CHAPTER NINE
RELIABILITY IN AIRCRAFT INSPECTION: UK AND USA PERSPECTIVES

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9.0 ABSTRACT

In response to recent concerns about the reliability of aircraft inspection and maintenance procedures, the CAA and the FAA have been investigating human factors issues. Two investigators who had separately studied human factors in civil aircraft inspection undertook to study each others' jurisdictions to compare techniques and problems in the USA and UK. Aircraft inspection sites were visited jointly and separately in both countries, with an analysis made of the overall inspection/maintenance system and of larger floor operations.

The overall conclusion was that similarities were more common than differences due to the technical specification of the tasks, the regulatory similarities and the skill and motivation of inspectors. Differences between companies outweighed jurisdictional differences in many areas, suggesting that a common policy can be followed to improve such areas as visual inspection lighting, physical access to inspected areas, and the informational environment.

Larger differences were observed in the areas of work organization and nondestructive testing (NDT), with sharing of experiences in both areas being possible for improved inspection reliability.

In the UK, the inspectors and maintenance technicians were closely integrated in the formal organization, with inspectors often acting as supervisors for a maintenance team which performed the repair. In the USA, a more formal division existed between inspection and maintenance, with coordination usually through the supervisory levels. While both approaches are viable, both need better support for integration and communications. Training is needed in supervisory skills, as well as management structures and documentation which allow all concerned to obtain the information necessary to successful task completion.

In NDT operations there was a difference in emphasis between the two countries, with the USA more concerned with rule-based performance and the UK with knowledge-based. In addition, inspectors in the USA were less likely to be NDT specialists, performing both NDT and visual inspection, although changes are now occurring in this. Although both jurisdictions require both operating modes at different times, this fact is not well recognized. Hence, the training and documentary support for both levels is lacking, as is a clear indication of switching rules between the two.

With the increasing internationalization of the aircraft maintenance industry, accelerated by publicized events with aging aircraft, differences may be expected to disappear over time. However, this should be a controlled process leading to utilization of the best features of different jurisdictions if the full potential of inspectors within the system is to continue to be realized.

9.1 OBJECTIVES

The first objective of this study was to combine into a single concise document material collected jointly and separately by the investigators so as to highlight the similarities and differences in aircraft inspection between the UK and the USA.

The second objective was to draw any conclusions which would allow the transfer of techniques or information relating to human factors in aircraft inspection between the two systems to the benefit of airworthiness.

9.2 BACKGROUND

The application of Human Factors techniques to aircraft inspection is relatively recent on both sides of the Atlantic. A major 1981 UK study (Lock and Strutt, 1985) was not complemented by equivalent work in the USA until after the interest in continuing airworthiness spurred by the Aloha incident in 1988. Because of the commonality of interest in improving inspection reliability in the two jurisdictions, the FAA and the CAA signed a Memorandum of Cooperation in April 1990 to cover joint work in this field. This would build on the then-current human factors work in both countries, as well as various studies of structural mechanics and flight loads.

Since that date, M. W. B. Lock and C. G. Drury have been co-operating specifically on cross comparisons of USA and UK practice as part of their contract work with the FAA and CAA respectively. The aim was to take two scientists who had studied aircraft inspection from a practical viewpoint, but from different academic backgrounds, and have them jointly observe a number of inspection operations in both countries in addition to their other contractual observations. The disciplines of the two participants were complementary in that Dr. Lock is an applied physicist with a particular expertise in Non Destructive Testing (NDT) while Dr. Drury is a Human Factors (HF) engineer with a particular expertise in industrial inspection.

This report is intended to be complementary to the reports issued by the two participants separately as part of their contract work. These other reports are listed in Section 9.6. In particular, the site visit - based work described here is also referred to in the following reports:

1.**Human Factors in Aviation Maintenance: Phase One Progress Report.** FAA Office of Aviation Medicine, September 1991

2.**Inspection Reliability for Transport Aircraft Structures: A Three-Part Study: Part 1 Initial Investigations.** CAA Paper 90003, April 1990

3.**Inspection Reliability for Transport Aircraft Structures: A Three-Part Study: Part 2 The Current Situation.** CAA Draft Paper, May 1991

9.3 METHODOLOGY

A number of visits were undertaken by each participant in each country, either separately or together. There was no attempt at comprehensive sampling; rather the knowledge of each participant was used to select sites which would be illustrative of various features. For example, in the UK visits were made to specialist third-party NDT companies which serviced civil aviation as they represent a major source of NDT expertise utilized by some airlines.

At each site, the visit was divided into two sections, although these often overlapped in coverage:

Systems Overview: First the management of the maintenance of the site was probed in management interviews. The structure of the maintenance and inspection organizations was elicited during discussions with managers, shift supervisors, foremen, and often with staff who were outside the line management structure. These could include training personnel, archive keepers, work card preparers, planners, and so on depending upon the initial discussions with management. The aim was to be able to write a short description of how the system **should** operate, and the management philosophy behind this system structure and functioning.

