VISION STANDARDS AND TESTING REQUIREMENTS FOR NONDESTRUCTIVE INSPECTION (NDI) AND TESTING (NDT) PERSONNEL AND VISUAL INSPECTORS

Final Phase I Report
29 August 2003

For

William K. Krebs, Ph.D.
Aviation Maintenance Human Factors Program Manager, AAR-100
800 Independence Avenue, S.W.
Washington, D.C. 20591

By

Gregory W. Good, O.D., Ph.D.
Professor of Clinical Optometry
The Ohio State University, College of Optometry
320 W. 10th Ave.
PO Box 182342
Columbus, Ohio 43218-2342

Van B. Nakagawara, O.D.
Vision Research Team Coordinator, AAM-630
Civil Aerospace Medical Institute,
Mike Monroney Aeronautical Center
6500 S. MacArthur Blvd.
PO Box 25082
Oklahoma City, OK 73125

Introductory Comments

Visual inspection is an important component of aircraft maintenance. The National Transportation Safety Board (NTSB) has cited the failure to identify visually detectable corrosion, cracks, or inclusions as the probable cause of several aviation accidents[1,2,3]. Non-Destructive Inspection (NDI) and Non-Destructive Testing (NDT) procedures require careful visual inspection of aircraft and aircraft components. NDI/NDT personnel must use their vision, with or without various aids, to make judgments grossly, as well as when inspecting aircraft using highly sophisticated imaging and scanning devices (borescopes, ultrasonic scans, eddy current imaging, X-ray, etc.). Presently, there is no existing national policy to ensure that persons performing aircraft maintenance and inspection tasks meet a specific vision requirement.

The FAA's Production and Airworthiness Division (AIR-200) recognized a general lack of national policy concerning qualification and certification of NDI/NDT programs and prepared a memorandum[4], dated September 26, 2001, to address the issue. Included within the memorandum were minimum vision requirements. This memorandum follows an FAA advisory circular[5] from February 1999 that addresses the same topics. Several national and international organizations have made recommendations for qualifications of NDI/NDT personnel. The September 2001 memorandum identified the standards found to be acceptable to the FAA for assuring that only qualified individuals perform NDI/NDT inspections and procedures. These include:

Nationally –

MIL-STD-410E, Military Standard. Nondestructive Testing Personnel Qualification and Certification. (This document has been rescinded by the Department of Defense, but is still considered acceptable to the FAA.)

ATA Specification 105, Air Transport Association, Guidelines for Training and Qualifying Personnel in Nondestructive Testing Methods.

AIA-NAS-410, Aerospace Industries Association, National Aerospace Standard, NAS Certification & Qualification of Nondestructive Test Personnel. (This document has superceded MIL-STD-410E.)

Internationally –

ISO 9712, "Non-Destructive Testing - Qualification and Certification of Personnel" or JAA JAR-66, "Certifying Staff Maintenance."

These "standards" provide recommendations for levels of initial and recurrent training, levels of competence, and vision testing. The memorandum further describes the generic elements of the different standards and states minimal requirements organizations developing NDI/NDT qualification procedures should meet. In terms of vision testing, the memorandum provides this description:

1. Vision Examinations: NDT personnel should receive documented vision and color blindness testing at reasonable intervals (one to two years, shorter preferred). The NDT inspector shall have documented evidence of satisfactory vision in accordance with accepted medical standards to be considered a qualified NDT inspector. Vision examinations can either precede or accompany the initial determination of qualification to perform NDT. Vision examinations shall be administered by personnel in accordance with the standard to determine qualification.

(a) Near Distance Vision Requirements:

The NDT inspector shall have natural or corrected near distance acuity in at least one eye capable of reading the Jaeger Number 1 Test Chart or equivalent at a distance of not less than 30 cm (12 in.).

(b) Color Vision Requirements:

The NDT inspector shall be able to differentiate among colors used in the NDT method(s) for which the inspector is qualified.

(c) Vision Examination Documentation Requirements:

Following initial qualification, the documented near distance and color vision examinations shall be administered as required above, and records thereof retained by the employer.

