Chapter Three
The Maintenance Technician in Inspection

3.1 INTRODUCTION

The problem of improving the reliability of aircraft inspection and maintenance is multi-faceted, so that this chapter only details one part of the Federal Aviation Administration and Galaxy Scientific Corporation approach to solutions. Justification in terms of fleet age, and maintenance philosophy is presented elsewhere in the NAARP and this report.

The objectives of this task can be stated as:

This aspect of the NAARP Human Factors plan is to determine typical human-system mismatches to guide both future research and short-term human factors implementation by system participants. Also, by providing a human factors analysis of aircraft inspection, it is intended to make human factors techniques more widely available to maintenance organizations, and to make aircraft maintenance more accessible to human factors practitioners.

To meet these objectives, the context of aging aircraft inspection is important to show the relationship of this task to improved airworthiness and public safety. If an aircraft is to be properly maintained, the maintenance system must either be error-free or error tolerant. Cracks and corrosion in the metal structure of commercial aircraft are a fact of life; there will always be defects present. Correction of defects demands detection of defects, and this is one area where systems improvements should be looked for. The system for defect detection consists of a human inspector aided by various machines. Humans and machines are both fallible, so that ways are needed to make these system components less error-prone, and the system more error tolerant. The detection/repair strategy used throughout the world is to specify a maintenance interval such that if the defect is too small to detect on one check, it will be both large enough to detect and small enough to be safe on the subsequent check. However, failure to detect a crack or corrosion which was in fact large enough to be detected does not give the same level of assurance that it will not cause a problem before the next check.

The aircraft inspection system is a complex one, taking place at sites ranging from large international carriers, through regional and commuter airlines, to the fixed-base operators associated with general aviation. Inspection, like maintenance in general, is regulated by the FAA in the U.S.A. and equivalent bodies in other countries. However, enforcement can only be of following procedures (e.g., hours of training and record-keeping to show that tasks have been completed), not of the effectiveness of each inspector. Inspection is also a complex socio-technical system (Taylor, 1990), and as such, can be expected to exert stresses on the inspectors and on other organizational players (Drury, 1985).

Just as effective inspection is seen as a necessary prerequisite to maintenance for safety, so human inspector reliability is fundamental to effective inspection. The inspection system will be described briefly to provide a background for the inspection Task Analysis which follows. Data was collected from six sites in the United States, two each for three major national/international carriers. (In addition, some observations were made at the maintenance sites of two European carriers, but no detailed Task Analysis data was collected at either site.) Major carriers were chosen to reduce the variability of inspection systems observed, with the aim of collecting usable data within a limited time frame. Regional and commuter airlines, and aircraft repair stations will be added during the second year of the project.

3.2 THE INSPECTION SYSTEM

Aircraft for commercial use have their maintenance and inspection procedures scheduled initially by a team including the Federal Aviation Administration, the aircraft manufacturer and start-up operators. These schedules are then taken by the carrier and modified, in a process which must meet legal approvals, to suit the carrier's requirements. For example, an item with an inspection interval of 5,000 hours may be brought forward to a 4,000 hour check so that it can be performed during a time when the aircraft is undergoing other planned maintenance. Within the carrier's schedule will be checks at many different intervals, from flight line checks and overnight checks, through A, B and C-checks (often in themselves subdivided, e.g., C-l, C-2, ...) to the "heaviest" level or D-check. This project has concentrated on C- and D-checks because these are the times at which most detailed structural inspection of airframe components is undertaken--the focus of the National Aging Aircraft Research Program (NAARP).

As an aircraft is scheduled for a heavy check, all of the required inspection and maintenance items are generated by a Planning Group within the carrier's maintenance organization. Items included scheduled known repairs (e.g., replace an item after a certain airtime, number of cycles or calendar time), repair of items discovered previously (e.g., from pilot/crew reports, flight line inspections, items deferred from previous checks), and scheduled inspections. The inspections are expected to lead to repairs in certain cases, i.e. if a defect is found by the inspection system. With the aging fleet, it is of some interest that scheduled repairs now account for perhaps 30% of all repairs, rather than the 60-80% seen in earlier years, due to the finding of more age-related structural defects in the aircraft.

Because such a large part of the maintenance workload on a particular check is discovered during inspection, it remains an unknown to the Planning Group. Maintenance technicians (AMTs) cannot be scheduled until the workload is known, and replacement parts cannot be ordered until they are discovered to be required. For these reasons, it is imperative that the incoming inspection be completed as soon as possible after the aircraft arrives at the maintenance site. This aspect of the organization of the inspection/maintenance system gives rise to certain peculiarities of ergonomic importance.

As it is imperative that all defects requiring repair be discovered as quickly as possible, there is a very heavy inspection workload at the start of each check. To keep the number of inspectors within bounds despite this sudden workload requirement, most airlines use considerable overtime during "check-in" of an aircraft. Thus, if there are ten inspectors regularly working each shift, double shifts can give effectively twenty inspectors for a short time. Hence, for the first, perhaps, six shifts after check-in, inspectors expect considerable overtime, leading of course to prolonged hours of inspection work. Also, as an aircraft typically arrives after service (e.g., 2200 to 2359) much of the incoming inspection is on night shift. Another factor predisposing towards night shift inspection work is Non-Destructive Inspection (NDI, or NDT for testing) involving hazardous materials such as X-ray or gamma-ray sources. For safety reasons, such NDI work is typically performed during work breaks on night shift when a minimum number of people need to be inconvenienced to prevent radiation exposure. Note that any time spent at the maintenance site between about 2300 and 0700 will not generally incur a loss of revenue as curfews prevent landings and take-offs between these hours at many U.S. airports.

Before each inspection can be performed, there are certain activities necessary for correct access. The aircraft may need to be cleaned inside and out (e.g., cargo hold below galleys and toilets), paint may need to be removed (e.g., on fuselage crown for NDI of lap-joint areas), parts of the aircraft may need to be removed (e.g., seats and cabin interiors for internal inspection of stringers or flaps and slats to inspect their tracks), or access panels may need to be opened (e.g., panels in vertical stabilizer for access to control wires and control actuation mechanisms). As inspection is performed, each defect found leads to a report being filed. This, variously called a Non-Routine Repair (NRR) report, or a Squawk, is added to the work pack of repairs required before the aircraft can complete its check. This NRR in itself generates the new workcards necessary for its completion, often via the Planning Group or Production Control. It may also generate the need for additional inspections, for example, to ensure that certain nuts are torqued correctly during installation, or that a skin patch ("scab") has been correctly added. These subsequent inspections are called "Buy-Back" inspections in the U.S. Typically, as a check progresses, the inspection workload both decreases due to completion of incoming inspection, and changes in nature due to a greater preponderance of buy-backs. Also, the rhythm of the work can change, as incoming inspection starts out with relatively few interruptions, but interruptions increase in frequency as AMTs call in inspectors to perform buy-backs of completed repairs.

3.3 METHODOLOGY

With the objective being to locate human/system mismatches which could lead to error, the basic methodology had to be one of direct observation of, and interviews with, system participants. Although an understanding had to be developed of how the system should work, the major emphasis was on how the system does work. The aim was not to evaluate the observed systems against published, legal standards, but to determine how the system functioned. Promulgation and change of regulations is only one way of enhancing system performance. In systems as large and complex as aircraft inspection it is natural to expect a variety of ways to accomplish multiple (often conflicting) objectives within an existing legal framework. All data was collected anonymously to enhance its validity. Two points should be noted:

1. All system participants were open and honest with members of the Task Analysis team. Every person we met was highly motivated, and honest, as well as genuinely concerned to improve system effectiveness.
2. If the team's task had been to measure compliance with existing regulations, it would have used an entirely different methodology.

Error-prone human/system mismatches occur where task demands exceed human capabilities. The necessary comparison is made through the formal procedure of Task Description and Task Analysis (Drury, et. al., 1987). Task Description is the enumeration of necessary task steps, at a level of detail suitable for the subsequent analysis. Task Analysis uses data and models of human performance to evaluate the demands from each task step against the capabilities of each human subsystem required for completion of that step. Examples of subsystems are sensing (e.g., vision, kinesthesis), information processing (e.g., perception, memory, cognition), and output (e.g., motor control, force production, posture maintenance). Thus, the system functions and tasks must be observed, and analyzed, through the filter of human factors knowledge, if more than superficial recommendations are to be made. There were two good starting points for this endeavor:

1. Existing human factors theory and case studies of inspection in manufacturing industry (Harris and Chaney, 1969; Drury and Fox, 1975; Drury, 1984).
2. Existing investigations of human capabilities in aircraft inspection (e.g., Lock and Strutt, 1985).

Although general Task Analysis systems are widely available (e.g., Drury, et.al., 1987), it is advantageous to use a system directly relating to inspection. Much human factors research in industrial inspection (quality control) has produced the following four major task steps for any inspection job:

1. Present item to inspector.
2. Search for flaws (indications).
3. Decide on rejection/acceptance of each flaw.
4. Take appropriate action.

Not all steps are required for all inspections. Thus, some processes require no search (e.g., judgement of the color match for painted surfaces), while others require no decision (e.g., noting the complete absence of a rivet head on a lap splice). In the aircraft inspection context, a rather longer Task Description is required, expanding the "Present item to inspector" task to include both setup of task/ equipment, and access to the correct point on a large and complex aircraft. Table 3.1 shows a seven-task generic Task Description, with examples from each of the two main types of inspections: Visual Inspection (VI) and Non-Destructive Inspection. Visual Inspection is still the dominant mode, at least 90% of the total workload. NDI includes eddy current, ultrasonic, X-ray and gamma-ray inspections to render cracks visible, as well as augmented visual inspection, such as dye-penetration testing and borescope use. Note that in both cases the Task Description unit is the workcard, or worksheet, and that the task is seen as continuing until a repair is completed and passed as airworthy. The workcard is the unit of work assigned to a particular inspector on one physical assignment, and can have a work content varying from one to eight hours, or perhaps longer. Typically, a workcard is expected to be completed by an inspector within a shift, although arrangements can be made for continuation across shifts. Because the workcard was taken as the unit of analysis, and given that a workcard can contain many inspection items, the count of workcards observed during the Task Analysis in fact includes a great quantity and variety of inspection tasks. As an example, the C-check workcard for detailed inspection of the empennage can include checks for broken or worn external parts (friction tabs), checks of each of several hundred rivets for integrity, checks for bumps, dents, buckling or other damage to skin, checks of freedom of movement of flight surfaces (elevators, rudder, time taps, servo tabs), checks of wear/play in activating cables or bushings, and checks for cracks or corrosion in internal structures.

TASK DESCRIPTION	VISDUAL EXAMPLE	NDI EXAMPLE
1. Initiate	Get workcard, read and understand area to be covered.	Get workcard and eddy current equipment, calibrate
2. Access	Locate area on aircraft, get into correct position.	Locate area on aircraft, position self and equipment
3. Search	Move eyes across area systematically. Stop if any indication.	Move probe over each rivet head. Stop if any indication.
4. Decision Making	Examine indication against remembered standards, e.g. for dishing or corrosion.	Re-probe while closely watching eddy current trace.
5. Respond	Mark defect, write up repair sheet or if no defect, return to search.	Mark defect, write up repair sheet, or if no defect, return to search.
6. Repair	Drill out and replace rivet.	Drill out rivet, NDT on rivet hole, drill out for oversize rivet.
7. Buyback Inspect	Visually inspect marked area.	Visually inspect marked area.

Table 3.1 Generic Task Description of Incoming Inspection with examples from visual and NDI inspection

From the Lock and Strutt (1985) report had come some detailed Task Descriptions of one particular inspection task (empennage inspection on B-707), and the Task Description/Task Analysis methodology used here was tested to ensure that it would cover such descriptions.

The methodology employed was to perform site visits to obtain detailed Task Descriptions. On a typical site visit, interviews with system participants at all levels helped to collect data on the structure and functioning of the system (e.g., organization, training) as well as collecting data on rare events such as system errors. Direct observations were performed by having human factors analysts work with an inspector during completion of a workcard. They followed the inspector, asking probe questions when necessary, and taking photographs to illustrate points such as lighting, field of view, access problems or appearance of discovered defects. Task Descriptions were then transcribed onto standard working forms (Figure 3.1), with a new page for each of the five steps in the generic task analysis. At a later time, knowledge of human factors models of inspection (e.g., Drury, 1984) and of the functioning of individual human subsystems (Sinclair and Drury, 1979) was used to list subsystems required (A, S, P, D, M, C, F, P in Figure 3.1) and any potential human / system mismatches under Observations in Figure 3.1 , to complete the Task Analysis.