Hangar-Floor Operations: Detailed observations of the practice of inspection, and its organizational constraints, were made by following an inspector for all or part of a shift. As the inspector progressed through a job, questions were asked concerning the inspection itself and ancillary operations, such as spares availability from stores, or time availability for training. Thus a reasonably complete task description and analysis could be written on the inspection task itself, while obtaining information on the wider context of the inspector's job. This technique also allowed the collection of anecdotal recollections of previous jobs, and other events from the past. While these had an obviously lower evidence value than direct observation of task performance, they did provide a valuable adjunct to the data collection process.

Sites visited included major air carriers, regional or second-level airlines, repair stations and NDT companies. In addition visits were made to FAA and CAA personnel and to a Royal Air Force base where maintenance and inspection procedures are written.

9.4 RESULTS AND DISCUSSION

In this section points of difference between the two systems will be described for a number of areas judged by the authors to represent potentially transferable ideas. No attempt is made to compare the legal framework in the two countries, as this information is rather well known to the two regulatory bodies, and to most airline managements, often from direct international experience. Rather, the experiences and evaluations of the participants will be stressed to determine how the systems worked in practice.

When an area is presented, the points of similarity are discussed first, including any observations on the relative variability between and within countries. Next, the different features of each country's practice are presented. These sections establish the factual basis for evaluation and discussion of the importance of differences, needs for improvement in both countries, and any transferable features which could improve airworthiness. Conclusions from all of the areas are brought together in the final section.

9.4.1 Maintenance/Inspection Responsibilities

Both countries: Maintenance and inspection tasks are separated in a similar manner in both US and UK, both within the maintenance schedule and on the task cards at hangar floor level. Task cards are individually assigned to either maintenance technicians or licensed inspectors. Defects arising from the inspection, also termed non-routine repair (NRR), squawks or snags, are the subject of further cards which are raised by the inspector and, after rectification, signed off, or stamped off, by an inspector.

UK variations: The management structure of maintenance and inspection is usually closely intermeshed. In the past it was sometimes the case that the engineering manager and the quality control chief were the same person and, although this is not the case in large transport aircraft it can still be the case in smaller commuter airlines. Work arising from an inspection can be allocated to maintenance technicians by the inspector who is often also a supervisor, or by a senior person who has responsibility for both inspection and maintenance. The inspector is frequently consulted during the defect rectification, in some cases is the actual supervisor of that work, and will usually be the person to accept the repair.

US variations: The management structure of maintenance and inspection is separated up to a level well beyond the hangar floor. A wide variation of management authority was found whereby either of maintenance and inspection, or even planning, could dominate (Taylor, 1990).

In a few companies visited there was provision for some coordination between the two, by an engineer whose job was to ensure some cross talk. This person could also serve the function of shift change co-ordinator.

Work arising from an inspection is often allocated by a maintenance supervisor so that the inspector who raised the defect has no responsibility for defect rectification and may not be the inspector who does the buy-back inspection. Some airlines have an inspector specifically assigned to perform only buy-back inspections.

Evaluation: The separating of the management structure in the USA is dictated largely by the existing Federal Aviation Requirements. The notion of the need for checks and balances as an error reduction mechanism is deeply felt. At the hangar floor level the general view is that repair and maintenance would suffer if the maintenance technician knew that certain inspectors were 'buying back' the work, as some are thought to be less stringent than others.

The general view in the UK was that the system of having the same inspector responsible throughout for any particular defect and its rectification was preferable as the repair could be monitored at appropriate stages ensuring that the job had been performed correctly.

In the event of an inspection resulting in a significant repair being necessary, the supervisors of both maintenance and inspection confer with the inspector while, for a small item, the inspector alone assumes responsibility. There must be a point at which the inspector has to decide which of these two courses is correct, although supervisors on their own initiate a review of NNR cards with inspectors. The decision might depend variously on safety, cost, time etc. but the crossover point does not seem to have been well defined and was seen to vary considerably between companies.

9.4.2 The Supervisor/Inspection Dichotomy

Both Countries: The supervision of the aircraft maintenance technician (AMT) or mechanic is of primary importance. There is always the need for monitoring their output whether for quality or quantity. The responsibility for this supervision varies both from operator to operator and from country to country.

UK Variations: There is a tendency for the supervision to come largely from the inspectorate side in UK. Indeed, in many companies each inspector will be wholly responsible for a small team of mechanics and the jobs to which they are allocated. In any case it is common for the mechanic to be in close contact with an inspector during a job, especially if it is a defect arising from inspection.

US Variations: Due to the way that accountabilities are allocated, the American system divorces the inspection and maintenance responsibilities at hangar level although some coordination is still maintained. The system involves inspectors locating defects and raising the appropriate paperwork as in the UK, but then the responsibility for the job becomes that of the maintenance organization and it is only after the repair is complete that the inspectorate are asked to re-inspect the area and 'buy-back' the completed job.