The September 2001 memorandum states that this description provides for a minimum level of performance; thus, individual organizations are able to implement stricter guidelines. However, this “standard” lacks the specificity that FAA vision requirements typically provide to ensure uniformity of compliance throughout the industry. Organizations, many with limited resources, are thus left to interpret the standard with insufficient guidance to develop a meaningful vision program for their employees. The color vision requirement, for example, leaves the decision for compliance totally to the discretion of organizational supervisory and/or medical personnel. An individual with a mild color vision defect may be allowed to perform NDI/NDT procedures for a carrier that interprets the standard loosely (e.g., accurate color naming of a fixed number of colored samples), but may be deemed “unqualified” for a carrier that supports a stricter interpretation (i.e., normal color vision).

In terms of visual acuity, the ATA Specification 105 standard includes a distant visual acuity measure, albeit lenient (20/50), while the AIA-NAS-410 and FAA guidance memorandum do not. The vision requirements set forth in various industry programs also are not uniform. The training manual[6] for NDI/NDT personnel for American Airlines lists visual acuity requirements at nearpoint of 20/25 in at least one eye and at distance of 20/30. At United Airlines, the requirements[7] are more strict with a nearpoint requirement of 20/20 and a distance requirement of 20/25. Additionally, the question of an intermediate distance visual acuity requirement is not addressed within any of the aforementioned documents, even though casual observation of inspectors performing NDI/NDT procedures shows that they frequently use working distances between 16 and 80 inches. Finally, no recommended or industry adopted vision standard suggests testing for stereopsis (depth perception), contrast and glare sensitivity, or dark adaptation, all of which appear to be necessary (to some extent) when performing various NDI/NDT inspection procedures. Such capabilities may be compromised in individuals with ophthalmic conditions, including: those who are monocular or utilize monovision correction; those with corneal haze (often present after laser refractive surgery), corneal scarring or incipient cataracts; and those experiencing the normal age-related decline in the ability to quickly adapt to changing light levels (due, in part, to the reduction in ocular media clarity and pupil size).

Based upon the lack of uniformity for vision requirements for NDI/NDT inspectors and the apparent setting of the present vision recommendations (e.g., ATA Specification 105, AIA-NAS-410) without regard to all NDI/NDT job tasks (e.g., visual inspection at intermediate distances), this report will review the present literature to determine if sufficient information can be gleaned to set vision requirements for NDI/NDT personnel that are based upon the essential tasks of the occupation. Additionally, information regarding the demographic makeup of the NDI/NDT workforce will be reviewed to help determine recommendations for intermediate and nearpoint visual acuity and focusing power and for the interval of vision testing (e.g., 6 months, 1 year, 2 years). Specific questions to be answered within this report are:

a) Has there been NDI/NDT and visual inspection human factors visual task analyses conducted?
b) Are there demographic statistics for NDI/NDT and visual inspection personnel?
c) Are there optometric data on NDI/NDT and visual inspection personnel?

To address these questions, a comprehensive literature search was conducted that included computer searches of several on-line databases. The database in which the most pertinent papers were found was that for the Human Factors in Aviation Maintenance and Inspection (hfskyway.faa.gov). Within the listing for *Aviation Maintenance and Inspection Research Phase Reports* from 1988 to 2002, "maintenance, visual, and inspection" were used as keywords for this search. One hundred fifty-six references were obtained from this database. Other databases searched were MEDLINE (Index to journal literature in health sciences) and COMPENDEX (Index to journal literature in engineering science). All documents considered relevant to the visual demands of NDI/NDT inspection procedures, NDI/NDT population demographics, and their optometric condition were obtained and reviewed.

Kleven and Hyvarinen[8] report that vision testing for inspectors goes back approximately 40 years. They found that in spite of the varied visual tasks inspectors in different occupations face, the vision requirements listed from various standards are surprisingly similar. The authors state that, irrespective of new technology and changes in specifications of inspections, "vision testing has changed little over time." This implies that the standards have been shared and not based upon essential tasks of individual occupations.

To the greatest extent possible, vision standards should insure 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 (detect) and to evaluate (decision) these areas as to whether further action is required[9]. 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, etc.), simple visual inspection may account for up to 80% of all inspections[10].

Exactly what constitutes the minimum acceptable vision for an NDI/NDT inspector is difficult to determine. In terms of visual acuity, the standard should be based upon the angular size of the smallest detail for which detection is required.