TASK DESCRIPTION	TASK ANALYSIS									
	SUB - SYSTEMS									
	A	S	P	D	M	C	F	P	O	OBSERVATIONS
SEARCH										
For each vane, search for the following indications: 1. Trailing edge burning 2 Trailing edge bowing 3. Airfoil bulging 4. Missing vane inner rear foot 5. Broken vane mounting bolt 6. Tilt, measured between lines A and F	x	x	x		x					* Nos. 1,2,3,4,6 illustrated in NDT manual. No. 5 described, not illustrated. * No. 4 is called "missing are a inner lug" on diagram in NDT manual. * No "perfect" vane shown in NDT manual illustration. * If film does not cover area completely then high level of glare from open area of screen. * Some films may be slightly misaligned, masking vane trailing edges. * All defects have low contrast.
DECISION										
1.0 Measure trailing edge width for widest and narrowest on each film using calipers. Difference determines time to remove engine from service.	x	x	x	x	x	x				Edges not perfectly sharp, making measurement difficult. No specific decision rule for No. 1 trailing edge burning. Twisted inner lug defect shown on figure in NDT manual but no reference in text and no decision rule.
2.0 Measure Line A to F distance to get tilt (calipers). Tilt limit determines time to remove engine	x	x	x	x	x	x				Reading calipers may be difficult in darkened room.

A: Attention **S:** Senses **P:** Perception **D:** Decision **M:** Memory **C:** Control **F:** Feedback **P:** Posture

Figure 3.1 Examples of Task Analysis

In addition to this work, other NAARP activities were undertaken, including CAA/FAA liaison, STPG Human Factors in Aircraft Maintenance contributions, and delivery of papers at FAA/NAARP meetings (see Appendix A). All contributed to system understanding.

3.4 RESULTS AND DISCUSSION

The basic system description has already been presented in the Introduction, so that only examples of Task Analyses will be given here. The total numbers of workcards for which Task Analyses were performed are shown in Table 3.2, classified by aircraft general area or zone.

AREA INSPECTED	VISUAL INSPECTION	NDI INSPECTION
Fuselage : Internal	1. left fuselage skin longitudinal lap splice, B - 747 2. Lower lobe body skin longitudinal lap joint, B - 747 3. Cabin area inspection, B- 727 4. Tail compartment inspection, DC - 9	
Fuselage : External	1. RH fuselage area inspection, B- 747 2. Fuselage skin longitudinal lap splice, B- 747 3. Fuselage skin lower panel inspection, B - 737	1. Pressure bulkhead skin splice, eddy current inspection, DC- 9
Fuselage : Apartures	1. Passenger cabin aft entry door, B- 727 2. Lower cargo door, B- 727 3. RH co-pilot's window replacement buy-back, B- 737 4. RH window # 9, crazed window replacement, B-737	
Wings	1. Right hand wing landing gear, B-747 2. RH wing inboard/outboard flap track #6, ultrasonic, B-747 3. LH/RH wing honey comb pane, B-747 4. Right wing, DC-9 5. Left handling gear and well, DC- 9 6. Engine pylon fuse pin-bush migration, B-727 7. RH OTBD wing edge and controls, B-727 8. Right wing and leading edge, B-727	1. PH slat closing rib- borescope, B- 727 2. RH wing inboard/ outboard flap track # 6, ultrasonic, B- 747 3. Right inboard elevator actuator, radiographic isotope, DC-10
Empennage	1. LH/RH horizontal stabilizer and elevator, LH/RH vertical fin and rudder, DC-9 2. Vertical fin tip/tension/ horizontal attachment and elevator. B-727 3. Empennage inspection, B-727	
Power Plant		1. Diffuser case rear rail, eddy current inspection, B-747 2. Combustion chamber, borescope (enchanced visual), B-727 3. JT9D-7/7A isotope, B-727
TOTAL	**23**	**8**

TABLE 3.2 Workcard Followed for Detailed Task Analysis

No statistical sampling method was used to choose these particular tasks, rather the aim was to schedule visits when heavy inspection was taking place and follow one or more inspectors during the observation period. Interviews with inspectors helped to ensure that all aspects of inspection were covered. The aircraft types involved were Boeing 727, 737, and 747 types, and McDonnell Douglas DC-9 and DC-10's. Some engine inspections were observed where they contributed techniques of interest, e.g., borescope or X-ray film reading (Figure 3.1). With NDI tasks, the area of concentration was the strictly inspection activities, e.g., film reading, while the extensive safety procedures required to clear the area for film exposure were not recorded. Again, the aim was to discover sources of inspection error rather than aspects of system safety.

The following figures show the Task Analysis documents for a VI and a NDI procedure, respectively.

	TASK ANALYSIS									
	SUB - SYSTEMS									
TASK DESCRIPTION	A	S	P	D	M	C	F	P	O	OBSERVATIONS
INITIATE										
1.0 Supervisor briefs the inspectors.										
2.0 Assign specific tasks.										
3.0 Collect workcard from card rack.										
4.0 Read workcard.							x			o No feedforward regarding the tasks.
4.1 Read instructions.			x							o Key points missing.
4.2 Identify area to be inspected.			x		x		x			o Figure inadequate to aid in locating the area.

Attention: Number of time-shared tasks **Memory:** STSS, Working, Long-term **Senses:** Visual, Tactile, Auditory
Control: Continuous, Discret **Perception:** **Feedback:** Quality, Amount, Timing
Decision: Sensitivity, Criterion, Timing **Posture:** Reading, Forces, Balance, Extreme Angles

Figure 3.2a Task Analysis of Visual Inspection Procedure

TASK DESCRIPTION	TASK ANALYSIS									
	SUB - SYSTEMS									
	A	S	P	D	M	C	F	P	O	OBSERVATIONS
ACCESS										
1.0 Ensure that elevators and spoilers are in raised position.							x			o No prior information to inspector inspector regarding the opening of panels.
2.0 Ensure the opening of panels by maintenance.										
3.0 Ensure availability of ladder platform.									x	o Availability of ladder a problem.
4.0 Carry the ladder to the area and adjust the height.	x								x	o Stability of ladder poor.

A: Attention **S:** Senses **P:** Perception **D:** Decision **M:** Memory **C:** Control **F:** Feed-back **P:** Posture

Figure 3.2b Task Analysis of Visual Inspection Procedure

TASK DESCRIPTION	TASK ANALYSIS: SUB - SYSTEMS									
	A	S	P	D	M	C	F	P	O	OBSERVATIONS
SEARCH										
1.0 Inspect slat structure, wiring and installation.										
1.1 Check wear on male duct of telescopic shaft duct.										
1.1.1 Check wear by moving it and seing if it is loose.			x		x					o No prescribed force
1.2 Inspect slatwell area for corrosion and cracks.								x		o No standards for wear.
1.2.1 Hold flashlight such that light falls perpendicular to the surface.								x		o Holding flashing for a long period at odd positions-strenuous.
1.2.2 Visually look for cracks or corrosion.			x	x	x					o Lack of information on type of cracks and figures.
1.2.3 The visual indication confirmed by tactile and move scrutinized inspection.			x	x	x					
1.3 Look for play in slat actuator nut.										

Attention: Number of time-shared tasks **Memory:** STSS, Working, Long-term **Senses:** Visual, Tactile, Auditory
Control: Continuous, Discret **Perception:** **Feedback:** Quality, Amount, Timimg
Decision: Sensitivity, Criterion, Timimg **Posture:** Reading, Forces, Balance, Extreme Angles

Figure 3.2c Task Analysis of Visual Inspection Procedures

TASK DESCRIPTION	TASK ANALYSIS									
	SUB - SYSTEMS									
	A	S	P	D	M	C	F	P	O	OBSERVATIONS
SEARCH (Cont'd)										
1.3.1 Move it by applying force and see									x	o No gauses provided.
if there is play.			x							o No recommended force
			x	x	x					o No limits for accaptable play given.
2.0 Inspect fueling bay and installations.										
2.1 Open fueling bay door.										
2.2 Perform intensified inspection of fueling. adapter flange		x								
2.2.1 Hold flashlight at an angle (grazing incidence).		x					x			o The inspector was not very clear about what he was actually looking for.
2.2.2 Look for the evidence of bending or other deformation.		x						x		o No specific diagrams to aid him in this.
2.3 Re-install cover.										
3.0 Visually inspect wing span.										
3.1 Manually check the clamps.										

A: Attention **S:** Senses **P:** Perception **D:** Decision **M:** Memory **C:** Control **F:** Feed-back **P:** Posture

Figure 3.2d Task Analysis of Visual Inspection Procedure

TASK DESCRIPTION	TASK ANALYSIS: SUB - SYSTEMS A	S	P	D	M	C	F	P	O	OBSERVATIONS
SEARCH (Cont'd)										
3.1 Shake the clamps by applying force.			X							o Very subjective task.
			X	X						o No standards or procedures
								X		o Very cramped position.
3.2 Check for corrosion on fuel shutoff cable.										
3.2 1. Hold flash light perpendicular to the area.										
3.2.2 Look (feel) for signs of corrosion.										
3.3 Look (feel) for softness in the panels.										
3.3.1 Tap the panel using a coin.										
3.3.2 Look for change in sound.				X					X	o No training of inspector to look for change of sound.
4.0 Inspect upper side of wing.										
4.1 Inspect the wing using belt attachment.										o Made the inspector free from safety hazard.

Attention: Number of time-shared tasks **Memory:** STSS, Working, Long-term **Senses:** Visual, Tactile, Auditory
Control: Continuous, Discret **Perception:** **Feedback:** Quality, Amount, Timimg
Decision: Sensitivity, Criterion, Timimg **Posture:** Reading, Forces, Balance, Extreme Angles

Figure 3.2e Task Analysis of Visual Inspection Procedure

TASK DESCRIPTION	A	S	P	D	M	C	F	P	O	OBSERVATIONS
SEARCH (Cont'd)										
4.2 Visually look for loose rivets or cracks.										
4.2.1 Hold flashlight at grazing or angular incidence.			x						x	o No prescribed method on workcard.
4.2.2 Feel for loose rivets.			x	x						o No prescribed force.
4.2.3 Feel for missing rivets.									x	o All this resulted in a cursory check
4.3 Look for signs of erosion due to contact between slat and the upper wing.										
4.4 Check for faults in the honecomb panel.										
4.4.1 Tap using a coin.										
4.4.2 Look for change in sound.									x	o External noise made listening difficult and inspector had to liosten very carefully.
5.0 Inspect leading edge flap and flapwell structure.										

(The column heads A–O stand under the printed headings TASK ANALYSIS and SUB - SYSTEMS.)

A: Attention **S:** Senses **P:** Perception **D:** Decision **M:** Memory **C:** Control **F:** Feed-back **P:** Posture

Figure 3.2f Task Analysis of Visual Inspection Procedure

TASK DESCRIPTION	TASK ANALYSIS: SUB - SYSTEMS									
	A	S	P	D	M	C	F	P	O	OBSERVATIONS
SEARCH (Cont'd)										
5.1 Visually check for signs of corrosion in flap hinge fitting.										
5.2 Check for cracks in hinge attachment and torque tiffes.										
5.2.1 Hold the flashlight such that area. is well lit.								x		o The space was very cramped. The inspector had difficulty in holding the flashlight.
5.2.2 Perform a tactile and visual inspection.									x	o This resulted in a very cursory inspection.
5.3 Visually check for leakage in hydrolic lines.		x	x	x						o No prescribed method on the workcard.
5.4 Look for signs for deterioration of switch wing.										
5.4.1 Use a scale to reach the wiring.										
5.4.2 Look for signs of looseness by pulling.									x	o This was not mentioned.
5.4.3 Look for trays visually and with hand									x	o This was not mentioned on the workcard.

