sequence. Since relationships between human error and using the workcard are not obvious, any possibility of increasing these checks' reliability is worth investigating.

8.5.4 Overall Results

Observations we made of mechanics using the job aid while performing a check generally revealed closer compliance with the task sequence the mechanics arranged while using the job aid than observations we made of mechanics using traditional workcards. Interviews and informal discussions revealed that mechanics had generally favorable responses to the job aid. The first workcard evaluation's results reflects this finding. In contrast, the second workcard evaluation's results revealed mostly neutral responses to the job aid. Most mechanics completing the second workcard evaluation were unfamiliar with the goals of this project. Hence, they were skeptical about the project and logistics of implementing the job aid. In contrast, the first workcard evaluation and direct observation involved a small numbers of people who understood the project's goal of increasing workcard compliance. After other mechanics begin using the job aid, we expect initial neutral reactions to be followed by acceptance with increased use.

8.6 Conclusion

In this study, we examined issues in developing a job aid for frequently performed, long, sequential tasks to increase reliability of task performance. Our most important recommendation from this project is to design flexible job aids meet individual work methods. To do so, it is important to identify factors influencing individual work methods. Our task analysis found that mechanics performing low-level checks and A-checks use the spatial locations of tasks and, sometimes, perceived task difficulty for sequencing the tasks. Other factors may be more important for sequencing less frequently performed checks.

Separating tasks allows for a natural division of work and, more importantly, makes it easier for mechanics to track completed tasks. The job aid should allow mechanics quickly to see what tasks are completed. Further, sign-offs for tasks located on different aircraft sections should be separated since generally they are not performed sequentially.

Another potential method for helping mechanics to track completed tasks is a bar code reader. A bar code could be printed on each card of a check. After a mechanic completes all tasks on a card, he or she could scan the bar code, using a small, lightweight computer attached to his or her belt. After the check is complete, the computer could identify any tasks mechanics missed. After mechanics are sure that all tasks are completed, they can do their "sign-offs" either manually or with the computer (when computer recognition of signatures becomes common). Either approach would significantly reduce mechanics' current reliance on memory. As bar code readers are relatively inexpensive, airlines should further investigate this option.

The job aid must be resilient to environmental factors and compatible with task factors. Task analysis should identify conditions under which mechanics will use the job aid. The job aid must not physically hinder users performing their tasks.

Mechanics must understand the importance of using workcards, especially the ways interruptions and distractions can lead mechanics to omit tasks. Factors such as weather, absences by co-workers, reassignment, and time pressure all contribute to the potential for distractions.

Finally, workcards, as a form of checklists, must meet objectives of checklists (Degani and Wiener, 1990; 1993). Workcards should aid users to recall procedures by outlining a convenient sequence for motor movements and eye fixations. Workcards should permit mutual supervision within a crew, as well as helping a crew distribute tasks among themselves. Taken together, these factors should increase a workcard's ability to function as a control tool for management and government regulators, thereby increasing the checks' reliability.

8.7 References

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APPENDIX 8-A

Results of Present Workcard Evaluations

I. Summary Statistics

Number of respondents = 8

Age of respondents: Mean=40.38 sd=7.73

Years worked as a mechanic: Mean=17.4 sd=9.80

Average number of lower-level checks performed per month:

Mean=14.25 sd=8.25

II. Open-Ended Questions

1. Do you normally perform the tasks on a lower-level 2 check in the same order every time you do the check?

Yes: 3

No: 4

Depending on aircraft type: 1

2. Normally, how do you sequence the tasks you must perform to complete a lower-level 2 check?

Subject 1: Starting at the nose of aircraft, I wrap around wings and empennage finishing at the nose again.

Subject 2: Nose to left side of aircraft to nose.

Subject 3: Sometime start on the outside, sometimes start inside.

Subject 4: Start at nose, work way around.

Subject 5: Outside, inside, work release items.

Subject 6: Inside right to left, inside back to front.

Subject 7: Outside, inside, pilot items.

Subject 8: Habit.

3. If you are doing the check with another person, how does this change your strategy for performing the check?

Subject 1: Assistant on check would service tires, APU oil, engine oil and CSD oil and hydraulic fluid.

Subject 2: None.

Subject 3: One person will do the outside, the other one will do the inside.

Subject 4: Usually split inside and outside.

Subject 5: Depends on level of experience.

Subject 6: None.

Subject 7: None.

Subject 8: One man assigned to inside, One man outside.

