An Analysis of the Visual Demands Associated with Aviation Maintenance Inspectors

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Background: Aircraft maintenance inspectors spend many hours searching for defects in aircraft. Vision guidelines exist for nondestructive inspection and testing (NDI/NDT) personnel, but not for visual inspectors. A detailed task analysis is required before job-relevant vision standards can be developed. This study is a descriptive investigation of the visual tasks of visual and NDI/NDT inspectors. **Methods:** Inspectors at aircraft maintenance facilities were observed performing inspections on aircraft and aircraft components. Fixation distances and directions were measured and recorded for inspectors performing visual, fluorescent penetrant, and borescope inspections. Additionally, a visual information survey was completed by 188 inspectors from the different worksites. **Results:** On over 4000 fixations during inspection procedures, near working distances of 50 cm or less were recorded 66.3% of the time. Intermediate distances (>50 cm to 1 m) comprised 23.3% of the fixation distances and were most frequently observed in the performance of borescope and visual inspections. The mean age of inspectors at these locations was 45.1 years. **Conclusions:** The primary duty of visual inspectors is the identification of defects in aircraft when viewed at near and intermediate distances. Data from this study support the need for vision standards for visual inspectors and for as the addition of an intermediate visual acuity requirement to the present distance and near vision standard for all inspectors over 50 years of age.

INTRODUCTION

Maintenance personnel working at aircraft maintenance facilities may have primary responsibilities as visual inspectors where they must use only their vision to assess the condition of aircraft and aircraft components; or they can work in areas where Non-Destructive Inspections (NDI) and Non-Destructive Testing (NDT) are performed. In these workareas, NDI/NDT inspectors often use highly sophisticated imaging and scanning devices (e.g., borescopes, ultrasonic scans, eddy current imaging, X-ray) to aid defect detection. However, even for these inspectors, performing a simple visual inspection is a vital component used to ensure that aircraft are safe to fly. In a recent survey of maintenance facilities, 52% of inspectors were classified solely as visual inspectors, 36% were classified as visual and NDI/NDT inspectors, while only 12% were classified solely as NDI/NDT inspectors (Nakagawara et al., 2003).

Recommended vision standards exist for NDI/NDT personnel (Production and Airworthiness Division, 2001); however, these guidelines do not appear to be based upon a job-task analysis, which documents viewing distances required for efficient task performance. Additionally, no such vision guidelines exist for inspectors who only perform visual inspection tasks. Because of the intimacy between the two inspection classifications (i.e., visual vs. NDI/NDT), most facilities use similar testing requirements for both types of inspectors. While their goals are similar, the two jobs are inherently different in terms of the visual task and sophistication of testing equipment used.

To the greatest extent possible, vision standards should ensure that workers have the necessary visual skills to perform job-relevant tasks in an efficient and safe manner. For NDI/NDT inspectors, vision skills should be adequate to identify areas of concern (i.e., *detect* potential defects) and to determine if further action is required (i.e., *decide* if a possible defect is within tolerances or if special tests are necessary) (Drury, 2001). Although the NDI/NDT personnel have many tools to aid in the detection of defects (e.g., fluorescent penetrant and magnetic particle inspections, eddy current and ultrasonic devices, borescopes, magnification aids), simple visual inspection may account for up to 80% of all inspections (Goranson and Rogers, 1983).

With advancing age, one gradually loses the normal physiologic ability to focus on near objects. This condition is termed presbyopia. Beginning at age 40, individuals often have difficulty focusing for extended periods at a normal reading distance. For an inspector over 40 years of age, the decline in accommodation may start to affect nearpoint searching. Typically by age 50 almost all focusing ability is lost.

Bifocal lenses can provide appropriate focus for a given working distance, for example, at 16 inches with a +2.5 Diopters (D) reading addition. For a normally-sighted presbyope, with vision correctable to 20/20, these bifocal spectacles would allow for passage of the present Air Transport Association

Specification 105 standard. Should the inspector be required to view at a distance of 32 inches, however, the search area would be 1.25 D out of focus in both the distance and near portions of his spectacles. He / she would now be inspecting the aircraft with reduced visual acuity, estimated to be 20/50 to 20/60. The FAA manages this situation for pilots 50 years of age and over by requiring that pilots see 20/40 or better at both 16 and 32 inches (Nakagawara and Wood, 1998). This age-related requirement is based upon the need for pilots to see cockpit instruments at intermediate distances and the normal physiological changes that limit a person's ability to focus at near and intermediate distances after 50 years of age.