Attention: Number of time-shared tasks **Memory:** STSS, Working, Long-term **Senses:** Visual, Tactile, Auditory
Control: Continuous, Discret **Perception:** **Feedback:** Quality, Amount, Timimg
Decision: Sensitivity, Criterion, Timimg **Posture:** Reading, Forces, Balance, Extreme Angles

Figure 3.2g Task Analysis of Visual Inspection Procedure

TASK DESCRIPTION	TASK ANALYSIS									
	SUB - SYSTEMS									
	A	S	P	D	M	C	F	P	O	OBSERVATIONS
DECISION										
1.1.1 Decide if wear exists			x	x	x					
1.2.2, 1.2.3 Decide if cracks or corrosion exists.			x	x	x					
1.3.1 Decide if play exists.			x	x						
3.1.2 Decide if looseness or wear is unacceptable.			x	x	x					
4.2 2 Decide if the rivet is loose.			x	x						
4.4.2 Decide if there is a change in the sound.			x	x	x				x	
5.4 Decide if wiring has any signs of deterioration.		x	x	x	x					

A: Attention **S:** Senses **P:** Perception **D:** Decision **M:** Memory **C:** Control **F:** Feedback **P:** Posture

Figure 3.2h Task Analysis of Visual Inspection Procedure

TASK DESCRIPTION	TASK ANALYSIS									
	SUB - SYSTEMS									
	A	S	P	D	M	C	F	P	O	OBSERVATIONS
ACTION AFTER										
1.0 Mark all the faults, fault by fault with a sticker having a discrepancy card number.										
2.0 At the end fill out the discrepancy workcard using stickers as memory aids.					x					o Memory call since the inspector had a tendency to forget about the exact nature of fault.
									x	o A lot of time was spent in phrasing the discrepancy card. The inspector was uncomfortable with the filling out of the discrepancy workcard (training issue).
3.0 If the task was not completed fill out the work interrupt card giving the status of items started but not signed off.									x	o The next person does not get a copy of the workload/ discrepancy card of the previous inspector.
4.0 Close workcard.										

Attention: Number of time-shared tasks **Memory:** STSS, Working, Long-term **Senses:** Visual, Tactile, Auditory
Control: Continuous, Discret **Perception:** **Feedback:** Quality, Amount, Timimg
Decision: Sensitivity, Criterion, Timimg **Posture:** Reading, Forces, Balance, Extreme Angles

Figure 3.2i Task Analysis of Visual Inspection Procedure

	TASK ANALYSIS									
	SUB - SYSTEMS									
TASK DESCRIPTION	A	S	P	D	M	C	F	P	O	OBSERVATIONS
INITIATE										
1.0 Collect workcard from the supervisor.							x			o Workcard did not provide any feedforward information (i.e. whether earlier defects had been found on this engine).
2.0 Read workcard.		x	x							o Inspector did not refer to workcard at this stage. o Inspector was experienced and did not feel it was necessary to consult the workcard.
3.0 Collect equipment necessary to perform inspection in the workcard.										
4.0 Calibrate the instrument.										
4.1 Apply a layer of tape to the surface of the probe.										
4.2 Connect the probe to the instrument and switch the instrument on.										

A: Attention **S:** Senses **P:** Perception **D:** Decision **M:** Memory **C:** Control **F:** Feed-back **P:** Posture

Figure 3.3a Task Analysis of NDI Procedure

TASK DESCRIPTION	TASK ANALYSIS									
	SUB - SYSTEMS									
	A	S	P	D	M	C	F	P	O	OBSERVATIONS
INITIATE (Cont'd)										
4.3 Set the operation mode on the instrument to FE (material of rail).				x						o Workcard calls for a sufficient (does not specify exact time) warm-up period after instrument is switched on. This procedure was not followed by the inspector in this case.
4.4 Place the probe on the standard template and lift off the compensate probe on the area away from the Elox slot (simulated defect).										
4.5 Move the probe over the standard.										
4.6 Observe the defection of the meter.										
4.7 Adjust sensitivity to give a 40% of full scale deflection.										
4.8 Observe the deflection as probe passes over the simulated defect.										
4.9 Observe the deflection for sensors " A" and "B" by passing over the Elox slot.										

Attention: Number of time-shared tasks **Memory:** STSS, Working, Long-term **Senses:** Visual, Tactile, Auditory
Control: Continuous, Discret **Perception:** **Feedback:** Quality, Amount, Timimg
Decision: Sensitivity, Criterion, Timimg **Posture:** Reading, Forces, Balance, Extreme Angles

Figure 3.3b Task Analysis of NDI Procedure

TASK DESCRIPTION	TASK ANALYSIS									
	SUB - SYSTEMS									
	A	S	P	D	M	C	F	P	O	OBSERVATIONS
ACCESS										
1.0 Verify with supervisor that engine is cool										
2.0 Go to inspection site.										
2.1 Check engine covers are open.									x	0 The engine covers had to be opened by maintenance
2.2 Verify no interferring parallel work in progress.									x	0 Parallel work in progress delayed inspection and also caused interruptions that disrupted continuity.
3.0 Inspector climbs on to the construction at site.										
4.0 Transfer NDT equipment to site on to the platform by the engine.										

A: Attention **S:** Senses **P:** Perception **D:** Decision **M:** Memory **C:** Control **F:** Feedback **P:** Posture

Figure 3.3c Task Analysis of NDI Procedure

TASK DESCRIPTION	TASK ANALYSIS									
	SUB - SYSTEMS									
	A	S	P	D	M	C	F	P	O	OBSERVATIONS
INSPECT										
1.0 Recalibrate the instrument to take into account the material difference between the standard and the rail.									x	o Recalibration procedure not documented in the workcard. o (Inspector perceived that there was a material difference between the standard and the rail.)
1.1 Move probe over rail edge (simulating a crack)										
1.2 Adjust deflectometer to get a 40% deflection.										
2.0 Insert flexible rod through the external just aft of the rear rail.										
3.0 Feed the rod clockwise around the engine until rod end visible at location "B".								x		o Inspector's work hampered due to difficulty in reaching the rear rail. o Poor lighting conditions.
4.0 Disconnect patch cord from the probe and attach the longest end of the probe cable to the rod.								x		o The task demands inspector to adopt uncomfortable work postures.

Attention: Number of time-shared tasks **Memory:** STSS, Working, Long-term **Senses:** Visual, Tactile, Auditory
Control: Continuous, Discret **Perception:** **Feedback:** Quality, Amount, Timimg
Decision: Sensitivity, Criterion, Timimg **Posture:** Reading, Forces, Balance, Extreme Angles

Figure 3.3d Task Analysis of NDI Procedure

TASK DESCRIPTION	TASK ANALYSIS									
	SUB - SYSTEMS									
	A	S	P	D	M	C	F	P	O	OBSERVATIONS
INSPECT (Cont'd)										
5.0 Move the rod in counterclock-wise directions until the cable end was seen at location "A".						x				o Lot of coordination is required on the port of the inspection to prevent it slipping from the groove.
6.0 Disconnect the cable from the rod and attach to the spring connector to complete wrap around.										
7.0 Assume that matching contours of probe are in contact with core by feeling probe movement.										
8.0 Attach patch core to probe and lift off the compensate probe.										
9.0 Slide probe clockwise traversing the rail to the rear of port # 8.										
10.0 Monitor the meter for rapid needle movements.	x							x		o Meter placed by the side of the inspector (rail is straight up front) making it difficult. for the inspector to monitor the meter continuously for deflections (attention problem).
11.0 Inspect similar area`of port #9 and remaining eight ports.										
12.0 Rotate Probe assembly counter-clockwise up to the original location of wrap around.										
13.0 Check for meter defections.										

A: Attention **S:** Senses **P:** Perception **D:** Decision **M:** Memory **C:** Control **F:** Feedback **P:** Posture

Figure 3.3e Task Analysis of NDI Procedure

	TASK ANALYSIS									
	SUB - SYSTEMS									
TASK DESCRIPTION	A	S	P	D	M	C	F	P	O	OBSERVATIONS
DECISION										
1.0 If crack present indicated by rapid full scale deflection of the meter, move probe back and forth over this area.	x				x					o Possibility of inspector making an error is increased as he has to time share between the two activities: 1. Motor control of probe movements. 2. Monitoring of display for deflections.
2.0 Rules for decisions.										
2.1 One full scale deflection is an "A" crack.						x				o Speed with which the probe is involved over the rail is critical.
2.2 Two full scale deflections is a "B" crack.										o Possibility of missing a crack if the movement speeds exceeds critical speed and inspector fails to fixate at that instant.
2.3 Three full scale deflections is a " C" crack.						x				o No storage of deflections. o High cost of FA for "C". cracks makes holding of a proper payoff matrix for decision making critical.

A: Attention **S:** Senses **P:** Perception **D:** Decision **M:** Memory **C:** Control **F:** Feedback **P:** Posture

Figure 3.3f Task Analysis of NDI Procedure

TASK DESCRIPTION	TASK ANALYSIS: SUB - SYSTEMS: A	S	P	D	M	C	F	P	O	OBSERVATIONS
ACTION AFTER										
1.0 Disconnect patch cord and cable attachment at the spring and probe.							x			o If there is a "C" crack present the inspector gets immediate feedback. o No feedback provided in case of "A" and "B" crack.
2.0 Extract rod from rear rail by pulling cable clockwise.										
3.1 If fault detected is "C" crack notify supervisor and maintenance immediately fill out discrepancy workcard.										
3.2 If fault detected is a "B" crack notify supervisor and mention this in the workcard.										
3.3 If fault detected is a "A" crack mention this in the workcard.										

A: Attention **S:** Senses **P:** Perception **D:** Decision **M:** Memory **C:** Control **F:** Feedback **P:** Posture

Figure 3.3g Task Analysis of NDI Procedure

It would be pointless to provide over thirty such analyses, as they are the equivalent of raw data in an observational study such as this. Rather, it was necessary to devise a methodology for integrating the findings, particularly the observations, which would lead towards discovering human/system mismatches.

However, it became apparent that the observations listed were those which occurred to the analysts during system observation and subsequent analysis. A more comprehensive way was required for detecting mismatches. It was decided to use a schema for classifying errors which was initially developed to aid the STPG process, and which has been further developed as part of the second year of the GSC/NAARP endeavor. This consisted of expanding each of the task steps given in the generic Task Description (Table 3.1) into its logically-necessary substeps, and for each substep to list all of the failure modes, similar in concept to those of Failure Modes and Effects Analysis (FMEA), for example Hammer, 1985. The current list is shown as below.

Table 3.3a

TASK	ERRORS	OUTCOME
TASK 1 - INITIATE		
1.1 Correct instructions written.	1.1.1 Incorrect instructions. 1.1.2 Incomplete instructions. 1.1.3 No instructions available.	Inspector has correct and correctly working equipment, and unserstands instructions.
1.2 Correct equipment procured.	1.2.1 Incorrect equipment. 1.2.2 Equipment not procured.	
1.3 Inspector gets instructions	1.3.1 Fails to get instructions.	
1.4 Inspector reads instructions	1.4.1 Fails to read instructions. 1.4.2 Partially reads instructions.	
1.5 Inspector understands instructions.	1.5 .1 Fails to understand instructions. 1.5.2 Misinterprets instructions. 1.5.3. Does not act on instructions.	
1.6. Correct equipment available.	1.6.1 Correct equipment not available. 1.6.2 Equipment is incomplete. 1.6.3 Equipment is not working.	
1.7 Inspector gets equipment.	1.7.1 Gets wrong equipment. 1.7.2 Gets incomplete equipment. 1.7.3 Gets non-working equipment.	
1.8 Inspector check/ calibrates equipment.	1.81 Fails to chekc/ calibrate. 1.8.2 Checks/calibrates incorrectly.	

TABLE 3.3 Task and Error Taxonomy for Inspection.

Table 3.3a Task and Error Taxonomy for Inspection

Table 3.3b

TASK	ERRORS	OUTCOME
TASK - ACCESS		
2.1 Locate area to inspect	2.1.1 Locate wrong aircraft. 2.1.2 Locate wrong area on aircraft. 2.1.3 Mis-locate boundaries of area.	Inspector with correct equipment at correct inspection site, is ready to begin inspection.
2.2 Area is ready to inspect.	2.2.1 Cleaning work is not completed. 2.2.2 Cleaning work is incorrect. 2.2.3 Maintenance access tasks area not completed. 2.2.4 Maintenance access tasks are incorrect. 2.2.5 Parallel work prevents access. 2.2.6 Parallel work impedes inspection.	
2.3 Access area to inspect.	2.3.1 Access equipment is not available. 2.3. 2 Incorrect access equipment. 2.3.3 Access equipment is poorly designed. 2.3.4 Access is not physically possible. 2.3.5 Access is discouragingly difficult. 2.3.6 Access is dangerous to inspection.	