4. What do you do when you find a discrepancy, e.g., do you make a note to fix it after you are finished with the check, or do you fix it as soon as you find it?

Subject 1: Make notes.

Subject 2: Make note of discrepancy.

Subject 3: Made a note and fix it after the check is done.

Subject 4: Make a note usually unless able to fix on spot.

Subject 5: Fix after.

Subject 6: Make a note.

Subject 7: Fix after the check.

Subject 8: Make a note.

5. Could you please comment on the usefulness of the workcard, e.g., do you need to refer to the workcard while performing the check?

Subject 1: No, unless there is a new revision.

Subject 2: No.

Subject 3: Sometimes.

Subject 4: Used as guide since things checked are usually more than required.

Subject 5: No.

Subject 6: No.

Subject 7: Sometimes.

Subject 8: The first 4 to 5 times you do the check on any specific a/c after that no.

III. General Questions on the Usefulness of the Present workcards

1. How useful do you find the workcard?

Mean=4 sd=0.535

[0= of no use 2= not very useful 4= useful 6= considerably useful 8= extremely useful]

2. How often do you refer to the workcard?

Mean=4.125 sd=1.727

[0= always 2= usually 4= sometimes 6= seldom 8= never]

3. Would you prefer a workcard that is:

Mean=4.688 sd=1.945

[0= more concise 4= about the same 8= more detailed

4. How would you rate the ease of understanding of the workcard?

Mean=5.125 sd=1.959

[0= very difficult 4= moderately easy 8= very easy]

5. Do you have any problems handling the workcard?

Mean=6.625 sd=1.408

[0= always 4= sometimes 8= never]

6. Do you perform the tasks in the order given by the workcard?

Mean=2.750 sd=1.389

[0= never 4= sometimes 8= always]

7. When do you sign off complete items on the workcard?

Five mechanics responded at end of workcard.

One mechanic responded between intermittently and end of workcard.

One responded after every section.

One responded after every task.

APPENDIX 8-B

Mechanics' Ratings of Probability of Discrepancy and Difficulty of B-737 Lower-Level 2 Check Tasks

The approximate likelihood of finding a discrepancy was rated:

0= never 4= sometimes 8= always

The difficulty of performing the task was rated:

0= very easy 4= moderately easy 8= very difficult

Task	Prob. of Discrepancy: mean (sd)	Difficulty of Task: mean (sd)
Check left engine inlet and reverser area.	1.2 (2.0)	2.2 (2.4)
Check right engine inlet and reverser area.	2.5 (1.3)	1.6 (1.6)
Check brakes for wear with pressure applied.	2.9 (1.7)	4.0 (2.3)
Check main landing tires for serviceability.	3.5 (1.3)	2.6 (1.4)
Check nose landing tires for serviceability.	2.8 (1.5)	1.8 (1.1)
Check nose tire pressure.	4.2 (1.8)	3.3 (2.8)
Check main landing tire pressure.	3.7 (2.0)	1.8 (1.6)
Accomplish a visual check of MLG wheels for broken or missing tie bolts.	2.2 (2.2)	2.9 (2.1)

Clean MLG strut piston with solvent. Clean MLG downlock viewers/indicators.	3.3 (1.8)	1.6 (1.6)
Clean NLG strut piston with solvent. Clean NLG downlock viewers/indicators.	3.3 (1.2)	2.3 (1.6)
Check fuselage for obvious damage as viewed from the ground.	3.1 (2.0)	1.8 (2.2)
Check empennage for obvious damage as viewed from the ground.	2.6 (1.1)	2.6 (2.4)
Check wings for obvious damage as viewed from the ground.	2.3 (1.1)	1.7 (1.4)
Check tail-skid (737-400 only)	1.8 (2.5)	0.5 (0.6)
Check engine fire bottle pressure.	1.1 (0.9)	0.9 (0.7)
Check APU fire bottle disc and thermal relief indicator.	0.6 (0.7)	1.1 (2.4)
Check exterior lights for proper operation.	4.1 (0.9)	1.9 (1.8)
Check fuel tank sumps.	3.3 (1.2)	2.1 (1.1)
Service hydraulic fluid for standby system.	3.3 (1.4)	2.5 (1.4)
Service hydraulic fluid for system B.	2.7 (1.7)	1.9 (1.8)
Service hydraulic fluid for system A.	2.7 (1.5)	1.7 (1.6)
Service auxiliary power unit oil to NON RON aircraft.	3.9 (1.8)	2.7 (1.9)
Service engine oil for engine #1.	4.9 (2.3)	1.1 (1.4)
Service engine oil for engine #2.	4.4 (2.6)	0.9 (0.6)
Service constant speed drive engine #1.	3.2 (1.6)	1.6 (1.4)
Service constant speed drive engine #2.	2.6 (1.4)	0.8 (0.8)
Service oxygen-crew, portable.	2.4 (1.4)	2.4 (2.0)
Check attendants' seats for proper operation and condition.	2.3 (1.0)	2.4 (1.9)
Ensure outboard seat in the emergency exit row has a non-standard thinner seat bottom cushion installed.	2.5 (1.9)	0.6 (0.6)
Check that a yellow lifevest is installed under each seat.	5.7 (2.3)	1.9 (1.8)
Check LH overhead stowage bin row (10) for 8 spare yellow passenger life vests.	3.0 (2.1)	1.2 (1.4)
Check forward LH closet for 2 each yellow demo lifevests.	2.4 (1.8)	0.6 (0.6)

