DESIGN OF THE AIRCRAFT INSPECTION/MAINTENANCE VISUAL ENVIRONMENT

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1.0 INTRODUCTION

This study was undertaken as a demonstration project in order to demonstrate how human factors techniques can be applied rapidly within the aircraft maintenance/inspection industry. Since visual inspection is such an important component of aircraft inspection, accounting for almost 90% of all inspection activities, it is imperative that the task be performed in the most suitable work environment (Drury, Prabhu, and Gramopadhye, 1990). Studies in aircraft inspection have shown that poor illumination, glare, and other adverse lighting conditions could be important reasons for "eye strain" or visual fatigue. Visual fatigue results in deterioration in the efficiency of human performance during prolonged work. The objectives of this study were: to identify potential sources of improvement in inspection task lighting, to suggest modifications so that the task can be performed under improved visual conditions, and to provide a guide which can be utilized to assess other visual environments.

2.0 LIGHT CHARACTERISTICS/LIGHTING SYSTEM DESIGN

Light Level. The required illumination level is task dependent. General lighting requirements for different tasks can be found in Flynn (1979) and IES (1987). Vision can be improved by increasing the lighting level, but only up to a point, as the law of diminishing returns operates. Excessive illumination could result in glare. According to IES (1987), direct, focussed lighting is the recommended general lighting for aircraft hangars. Inspection of aircraft takes place in an environment where specular reflection from airplane structures can cause glare so that low brightness luminaries should be installed. Often additional task lighting will be necessary when internal work, or shadowed parts around the aircraft, result in low illumination levels.

The required illumination levels for aircraft maintenance and inspection tasks are presented in **Table 1**. Generally, most maintenance tasks require between 75 f-c and 100 f-c, although more detailed maintenance tasks may require additional illumination. General line inspections (e.g., easily noticeable dents) may only require 50 f-c; however, most inspection tasks demand much higher levels. Many difficult inspection tasks may require illumination levels up to or exceeding 500 f-c.

Table 1 Levels of Illumination Required in Aircraft Inspection/Maintenance (IES, 1987)

TASK	F-C
Pre/post maintenance and inspection	30-75
Maintenance	75-100
Inspection	
Ordinary	50
Difficult	100
Highly difficult	200

Color Rendering. Color rendering is the degree to which the perceived colors of an object illuminated by various artificial light sources match the perceived colors of the same object when illuminated by a standard light source (i.e., daylight). The difference in the spectral characteristics of various light sources have a large effect on color rendering, and are described in detail in Hopkinson and Collins (1970) and IES (1984). The color rendering of task lighting is important, because often a change in color of sheet metal is used as a clue to indicate corrosion, wear, or excessive heating. Commonly used lighting sources with their characteristics can be found in Lumineering Associates (1979) and Ross and Baruzzini, Inc. (1975).

Glare. Glare reduces an inspector's ability to discriminate detail and is caused when a light source in the visual field is much brighter than the task material at the workplace. Thus, open hangar doors, roof lights, or even reflections from a white object such as the workcard can cause glare. Glare can also arise from reflections from the surrounding surfaces, and can be reduced by resorting to indirect lighting.

Reflectance. Every surface reflects some portion of the light it receives as measured by surface reflectance. High reflectance surfaces increase the effectiveness of luminaries and the directionality of the illumination. Thus, for an aircraft hangar, it is important that the walls and floors are of high reflectance so that they help in reflecting light and distributing it uniformly. This can be achieved by having the floor and the walls composed of reflective materials, or existing structures painted a lighter color. This is more critical under the wings and fuselage where there may not be adequate lighting, due to aircraft shadows. **Table 2** presents recommended surface reflective values, to assist in obtaining an adequate visual environment.