TABLE 3.3 Task and Error Taxonomy for Inspection (cont'd)

Table 3.3b Task and Error Taxonomy for Inspection

Table 3.3c

TASK	ERRORS	OUTCOME
TASK 3 – SEARCH*		
3.1 Move to the next lobe.	3.1.1 Misses parts of access area. 3.1.2 Multiple searches of parts. 3.1.3 It is too close or far between lobes. 3.1.4 Move to non-required area.	All indications located in all access areas.
3.2 Enhance lobe (e.g. illuminate, magnify for vision, use dye penetrant, tap for auditory inspection).	3.2.1 Enhance wrong area. 3.2.2 Enhance area inadequately. 3.2.3 Fail to use enhancing equipment.	
3.3 Examine lobe.	3.3.1 Fail to examine lobe. 3.3.2 Examine for too short or long time. 3.3.3 Incorrect depth of examination. 3.3.4 Incomplete examination of lobe. 3.3.5 Fatigue from a fixed posture.	
3.4 Sense indication in robe.	3.4.1 Fail to attend to lobe. 3.4.2 Fail to use cues present. 3.4.3 Fail to sense indication. 3.4.4 Sense wrong indication.	

* **Note:** Search proceeds by successively examining each small area, called here a LOBE, within a single area accessible without performing a new access, called here an ACCESS AREA. When all lobes have been examined in that access area, a new access is performed followed by a new search. The concept of a lobe comes from visual search where it is called a VISUAL LOBE. Here it is generalized to include the area felt by a tactile inspection, the area probed by tapping in an auditory inspection, and the area covered by the probe of an eddy current or ultrasonic device and seen on its screen.

TABLE 3.3 Task and Error Taxonomy for Inspection.

Table 3.3c Task and Error Taxonomy for Inspection

<u>Table 3.3d</u>

TASK Task 3 (cont'd)	ERRORS	OUTCOME
3.5 Match indication against list.	3.5.1 Match against faults not listed. 3.5.2 Fail to match against full list. 3.5.3 Incorrect match.	
3.6 Remember matched indication.	3.6.1 Fail to record matched indication. 3.6.2 Forget matched indication.	
3.7 Remember lobe location.	3.7.1 Fail to record lobe location. 3.7.2 Forget lobe location.	
3.8 Remember access area location.	3.8.1 Fail to record access area location. 3.8.2 Forget access area location.	
3.9 Move to next access area.	3.9.1 Miss parts of area. 3.9.2 Multiple searches of parts. 3.9.3 Move to non-required area.	
TASK 4 - DECISION		
4.1 Interpret indication.	4.1.1 Classify as wrong fault type.	All indications located are correctly classified, correctly labelled as fault or no fault, and actions correctly planned for each indication.

TABLE 3.3 Task and Error Taxonomy for Inspection.

Table 3.3d Task and Error Taxonomy for Inspection

Table 3.3e

TASK	ERRORS	OUTCOME
Task 4 (cont'd)		
4.2 Access measuring equipment.	4.2.1 Choose wrong measurement equipment. 4.2.2 Measurement equipment is not available. 4.2.3 Measurement equipment is not working. 4.2.4 Measurement equipment is not calibrated. 4.2.5 Measurement equipment is wrong calibration. 4.2.6 Does not use measurement equipment.	
4.3 Access comparison standard.	4.3.1 Choose wrong comparison standard. 4.3.2 Comparison standard is not available. 4.3.3 Copmarison standard is not correct. 4.3.4 Comparison standard is incomplete. 4.3.5 Does not use comparison standard.	
4.4 Decide on if it is a fault.	4.4.1 Type 1 error, false alarm. 4.4.2 Type 2 error, missed fault.	

TABLE 3.3 Task and Error Taxonomy for Inspection (cont'd)

Table 3.3e Task and Error Taxonomy for Inspection

<u>Table 3.3f</u>

TASK	ERRORS	OUTCOME
Task 4 (cont'd)		
4.5 Decide on action.	4.5.1 Choose wrong action. 4.5.2 Second openion if not needed. 4.5.3 No second opinion if needed. 4.5.4 Call for buy-back when not required. 4.5.5 Fail to call for required buy-back.	
4.6 Remember decision/ action.	4.6.1 Forget decision/ action. 4.6.2 Fail to record decision/ action.	
TASK 5 - RESPOND*		
5.1 Mark fault on aircraft.	5.1.1 Fail to mark fault. 5.1.2 Mark non-fault. 5.1.3 Mark fault in wrong place. 5.1.4 Mark fault with wrong tag. 5.1.5 Mark fault with wrong marker.	All faults and repair items are correctly recorded.

* Note: In some contexts, the only record of a fault is in the repair action. Both 5.2 and 5.3 have been included above to indicate that there may be some faults which should be recorded even though no repair action is needed at that inspection period.

TABLE 3.3 Task and Error Taxonomy for Inspection (cont'd)

Table 3.3f Task and Error Taxonomy for Inspection

Table 3.3g

TASK	ERRORS	OUTCOME
Task 5 (cont'd)		
5.2 Record fault.	5.2.1 Fail to error fault. 5.2.2 Record non-fault. 5.2.3 Record fault in wrong place. 5.2.4 Record fault incorrectly.	
5.3 Write repair action.	5.3.1 Fail to write repair action. 5.3.2 Write repair action for non-fault. 5.3.3 Write repair action for wrong place. 5.3.4 Mis-write repair action. 5.3.5 Specify buy-back if not needed. 5.3.6 Fail to specify needed buy-back.	
TASK 6 - REPAIR		
6.1 Repair fault.	6.1.1 Fail to repair fault. 6.1.2 Repair non-fault. 6.1.3 Mis-repair fault. 6.1.4 Prevent access for buy-back.	All recorded faults correctly repaired and accessible for buy-back inspection.

TABLE 3.3 Task and Error Taxonomy for Inspection (cont'd)

Table 3.3g Task and Error Taxonomy for Inspection

Table 3.3h

TASK	ERRORS	OUTCOME
Task 7 (cont'd)		
7.1 Initiate.	7.1.1 Fail to call inspector. 7.1.2 Call inspector when not needed. 7.1.3 Inspector fails to initiate, see (1). 7.1.4 Initiates buy-back out of sequence. 7.1.5 Misreads record of fault.	All repaired items corretly assessed at buy-back, and results recorded correctly.
7.2 Access.	7.2.1 Inspector fails to access, see (2).	
7.3 Search .	7.3.1 Inspector fails to locate, see (3).	
7.4 Decision.	7.4.1 Inspector accepts faulty repair. 7.4.2 Inspector rejects good repair. 7.4.3 Inspector fails to get second opinion.	
7.5 Respond.	7.5.1 Fails to record buy-back. 7.5.2 Records wrong buy-back. 7.5.3 Records buy-back incorrectly.	

TABLE 3.3 Task and Error Taxonomy for Inspection (cont'd)

Table 3.3h Task and Error Taxonomy for Inspection

This list formed the basis for classifying each observation by how it could cause a failure of the inspection system. What was found, when these were counted, was that many of them involved factors which would tend to increase the probability of errors, rather than strictly leading to an error in a single step. Table 3.4 shows how these observations were classified.

	HUMAN SUBSYSTEM								
TASK	A	S	P	D	M	C	F	Ps	O
1. INITIATE	1	4	39	12	34	0	12	0	6
2. ACCESS	0	11	4	0	3	0	0	32	27
3. SEARCH	10	45	47	36	31	3	1	8	1
4. DECISION	0	86	105	118	79	0	0	0	0
5. RESPOND	0	6	0	0	5	0	0	6	5
(6. REPAIR)	—	—	—	—	—	—	—	—	—
7. BUY-BACK	0	0	2	2	2	0	0	0	0

Table 3.4 Number of Instances of Human Factors Implications From Task Analysis
(Note: A single task step may generate more than one human factors implication.)

Table 3.4 Number of Instances of Human Factors Implications From Task Analysis

3.4.1 Potential Human/System Mismatches

The most obvious way was to form a data base of all of these observations, so that they could be counted and listed in various ways. Such a data base was indeed constructed using the REFLEX package, and is available upon request.

Note the large numbers of postural and other (mainly environmental) implications for Access, and the high numbers of cognitive implications for Initiate, Search, and Decision. For Access, the implications mainly concern the physical difficulties of reaching and viewing the inspection site. Inadequate work platforms, limited space inside aircraft structures, the awkward postures required to hold a mirror and a flashlight for visual access, and the often non-optimal levels of glare, temperature/humidity, and ambient noise all contribute. For Initiate, the major difficulties are with the content and layout of the workcards, calibration standards for the NDI equipment, NDI equipment human/machine interface inadequacies, and coordination of inspection activities with other aspects of maintenance. Search implications were largely visual (for sensing) due to inadequate lighting at the workpoint, but also included omissions of specific feedforward and directive information on the workcard, and lack of memory aids for Search. For Decision, the major difficulties were in obtaining and applying standards at the inspection point for each defect found.

While it provides evidence for opportunities for error, Table 3.4 naturally misses some of the ergonomic detail required if Human Factors expertise is to contribute to improved inspection. However, it does serve to emphasize that not all errors lead to failure to detect a defect. Three types of errors are possible in an inspection system (e.g., Drury, 1984).

1. Type 1 error: a non-defect is classified as a defect and unnecessary repairs are thus undertaken.
2. Type 2 error: a defect is not recorded, so that necessary repairs are not undertaken.
3. Delays: the inspection process is delayed or interrupted, leading to longer inspection/ repair periods.

Although only Type 2 errors have a direct impact upon airworthiness, the other two errors can have an indirect effect, both by frustrating the inspector, and by directing resources away from the critical tasks. It needs to be pointed out that Type 2 errors can occur in multiple ways. Indeed, a Type 2 error will only not occur if all of the steps in the Task Descriptions are carried out correctly. That is, the correct initial actions must be undertaken, the correct area accessed, the search must locate the indication, the correct decision that the indication is indeed a defect must be made, the correct response of writing up and marking the defect must occur, repair must be carried out correctly, and the buy-back decision must be correct. For Type 2 errors, the inspection/repair system is a parallel system, which naturally increases the probability of a Type 2 error. If $P1^2$ through $P7^2$ represent the probabilities of correct performance at each of the seven stages in the presence of a defect, then the probability of Type 2 errors is: (see Equation 1)

$$e_2 = 1 - \prod_{i=1}^{7} (1 - P^2_i)$$

Equation 1

For Type 1 errors and delays, error recovery is possible at each step, so that the only way in which an error can be made is if all steps are performed incorrectly. Thus, the probability of a type 1 error delay is: (see Equation 2) where Pi^1 is the probability of correct performance of each step in the absence of a defect. Clearly, no matter how rare Type 2 errors are, decreasing them further means improving the reliability of each step in the inspection process.

$$e_1 = \prod_{i=1}^{7} (1 - P^1_i)$$

Equation 2

Against these three possible errors, the role of human factors is to change the human/machine system so as to reduce the error incidence, that is to make the system more reliable. These are only two possible interventions: changing the system to fit the human inspector, or changing the human inspector to fit the system. The former has long been the province of ergonomics/human factors, with interface design receiving a prominent place. The latter, primarily selection, placement and training, has also been a concern of human factors engineers, but other disciplines (such as industrial psychology and educational psychology) have contributed. A more reasonable view than the advocacy of either as an alternative is to consider both as complementary aspects of achieving enhanced human/system fit. This fit is necessary both to ensure performance and to reduce the stresses on the human due to mismatches (Drury, 1989). Human stresses can, in turn, effect human performance in inspection tasks (Drury, 1986). Thus, the goal of the human factors effort in NAARP can be restated as choosing the optimum intervention strategy (changing the system or the human) to minimize human/system mismatches at each task step, so that the incidence of error is reduced.

3.4.2 Choice of Intervention Strategies

A major review of the field of human factors in inspection (Drury, 1990b) concludes that the practical potential for improvement due to selection and placement of inspectors is low, but that training and system redesign are particularly effective. With this in mind, Table 3.5 was produced part way through the current project, showing potential interaction strategies for improving inspection performance. As can be seen, only the first five steps of the inspection task are included, and potential improvements rather than specific prescriptions are given. There is, however, enough detail to compile lists of human factors interactions which can proceed rapidly based on existing human factors knowledge, and those interaction strategies which require more research before detailed prescriptive advice can be given. It should be noted that even in the absence of direct human factors advice, many system improvements have been, and will continue to be, implemented by inspection organizations. Improvement is a continuous process in an industry with a long record of innovation, so that it should not be surprising that there are few improvements which can be implemented with no additional effort. For example, there is an urgent need (recognized both in this study and the (Lock and Strutt study) for improved portable task lighting. However, without at least a short study, it will not be possible to give the make and model number of the best flashlight currently on the market. Some interventions can be immediate, for example replacing workcards which are entirely written in capital letters with ones using both upper case and lower case fonts. Still other interventions require major studies, for example designing an integrated information environment for the inspector.