Check LH emergency equipment bin for 2 demo lifevests.	3.0 (2.3)	1.1 (1.7)
Check protective breathing equipment for serviceability.	0.8 (1.0)	1.2 (1.4)
Check lavatory flush pumps/timers.	2.7 (2.3)	1.8 (1.8)
Check emergency lighting system.	2.7 (1.9)	2.8 (1.9)
Check and repair the entrance area for appearance and condition.	3.3 (1.2)	2.1 (2.3)
Check cabin area for appearance and condition.	4.3 (1.8)	2.5 (1.7)
Check galley area for general appearance and condition.	2.4 (1.8)	2.2 (1.6)
Check forward lavatories for general appearance and condition.	2.4 (1.5)	2.0 (1.2)
Check rear lavatories for general appearance and condition.	2.8 (1.3)	1.9 (1.4)

APPENDIX 8-C

Sequence of Tasks for Lower Level-Check 2 on B-737

Five mechanics completed this evaluation. The first two respondents were also videotaped performing this check.

In Table A2, the order in which each task was performed is indicated by its task number. Mechanics m1-m5 completed the evaluation and are denoted by m1q-m5q. Mechanics m1 and m2 were also videotaped and are denoted by m1-v and m2-v. Note that mechanic 2 split the check with another mechanic, so many tasks were not observed. For mechanic m1, some tasks could not be seen due to the video camera's position.

Table A1. Workcard Order for Tasks 1-27

Task #	Description
1	Check engines inlet and reverser area.
2	Check brakes for wear with pressure applied.
3	Check tires for serviceability.
4	Check tire pressure.
5	Accomplish a visual check of the main landing gear for broken or missing tie bolts.
6	Clean MLG & NLG strut piston with solvent.

7 Clean MLG & NLG downlock viewers/indicators.
8 Check fuselage, empennage, and wings for obvious damage or irregularities as viewed from the ground.
9 Check tail skid.
10 Check engine fire bottle pressure.
11 Check APU fire bottle discharge disc (yellow) and thermal relief disc (red).
12 Check exterior lights for proper operation.
13 Fuel tank sumps.
14 Hydraulic fluid (System A, B, and Standby).
15 Auxiliary Power Unit Oil.
16 Engine oil.
17 Constant speed drive #1, #2.
18 Oxygen-Crew, portable.
19 Attendants' seats for proper operation and condition.
20 Ensure outboard seat in the emergency exit row has a non-standard thinner seat bottom cushion installed.
21 Check passenger life vest, for aircraft that are equipped for over water operation.
22 Protective breathing equipment (PBE) for serviceability.
23 Lavatory flush pumps/timers.
24 Emergency lighting system.
25 Entrance area for appearance and condition.
26 Galley area for general appearance and condition.
27 Cabin area for general appearance and condition.
Lavatories for general appearance and condition.

Table A2: Order of Performing Tasks on B-737 Lower-Level Check 2.