Rummel[11] generated probability of detection (POD) curves using NDT procedures to standardize testing by NASA for the space shuttle system. This and other research led to the use of an anomaly size of 1.3 mm (0.05 in) as the 90 / 95 level that operators performing special NDT procedures must detect 90% of the time with 95% confidence. In a benchmark POD study, Spencer, Schurman, and Drury[12] had visual inspectors identify cracks in an out-of-service Boeing 737. In this study, the 90% detection point was found for cracks around 0.3 inches. As expected, this value is much larger than the 90 / 95 value (0.05 inches) for NDI/NDT specialty procedures. Also, the authors state that, for the visual inspection, the length of the crack, crack width, contrast, and inspector accessibility all affected detection performance. These data suggest that calculation of a minimum acceptable visual acuity limit is not possible given the many variables at work. Defect length, width, and contrast, light level, as well as viewing distance are all factors contributing to the visual acuity demand of a given defect. In none of the studies mentioned, did the researchers attempt to manipulate, restrict, or even document viewing distances. With a greater viewing distance, a defect of a given size subtends a smaller angle, hence will have a greater visual acuity demand.

Drury[9] analyzed the visual task for inspections in terms of identifying a signal from background noise. He concluded that the greater the strength of the signal (visibility of the crack), relative to the noise (background detail), the more likely detection will occur (for an on-site inspection). Relative signal strength can be increased by decreasing the viewing distance (crack subtends larger angle to the observer), ensuring a focused retinal image (proper correcting lens for the specific working distance), or by improving the quality (eliminate glare) and quantity (increase illumination) of light on the search area. Unfortunately, in practice, decreasing the viewing distance, quality, and quantity of light can be difficult depending on the proximity and accessibility of the search area. Therefore, just as performance is enhanced by increasing target size and contrast above threshold levels, requiring better vision than that predicted from a direct calculation of minimum target detail is advisable whenever possible. This is particularly important when considering the "sensitivity decrement" that is found with extended search times especially when finding defects are relatively rare events, a phenomenon known as "vigilance decrement"[13].

Since 1988, the FAA has funded numerous human factors projects for Aviation Maintenance Technicians (AMTs) and Inspectors[14]. These projects were intended to increase the efficiency and accuracy of work performance. For NDI/NDT personnel, contributions were made in the development of "Good Practices" for several inspection procedures[9,15,16]. Additionally, several studies have documented the essential tasks of Aviation Maintenance Personnel (AMP)[17,18]. These studies provided beneficial data for job-related curriculum development at AMT schools and provided excellent human factors guidance to increase job accuracy and/or efficiency. However, the studies failed to document measures of visual detail and working distances, which are required to develop job-relevant vision standards.

For an inspector over 50 years of age, the lack of near focusing ability can greatly affect nearpoint searching. 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 inspector, with vision correctable to 20/20, these bifocal spectacles would allow for passage of the present ATA Specification 105 standard. Should such an inspector be restricted to a viewing 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 would now be inspecting the aircraft with reduced visual acuity, estimated to be 20/50 to 20/60. The FAA deals with this situation by requiring pilots 50 years of age and over, who apply for first- or second-class airman medical certificates, possess the ability to see 20/40 or better at both 16 and 32 inches[19]. This age-related requirement is based upon the need for pilots to see cockpit instruments at intermediate distances and the physiological finding that active focus ability deteriorates with age.

A detailed task analysis, with documentation of required working distances and visual detail dimensions, is not present in the aviation literature for NDI/NDT inspectors. This type of vision-related task analysis is required for these inspectors before a job-relevant vision standard can be developed.

NDI/NDT Demographics

Understanding the demographics of a workforce is an important element in the setting of a vision standard. As visual functioning (specifically, accommodation) and prevalence of eye disease are age related, demographic predictors should be considered before the setting of vision requirements related to working distance and focus ability (i.e., near and intermediate visual acuity) and the period for re-examination. An additional consideration is that many maintenance facilities lack medical personnel that would be required to administer sophisticated testing.

Complete demographic information on NDI/NDT and Visual Inspection personnel does not appear to be present within the aviation literature. When a paper dealing with AMP provides any demographic information, it is generally not clear if the study participants and/or respondents represent the entire population of AMP or are just a sample of convenience. There does not appear to be any scientific papers that use statistically valid random samples of participants. Additionally, a typical paper will discuss AMTs or AMP and combine all mechanics and inspectors into one of these general groups. Current demographic information specific to NDI/NDT personnel and Visual Inspectors is not available.