Table 2 Recommended Reflective Values (Adapted from IES, 1987)

SURFACE	REFLECTANCE
Ceiling	80 to 90%
Walls	40 to 60%
Equipment	25 to 45%
Floors	not less than 40%

3.0 THE VISUAL ENVIRONMENT IN AIRCRAFT IN INSPECTION

Classification of Light Sources. The lighting sources employed in aircraft inspection include the following: *ambient lighting* which is comprised of daylight, area, and specialized lighting (built into aircraft), and *task lighting* which includes portable lighting (set up at the inspection site) and personal lighting (e.g., flashlight). The ambient lighting represents the minimum lighting level available on a task, while task lighting represents the maximum lighting level, both from portable and personal lighting devices. Note that to provide adequate lighting for any task it should be possible to reduce glare from ambient lighting and use the task lighting in a focussed manner to illuminate the task without causing unnecessary glare.

Site Observations. Shepherd et al., (1991) report the results of Phase I of the program, during which many inspection/maintenance sites were visited. Detailed Task Analyses were performed on numerous inspection activities, resulting in a list of examples of poor human factors design. Each represents an opportunity for intervention to improve the human/system fit and hence, increase job performance with decreased work stress. The conclusions to be drawn from these observations are that lighting in some cases can range from inadequate to poor for performing inspection tests. Task lighting was not adequate, lighting equipment was not always portable, and the lighting level was well below the IES recommended level of 75- 100 f-c for most visual aircraft inspection tasks (IES, 1987).

4.0 EVALUATION OF EXISTING VISUAL ENVIRONMENT

As a demonstration of how to perform a human factors study of lighting in a facility, an investigation of the visual environment at a representative maintenance hangar was performed. This study included an evaluation of the ambient lighting, task lighting, and perceived lighting characteristics based upon input from inspectors.

Evaluation of Ambient Illumination, Luminance, and Reflectance. The survey measured the illumination and luminance levels produced by the ambient light sources only. Lighting characteristics of the personal and portable lighting were not considered at this stage. The illumination and floor luminance levels were obtained in two different aircraft bays, bay #1 (with an aircraft present) and bay #2 (without an aircraft present). Each bay area was divided into columns and zones. The columns correspond to floor markers in the hangar, and are 22 ft apart. The five zones represent floor locations corresponding to an aircraft area (i.e., nose, front of the fuselage, wings, back of the fuselage, and tail). Several readings were taken in each area, at night with the hangar doors closed. Average illumination and luminance values were calculated, illumination is presented by floor location (Figure 1) and by aircraft area (**Figure 2**). Floor reflectance values, the amount of light reflected off the floor compared to the amount of light falling on the floor, (i.e., floor luminance/illumination) were calculated and given in **Figure 3**.