Evaluation: While the reasons for, and technical consequences of, the separation of responsibilities were covered in 1 (above), there are still issues of management and communications which need addressing. First it should be noted that the standards of repair deemed acceptable by the inspectors did not appear to differ between the two countries. An aircraft was judged safe when it not only met the written standards but also when, as many expressed it "the plane is safe enough for my family to fly in".

There are two sides to the question of whether the inspector should act as supervisor or have a team of mechanics. One has to weigh the advantages of having close communication between the inspector and mechanic against the continual interruption of the inspector's train of thought caused by requests to check current situation of a repair or for further work. Some companies use a leading hand (an long-experience mechanic) as an intermediary and in a large company, where there is sufficient work, this seems a good alternative.

It is rare for an inspector/supervisor to have any personnel-management training beyond a couple of days. The tasks to be communicated are frequently complex: the difficulty of scheduling and supervising several different simultaneous maintenance activities and the communication skills required to secure proper repairs should not be underestimated.

Not all tasks are straightforward or even repeats of those previously performed so that it will probably be quicker and more accurate for the mechanic to be informed directly by the inspector/supervisor than by documentation and a third party. However, freedom from the supervisory role enables the inspector to assume the role of final arbiter at buy-back.

If the potential difficulty with the UK system is in ensuring an ability to lead as well as inspect, the potential difficulty in the US system is with communication.

There is a need to communicate both within a single shift and across shifts between the following groups:

- Inspectors
- Maintenance technicians
- Inspection management
- Maintenance management
- Quality control
- Planning

Some of this communication is written, for example, in job cards and NRRs, and some is verbal. The quality of written NNRs had considerable variability between inspectors, between companies and between countries. In the US, this assumes more importance as not only the maintainer has to understand the NRR to carry out the (often complex) repair, but so must the buy-back inspector to ensure that the original fault has indeed been eliminated. Little formal training in written or verbal communication was seen. While formal coordinators were seen at some companies, and other companies were small enough that direct communication was inevitable, there is still a need for formal training of inspectors and maintenance technicians.

Inter-shift communications varied widely by company. Some had an informal talk between equivalent supervisors at shift change, some had a written checklist, while one company had a formal half-hour combined written report and tour of the on-going jobs by both supervisors. At the individual inspector and mechanic level, shift change ranged from merely receiving the supervisors' instructions to formal start-of-shift meetings. With many maintenance operations, and even some inspection jobs, covering multiple shifts, systems are needed to ensure that the complex communications required do indeed take place. It is vitally important that the incoming shift have complete information on the status of each repair/inspection. A failure of such information flow was recently cited as being causal in a recent accident in the USA.

9.4.3 Non Destructive Testing

Both Countries: The 1980's saw a large increase in the application of NDT to aircraft inspection practises and this rise has been continued. The situation is largely manufacturer-driven so that a similar situation exists in all maintenance/inspection shops.

In many applications, the bulk and weight of the NDT electronics box is such as to make location of it within easy visual range, difficult. More use of secondary visual or aural devices is required. Such devices are small repeater screens, LEDs on probes, and earphone systems (especially where the tone changes with the size of the ultrasonic or eddy current parameter).

UK Variations: Training is currently based on the PCN (Personnel Certification in NDT) scheme monitored by the British Institute of NDT and the industries it serves.

In the aircraft industry, training corresponds, in the main to PCN level 2, with the necessary endorsements, which allows the inspector to perform NDT tasks and to define new methods which are used subject to manufacturer's approval. Training to this level can be done in-house or through a registered and certified establishment specific to aircraft NDT. This is followed by a period of about 6 months on-the-job instruction.

A further grade, level 1, is also common which qualifies the technician to make go/no go decisions. This is mostly used for simple MPI or Dye Penetrant examinations in the workshops.

Some effort is being made to ensure that the signatories for the operator under BCAR A8-6 are level 3, a supervisory grade.

US Variations: Here the reliance is on task-specific instruction, being a combination of teaching the techniques and general on-the-job training although some organizations do require ASNT level II certification. In essence, the training schedules and content are similar to the UK but without the outside qualifying body. This has resulted in widely differing depth and duration of the training. An especial example is that of impedance plane eddy current methods where training periods from a few hours to several days were reported to the authors by inspectors. In addition, airlines in the USA have typically had NDT as part of regular inspection duties, rather than having a specialist NDT department or section. This situation is now changing to some extent, with many operators establishing new NDT sections and others reverting back in some instances. There are regulatory moves towards creating uniform and separate NDT qualifications.

Evaluation: There are fundamental differences between visual and NDT inspection techniques. Foremost is the extra time spent setting up and calibrating the equipment, and the actual inspection can take considerably longer. Then there is the problem of validation of the techniques (i.e. do they find the defects as designed and with what reliability) as well as with confirming the actual defect found by NDT, which may take considerable maintenance time to uncover for visual confirmation. Also, NDT is used at times to confirm the extent of a visually-discovered crack.