An early 1990's Bureau of Labor Statistics study reported in a Drury et al.[20] paper listed the median age of AMTs as 36.2 years. Additional data was included in the "Final Report on the Job Task Analysis of AMTs," prepared by the Northwestern University Transportation Center in 1999[17]. Data from 2400+ AMP who completed their survey showed a bimodal distribution of work experience (10 years and 29 years) with an overall median of 14 years. It was noted that few respondents had less than 4 years of experience. As NDI/NDT inspectors typically have general AMT experience, and inspector positions are most often sought from within the AMT community, it is logical to assume that NDI/NDT inspectors are in the older and more experienced segment of the AMT population. This supports the notion that a large percentage of NDI/NDT inspectors are presbyopic and that these workers are at greater risk of ocular disease based solely upon worker age.

While gender and ethnicity statistics for NDI/NDT inspectors are not in the literature, several papers report the general under-representation of minorities and women in the overall AMT workforce[21,22]. The Pilot and Aviation Maintenance Technician Blue Ribbon Panel report[21] from 1993 reported 9% of AMTs are black, 4.8% are Hispanic, and only 7.8% are women. Again, however, it is important to note that these figures are more representative of the AMT workforce in general and not necessarily directly applicable to the NDI/NDT and Visual Inspector population.

Finally, more complete knowledge of other factors that would aid in the development of a practical vision standard for NDI/NDT personnel include the ophthalmologic characteristics of the existing workforce, workplace ergonomics, facility data (i.e., number, type, and size), and the frequency and type of inspection procedures typically performed at different facilities. For example, with respect to the latter, it would be overly restrictive to impose a vision requirement on the entire NDI/NDT community based on a single inspection procedure that is rarely performed by only the most highly qualified and skilled individuals. Furthermore, once a vision standard is developed, it would be important to know how it may impact the recertification of the existing NDI/NDT workforce and the hiring of new applicants. Therefore, due to the general lack of information specific to the NDI/NDT and Visual Inspector population, the development and dissemination of appropriate survey questionnaires, as well as an impact study, would appear to be necessary undertakings.

SUMMARY

A review of the literature was undertaken concerning the essential job tasks performed by NDI/NDT personnel and Visual Inspectors. Three specific questions were addressed. These questions related to the job relevancy of the present vision recommendations for all inspectors and the ramifications regarding the present workforce should the present recommended vision standard be modified.

a) Has there been NDI/NDT and visual inspection human factors visual task analyses conducted?

Detailed job task analyses have been reported for AMTs. The most detailed report was performed to review and recommend AMT school curricula. These analyses have documented the many varied tasks performed by these technicians; however, they have failed to document the specific tasks performed by NDI/NDT and Visual Inspectors. Within several other reports, recommended practices are documented for NDI/NDT specialty procedures (e.g., borescope, fluorescent penetrant inspection, and visual inspection). In none of these reports, however, are the visual job tasks delineated in terms of size of visual detail, required working distances, or level of visual discrimination required for efficient job performance.

b) Are there demographic statistics for NDI/NDT and visual inspection personnel?

Demographic statistics specifically for NDI/NDT and visual inspection personnel have not been reported in the literature. For general AMT personnel, however, studies from the 1990’s report a mean age of 36.2 years, a bimodal AMT experience distribution (peaks at 9 and 31 years), and an under-representation of minorities.

c) Are there optometric data on NDI/NDT and visual inspection personnel?

There are no reports in the literature, which discuss the refractive needs, corrective modalities, or overall visual health of NDI/NDT personnel in the aviation industry.

The lack of a specific visual job task analysis and a demographic description of NDI/NDT and visual inspection personnel mandates that further analyses and measurements are required in order to develop a job-relevant vision standard. We recommend proceeding with Phase II of the project.

REFERENCES

1 National Transportation Safety Board. Uncontained engine failure. Delta Airlines Flight 1288. McDonnell Douglas MD-88, N927DA, Pensacola Regional Airport, Pensacola, July 6, 1996. NTSB/AAR-98/01. 1998.