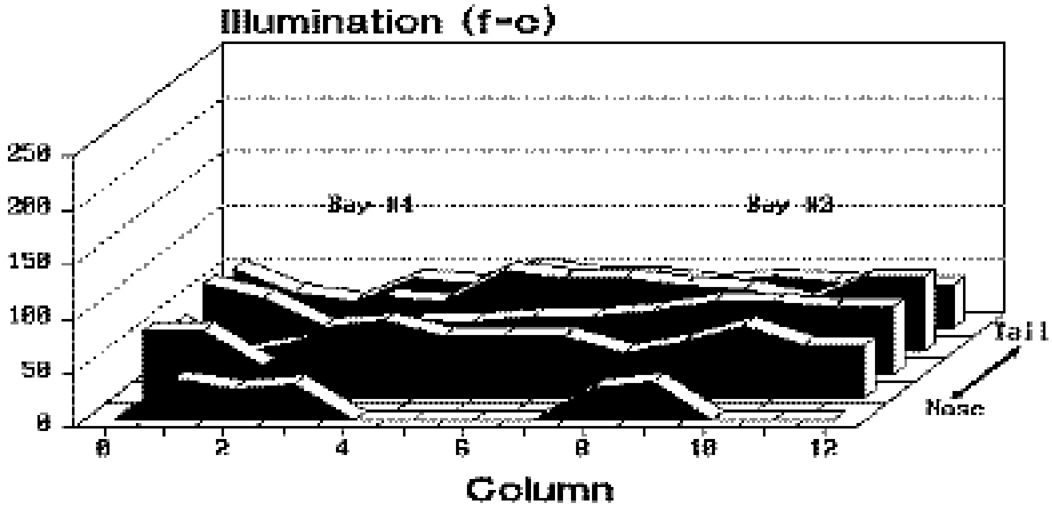

Figure 1 General Illumination Levels in Aircraft Hangar

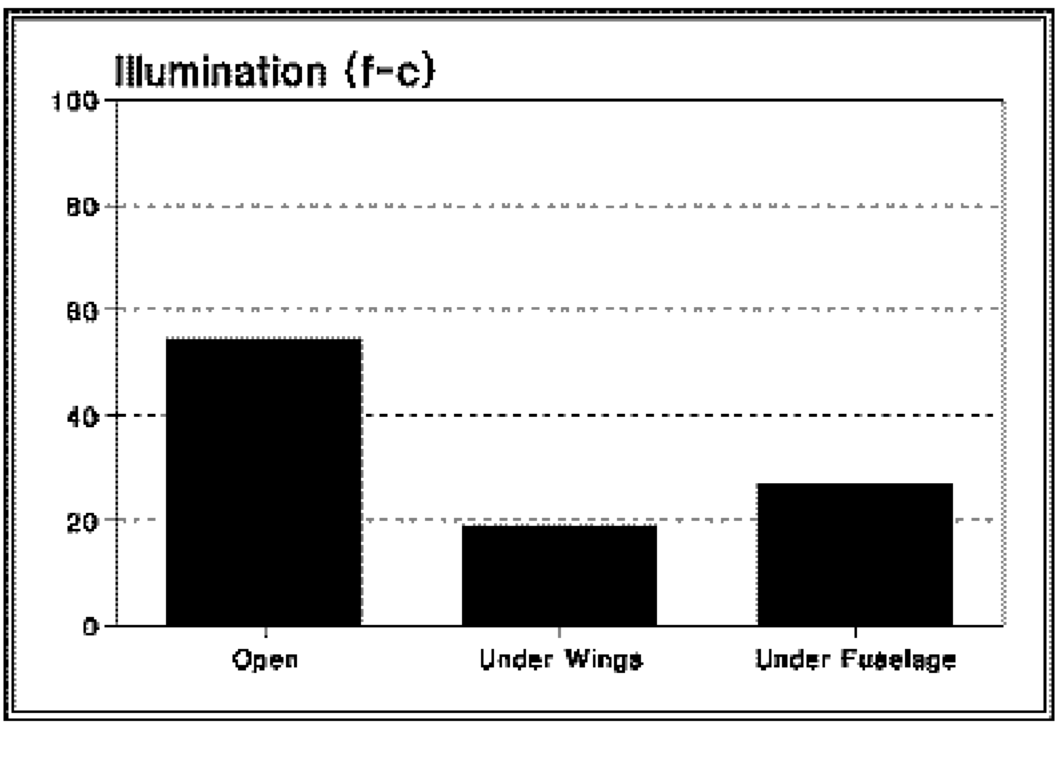

Figure 2 General Illumination Levels by Aircraft Area

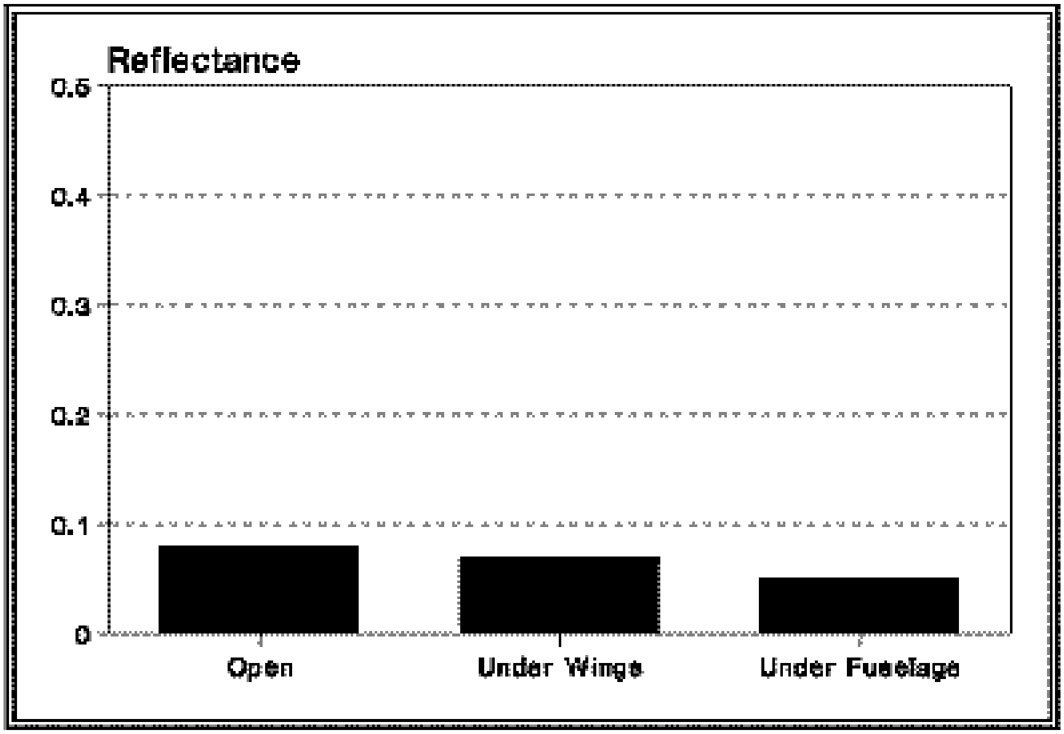

Figure 3 Floor Reflectance by Aircraft Area

The average illumination levels varied dramatically between areas. Figure 2 indicates that the areas under the fuselage and wings had considerably lower illumination than the open areas (i.e., where no aircraft was present). This is a concern, for many visual inspection tasks occur in these poorly lit areas (i.e., under the wings and fuselage). The floors are presently a natural grey color (cement), thus resulting in low average floor luminance, and reflectance levels well below those recommended across all areas (**Figure 3**). Existing floors could be painted a lighter color (e.g., white), which would improve the overall illumination levels, especially under the wings and fuselage. However, any paint used should be non- glossy to eliminate specular reflections from the floor surface. For new hangars, or major renovations, lighter colored flooring could be installed to improve reflectance.