A detailed task analysis with documentation of required working distances is not present in the aviation literature for NDI/NDT and visual inspectors. This study investigated the visual task performed by aviation maintenance inspectors and looks specifically at the viewing distances and directions required to conduct fluorescent penetrant, borescope and visual inspections.

METHODS

The research protocol was approved by the Institutional Review Board of the Ohio State University. Visual and NDI/NDT inspectors at five aircraft maintenance facilities were observed as they performed inspection duties on several types of commercial aircraft (e.g., B727, B737, B767, A320, DC8, DC9, MD80). Various measures of the visual tasks were recorded, along with the specific auxiliary aids used (i.e., flashlight, magnifier, measuring rule), during fluorescent penetrant, borescope, and visual inspection procedures. Additionally, visual inspection tasks were divided into two categories depending upon the major intent of the procedures. These categories were termed "buy-back" and "primary" inspection tasks.

Fluorescent Penetrant Inspections. Fluorescent penetrant inspections (FPI) were observed at only one maintenance facility. Inspections were mainly performed on engine parts. These parts were inspected at the "case" shop or the "rotary" shop, depending on whether the part was a rotating or non-rotating engine component. While good practices for FPI lists 7 moderately independent steps (Drury, 1999), only the inspection (visual detection and decision) portion of the procedure was observed and assessed. Within both shops, engine parts would move along while suspended from an overhead conveyor. Workers would divert individual parts from the main conveyor and move it to their workstations in order to complete the fluorescent penetrant inspection procedure.

Borescope Inspections. Borescope inspections (BI) were observed at 2 of the maintenance centers. The inspection procedure involved using a video borescope to inspect internal engine parts (Drury and Watson, 2000). Inspectors viewed a video monitor as they searched for internal engine defects. At one facility, the engines were separated from the aircraft, while at the other, the engines were inspected while still mounted under the wing.

Visual Buy-Back Inspections. Inspections were termed "buy-back" when inspectors checked jobs individually completed by aviation maintenance technicians (AMTs, i.e., mechanics). These tasks were very specific and generally involved repair or replacement of individual parts or aircraft assemblies. Many involved the inspectors reviewing the AMT's job card for repair descriptions at an inspection station before traveling to the AMT's work bench or aircraft section. A "buy-back" inspection would typically last only 30 to 60 seconds, but could last several minutes when a complicated visual inspection was necessary.

Visual Primary Inspections. Primary inspections were those tasks where workers checked general areas during the initial phases of maintenance to identify specific types of defects identified on work cards. Overall, these inspections could last between several minutes for small jobs to several hours for inspections of large areas.

For FPI, BI, and visual primary inspections, researchers recorded viewing distances and directions at specific points in time while workers performed inspection procedures. Depending upon the type of work and areas under inspection, researchers would record viewing information at 30-second or 1-minute intervals. Therefore, the data represents viewing information similar to that which would be collected if a video recording were sampled at every "n^{th}" frame. For visual buy-back inspections, workers would typically view the indicated parts for only 30 seconds to several minutes. Because of this, only a single fixation distance was recorded for these inspections.

For viewing distance, researchers indicated the distance from the inspector's eyes to the visual target using 7 different distance categories (≤ 33, 34 to 40, 41 to 50, 51 to 66, 67 to 100, 101 to 200, and > 200 centimeters). These categories represented equal steps in focusing units (i.e., 0.50 Diopters or inverse meters).

For this report, the 7 fixation distance groups were reduced to 3 by merging data from appropriate groups. The fixation distance data in this report are presented as follows:

a) Near – 50 cm or less,

b) Intermediate – over 50 cm to 1 meter, and

c) Far – over 1 meter.

For viewing direction data, "up" was marked when the object of regard (OR) was above the level of the inspector's eyes, "down" was marked when the OR was between eye level and the inspector's waist, and "full-down" was marked when the OR was below the inspector's waist.

A Chi Square analysis of the distributions of fixation distance and fixation direction was performed across the three types of inspections (visual, fluorescent penetrant, and borescope).