2 National Transportation Safety Board. Aircraft Accident Report. United Airlines Flight 232, McDonnell Douglas DC-10-10, Sioux Gateway Airport, Sioux City, July 19, 1989. NTSB/AAR-90/06. 1990.

3 National Transportation Safety Board. Aircraft Accident Report. Aloha Airlines Flight 243. Boeing 737-200, N73711, near Maui, Hawaii, April 28, 1988. NTSB/AAR-89/03. 1989.

4 Production and Airworthiness Division (AIR-200), FAA. *Qualification standards for nondestructive testing (NDT) inspection/evaluation personnel*. @ URL: http://www.faa.gov/certification/aircraft/NDTQUALSTDMEMO.htm. Oct 2002.

5 Federal Aviation Administration (1999). *Training qualification certification of nondestructive inspection (NDI)*. Advisory Circular AC NO. 65-XX . @ URL:http://hfskyway.faa.gov. Oct 2002.

6 American Airlines. *Nondestructive training manual: qualifications program*.

7 United Airlines. *Administrative and operating procedures: vision standards.*

8 Kleven S, Hyvarinen L. Vision testing requirements for industry: Back to basics. *ME*. Aug 1999; 57(8):797-803.

9 Drury CG. (2001). Good practices in visual inspection. Human factors in aviation maintenance - phase nine, progress report, FAA/Human Factors in Aviation Maintenance. @URL: http://hfskyway.faa.gov. Oct 2002.

10 Goranson UF, Rogers JT. (1983). Elements of damage tolerance verification, *12th Annual Symposium of International Commercial Aeronautical Fatigue*, Toulouse.

11 Rummel WD. Probability of detection as a quantitative measure of nondestructive testing end-to-end process capabilities. *ME*. Jan 1998; 56(01):29-35.

12 Spencer F, Schurman D, and Drury CG. (1996). Visual inspection research project report on benchmark inspections, prepared for the FAA Aging Aircraft NDI Validation Center.

13 Mackworth NH. (1948). The breakdown of vigilance during prolonged visual search. *Quarterly Journal of Experimental Psychology*. 1:6-21.

14 Johnson W, Watson J. (1999). An assessment of industry use of FAA human factor research from 1988 through 1998. FAA/Office of Aviation Medicine. Washington, D.C. @ URL: http://hfskyway.faa.gov. Oct 2002.

15 Drury CG, Watson J. (2000). Human factors good practices in borescope inspection. FAA/Office of Aviation Medicine, Washington, D.C.. @ URL: http://hfskyway.faa.gov. Oct 2002.

16 Drury CG. (1999). Human factors good practices in fluorescent penetrant inspection. Human factors in aviation maintenance - phase nine, progress report, FAA/Human Factors in Aviation Maintenance. @ URL: http://hfskyway.faa.gov. Oct 2002.

17 Adams LK, Czepiel EJ, Krulee GK, Watson J. (1999). Job task analysis of the aviation maintenance technician. FAA/Office of Aviation Medicine, Washington, D.C. @ URL: http://hfskyway.faa.gov. Oct 2002.

18 Allen D. (1970). Phase III Report: A national study of the aviation mechanics occupation. FAA, Washington, DC. [Cited by Adams et al. (1999). Job task analysis of the aviation maintenance technician. FAA/Office of Aviation Medicine, Washington, D.C. @ URL: http://hfskyway.faa.gov. Oct 2002.]

19 Nakagawara VB, Wood KJ. (1998). Clinical application of new civil airman vision standards and certification procedures. *J Am Optom Assoc*. Mar 1998; 69(3):144-50.

20 Bureau of Labor Statistics. (1991). Washington, D.C. [Cited by Drury et al. (2000). Measuring the effectiveness of error investigation and human factors training. @ URL: http://hfskyway.faa.gov. Oct 2002.]

21 Pilot and Aviation Maintenance Technician Blue Ribbon Panel. (1993). Pilots and aviation maintenance technicians for the twenty-first century – an assessment of availability and quality. FAA, Washington, D.C.@ URL: http://hfskyway.faa.gov. Oct 2002.

22 Identification of barriers to success for nontraditional participants in aviation maintenance careers. @ URL: http://hfskyway.faa.gov. Oct 2002.