STRATEGY		
TASK STEP	**CHANGING INSPECTOR**	**CHANGING SYSTEM**
Initiate	-Training in NDI calibration (procedures training)	-Redesign of job cards -Calibration of NDI equipment -Feedforward of expected flaws
Access	-Training in area location (Knowledge and recognition training)	-Better support stands -Better area location system -Location for NDI equipment
Search	-Training in visual search (cueing, progressive- part)	-Task lighting -Optical aids -Improved NDI templates
Decision	-Decision training (cieing feedback, understanding of standards)	-Standards at the work poing -Patterm recognition job aids -Improved feedback to inspection
Action	-Training wtriting skills	-Improved fault marking -Hands-free fault recording

Table 3.5 Potential Stratagies for Improving Inspection

Table 3.5 Potential Strategies for Improving Inspection

Key areas requiring intervention are those listed in Section 3.4.1 and in Table 3.5. It is possible to use the human factors knowledge of inspection processes to help generate and classify interventions. For example, Drury, Prabhu and Gramopadhye (1990) used earlier knowledge of search and decision-making (Drury, 1984) to list the following interventions aimed at system (rather than human) changes:

1. Increasing visual lobe size in search-lighting, contrast, target enhancement, optical aids, false colors on video.
2. Improving search-briefing/feedforward, aids to encourage systematic search.
3. Enhancing fault discriminability-standards at the workplace, rapid feedback.
4. Maintaining correct criterion-recognition of pressures on inspection decisions, organization support system, feedback.

The list can be extended to include redesign of the system for better access and improved inspectability (Drury, 1990c).

3.4.3 Short-Term Interventions

From all of these ways of generating and classifying interventions, the following can be listed as short-term interventions to overcome stated mismatches. Note that the two major issues of the information environment and training design are given more complete treatments later, taken from (Drury 1990a) and Drury and Gramopadhye (1990), respectively.

3.4.3.1 Initiate

3.4.3.1.1 Design of Worksheets

Even within this relatively homogeneous sample of major air carriers, there was considerable variability in Workcards, or Job Cards. Many were now computer-printed, reducing earlier problems of copy legibility, but some were generated by computer systems lacking graphics capabilities. For these, the graphics necessary for location and inspection were attached from other sources, often with imperfect matching of nomenclature for parts and defects between workcard and secondary source material. These additional cards were often from microfiche, which has poor copy quality and a shiny surface, making reading on the job difficult. Other cards were all in capitals, a known violation of human factors principles. Still others did not call out particular faults using the latest information on that aircraft type. There were differences in level and depth between different workcard systems, and none attempted to provide layered information, so that those familiar with a particular inspection could use more of a checklist, while back-up information would be available to those who had not performed that particular inspection recently. Some systems did, however, have an integrated "Inspector's Clipboard" which had a place for the workcard, Non-Routine Repair cards and other necessary paperwork, in a package convenient for carrying at the worksite.

Short-term interventions for workcards thus include:

1. Changing the format and font to improve ease of use and legibility.
2. Ensuring that visual material is incorporated into the workcard.
3. Consistent naming of parts, directions, defects, and indications between all documents used by inspectors.
4. Multi-level workcard systems, useable by inspectors with different levels of immediate familiarity with the worksheet content.
5. A better physical integration between the workcard and the inspector's other documents and tools needed at the worksite.

3.4.3.1.2 NDI Equipment Calibration

The calibration procedures used for NDI equipment involve a human/machine interface on the equipment, one or more calibration standards, and a knowledgeable inspector. Potential mismatches were seen in all three areas. The following are recommended in the short term:

1. Better labelling and control of all calibration standards, as is common in manufacturing industry. An inspector must know which standard is being used and be assured that the standard is still valid. Procedures are available for standards control: most (but not all) inspection systems in the sample appeared to follow them.

2. Improved human/NDI instrument interface designs standard texts on human factors (e.g., Salvendy, 1987) have considerable information on interface design to reduce error: this information needs to be used. As NDI equipment incorporates more computer functions, the data on human-computer interaction (e.g., Helander, 1988) becomes crucial to design. Any design improvements in the human interface will also benefit the Search and Decision tasks.

3. Design the NDI interface for multiple levels of inspector familiarity. In many organizations, NDI is not a full-time job, so that many inspectors have considerable time periods between repetitions of a particular NDI procedure. They obviously require a different level of guidance from the interface than inspectors who perform the same calibration each day. Multiple levels of user need to be considered, as at present there is a marked tendency for the inspector to rely on knowledge of other inspectors to perform the calibration.

3.4.3.2 Access

3.4.3.2.1 Provide better support stands

Custom-made stands for each area of each aircraft type are expensive and difficult to store when not in use, but they do provide a security for the inspector, and optimum accessibility for each task. In large facilities dedicated to a homogeneous fleet, such stands are almost always provided, but there are exceptions. Cherrypickers are used for some surfaces, despite their control difficulties (poor control/display relationships) and their unsteady working platforms. Scaffolding and stairs are used (at times) which would not be allowed by safety departments in most manufacturing industries. Without adequate support stands, access is jeopardized and pressures are placed on the inspector to minimize the time spent inspecting. Both can directly cause inspection errors. For each worksheet, there should be an optimally-designed support stand specified and available.

3.4.3.2.2 Better area location system

Much time is wasted, and occasionally errors are caused, because the inspector cannot positively locate parts of the area to be inspected. Some task cards have no diagrams, and rely on written instructions: others have diagrams that can mislead the inspector when searching for the area to be inspected. The inspector needs clear instructions to reach the area, and clear confirmation that the correct area has indeed been reached. These can be provided simply in the worksheets, but for aircraft which are always precisely located in the maintenance hangar, more elaborate electronic or optical location systems are possible.

3.4.3.2.3 Better locations for NDI equipment

When the inspector needs to use NDI equipment, there is often no convenient place to put the equipment during the inspection process. The inspector must frequently place the equipment (with its associated display) out of convenient sight lines. This makes it particularly difficult to perform the inspection and simultaneously read the display: errors are to be expected in such situations. Design of stands (Section 3.4.3.2.1 above) should include provision for location of NDI equipment as part of the workstand.

3.4.3.3 Search

3.4.3.3.1 Improved lighting

The factors affecting the conspicuity of a defect are defect size, defect/background contrast, and lighting intensity. The latter two are functions of the lighting and can be improved without changing the aircraft design. Defect/background contrast is a function of the angles between the inspector's eye, the defect, and any light sources. In general, an adequate level of illumination needs to be provided at the inspection point, with levels of 500-1000 lux being typically recommended. However, the distribution of the light is at least as important as its intensity. For example, glare drastically reduces visual performance, and can be caused by any objects or areas in the visual field higher in luminance than the area immediately surrounding the defect. Thus, open hangar doors, roof lights, or even reflections off the worksheet can cause glare. Of particular concern is that in inspecting partially-hidden areas (e.g., inside door panels), the lighting used to illuminate the defect may cause glare from surrounding surfaces. Carefully designed combinations of general area lighting, portable area task lighting, and localized spotlighting need to be produced. At least as an interim measure, the flashlights used by inspectors need to be standardized within an organization, and training is needed in how to use the flashlight correctly.

3.4.3.3.2 Optical enhancement

Any device which increases the conspicuity of the defect can be classified as an optical enhancement. Thus, dye penetrant and magnetic particular inspection techniques fall under this heading. However, it is now possible to use the control inherent in video cameras and monitors to enhance luminance contrast, and to optimize color contrast. With a computer between the camera and the monitor, it should be routinely possible in the future to use false colors in the image presented to the inspector to increase defect conspicuity. Borescopes with video monitors are currently available to begin this process, but research will be needed to optimize such systems for defect detection.

3.4.3.3.3 Improved NDI templates

With NDI techniques such as Eddy Current or Ultrasonics inspection, location of a probe on the inspected surface is critical. At present, some use is made of what would be termed jigs or fixtures in manufacturing industry to aid this accurate positioning process. An example is the use of circular hole templates to guide the Eddy Current probe ground, the heads of rivets in lap splice inspection. With such a device, the need for the inspector to perform an accurate control task at the same time as attending to the display is removed, with an attendant reduction in the opportunity for error. Note that the template should not require a second hand to keep it in place, as the inspector may not be able to maintain balance or reset the equipment if both hands are occupied.

3.4.3.4 Decision

3.4.3.4.1 Standards at the work point

It has been known for many years that if comparison standards are available at the work point, more accurate inspection will result. Yet in many cases such standards are not available to the aircraft inspector. If the maximum allowable depth of a wear mark is given as 0.010 inches, there is neither a convenient way to measure this, nor a readily available standard for comparison. Other examples are play in bearings and cable runs, areas of corrosion, or looseness of rivets. All are considered to be "judgement calls" by the inspector, but simple job aids, perhaps as part of the worksheet, or standard inspection tools, would remove a source of uncertainty. Leaving standards to unaided human memory may be expeditious, but it is also unreliable.

3.4.3.4.2 Pattern-recognition job aids

Wherever a complex pattern must be recognized by the inspector, such as in the appearance of corrosion on a painted surface, or the shape of an oscilloscope trace in NDI, it is possible to provide job aids which will increase the inspector's ability to discriminate a true defect from visual noise. For visual inspection, these job aids can be simply an extension of Section 3.4.3.4.1, standards at the work point. Visually-presented standards were found to be very effective in the notoriously difficult task of judging solder joints in electronic assembly (Chaney and Teel, 1969). For NDI equipment, some pattern-recognition capability is now being incorporated into the software, but more can be done. More flexibility is required, the interface with the user should be improved, and the allocation of final decision between human and machine should be made more flexible.

3.4.3.5 Respond

3.4.3.5.1 Improved defect indicating system

Even as simple a task as marking the aircraft to show the point of repair needs to be improved. Methods observed have included "chinagraph" pencils in various colors, soft pens, and stick-on paper tags. Marking systems can be difficult to remove completely when the repair is completed, leading to unsightly marks which can impair the confidence of the travelling public. Tags can also be left on the aircraft, or leave behind a residue which impairs the finish. One site had moved to a marker system so pale that it was difficult for the repair personnel to see. The requirements for a marking system are relatively simple to write: a wholly satisfactory system now needs to be devised to meet these requirements so that an error-free communication from the inspector to the repair personnel can result.

3.4.3.5.2 Hands-free defect recording

When the inspector discovers a defect, both hands are typically occupied, and the Non-routine repairs (NRR) forms may not be close enough to use. The inspector will often "remember" one or more defects until there is a convenient time to record them. This is a potentially error-prone procedure. Not all of the data on the NRR form needs to be recorded at this time (e.g., inspector and aircraft identifications, date), but some temporary information storage is required to aid human memory. Some inspectors **do** record each defect as it is found, accepting the inconvenience of leaving and re-accessing the inspection point as a necessary step. However, there is no guarantee that search will resume at the correct point following recording. Others use miniature tape recorders to provide a voice-input information storage. The recorder (e.g., dictation machine) is often taped to the flashlight, or clipped to the inspector's clothing. Tapes are transcribed later onto NRR forms. Although errors of transcription are possible, the system appears to work well. Improvements would be voice-actuated recorders built into headsets for true hands-free recording, and training in a standardized procedure for **what** to record. A review of all such systems is needed to determine how best to meet operational requirements.

3.4.3.5.3 Prevention of "serial responding"

In some systems, the inspectors will record a minimum of information at the inspection site (see Section 3.4.3.5.2 above), and complete the data recording as part of the "paperwork" at a later time. This may involve filling in all of the "constant" parts of the NRR forms (e.g., aircraft ID), and signing/stamping each task step on the worksheet. There is a tendency to wait until all paperwork is completed before signing/stamping the whole sequence of tasks. Such "serial responding" can lead to inadvertent signing-off on a task step which was not, in fact, completed. While such errors are presumably rare, the written record is the only permanent recording of inspection/repair information, and is relied upon by regulatory bodies. There are Quality Assurance checks of the paper record against the condition of the aircraft, but only on a sampling basis, and only if the indication is visible, i.e. a repair or very obvious defect. While it is difficult to provide a perfect procedure to prevent "serial response" it should be noted as a possible error mode and improved systems investigated.

3.4.3.6 Repair

(Repair was not considered as part of this study.)