Between the UK and USA are two major differences in philosophy, which can affect the practice of NDT. First, the UK assumes a what could be classified (Rassmussen, 1984) as a knowledge-based inspector, i.e. one who has a considerable depth of knowledge in the subject and who is expected to use such knowledge relatively frequently to solve problems from first principles. The USA inspector is more frequently expected to rely on **rule-based** reasoning, using well-learned and (reasonably) well-documented IF-THEN rules to complete the inspection. The distinction is one of emphasis rather than bifurcation, with the UK inspector having reasonable rules and the USA inspector having reasonable knowledge, but the difference does exist. Inspectors have to switch between these two levels of abstraction at appropriate times. Thus, both forms must be adequately supported by the system, for example by training, clear documentation, and explicit switching rules between the two. Both operating philosophies can be expected to produce reliable results under ideal conditions, but each has its characteristic errors. Knowledge-based reasoning is difficult to reproduce in different inspectors, and in the same inspector at different times, whereas rule-based reasoning can lead to inappropriate decisions if the situation does not exactly match the rules. One observation was made of an inspector mis-calibrating an eddy current device by setting the frequency in Mhz rather than in Khz, an error extremely unlikely for a knowledge-based inspector. Rule-based reasoning in complex systems is often characterized as "brittle", while knowledge-based reasoning allows more discretion, which can lead to errors when the reasoning, or the perception of the situation, is false.

Second in the differences of consequence is the distinction between specialist NDT inspectors and generalists, who perform NDT activities along with visual inspection when needed. The generalist has a broader knowledge of the particular aircraft and its recent history such as indications of wear or unexpected service conditions. Such an inspector is also able, and expected, to use well-practised visual inspection skills to observe areas around the site of the NDT inspection for other, non-NDT, indications. The specialist, on the other hand, can be expected to be recently practised in the NDT technique required at that instant, and also to have a broader and deeper knowledge of NDT methods as well as specific techniques. Such an inspector will have less of a problem of skill maintenance under long periods of disuse, and thus be less prone to the errors associated with lack of recent practice. A number of occasions were observed where a generalist inspector had to seek help from others who had performed the particular NDT inspection recently, as the instructions on the work card or in the manuals were ambiguous.

9.4.4 Bonding

Both Countries: In both countries there is a projected lack of trained inspection staff: indeed of all maintenance staff, (Shepherd, 1991). It is inevitable that there will be some movement of staff from one operator to another; this happens in all industries and is quite acceptable. However on occasions, when a new repair station is set up or an operator expands quickly, there have been as many as 100 maintenance staff 'poached' in a short time.

In an effort to stop this, many companies have implemented policies of bonding in one form or another. This usually takes the form of requiring personnel who are taking a training course to sign a declaration to the effect that they will not leave the company for a period of time, or that if they do they will repay a proportion of the training costs. The repayment is usually scaled from the full cost immediately following qualification and reducing, on a sliding scale, to zero after 1-3 years.

UK Variations: Only one company visited had a current bonding policy and that only asked for proportional repayments for lodging and travel etc. when they were on a course at another site. No training costs were included even though these could be as high as £40k. In only one case had this policy been implemented in recent memory and that involved the sum of under £2k.

Many other companies had such a policy and the main reason that they had abandoned it was that legal advice suggested it to be untenable and 'binding in honour only'.

USA Variations: In the USA, bonding is the rule rather than the exception at the engineering sites visited. In one company, staff were even bonded for a first-aid course.

Evaluation: In any industry a pool of skilled personnel is necessary. The time for inspectors to reach fruition is longer than for most skilled technicians and they therefore have a rarity value.

It is reasonable that employers should want to protect their investment in time and money. However, it is also reasonable that any person should be able to sell themselves freely in the market place.

Due to legal uncertainties, especially in the UK, it may no longer be realistic to bond employees but the industry needs a stable work-force. One solution offered to some industries in the UK was the government-sponsored training boards. Here, there was some sharing of training costs by an industry-wide levy which was redistributed to companies who provided training themselves.

It would act as a deterrent for mass poaching if the operators had a common agreement; perhaps not to have a general levy but to repay training costs if personnel changed employment. This could be done on a reducing scale, as in the bonding agreements.

It would do several things:

1. It would compensate the previous employer to some extent, and not penalize employers who run extensive training programs.
2. It would act as a deterrent to large poaching operations.
3. It would not prevent staff movement completely but would act as a brake on the recently qualified who are, as far as the operator is concerned, an important investment.
4. Abuse of the mutual repayment system might be thought to be a potential problem but withdrawal of cooperation when the abuser has an aircraft on the ground in need of parts could allay that.

Several managers with hangar responsibility have responded to this suggestion positively and said that they certainly consider paying compensation to get the right employee.

Job advertisements in the aeronautical press frequently mention bonding as one of the condition of employment. In view of the legal situation this should be discontinued.

The most appropriate source of actions on the above suggestions would be the representative groups such as IATA and ATA, rather than the regulatory bodies.

9.4.5 Working Times

Both Countries: Because of airline flight schedules being confined largely to daytime operations, it follows that much regular inspection and maintenance activity involves night work. Inspection in particular must precede maintenance in heavy checks, so that there is considerable pressure on the inspection department to complete the incoming inspection in a timely manner. This is usually achieved by a mixture of shift work and overtime.