Evaluation of Task Illumination, Luminance, and Reflectance. A representative sample of aircraft visual inspection tasks was selected from various locations on a Fokker F-100; specifically, air conditioning access (A/C), cargo compartments (cargo), exterior fuselage-nose, nosewell, and wheelwell. A lighting survey was performed (i.e., illumination and luminance) with the results shown in Table 3. Each task light environment is indicated and includes the contribution of the ambient levels in conjunction with any additional personal/portable lighting. Values were obtained from various locations in each task area under actual inspection conditions; that is, while the task lighting of choice (i.e., personal/portable) was utilized.

Table 3 Task Light Environment and Illumination by Task Area

AREA	TASK CONDITIONS	
	Light Environment	Illumination (f-c)
A/C	3D-Cell Mag Lite	115 SD=138.0
Cargo	Justrite Headlamp Specialized, General	182 SD=72.4
Fuselage-Nose	3D-Cell Mag Lite General	97 SD=46.0
Nosewell	3D-Cell Mag Lite Specialized, General	42 SD=22.6
Wheelwell	3D-Cell Mag Lite Specialized, General	102.1 SD=40.0

Table 3 Task Light Environment and Illumination by Task Area.

Each of these tasks, may require different lighting conditions, based upon the task demands. Thus, task analyses were performed to determine the visual and lighting requirements for each selected task. These surveys and analyses allow the comparison of the existing task lighting conditions with the task requirements.