Order	**m-q**	**m1-v**	**m2-q**	**m2-v[1]**	**m3-q**	**m4-q**	**m5-q**
1	11	7	3	6	2	7	15
2	4	6	6	7	3	6	16
3	6	4	7	1	3	6	15
4	3	6	7	1	5	7	16
5	6	3	7	16	4	12	2
6	7	4	1	7	4	13	3
7	16	6	16	2	1	13	3
8	4	7	2	3	1	13	3
9	3	1	3	2	7	15	4
10	5	16	5	6	7	15	5
11	2	7	6	8	7	16	1
12	1	1	9	13	9	1	6
13	9	7	10	7	9	1	6
14	7	3	13	2	10	1	6
15	7	2	13	6	6	3	7

16	10	5	13	6	6	3	7	
17	8	4	1	2	6	3	8	
18	16	6	11	3	12	4	9	
19	1	13	16	4	14	4	10	
20	12	6	18	6	15	5	11	
21	14	9	20	9	15	6	13	
22	13	10	23	13	16	6	13	
23	13	7	25	2	16	7	13	
24	13	7	26	3	13	8	7	
25	23	14	27	4	13	9	14	
26	20	7	20	6	13	10	17	
27	18	7	21	1	18	14	18	
28	20	7	22	7	17	11	19	
29	21	3	27	1	21	27	20	
30	27	6	23	9	19	23	20	
31	27	2	20	13	20	22	20	
32	19	5	20	7	20	18	20	
33	25	4	19	24	20	21	21	
34	20	6	8	21	20	20	22	
35	22	13	14	20	27	20	23	
36	17	1	17	20	22	24	24	
37	24	7	6	22	24	25	25	
38	26	1	6	27	25	26	26	
39	20	7	4	22	26	27	12	
40	15*	17	4	27	27	20	27	
41		22	12*	17	23	20	27	
42		27	15*	8*		19		
43		23		10*		17		
44		21		11*				
45		20		12*				
46		19		14*				
47		18		15*				
48		20		18*				

49	24	19
50	21	23*
51	20	25*
52	26	26*
53	8	
54	11*	
55	12*	
56	15*	
57	25*	

*** Asterisks represent tasks performed by other mechanics or not observed due to video restrictions.**

APPENDIX 8-D

Tasks Occurring Sequentially

Tasks which follow each heading task are listed.

Check left engine inlet and reverser area.

Check main landing tire pressure.

Accomplish a visual check of MLG wheels for broken or missing tie bolts.

Check fuselage for obvious damage as viewed from the ground.

Check wings for obvious damage as viewed from the ground.

Service constant speed drive engine #1.

Service constant speed drive engine #2.

Check right engine inlet and reverser area.

Check main landing tires for serviceability.

Check main landing tire pressure.

Clean MLG strut piston with solvent. Clean MLG downlock viewers/indicators.

Check fuselage for obvious damage as viewed from the ground.

Check wings for obvious damage as viewed from the ground.

Check fuel tank sumps.

Check brakes for wear with pressure applied.

Check main landing tire pressure.

Accomplish a visual check of MLG wheels for broken or missing tie bolts.

Check empennage for obvious damage as viewed from the ground.

Check wings for obvious damage as viewed from the ground.

Check main landing tires for serviceability.

Check main landing tire pressure.

Accomplish a visual check of MLG wheels for broken or missing tie bolts.

Clean MLG strut piston with solvent. Clean MLG downlock viewers/indicators.

Check fuselage for obvious damage as viewed from the ground.

Check wings for obvious damage as viewed from the ground.

Service constant speed drive engine #1.

Check nose landing tires for serviceability.

Check nose tire pressure.

Clean NLG strut piston with solvent. Clean NLG downlock viewers/indicators.

Check fuselage for obvious damage as viewed from the ground.

Check nose tire pressure.

Clean NLG strut piston with solvent. Clean NLG downlock viewers/indicators.

Check fuselage for obvious damage as viewed from the ground.

Check main landing tire pressure.

Accomplish a visual check of MLG wheels for broken or missing tie bolts.

Clean MLG strut piston with solvent. Clean MLG downlock viewers/indicators.

Accomplish a visual check of MLG wheels for broken or missing tie bolts.

Clean MLG strut piston with solvent. Clean MLG downlock viewers/indicators.

Check fuselage for obvious damage as viewed from the ground.

Clean MLG strut piston with solvent. Clean MLG downlock viewers/indicators.

Check empennage for obvious damage as viewed from the ground.

Check wings for obvious damage as viewed from the ground.

Service constant speed drive engine #2.

Clean NLG strut piston with solvent. Clean NLG downlock viewers/indicators.

Check fuselage for obvious damage as viewed from the ground.

Check exterior lights for proper operation.

Check fuselage for obvious damage as viewed from the ground.

Check empennage for obvious damage as viewed from the ground

Check wings for obvious damage as viewed from the ground.

Check exterior lights for proper operation.

Check fuel tank sumps.

Service APU unit oil to NON RON aircraft.

Service constant speed drive engine #1.