UK Variations: In many maintenance organizations, shift work is allocated generally across the organization, with rotating shifts and moderate use of overtime and weekend work, although inspectors still voice complaints about shift lengths and allocations.

US Variations: In many airline maintenance operations, shift work is allocated on the basis of seniority. Thus the bulk of the socially-unpopular night work is given to junior inspectors. Relatively high amounts of overtime are worked whenever an aircraft arrives for maintenance. At some sites an additional problem was caused by the maintenance site being located in an area whose housing costs are too high for maintenance and inspection employees, leading to long commutes, usually by private automobile due to the lack of public transport at shift change times.

Evaluation: Inspection work can involve constant alertness in the face of little stimulation, with some use of complex decision making. Both of these activities show degraded performance under conditions of sleep loss or disrupted schedules. To mitigate these effects despite a continuing requirement for night operations requires the detailed application of human factors knowledge relating to shift work (e.g., Schwarzenau et al, 1986). Shift workers rarely invert their body rhythms, so that a frequently-rotating system is to be preferred to one with long blocks of time on each shift. Because organization of working time is so heavily influenced by social needs, the system used should be a simple as possible for predictability. Obviously, spreading night work over a larger population, rather than having some groups bid out of it, will minimize the overall effects of shift work, and prevent the concentration of experience onto the day shift. As with considerations of overtime, there are historical reasons for the current systems, so that any change will not be easy in organizational terms.

The situation is exacerbated by the lack of unanimity amongst workers: some preferring 12 hour shifts; others, night work etc. A solution involving rotating shifts or, at least, volunteering for the generally less popular shifts and some form of flexi-time might be attempted although the problems at shift-change could be too complex.

Overtime for inspectors is, in general, not a good idea from a strictly technical, human factors viewpoint. Data from laboratory studies shows decreased detection abilities with prolonged work, although degradation of decision performance in job operations is more difficult to document. When combined with long commutes involving active driving, there are also implications for worker safety at the end of an overtime period as well as for job performance.

9.4.6 Demand and Supply of Mechanics/Inspectors

Both Countries: The typical progression to inspector is from mechanic, so that the supply of inspectors is largely dependent upon the survivorship function of mechanics. With the increased demands for inspection, caused in part by aging aircraft (or continuing airworthiness) considerations, both supply of new inspectors and loss of existing inspectors are critical issues for the present and the future. Recent studies in the USA and Canada (Shepherd, 1991) have documented that a crisis may soon be reached.

UK Variations: Here the tradition has been to apprentice a school-leaver to a company to learn the job of mechanic, with CAA examinations and company examinations both being given at regular intervals throughout the apprenticeship. When mechanics are certified, after a certain time, and more training, they can be recertified as inspectors. Not all who are qualified are given inspection jobs, depending upon current employment opportunities within that company. Other ways of entry are via the services (RAF, Army, Navy), which accounts for a large proportion in some fields (e.g., up to half of NDT inspectors), and occasionally from the shop mechanics. Leaving is often to other airline companies (see Bonding above), but does occur to other industries at times. Pay is considered to be poor, but rarely poor enough to cause a move. The typical grumble is that the job status is not perceived highly outside the aircraft industry.

US Variations: Most mechanics attend an A&P School after leaving high school, to be trained at their own expense for approximately two years. The output from these schools has a high wastage (perhaps up to 50%) to other industries, such as automobile mechanic or dental equipment technician. There is some recruiting from the services, but the numbers are too small to provide a large fraction of inductees. At the same time, retirements are increasing due to previous cycles of hiring and freezing. Over the next ten years there is predicted to be a severe shortfall between the demand for mechanics and the supply, even with relatively optimistic assumptions about recruiting, retention, and productivity.

Evaluation: Apprenticeship schemes are starting in the USA after a considerable lapse, and are being revitalized in the UK after considerable recent neglect. Such schemes hold promise for increased supply, as trainees are paid during training, and have a strong company identity after certification. However, they represent a considerable cost outlay for the company; an outlay which may not always be repaid (see Bonding above). Joint ventures between companies, high schools and junior colleges have been tried with some success both in USA and Europe as a way to expose more people to careers in aviation. Similar schemes between companies and A&P schools are now under way, with results which appear to be encouraging. Low pay and poor working conditions must also be addressed. Pay rates in the starting jobs are particularly low. This is even more of a factor at the second-level companies, who are often considered as 'holding areas' for staff by the major carriers, leading again to a high rate of leaving in the industry.

Working conditions such as shift work, dirt, confined spaces, and lack of amenities can be changed only by action on many of the human factors points made in this and previous reports. Such conditions are not acceptable in the current market place, and indeed would not be tolerated by most of the office staff in many of the companies visited. If the mechanics who will become the inspectors are to be recruited and retained in sufficient numbers to ensure continued safety, the conditions will have to improve.