Generally, the *average* task illumination levels were adequate, with the exception of the nosewell. However, large variability existed in these levels, primarily dependent upon whether it was possible to aim the lighting equipment at the point of inspection. In many instances, these areas were difficult to access with the lighting equipment, thus not allowing adequate levels of light to be obtained. Task lighting was necessarily the primary light source in all task areas, for the ambient illumination levels were inadequate. Thus, the accessibility of the area and the portability of the personal/portable lighting determined the light level at a majority of the inspection points.

Inspector Perceptions. In addition to the detailed measurements obtained at one facility, a survey was conducted to access inspectors' perceptions of their visual environment at several other facilities. The results are based on feedback from 51 inspectors and maintenance personnel (51% response rate). Verbal feedback was obtained from inspectors, to allow a detailed assessment of the perceived quantity and quality of the ambient and task lighting. Inspectors and maintenance personnel were asked to evaluate the lighting characteristics of the visual environment (i.e., contrast, glare, flicker, color rendering), as well as the adequacy of the personal lighting equipment (i.e., light level, ease of handling, and focus control) and portable lighting equipment (i.e., light level, ease of handling, and aiming ability).

Verbal feedback was obtained on the visual environment and combined by aircraft area (i.e., upper exterior areas/above wing chord line, lower exterior areas/below wing chord line, and interior areas). Generally, according to the frequency distributions, the perceived light levels and contrast were adequate in the upper exterior areas, but there were many instances of perceived glare. Conversely, the perceived light levels and contrast were frequently inadequate in the lower exterior and interior areas, but there was less perceived glare. Color rendering was perceived to be adequate by most personnel, although this distribution was skewed towards inadequate in the lower exterior and interior areas.

In the upper exterior areas, a majority of personnel indicated a reliance on primarily general lighting (over 90%), with a smaller dependence on daylight and personal lighting (**Figure 4**), there was minimal reliance on portable lighting. In contrast, in the lower exterior and interior areas, personal lighting was indicated to be the primary light source, with general and portable lighting being somewhat utilized. Daylight contributes minimally to the visual environment in the lower exterior and interior areas. This is presumably the reason why color rendering was perceived to be better in the upper exterior areas, for the other areas rely almost solely on artificial light.