Finally, a voluntary survey was distributed to visual and NDI/NDT inspectors at the various maintenance facilities that solicited demographic and refractive error correction information (e.g., glasses, contact lenses, refractive surgery).

RESULTS

Data analyzed were from 5 maintenance facilities in the continental United States. Three of these facilities were private, one was a major airline, and one was at a military installation.

Survey. The mean age of inspectors responding to the survey administered at these facilities was 45.1 ± 8.5 years (n = 188), and survey responses are summarized in Table 1. Of those responding to the survey (approximately 30% of the entire inspection workforce for these facilities), 49.5% reported wearing spectacles for near work activities, 8.0% reported wearing contact lenses at some time on the job, and 6.9% reported to have undergone refractive surgery. Approximately 30% of the respondents wore no refractive correction at either distance or near. For inspectors over 40 years of age using nearpoint correction, 35% reported wearing single vision lenses, 24% reported wearing traditional bifocals, 35% reported wearing progressive bifocals, 4% reported wearing trifocals, and 2% reported wearing double bifocals. For those wearing contact lenses, 80% reported to wear soft lenses while none of the respondents reported to wear bifocal or monovision contact lenses.

A slight majority of inspectors completing the survey rarely performed any NDI/NDT procedures. Of the respondents, 57.6% reported that less than 10% of their work time is devoted to NDI/NDT procedures. As a group average, however, it was reported that 26.8% of overall inspector time was devoted to NDI/NDT procedures.

Observations. The distribution of fixation distances and directions for visual inspections, fluorescent penetrant inspections, and borescope inspections for over 4,000 recorded fixations are summarized in Table 2.

Fixation Distance. For all inspections, visual detail was often viewed at "normal" reading distances (less than 50 cm for 66.3% of fixations). This was particularly true for fluorescent penetrant inspections where working distances at 50 cm or less were observed over 93% of the time. On the other extreme, however, near fixation distances were observed for borescope inspections 33.4% of the time. For these inspections, borescope inspectors primarily viewed a video monitor positioned at an intermediate distance. Visual inspection tasks were most often performed at near viewing distances (72.2%).

Fixation Direction. With borescope and fluorescent penetrant inspections, fixation direction was mainly confined to normal reading locations (down position). For both inspection types, workers had control of the work environment and could move the visual target to a comfortable position. For visual inspections, workers often had to position their bodies relative to a fixed visual target and, therefore, more variable fixation directions were required. This resulted in viewing up nearly 30% of the time with visual inspections and viewing below the waist nearly 16% of the time. Further analysis showed that for the upward fixations, a vast majority (75%) involved focusing within 50 cm.

Chi-square analysis results across inspection types are shown in Table 2. The distributions for both fixation distance and fixation direction are shown to be different across the 3 inspection methods. Fluorescent penetrant inspection is heavily weighted at the near fixation distance in the normal down position. Borescope inspections are more evenly distributed across all viewing distances but are heavily weighted in the down viewing position. For visual inspections, a wide distribution is found across both fixation distance and direction.

Table 1. Survey Responses.
Inspectors were those respondents that reported to perform NDI/NDT or VI procedures over 50% of their work time.

Outcome	All n = 188	**NDI/NDT n = 46**	**VI n = 103**
Mean Age (yrs)	45.1	44.3	45.6
	[a]t = 0.67, p = 0.50		
Glasses for Near Inspection	49.5 %	**67.4%**	**42.7%**
	[a]Chi-Sq = 7.74, p = 0.005		
CL Wearer	8.0%	10.9%	5.8%
	Chi-Sq =1.18, p = 0.277		
Refractive Surg	6.9%	4.3%	8.7%
	[a]Chi-Sq = 0.90, p = 0.344		

[a] T-test and Chi-square tests for NDI/NDT and VI comparison.

Table 2. Fixation Distances and Directions (percentages).

Distance	VI	FPI	BS	All
Near	72.2	93.3	33.4	66.3
Intermediate	18.7	6.5	44.7	23.3
Far	9.2	0.2	21.9	10.4
	[a]**Chi-Sq = 620.6, p < 0.001**			
Position				
Up	29.0	14.2	8.1	17.1
Down	55.4	85.8	88.9	76.7
Full Down	15.7	0.0	2.9	6.2
	[a]**Chi-Sq = 494.2, p < 0.001**			

[a]Chi-square tests for comparison of 3 type inspections.