Check and repair the entrance area for appearance and condition.

Check empennage for obvious damage as viewed from the ground.

Service APU unit oil to NON RON aircraft.

Check wings for obvious damage as viewed from the ground.

Check fuel tank sumps.

Service hydraulic fluid for standby system.

Service constant speed drive engine #1.

Service constant speed drive engine # 2.

Service oxygen-crew, portable.

Service hydraulic fluid for standby system.

Service hydraulic fluid for system B.

Service hydraulic fluid for system B.

Service hydraulic fluid for system A.

Service oxygen-crew portable.

Check LH emergency equipment bin for 2 demo lifevests.

Check protective breathing equipment for serviceability.

Check lavatory flush pumps/timers.

Check forward lavatories for general appearance and condition.

Check attendants' seats for proper operation and condition.

Check that a yellow lifevest is installed under each seat.

Check LH emergency equipment bin for 2 demo lifevests.

Check lavatory flush pumps/timers.

Check emergency lighting system.

Check and repair the entrance area for appearance and condition.

Check forward lavatories for general appearance and condition.

Ensure outboard seat in the emergency exit row has a non-standard thinner seat bottom cushion installed.

Check that a yellow lifevest is installed under each seat.

Check emergency lighting system.

Check cabin area for appearance and condition.

Check that a yellow lifevest is installed under each seat.

Check LH overhead stowage bin row (10) for 8 spare yellow passenger life vests.

Check LH emergency equipment bin for 2 demo lifevests.

Check protective breathing equipment for serviceability.

Check lavatory flush pumps/timers.

Check cabin area for appearance and condition.

Check LH overhead stowage bin row (10) for 8 spare yellow passenger life vests.

Check cabin area for appearance and condition.

Check forward LH closet for 2 each yellow demo lifevests.

Check and repair the entrance area for appearance and condition.

Check cabin area for appearance and condition.

Check LH emergency equipment bin for 2 demo lifevests.

Check and repair the entrance area for appearance and condition.

Check cabin area for appearance and condition.

Check protective breathing equipment for serviceability.

Check emergency lighting system.

Check and repair the entrance area for appearance and condition.

Check cabin area for appearance and condition.

Check lavatory flush pumps/timers.

Check rear lavatories for general appearance and condition.

Check emergency lighting system.

Check forward lavatories for general appearance and condition.

Check and repair the entrance area for appearance and condition.

Check forward lavatories for general appearance and condition.

Check cabin area for appearance and condition.

Check rear lavatories for general appearance and condition.

APPENDIX 8-E

First Evaluation Feedback on the Proposed Job Aid

I. Mechanics' Ratings of Job Aid

Three mechanics (M1-M3) responded.

Question	M1	M2	M3	Mean
How useful would you find the placemarker page? 0=of no use 4=useful 8=extremely useful	5	3	4	
How useful do you think the division of tasks into small cards would be? 0=of no use 4=useful 8=extremely useful	5	6	5	5.3
Would you rearrange the cards to suit your individual work habits? 0=never 4=sometimes 8=always	7	8	5	6.7
Would you read the interim page at the end of the "official" w/c before starting the check? 0=never 4=sometimes 8=always	4	3	3.5	
Would you use the grease pencil to make notes while completing the check? 0=never 4=sometimes 8=always	7	8	1	5.3
How would you rate the size of the cards? 0=too small 4=about right 8=too big	5	6	1	4
How useful do you find the present w/c system? 0=of no use 4=useful 8=extremely useful	4	1	5	3.3

How useful do you think the proposed job aid would be? 0=of no use 4=useful 8=extremely useful	6	6	5	5.7
Do you perform the tasks in the order given by the present w/c? 0=never 4=sometimes 8=always	0		0	
Would you perform the tasks in the order you arranged using the job aid? 0=never 4=sometimes 8=always	6	8	5	6.3
How often do you refer to the present workcard as you perform a lower-level 2 check? 0=never 4=sometimes 8=always	4	0	5	3
How often would you refer to the job aid as you perform a lower-level 2 check? 0=never 4=sometimes 8=always	6	6	3	5
How often do you refer to the present workcard as you perform an A-check? 0=never 4=sometimes 8=always	5	5	7	5.7
How often would you refer to the job aid as you perform an A-check? 0=never 4=sometimes 8=always	6	6	7	6.3

II. Open-Ended Questions

1. Comments and suggestions on the design of the cards:

a. Size of the cards

Subject 1: Could be a little smaller to stow in pockets when both hands are needed.