3.4.3.7 Buy-Back Inspection

3.4.3.7.1 Integrated inspect/repair/buy-back system

Final disposition of a defect depends critically upon the communication between the original inspector, the repairing technician(s), and the buy-back inspector. In most current systems it is entirely possible for different inspectors to be involved in the initial inspection, in consultation at critical points in repair, and in final buy-back. The only communications between these inspectors are those between the initial inspector and the repair technician, i.e., the NRR form and any markings on the aircraft. Because of this, there are opportunities for error at each interaction in the process. Hence, these two forms of communication need to be highly error-resistant, or lines of verbal communication between the participants need to be opened. In other countries' systems, e.g., United Kingdom, one inspector remains with the repair team throughout all stages, thus reducing these problems. However, the potential for multiple independent assessment is lost with such a system. The solution to this integration problem is not simple, but many steps to improve participant communication can be taken. Examples are communication training, standard practices for writing and marking, and even the use of voice or video to supplement written communications.

3.4.4 Long-Term Interventions

While many of the short-term interventions listed in Section 3.4.2 have some long-term implications, four major areas are recommended for more detailed study:

3.4.4.1 Error Control

In order to control errors in the aircraft inspection process, it is necessary to be able to define these errors accurately and unambiguously. With properly defined errors, they can be identified, recorded, collected and analyzed, as the first step towards control. Systems safety emphasizes such error identification and control for all complex systems, including civil aircraft. There is a need to apply the same techniques to the human/machine system of aviation inspection, the necessary first step in any program of maintenance to ensure safety of the travelling public.

A first step has been taken towards a classification system for inspection (and to a lesser extent, repair) errors in the error taxonomy presented here as the tables below:

Double-click here to see Tables 3.3 a-h

For each sub-task, the logically-possible errors are listed to form an error taxonomy. Each error is unique, but the same effects may be caused by several different errors. Thus, a fault may be missed because of failure to calibrate equipment, failure to reach the correct inspection point, failure to examine the area and so on. This concept needs to be refined and expanded if it is to form the basis for an error control system. For example, in the tables below, Double-click here to see Tables 3.3 a-h

Visual Inspection (VI) and Non-Destructive Inspection (NDI) are covered by the same task and error taxonomy. This has meant expanding some of the concepts, such as the visual lobe in VI, to cover other NDI situations. In this way, separate error taxonomies are not required for VI and NDI, although in practice it may be easier to produce separate but related taxonomies, and merge the data from each at the analysis stage. A second expansion is also needed. Errors in the tables below are classified by their immediate causes (e.g., "1 6 1 Correct Equipment not available"). However, this does not lead to more distant causes. Why was correct equipment not available? Was it poor scheduling or was the equipment being repaired? For more obviously human functions, such as "1.5 Inspector understands instructions", the failure modes (errors) need further classification as to **why** instructions were not understood, misinterpreted, or not acted upon. Were the instructions illegible, was the illumination poor, was confusing language used, etc.? A matrix rather than the long list of the tables below is eventually required if we are to proceed from the necessary first step of counting errors to the ultimate goal of selecting interventions to control or eliminate these errors.

Double-click here to see Tables 3.3 a-h

3.4.4.2 Integrated Information Environment

While many of the interventions listed under Section 3.4.3 were concerned with aspects of the information flow between the inspector and the rest of the inspection/repair system, there is an urgent need to devise information systems which are integrated rather than piecemeal. This section, based on Drury (1990a), is aimed at integration. A unified view of the inspection process as a closed-loop control system will be used to introduce some of the relevant inspection/information literature, and to demonstrate inspection needs at each step in the inspection task.

Any system involving a human is typically closed loop (e.g., Sheridan and Ferrell, 1977). Obvious examples are in flying an aircraft or driving a car, but the concept applies equally to inspection tasks. As shown in Figure 3.4, the human in the task receives some instruction, or command input to use systems terminology. The operator and any associated machinery transform this command input into a system output. To ensure stable performance, the system output is fed back to the input side of the system, where it is compared against the command input. If there is any difference (command minus output) the system responds to reduce this difference to zero. A closed-loop model of the inspector (Figure 3.4) can be applied to the generic task description of inspection (Table 3.1) to locate and evaluate the sources of input (command) and output (feedback) information.

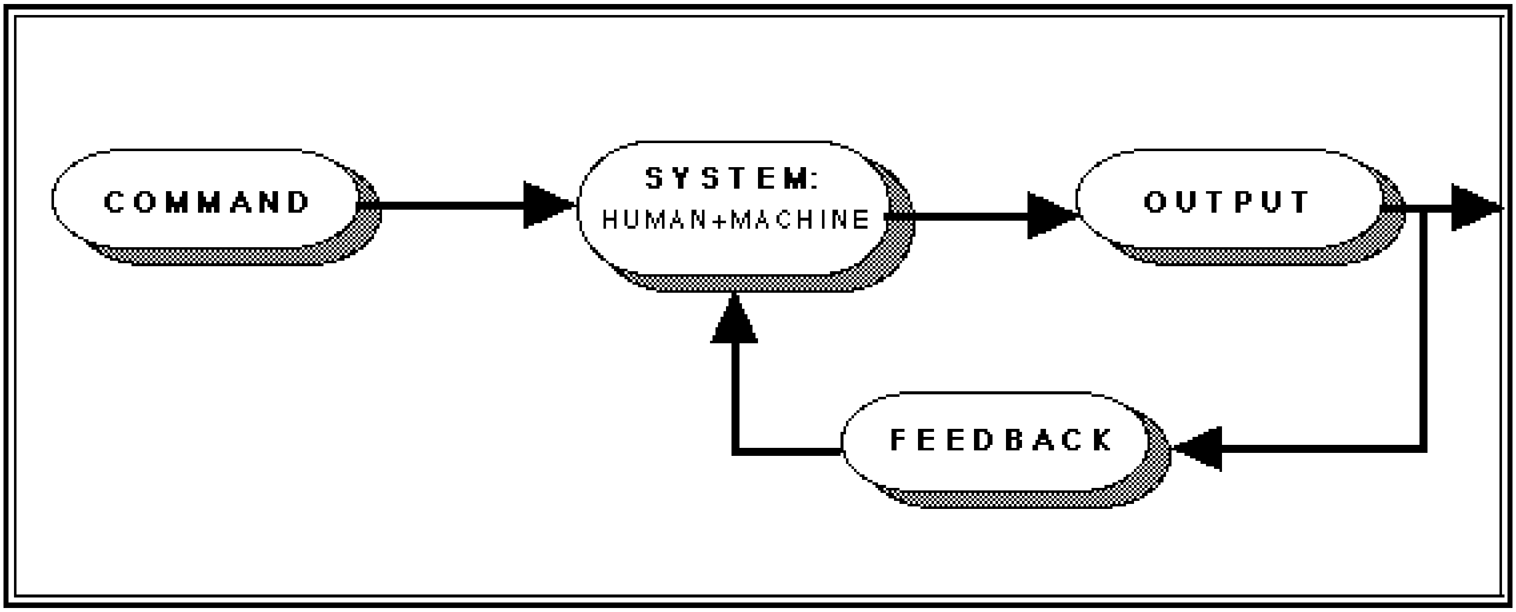

Figure 3.4 Closed-Loop Control

3.4.4.2.1 Information in Inspection

While it is not obvious from Figure 3.4, the command input may be complex, and include both what needs to be accomplished and help in the accomplishment; i.e. directive and feedforward information. For example, a workcard may contain "detailed inspection of upper lap joint" in a specified area (directive) and "check particularly for corrosion between stations 2800 and 2840" (feedforward). Thus, there are really three potential parts to the information environment: directive information, feedforward information and feedback information. All are known to have a large effect on manufacturing inspection performance.

Directive Information involves the presentation of information in a form suitable for the human, the basis of good human factors. An example from inspection is the work of Chaney and Teel (1967) who used simplified machinery drawings as an aid to inspectors. These drawings, of machined metal parts, were optimized for inspection rather than manufacture, with dimensions and tolerances in the correct placement and format, and with similar characteristics grouped together to encourage systematic inspection. Compared to a control group with the original drawings, inspectors using the optimized drawings found 42% more true errors in a test-batch.

Feedforward Information can consist of two parts: telling the inspector what defects are expected and providing the probability of the defects. Because there are typically a large number of potential defects, any information made available to the inspector is valuable in focussing the search subtask in particular. Many investigators (e.g., Gallwey and Drury, 1985) have found that looking for more than one type of defect simultaneously can degrade detection performance, so that focussing on likely defects can be expected to result in more detections. Drury and Sheehan (1969) gave feedforward information on fault type to six inspectors of steel hooks. Missed defects were reduced from 17% to 7.5%, while false alarms were simultaneously reduced from 5.5% to 1.5%. Information to the inspectors on the probabilities of a defect being present has not led to such clear-cut results (e.g., Embrey, 1975), and indeed a recent experiment (McKernan, 1989) showed that probability information was only useful to inspectors for the most difficult-to-detect defects.

Feedback Information has had consistent positive results in all fields of human performance (e.g., Smith and Smith, 1987), provided it is given in a timely and appropriate manner. Wiener (1975) has reviewed feedback in training for inspection and vigilance, and found it universally beneficial. Outside of the training context, feedback of results has had a powerful effect on the inspector's ability to detect defects. Embry's laboratory studies (1975) showed a large effect, but so did Gillies (1975) in a study in the glass industry where missed defects were reduced 20% when feedback was implemented. Drury and Addison (1973), another glass industry study lasting almost a year showed a reduction in missed defects from 15% to 8.8% after rapid feedback was introduced. More recently, Micalizzi and Goldberg (1989) have shown that feedback improved the discriminability of defects in a task requiring judgment of defect severity.

With the background of the effectiveness in manipulating the information environment, each task in inspection will be considered in turn.

Task 1: *Initiate* Here, the command information predominates. The workcard gives the location type of inspection to be performed, and at times also feedforward information of use in the Search and Decision phases. Typically, however, this information is embedded in a mass of other necessary, but not immediately useful, information. Often the information contains attached pages, for example with diagrams of parts to be inspected. While laser printers making a new copy for each workcard have helped diagram quality, inspectors still find some difficulties in interpreting this information. Supplemental (feedforward) information is available in manufacturers manuals, FAA communications, and company memos/messages, but these sources are typically not used at inspection time. This can place a burden on the inspector's memory, suggesting an integrated system is appropriate.

Feedback from the initiate task is obvious in many cases because it comes from Task 2 - Access. An exception is feedback for NDI calibration, which must be provided during the calibration process or there will be no assurance that Search and Decision can be performed correctly.

Task 2: *Access* In order to access an area of an aircraft the area must first be opened and cleaned, neither of which are under the control of the inspector. Thus, scheduling information required for access is the assurance that the area is ready to inspect. Work scheduling systems typically assure this, but wrong information does get to the inspector at times, giving time loss and frustration. It is at Access that confusions in location from Task 1 should become apparent. Improved information systems for locating an area on an aircraft unequivocally are needed, and need to be integrated with other information system components.

It should be noted that feedback on access can be given in any system by incorporating unique landmarks so that the inspector can be assured that the correct area has been reached.

Task 3: *Search.* It is in the tasks of Search and Decision-making that information has the largest potential impact. In visual search the inspector must closely examine each area for a list of potential faults. Which areas are searched is a matter of prior information--either from training, experience or the workcard. The relative effort expended in each area is similarly a matter of both directive and feedforward information. If the area of main effort is reduced, the inspector will be able to give more thorough coverage in the time available. An information system can be used to overcome the prior biases of training and experience, if indeed these biases need to be overridden in a particular instance. The fault list which the inspector uses to define the targets of search comes from the same three sources. This fault list must be realistic, and consistent. In many industrial inspection tasks, developing a consistent list and definition of fault names to be used by all involved is a major contribution to improving inspection performance (e.g., Drury and Sinclair, 1983). Faults often go by different names to inspection personnel, manufacturers, and writers of worksheets, causing mis-directed search and subsequent errors in decision and responding. Probabilities of the different targets or defects are rarely presented. Again, system integration can help.

Feedback of search success only comes from Task 4 - Decision Making, and only then if an indication was found. If the indication was missed, then feedback awaits the next inspection or audit of that area, presumably before the fault affects safe operation. Note that if an indication is found, feedback is immediate, but if missed, feedback is much delayed. Delayed feedback is often no better than no feedback.