When inspectors rather than mechanics are considered, there are additional problems. If a mechanic chooses to become an inspector he will move from the top of the seniority levels in one group to the bottom in another. This often entails a reversion to an unpopular shift, and more isolation from the management function (who are often concentrated on the day shifts), before seniority in the new occupation is established. The inspectors studied for this report had all, by definition, survived these problems. Maintaining adequate future supplies requires similar studies of those who chose not to continue to inspector level.

The route into civilian inspection, especially for NDT, from a military background is unnecessarily difficult. A joint committee on training would benefit both parties: morale would be boosted for those in a service environment and the civilian sector could have a ready supply of personnel who would only need training in the company system.

9.4.7 Visual inspection and eye tests

Both Countries: Conditions for visual inspection varied greatly from operator to operator with a similar variation of the good, the bad and the ugly in each country.

The provision of lighting varied widely with respect to both hangar fixtures and portable sources.

Provision for ensuring that an inspector could actually see differed widely.

UK Variations: No mandatory eyesight test is required for visual inspectors except as part of the medical examination when entering the company. The situation varied from greatly from regular two-yearly tests to none at all. There seems a great reluctance for operators to finance this programme. NDT specialist inspectors are better served with mandatory examination being part of the annual requirement.

US Variations: All inspectors have regular eye tests (??as part of the FAA requirement??). Particular vision standards are defined, e.g., 20/25 Snellen (near) and 20/30 (distance). Colour vision is handled as part of the physical requirements.

Operators generally finance these tests either in their own medical centers or out-of-house.

Evaluation: Lighting within the hangar together with supplementary sources on docking and independent stands is usually sufficient to allow inspection of the outer surfaces of the aircraft. However these lights are frequently bright point sources which also reflect off the bare r painted metal surfaces of the aircraft. If an inspector glances at these, a mild form of arc eye may result from the direct or reflected glare. This degrades the acuity of vision and can take several minutes to revert to normal. Inspection quality during this time is greatly reduced. A greater number of less bright sources such as daylight fluorescents is recommended.

It must be a universal requirement for an inspector to be able to see. Without regular testing, the inspector may easily drift into inadequate vision. Gradual receding of the in-focus plane is all part of the aging process. An elementary test in the UK, (Lock & Strutt, 1985) showed there to be little or no correlation between the distance at which typescript could be read and whether an inspector had had a recent eye test or whether he wore glasses.

There is a reluctance on the part of the operator to declare an inspector unfit to continue inspection duties on the grounds of failing eyesight whereas they would not hesitate if the inspector was otherwise medically unfit.

9.4.8 Reporting imminent indications

Both Countries: (This is not an area where there are transatlantic differences but, if taken up it might have implications in both the UK and the USA.) During much inspection work there are occasions when some indication of a possible defect is seen. For visual inspection this is not easy to exemplify, but may take the form of incipient corrosion or slight rubbing. In NDT such an indication is much easier to define. Most techniques have a calibration step which sets a standard for defect reporting. In ultrasonics, for instance, this may be the height of the oscilloscope signal or simply a measured skin thickness. There is usually a substantial difference in these reportable indications and the perfect component or material appearance, in the visual case, or the background electronic noise for ultrasonics or eddy currents etc.

Evaluation: It would not take a great deal of effort for the inspector to make an official note of such a sub-reportable indication so that it could be appended to the task card on the next inspection check.

With the solid establishment of computer-enhanced task card preparation, this should present few problems. Corrosion initiation points might be detected early and the system would also provide a useful source of fracture mechanics data if, on a subsequent inspection, a crack were found.

Operators could utilize this information on all their aircraft and, if it proved useful in early identification of future trouble, it might be even be made a fleet-wide index. For any form of human inspection, feedforward information such as previously-reported sub-threshold defects, can substantially improve defect detection performance (Prabhu and Drury, 1991).

9.4.9 Work Cards, Information and Automation

Both Countries: The Work Card (also called Job Card or Task Card) is the primary command document for any inspection task. It is also the primary record of work performed, being signed and dated by the inspector and used as a reference for all Non Routine Repair (NRR) cards raised during its execution. As such, it must be well designed from the inspectors perspective if it is to be used without error. In both countries, many types of card were seen, with differing degrees of user-friendliness, and with differing levels of automation. Also the integration of the work card with other tools used by the inspector varied widely. Further information on the shortcomings of many work card systems can be found in Drury, Gramopadhye, and Prabhu, 1991 (see Appendix I). Hence specific instances are selected from our observations to show how improvements may be possible, rather than contrasting systems between countries.

UK Variations: One airline visited had a computer assisted method of job control and defect reporting which was of general interest. Work Cards had bar codes attached, as did inspectors badges. Thus to register that a job has started, the inspector swipes the bar code reader across the Work Card and across his badge. Then after inspection is completed, all defects arising are entered with a swipe of the work card, a swipe of the badge, and swipes of each of a set of defect bar codes located beside the reader. These defect bar codes have names and illustrations of the possible defects attached to them, and lead directly to computer generated NRRs.