Subject 2: Shirt pocket with a grommet to allow the cards to fan open, or some firm type of clip.

Subject 3: Good size for information that is on each card.

b. Groupings of the tasks

Subject 1: OK-after rearranging to preference.

Subject 2: From aircraft access (fwd med) toward nose and around to right buy areas (normal course).

Subject 3: Good idea. I think it's easier to start at the nose gear and continue around the aircraft in one complete circle.

c. Placemarker/instructions page

Subject 1: OK.

Subject 2: Instructions on front as a cover. Check boxes at item number with back page having colored stripes-"Check off area" to recall page with check.

Subject 3: Once I got used to doing a check on an aircraft, I don't think I would use the placemarker/instruction card and just use the sign-off sheet.

d. Wording of the cards/instructions

Subject 1: Wouldn't hurt to go into more detail.

Subject 2: Revision date in large print to match sign-off sheet date. Common abbreviation naming component only. Include limits. Leave out procedure (manuals dictate procedure).

Subject 3: Simplified and easy to understand.

e. Ease of understanding the instructions

Subject 1: Good.

Subject 2: Very brief-reference changes only-new or limited experience personnel should consult M/M until they are confident in their procedure.

Subject 3: The cards are very easy to understand.

f. Ease of rearranging the order of the cards

Subject 1: OK.

Subject 2: Not necessary if color-code by geographic areas of aircraft.

Subject 3: Rearrange the cards in order of doing the check.

2. How well do you think this idea can be extended to other checks?

Subject 1: The more involved the check, the more useful the cards.

Subject 2: Very well.

Subject 3: Very easily.

3. General comments

Subject 1: I like the card system better.

Subject 2: Its nice to see that people are interested in approaching these tasks in a real-world manner.

APPENDIX 8-F

Evaluation Feedback on Revised Job Aid

Statistical Data on Respondents

N = 17

Age = 36.47(8.15) years

Number of years in civil aviation = 14.35(7.58)

Number of years as a mechanic = 12.94(6.95)

Number of years as an inspector = 0.29(0.99)

Number of years performing lower-level 2 checks = 9.59(6.76)

Approximate number of lower level 2 checks performed in a month = 15.85(9.07)

Number of years performing A-checks = 9.59(6.76)

Approximate number of A-checks performed in a month = 4.65(4.00)

Question	Present Workcard Mean (sd)	Job Aid Mean (sd)
How would you rate the ease of readability of the text? 0=terrible 2=poor 4=fair 6=good 8=excellent	5.47(1.42)	6.12(1.27)
In general, how easy is the information to understand? 0=very difficult 4=moderately easy 8=very easy	6.06(2.19)	6.12(1.65)
How would you rate the effort required in locating a particular task? 0=very difficult 4=moderately easy 8=very easy	5.35(2.42)	5.59(1.77)
What would be the chance of you missing a sign-off or a task? 0=always 2=usually 4=sometimes 6=seldom 8=never	5.94(1.84)	6.35(1.27)
How would you rate the ease of physically using the workcard/job aid? 0=very difficult 4=moderately easy 8=very easy	5.47(2.10)	6.06(1.92)
Would you perform the tasks in the order given by the workcard/job aid? 0=never 2=seldom 4=sometimes 6=usually 8=always	2.47(2.40)	5.18(2.40)

How often do/would you refer to the workcard/job aid as you perform a lower-level 2 check? 0=never 2=seldom 4=sometimes 6=usually 8=always	5.12(2.42)	5.41(2.09)
How often do/would you refer to the workcard/job aid as you perform an A-check? 0=never 2=seldom 4=sometimes 6=usually 8=always	6.18(1.85)	6.47(1.59)
How useful do you find the workcard/job aid? 0=of no use 4=useful 8=extremely useful	4.06(2.19)	5.12(2.12)
How useful would you find the color-coding of the tasks into areas? 0=of no use 4=useful 8=extremely useful		3.65(1.90)
How useful do you think the division of tasks into small cards would be? 0=of no use 4=useful 8=extremely useful		3.82(1.98)
Would you rearrange the cards to suit your individual work habits? 0=never 2=seldom 4=sometimes 6=usually 8=always		5.76(2.44)
Would you read the interim page at the end of the workcard before starting the check? 0=never 2=seldom 4=sometimes 6=usually 8=always		6.00(2.21)
Would you use the grease pencil to make notes while completing the check? 0=never 2=seldom 4=sometimes 6=usually 8=always		3.88(2.34)