Task 4: *Decision Making.* The information required to make a correct decision on an indication is in the form of a standard against which to compare the indication. Such standards at the working point can be extremely effective, for example McKennel (1958) found that they reduced the average error of a trained inspector to 64% of its magnitude without such standards. The need for these comparison standards has been noted earlier (Section 3.4.3.4.1), but the recommendation here is to incorporate such a standard within a unified system.

Feedback to the inspector in the Decision Making task is not rapid or obvious. If an inspector marks a defect (and writes it up), it will be repaired and go to a buy-back inspection. Currently (Section 3.4.3.5.3), because of scheduling constraints and shiftwork, it will rarely be the same inspector who gets to re-inspect that repair. Thus, an opportunity for feedback is being missed. In addition, some repairs will destroy the defect without confirming it, e.g., drilling an oversize hole to take a larger rivet when Eddy Current inspection has indicated a small crack in the skin by that rivet.

Task 5: *Response.* The physical response made by the inspector represents the output information from the inspector to the system. It is as much a part of the information environment as input and feedback. As noted earlier (Section 3.4.3.5.2), recording currently places a memory load on the inspector, or means that interruptions occur in the inspection job. Other interruptions come from scheduling (e.g., an extra inspector is required on another job), from unscheduled events such as more cleaning being required before an inspector can complete a workcard, and from maintenance operators interrupting the inspector to buy-back any repairs which have been completed.

Feedback as a result of the Response is rare. Only a small sample of work is audited, and any feedback from this is typically negative rather than positive. If a defect is reported, then feedback to the inspector who reported it can be arranged. However if the inspector does not report the defect (either search failure or a wrong decision) only an audit or subsequent inspection will give feedback.

For many defect types, a defect may only be an indication, not required to be reported, and hence not reported. Unfortunately, the fact that the inspector found it is then lost forever, as the chance of the same inspector being assigned to the same part of the same aircraft on subsequent checks is small. Capture of some of these indications may be a way to provide more detailed feedforward for subsequent inspections and once more, an integrated system will be required.

Task 6: *Repair.* From the inspector's point of view, information is flowing outward at this task, i.e. to the repair technician. Potential difficulties of the recording and marking system for other participants have already been noted Section 3.4.3.7.1).

Task 7: *Buy-Back.* Both command and feedforward information to the buy-back inspector come from the NRR form and any markings in the aircraft. Feedback to the buy-back inspector is, like that to the original inspector in Task 5 only, from audit or subsequent inspection.

In all of the above tasks, information needs can be seen, and be seen to be met less than perfectly by current systems. Although Section 3.4.3 provides suggestions for specific improvements, the opportunity needs to be taken to devise more integrated solutions. The coming of powerful, but portable, computers with networking capabilities, can aid this systems integration. Already prototype systems exist for aiding fault diagnosis in aircraft systems (Johnson, 1990), so that the practicality of aiding the airframe inspector is real. The challenge is to understand what information needs to be given, and captured, by such a system, and to understand how information technology can be applied to fault detection rather than fault diagnosis.

Research is needed to provide more detail of how much of each type of information (command, feedforward, feedback) needs to be provided for optimum inspection performance in each task step. In parallel, the technology of information capture, interface design and hardware functioning needs more research to make it applicable to the specific needs of aircraft inspection.

3.4.4.3 Training Design and Implementation

An obvious intervention in improving inspection performance is to call for improvements in training. As will be shown, training has a powerful effect on inspection performance, even when applied to experienced personnel. Also, a basic Task Description of inspection, the first step in any training scheme design, is available (Table 3.1). From this task description, it is seen that both manual/ procedural tasks (Initiate, Access, Respond) and cognitive tasks (Search, Decision) are represented. While training for procedural tasks is relatively straightforward (e.g., Johnson, 1981), most of the opportunities for error occur in the cognitive aspects of inspection (Drury, 1984).

The current state of aircraft inspection training is that much emphasis is placed on both procedural aspects of the task (e.g., how to set up for an X-ray inspection of an aileron), and on diagnosis of the causes of problems from symptoms (e.g., trouble shooting an elevator control circuit). However, the inspectors we have studied in our task analysis work have been less well-trained in the cognitive aspects of visual inspection itself. How **do** you search an array of rivets--by columns, by rows, by blocks? How **do** you judge whether corrosion is severe enough to be reported?

Most inspectors receive their training in these cognitive aspects on the job, by working with an experienced inspector. This is highly realistic, but uncontrolled. Experience in training inspectors in manufacturing industry (Kleiner, 1983) has shown that a more controlled training environment produces better inspectors. If training is entirely on-the-job, then two of the main determinants of the training program, what the trainee sees and what feedback is given, are a matter of chance, i.e. of which particular defects are present in the particular aircraft inspected. There is a large difference between training and practice. Figure 3.5 (Parker and Perry, 1982) shows how the effective discriminability of a target changed between two periods of practice, compared with periods before and after training. There was a highly significant improvement with training but not with practice. The challenge is to apply what is known about human learning of cognitive tasks so as to maximize the effectiveness of training for the aviation inspector.

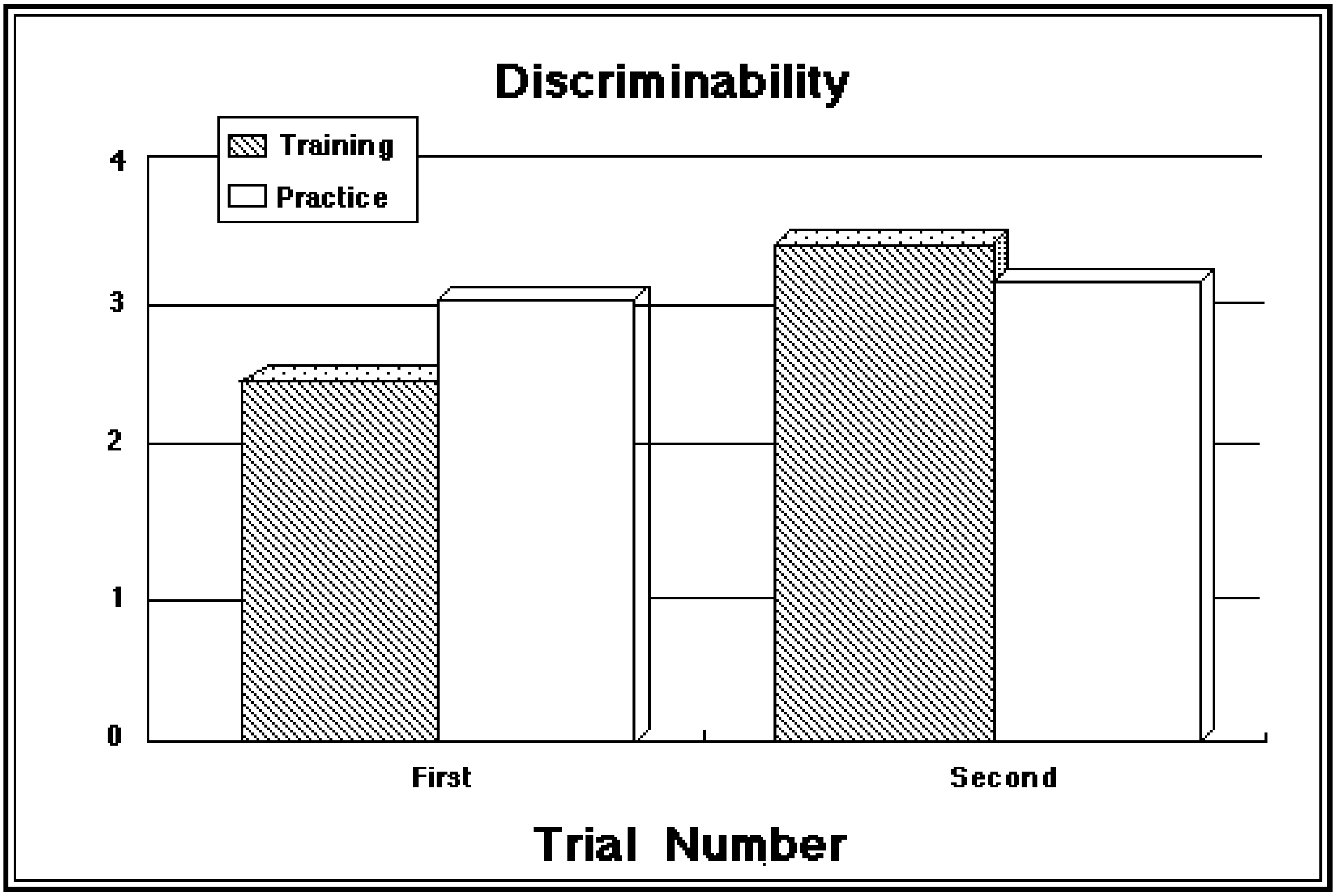

Figure 3.5 Training Versus Practice

A basic principle of training is to determine whether the activity is indeed trainable. Studies of visual search (Parkes, 1967; Bloomfield, 1975) have shown that both speed and accuracy improve with controlled practice. Embrey (1979) has shown that for decision-making, discriminability can be trained. Thus, both cognitive factors (Search, Decision) can be trained.

The principles on which training should be based are relatively well known, and can be summarized (Goldstein, 1974):

1. Develop and maintain attention, i.e. focus the trainee.
2. Present expected outcomes, i.e. present objectives.
3. Stimulate recall of prerequisites, i.e. get ready to learn.
4. Present underlying stimuli, i.e. form prototype patterns.
5. Guide the trainee, i.e. build up skills progressively.
6. Give knowledge of results, i.e. rapid feedback.
7. Appraise performance, i.e. test against objectives.
8. Aim for transfer, i.e. help trainee generalize.
9. Aim for retention, i.e. provide regular practice after training.

Control is important, e.g., 4, 5 and 6 above all require the trainee to receive a carefully-tailored experience to obtain maximum benefit. Some particular ways in which these principles have been applied are:

1. **Cueing.** It is often necessary to cue the trainee as to what to perceive. When a novice first tries to find defective vanes in an engine, the indications are not obvious. The trainee must know what to look for in each X-ray. Many organizations have files of X-ray film with known indications for just this purpose. Specific techniques within cueing include match-to-sample and delayed-match-to-sample.
2. **Feedback.** The trainee needs rapid, accurate feedback in order to correctly classify a defect or to know whether a search pattern was effective. However, when training is completed, feedback is rare. The training program should start with rapid, frequent feedback, and gradually delay this until the "working" level is reached. More feedback beyond the end of the training program will help to keep the inspector calibrated (e.g., Drury, 1990a).
3. **Active Training.** In order to keep the trainee involved and aid in internalizing the material, an active approach is preferred (Belbin and Downs, 1964). In this method, the trainee makes an active response after each new piece of material is present, e.g., naming a fault, waiting a discrepancy card. Czaja and Drury (1981) showed that an active training program was much more effective than the equipment passive program (Figure 3.6) for a complex inspection task.