US Variations: In two sites, the work card was integrated into a carrying case which also held the NRR forms, aircraft station diagrams, pens, and even mirrors. At one site the work cards were full size, approximately A4, while at the other they were smaller, approximately A5, with the carrying cases scaled appropriately.

Evaluation: Work cards will become more automated. Portable computers with multi-level task information have been proposed already (Reference 1). The advantages of automation are consistency, access to aircraft-specific information, and a less error-prone human interface. But automation must be undertaken correctly, or errors and frustrations will result. For example, work cards which were generated by early computer systems (still in use) have low quality dot-matrix printing, even in all capitals in places, leading to low legibility. Moves towards "good" automation need to be encouraged. Thus the use of named examples of defects on the bar code cards has the effect of reinforcing correct naming of defects. NRRs are then raised with the appropriate and correct names on them, reducing the possibilities of mis-interpretation by mechanics and buy-back inspectors. One can foresee the use of a portable computer containing the work card, with the ability to read bar codes from the aircraft structure to ensure correct location of areas for inspection, and built in defect menus keyed to the defect types possible in that inspection. Hypermedia formats can be applied to the presentation of knowledge and rules at multiple levels.

An integrated solution to the clutter of carrying the work card, other paperwork, and small tools is urgently required in many sites. Inspectors access the inspection area along ladders and scaffolds with their hands full of equipment, adding to the hazard of the task. One inspector entering a wing tank was observed as he removed items from his pockets, belt and hands to be able to fit through the access cover. There was a considerable pile of equipment resting on the wing after the removal was completed. New solutions need to be devised, of which the quoted examples are best considered as early prototypes.

9.4.10 Access

Both Countries: The modes of access for inspection of aircraft have been greatly improved in the past 10 years. This may be due to the fact that wide-bodied jets cannot be inspected standing on an oil drum or the top of a step ladder and that custom built docking is more efficient. Fortunately, this attitude has spread to smaller aircraft in a few companies although not down to the older aging aircraft such as the 707s and BAC 111s where the extra heavy engineering occasioned by the SSID programmes etc. render good docking most advantageous.

UK and US Variations: There are no essentially British or American variations although the closer and more frequent contact with the government inspectorate (HSE) in the UK than with the OSHA in the USA results in a safer environment with greater adherence to details such as toe-boarding and plank ends in scaffolds, and toxicity levels in composite repair work.

Evaluation: There is still a need for improved access. All establishments visited had examples of steps which were poorly designed or ed. Steps, mobile staircases and ladders vary enormously in quality and safety. Most have wide bases to avoid tipping and many have hand rails but there are still too many that tip easily, that are rickety with loose joints and that have wheels which do not lock. One otherwise sturdy staircase had only one wheel that was lockable and so moved around gradually during inspection; others could not be adjusted for foot height and rocked continually during inspection. The worst case involved steps that were ten feet tall with a top barely large enough for two feet so that the inspection of the fwd service door, an intricate enough task involving much torso movement to enable a close scrutiny of a complicated structure, necessitated one foot on the steps and the other on the aircraft.

On top of the wing, there is still an unwillingness to fence the perimeter yet the curve and camber of the wing make it a genuine danger where each succeeding step becomes the more hazardous.

Particular problems, such as production break inspection, can give rise to excellent access solutions: the arced bridges used being perfect for that particular job. However, they were extremely awkward when used subsequently for a horizontal lap joint.

The height of the platform is of some importance. The ideal eye position for visual inspection and NDT probe manipulation are not the same nor is that required for engineering work. There is also the need for a place to conveniently locate the NDT equipment itself. More adjustability in heights is required, preferably power driven from on board. It is very time wasting for the worker to demount to adjust the jack-up leading to the temptation to forego adjustment and work at a non-optimal height. Tailplane vertical surfaces are a particular case where this is required e.g., for manipulation and alignment of an Xray set outboard of the rudder. The popularity of the cherry-picker is due largely to the independence and variability of height and position even though it is frequently far from being a stable platform.

The most frequent problem, however, was simply of an insufficient supply of access equipment with inspectors and mechanics continually borrowing each others access stands. This wastes, time and effort, suggests to an inspector the company's lack of concern for the importance of the job, and may be the cause of an incomplete inspection due to either forgetfulness or exasperation.

Despite the plethora of access aids, the inspector will still find himself in spaces where access is difficult due to the overall aircraft design. Hatches can be too small to enter comfortably, internal spaces too small to allow for the focusing distance of the eye: if one is already holding a torch (flashlight) and a stick mirror then an additional magnifying lens becomes almost an impossibility.

Finally, the general clutter beneath and around most aircraft needs eliminating. This is generally a mix of portable work benches which can easily be moved or avoided and services such as air or electricity supplies which cannot. These trailing services are especially hazardous when they originate away from the aircraft bay e.g., the hangar walls and so hinder the movement of wheeled equipment, e.g., staircases. In some hangars, the services come from a central line below the aircraft belly and this is to be recommended as it alleviates much of the more hazardous clutter; service lines tending to remain within the footprint of the aircraft.