DISCUSSION

The establishment of a vision standard shares many similarities with the determination of a cut-off score for any ability test. The essential job functions must be identified as well as the consequences of non-performance. While the frequency of task performance is an important element in setting a standard, task frequency cannot always be equated with task importance. When the consequences of an error are dire (missed crack in a critical component, for example), even a rarely performed task can drive a vision standard. The majority of inspection work performed by all inspectors in this study was performed at viewing distances of less than 50 cm (i.e., 66.3%). Thus, the essence of this work is the identification of defects at near working distances. Coupled with the extreme potential consequences of missing a defect, the frequency data greatly supports the need for a nearpoint visual acuity standard for visual inspectors who are currently not required to meet acuity requirements at any distance.

The data supporting the need for an intermediate visual acuity standard is also strong, especially for visual and borescope inspections. Visual inspectors must observe aircraft components that are difficult to reach and to visualize. These inspectors often cannot physically position themselves to obtain "normal" viewing distances and directions. Intermediate distance viewing is often required. For borescope inspections, workers do have greater control for the inspection. Inspectors can position television monitors for viewing at convenient locations, even though the parts inspected can be relatively inaccessible to the inspector. Borescope inspectors, however, often chose intermediate viewing distances for viewing the monitor to allow for full body movements to more easily hold and position the borescope probe.

The differences in the distributions of working distances and directions across the different types of inspections are due both to the nature of the inspection task and to the control (or lack of control) the inspector has on the part being inspected. With FPI, the majority of the work is done at near working distances in a normal reading position (down). This was the case for fluorescent penetrant because most inspections are done on individual parts taken off aircraft, allowing greater control of part positioning.

Visual inspectors have the least viewing flexibility as the object of regard is often firmly fixed to the aircraft and inspectors must change body and head position, often in cramped quarters, to gain an acceptable viewing posture. Nearly 20% of visual inspections are done at an intermediate viewing distance (between 50 cm and 1 meter). Visual inspectors often inspect large areas of an aircraft for cracks and other defects from intermediate distances. Because a longer working distance translates into smaller visual angles for visual detail subtended to the eye, it could be argued that it is more important for inspectors to be capable of clear focusing at intermediate distances than it is for near working distances. For borescope inspections, nearly one-half (44.7%) of the viewing distances were observed to be between 50 cm and 1 meter. It is clear that a large portion of aircraft inspection must be done with a fixation distance of greater than 50 cm.

Because of our normal physiologic accommodative ability, if a worker under 40 years of age can pass a vision standard at a given distance using normal, single vision glasses, he/she should be able to pass the same standard at all working distances. For workers older than 50 years, however, specially designed multifocal lenses may be required to allow sharp vision at intermediate and near working distances.

As the mean age of surveyed inspectors is 45.1 years, a large proportion of inspectors have lost significant natural accommodative power. Eyewear must be designed with viewing distances and directions in mind. Although the majority of fixation directions for aircraft inspection correspond to the normal bifocal position (slightly down), much visual inspection activity is directed upward (29.0%) and at intermediate to long viewing distances (27.9%). Inspectors should thoroughly discuss the variations in object distance

and direction required of their jobs with their eye care practitioners. In order to ensure clear and comfortable vision at all working distances, special eyewear designs may be required. Inspectors older than 50 years may require trifocals or progressive addition bifocals (i.e., no-line) to allow clear vision at all required viewing distances. As working distances vary regardless of the viewing directions, it may be beneficial to use clip-on near lenses to accommodate some working distances and/or awkward directions. A set of clip-on lenses of different powers can be obtained to ensure that clear focusing is obtainable at all fixation distances.

The data presented supports vision requirements for visual inspectors as well as the addition of an intermediate visual acuity requirement to the present distance and near vision standard for all inspectors over 50 years of age. As inspectors age, more frequent vision screenings would help ensure that refractive correction is adequate to accommodate the three working distances. It is impossible to design eyewear, however, that will allow all fixation directions and head positions to be capable of clear vision at distance, intermediate and near distances. Therefore, a worker education program should be included within the overall vision program. Such a program will help inspectors understand the limitations of multifocal lenses for aviation inspection tasks and learn what lens devices are available to better accomplish their visual tasks in a safe and efficient manner.

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