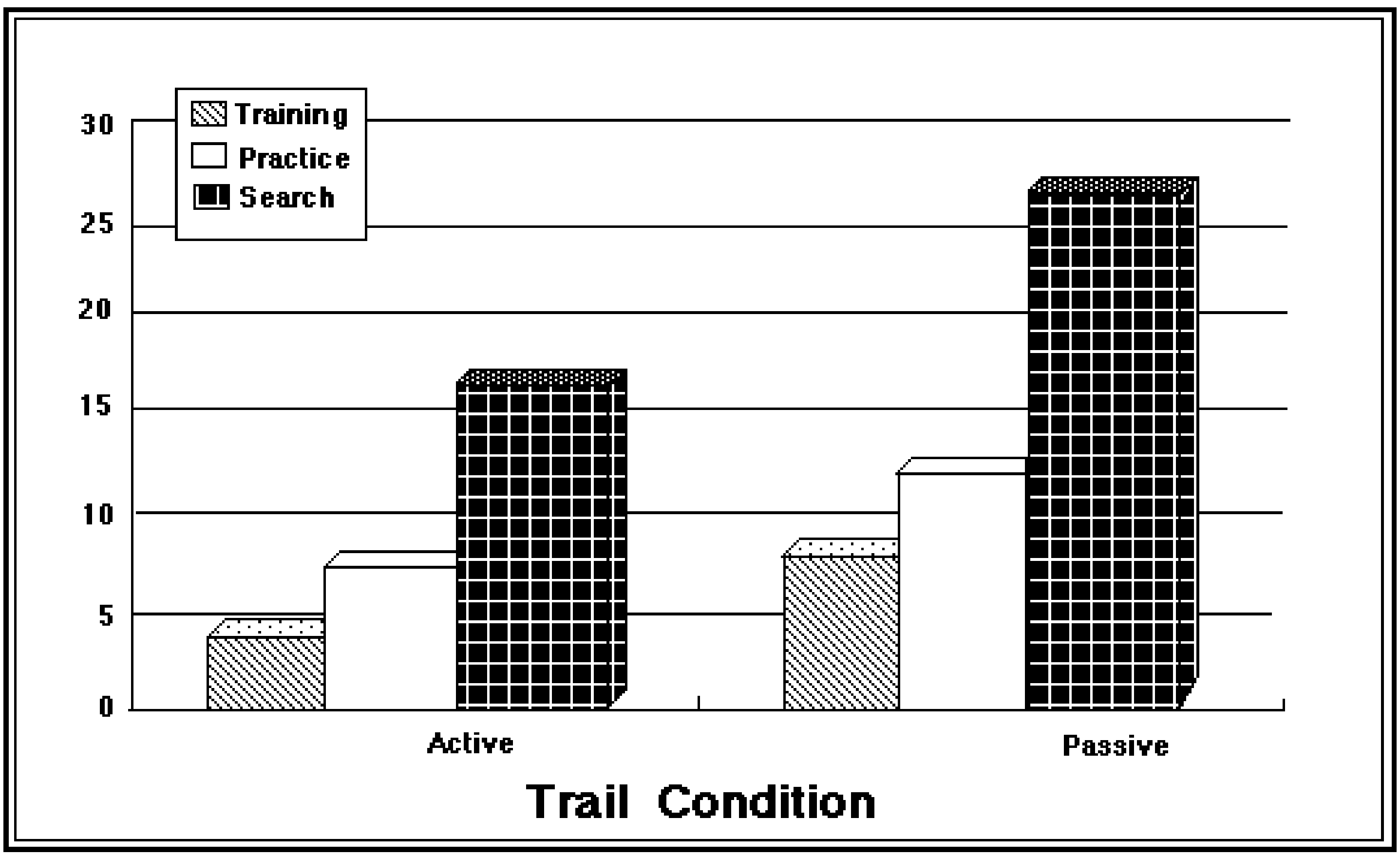

Figure 3.6 Training Condition

4. **Progressive Part.** A standard methodology in industrial skills training (e.g., Salvendy and Seymour, 1973) is to teach parts of the job to criterion, and then successively larger sequences of parts. Thus, if four task elements were E1, E2, E3 and E4 we would have

- Train E1, E2, E3, E4 separately to criterion.
- Train E1 and E2, E3 and E4 to criterion.
- Train E1 and E2 and E3, E2 and E3 and E4 to criterion.
- Train whole task E1 and E2 and E3 and E4 to criterion.

This technique enables the trainee to understand task elements separately and also the links between them which represent a higher level of skill. Czaja and Drury (1981) and Kleiner (1983) used progressive part training very effectively.

5. **Develop Schema.** The trainee must eventually be able to generalize the training experience to new situations. For example, to train for every possible site and extent of corrosion is clearly impossible, so that the trainee must be able to detect and classify corrosion wherever it occurs. Here, the trainee will have developed a "schema" for corrosion which will allow the correct response to be made in novel situations which are recognizable instances of the schema. The key to development of schema is to expose the trainee to controlled variability in training (e.g., Kleiner and Catalano, 1983).

Not all of these techniques are appropriate to all aspects of training aircraft inspectors, but there are some industrial examples of their use, which can lead to recommendations for aircraft inspection training.

3.4.4.3.1 Examples of Inspection Training in Manufacturing

Table 3.6, modified from Czaja and Drury (1981), shows the results achieved by industrial users of the training principles given above. In each case, the inspectors were experienced, but the results from new training programs were dramatic. To provide a flavor of one of these successful programs, the final one by Kleiner and Drury will be illustrated. The company-manufactured precision roller bearings for aircraft, and the training scheme was aimed at improving the performance of the inspection function for the rollers. All inspectors were experienced, from 2 to 14 years, but measurements of performance (Drury and Sinclair, 1983) showed much room for improvement. Based on a detailed Task Analysis, a two-day training program was developed. Inspectors were taught using a task card-based system. Each card had a color-coded task section.

INVESTIGATORS	TRAINING TECHNIQUE	TYPE OF TASK	RESULTS
Tiffin, J. and Rodgers, H.B. (1941)	Knowledge of results (K of R) and training sessions which included lectures and demonstrations	IInspection of tin plates	General improvements in inspection perfomance; greater detection of faults.
Evans (1951)	30 min class instruction; 11 tests with k of R over 2 weeks.	Micrometer inspection of blocks	50% reduction in average error, but no effect on retention
Martineck, H. and Sadacca, R. (1965)	Knowledge of results using and error key	Photointerpretation	Decrease in errors of commision
Chaney, F.B. and Teel, K.S. (1967)	Four, 1-hr sessions which included lectures, demonstration, and K of R from a question and answer period.	Inspection of machine parts	Training resulted in a 32% increase in defects detected
Cockrell, J.T. and Sadacca, R. (1967)	Knowledge of results and group discussion	Photointerpretation	Significant improvement in inspection performance and a decrease in false alams
Parker, G.C. and Perry G. (197210	Demonstrations, use of photographs simulating items and faults, examples of faulty items, practice with K of R	Inspection of glass bowls	50% increase in faulty detection, 50% increase in false rejections
Duncan, K.D. and Gray, M.J. (1975)	Gradual approach to the task (diagnosis of faults then verification) using programmed instruction	Fault detection in a petroleum refinery process	Training resulted in an increase in faults detected, decrease in detection time, and decrease in false rejection
Houghton, S. (1982)	Product knowledge, standards, search training, practice with K of R, progressive part	Solder joint, inspection	Efficiency up from 33-67% to 89-97%
Kleiner (1983)	Progressive part, cueing, K of R, active	Aircraft bearing inspection	Rest error reduced to zero, 50% scrap reduction

TABLE 3.6 Summery Table of Practical Applications of Inspector Training Programs

Table 3.6 Summery Table of Practical Applications of Inspector Training Programs

- Naming of defects (flaws)
- Naming of parts (surfaces)
- Handling methods (handling)
- Visual search (search)
- Decision making (standards, decision making)
- Process interface.

For each section, there were a progressive set of cards with information, possible physical examples or test procedures, and a sequence indication. Each card required an active response.

This training program was evaluated in two ways. First, two new recruits were able to achieve perfect scores on the test batch at the completion of the program. Second, the quality of feedback from inspection to manufacturing increased so much that scrap was halved between the six months before the training and the six months after. The whole program was replicated for the inner and outer races of the bearings, entirely by company personnel using the roller training program as an example.

Such a training program in the cognitive skills underlying fault detection is needed for aircraft inspectors. Drury and Gramopadhye (1990) show how it can be applied to one aircraft inspection task, but a more complete design is needed if an impact is to be made. It is recommended that, in addition to the training in fault diagnosis in avionics systems being undertaken by Johnson (1990), more effort be made to use the task analysis data already collected to devise improved training programs for airframe inspectors using the above principles. The training programs for the cognitive and manual skills of fault detection then need to be evaluated to demonstrate their effectiveness, as was done for the studies in Table 3.6. From these demonstrations, a standard methodology needs to be developed so that aircraft repair sites can apply the same principles on a routine basis to all existing and new inspection tasks.

3.4.4.4 Selection/Placement Procedures

Throughout manufacturing industry, a major emphasis has traditionally been placed by management on finding the right person for the right job. Aircraft inspection appears to be no exception. If there **are** individual differences in performance, then it appears reasonable to select initially those applicants who have a higher probability of achieving high job performance, and placing individuals throughout their career into jobs which in some way match their abilities. Unfortunately, the evidence in inspection tasks does not support this common sense approach at all strongly. A major review by Wiener (1975) concluded that emphasis on training and job/equipment design would yield much higher benefits than pursuing the search for good selection/placement tests. For the specific job of aircraft inspection, a study is needed to make a definitive decision, so that resources can be applied to devising such tests, or the whole concept can be put aside.

Wiener raised the issue of test validity. If the inspector's task is to detect true defects, while ignoring non-defects, then any potential tests should correlate with these measures, rather than with less-related measures such as supervisor ratings. Harris and Chaney (1969) devised a well-validated selection test for electronic inspectors, using the criteria of detection ability to establish validity. However, the test was found to be not valid for mechanical inspectors. A large study of selection tests for inspectors in general (Gallwey, 1983) showed that general tests such as intelligence or cognitive style were not strongly correlated with performance. A simplified version of the actual inspection task was the only selection device to show reasonable correlations with performance. Further study by Wang and Drury (1989) found that using a task analytic approach allowed tests of somewhat higher validity to be chosen, but the power of such tests to discriminate between successful and unsuccessful inspectors was not high.

Analysis of the same data (Drury and Wang, 1986) determined that inspection performance was highly task-specific. Good inspectors on one inspection task may be poor on other tasks. This fact would explain why Harris and Chaney's test only worked for the electronic inspectors for whom it was originally designed.

Aircraft inspection tasks are diverse, as was found clearly in the current study. They range from visual detection of many discrete defects, though kinesthetic detection of play in bearings or cables, to tactile inspection for loose rivets. NDI tasks represent another spectrum of required inspection skills. If inspection ability is indeed task specific, the prospects for a single "inspection test" are not good. However, it is worth recommending a definitive study of individual differences in aircraft inspection because the payoff for establishing a reliable and valid inspection test would be large. This recommendation has thus a low probability of success but a high value if it does succeed, and on balance is probably worth performing. It should have the lowest priority of the four recommended long-term studies.

3.5 CONCLUSIONS

The work reported here represents the results of the first year of a process designed to use the known results of human factors in manufacturing inspection to aid in improving the reliability of aircraft inspection. As such, it has concentrated on detailed observation of the current aircraft inspection system, and the analysis of that system in terms of models found useful in improving manufacturing inspection. The sample was restricted initially to major national carriers, and all methodology had to be devised specially for aircraft inspection by analogy. Despite these inevitable limitations of any starting endeavor, solid conclusions can be drawn.

1. Task Analysis of aircraft inspection is possible, and has proven useful in locating human/system mismatches which can cause inspection errors. The principles and models derived from human factors in manufacturing inspection have been readily adapted to aircraft inspection. This effort needs to continue with a more diverse sample.
2. A set of short-term and long-term interventions has been generated, to guide both relatively rapid implementation and the search for new data and techniques (Sections 4.3 and 4.4). Implementation can only be achieved by the organizations whose mission is aircraft inspection and maintenance. The research team and the FAA should work closely with these organizations both to implement changes, and to measure the effectiveness of these changes.
3. A firm conclusion must be that the current system is good. Major improvements have been made over the years (e.g., NDI equipment), and all participants encountered during this study have shown a keen commitment to system safety. The improvements which now need to be made are not always obvious or easy: if they were they would probably already have been made. Recommended improvements are the result of bringing new expertise (human factors) to bear on an already error-resistant system.

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APPENDIX A

The following is a list of papers written for and presented with Federal Aviation Administration/Galaxy Scientific Corporation during the first year of the contract #891014SC03:

1. Drury, C.G., 1989. The Information Environment in Aircraft Inspection, In *Proceedings of* the Second International Conference on Human Factors in Aging Aircraft, Biotechnology, Inc. Falls Church, Virginia.
2. Drury, C.G. and Gramopadhye, A., 1990. Training for Visual Inspection, In *Proceedings of the Third Federal Aviation Administration Meeting on Human Factors in Aircraft Maintenance and Inspection: Training Issues.* Atlantic City, New Jersey.
3. Drury, C.G., 1990. Design for Inspectability, In *Proceedings of the IEA Human Factors in Design for Manufacturability and Process Planning,* Honolulu, Hawaii.

4. Drury, C.G., Prabhu, P. and Gramopadhye, A., 1990. Task Analysis of Aircraft Inspection Activities: Methods and Findings, In *Proceedings of the Human Factors Society Annual Conference.*

5. Drury, C.G., 1990. Exploring Search Strategies in Aircraft Inspection, In *Proceedings of the Second International Conference on Visual Search,* University of Durham, England.

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1. Drury, C.G., 1990. Inspection Performance. In *Handbook of Industrial Engineering (2nd Edition),* edited by G. Salvendy, New York: John Wiley and Sons.

2. Drury, C.G. and Kleiner, B.M., 1990. Training in Industrial Environments. In *Proceedings of the Human Factors Association of Canada Meeting,* Ottawa, Canada.