9.5 CONCLUSIONS

In this study, as in the previous studies of Appendix I, it was apparent that all concerned with civil aircraft inspection took their jobs most seriously, and had very high standards. Nevertheless, there are still areas for system improvement which can fully capitalize upon this highly motivated workforce.

Most of the system differences were found between individual companies rather than between the two countries. In any case, technical differences were few, as these are dictated by written regulations in each jurisdiction and circumscribed by the manufacturers' requirements for inspection tasks.

The main points raised in each of the results sections follow, arranged in the order of occurrence and not that of importance.

9.5.1 Maintenance/Inspection Responsibilities

The organizational position of inspectors could vary between the separation of inspectors from maintainers in the USA to the inspector serving as a maintenance supervisor in some UK companies. There are arguments in favor of each system with close integration of maintenance and inspection, especially through long tasks with multiple buy-back stages, weighted against perceived impartiality of a separate inspectorate.

9.5.2 The Supervisor/Inspection Dichotomy

Whether inspectors have supervisory responsibility or not, they require better support in the areas of communications (written, verbal), the organization to support these communications, and, where appropriate, some interpersonal skills development. Training and systems modifications are needed to fully support these activities.

9.5.3 Non-Destructive Testing

In the NDT area, there was a difference in the depth of training and degree of specialization between the USA and the UK, with the UK inspectors required to have deeper knowledge and more specialization. Both countries require inspectors to use rule-based and knowledge-based behavior, although to different extents. This should be realized and support in training, hardware, and documentation provided in both countries to enable inspectors to move easily and recognizably between the two modes.

With the advent of increased NDT use and much more complex systems, the current moves towards NDT specialists with at ASNT level II or PCN level 2 should be encouraged.

Equipment should be made more portable with greater use of repeater units in the same visual envelope as the probe elements in ultrasonic and eddy current techniques.

9.5.4 Bonding

In the UK, it is generally accepted that 'bonding' personnel to pay back all or part of their training costs on leaving a company is untenable in law. The practice is endemic in the USA and is universally disliked by the inspectorate force. The cost in terms of dissatisfaction probably exceeds the monetary considerations.

A replacement system, involving mutual cooperation and compensation by participating aircraft engineering companies could solve the major problems of poaching and uneven distribution of training costs. IATA or ATA or a similar body would be the best source of such an agreement.

9.5.5 Working Times

There is a great difference in the length and rotation of shifts in both countries. In the USA there is a greater tendency for the older inspectors to be given preference in a choice of shifts. The effect of this in companies where no shift-rotation occurs is often to condemn the younger, less experienced inspectors to nightwork with the concomitant difficulties of travel and social problems. This is especially significant for the married inspector with a family who, due to the high housing costs around many airport locations, has furthest to travel.

9.5.6 Demand and Supply of Mechanics/Inspectors

An upturn in demand caused both by expansion and retirement of the original generation of aircraft maintenance personnel has resulted in a resurgence of apprenticeship schemes in both countries. In the USA, the onus of training to AMT standard is on the worker whereas the UK route has been predominantly based on day-release to training centre or technical college.

Attraction of the high-grade personnel required could be improved by improvements in low starting pay, poor working conditions and a cessation of bonding.

An improved interface is recommended between military and civilian aircraft maintenance employment.

9.5.7 Visual Inspection and Eye Tests

There are no mandatory requirements in the UK or in the USA for annual checks of visual inspectors' eyesight to specified standards. USA operators tend to have an in-house requirement and this is frequently financed by the company. UK operators rarely have tests other than on initial entry into a company.

There is such a requirement for UK NDT personnel: there should be for all inspectors.

Hangar lighting is frequently insufficient, especially secondary, portable lighting. Fluorescent sources are to be preferred to bright, point-source bulbs which can cause unnecessary glare either directly or on reflection.

9.5.8 Reporting Imminent Indications

Where NRRs arise from a reportable level, there could exist a secondary reporting system for sub-reportable, but still visible, indications. This might be incorporated within the task card or some other computer system to act both as a highlight for future inspection, and a source of data for fracture mechanics analysis.

9.5.9 Work Cards, Information and Automation

Increased use could be made of computer-technologies in the near future to provide the inspector with enhanced on-line information of the task in hand. This might be implemented as a small portable computer indirectly accessing a company mainframe. The information could consist of a multiple choice level of presentation of the task description to suit the inspector's experience, the past history of that particular aircraft or of the relevant fleet statistics.

9.5.10 Access

There are no great regional differences in access provision. The problem area is for the older aging aircraft which is unlikely to have custom-built staging or docking and yet will be liable to extended structural inspection. Indeed, even the access stairs etc. available are frequently in very poor condition through age and neglect.

Services are centrally located under the fuselage more frequently in the USA, eliminating much of the problem of trailing wires, cables and hoses which can be a source of hazard in the movement of wheeled access platforms.

9.6 Bibliography of Complementary

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