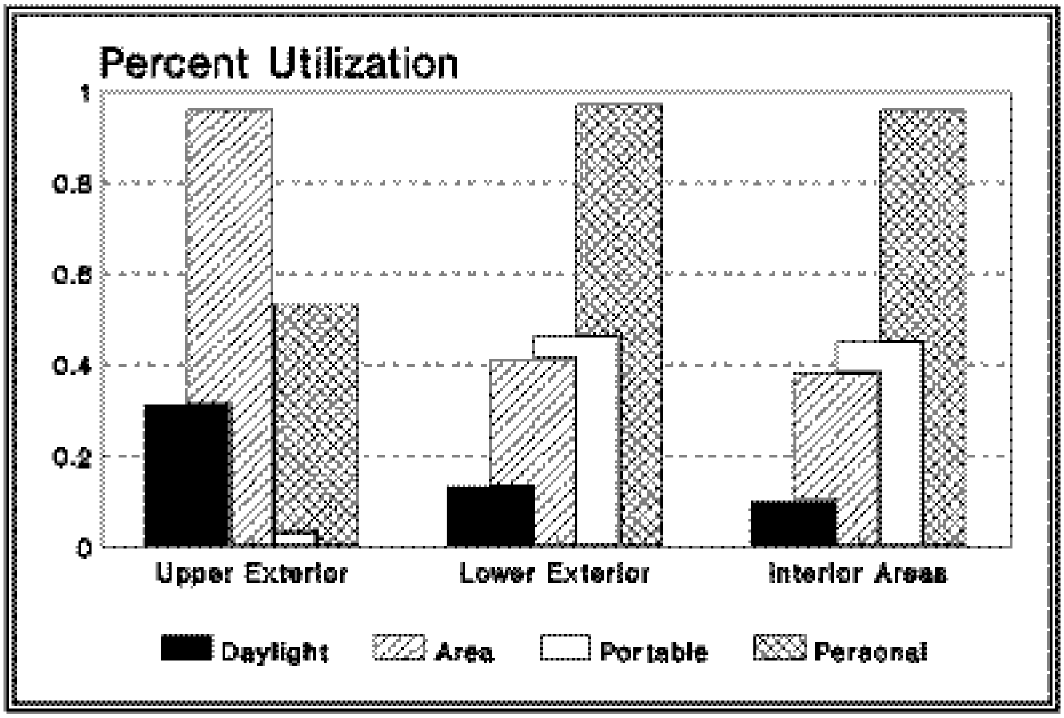

Figure 4 Lighting Source Utilization by Aircraft Area

A majority of personnel indicated both personal and portable lighting equipment were necessary to produce adequate light levels. There were varied perceptions with respect to the handling of lighting, although a majority felt personal lighting was adequate and portable lighting was inadequate. Likewise, a majority of personnel felt the focus ability of personal lighting was good, while the aiming ability of portable lighting was inadequate. These perceptions may indicate why personal lighting is relied on more than portable lighting (**Figure 4**); it is easier to handle and control. A need exists for better portable lighting to decrease reliance on personal lighting in restricted spaces.

Finally, general comments and concerns related to personal and portable lighting systems and the visual environment were obtained. The major considerations, which can be utilized to assist in standardizing the visual environment evaluation process, fall within the categories of: light characteristics, ease of handling, durability, work shift, hangar maintenance, flexibility, and other attributes.

5.0 EVALUATION OF ALTERNATIVE LIGHTING SOURCES

An evaluation of lighting sources was performed to identify systems which possess features which may contribute to the existing visual environment of aircraft inspection/maintenance operations. This evaluation included a survey of available systems, and both laboratory and field evaluation of the selected sources.

Laboratory Evaluation. A number of both personal and portable lighting systems were selected to represent the types currently being used in inspection and alternative sources available in catalogs. Several attributes (light output/distribution, weight, etc.) of these selected personal and portable lighting systems were investigated in a controlled environment.

Field Evaluation. A sample of the lighting systems evaluated above were further investigated to determine their perceived suitability during actual task performance. Personal and portable lighting sources, which appeared to hold promise in the laboratory evaluation, were evaluated. **Table 4** and **Table 5** present information related to the portable and personal lights. Evaluation was based upon verbal feedback obtained from five on-site inspectors. The authors felt that the selected sample of light sources provided adequate coverage of the various types of lighting sources with respect to size/ portability, type of light, and power source. Verbal feedback was obtained from the inspectors after they used the sample of lights to perform different tasks in various locations of the aircraft.

Table 4 Specifications of Selected Portable Lighting Equipment (Center illumination measured at: *0.5 m or **2.0m)

Light Source		Wt. (lbs.)	Aiming	General Durability	Safety Req'ments	Accessories
Ericson Twin-tube Handlamp #900-25	Fluorescent 13 Watts 85 f-c*	0.8	No	Adequate	NEC #410-35(a)(b),36,42(a)(b),44,45 OSHA #1926.405(E)(F)(I)(i)(ii)(iii)(A)(B)(V) UL listed	Hook
Ericson Portable Lamp #1227	Fluorescent 27 Watts 164 f-c*	10	No	Adequate	NEC #410-35(a)(b),36,42(a)(b),44,45 OSHA #1926.405(E)(F)(I)(i)(ii)(iii)(A)(B)(V) UL listed	Hangers, Magnets
Fostoria PUL-500Q-HC	Halogen 500 Watts 1200 f-c*	9	Yes	Adequate	UL listed for indoor/outdoor use	Handle Stand

Table 5 Specifications of Selected Personal Lighting Equipment (* center illumination measured at 0.5m)

Light Source		Wt. (lbs.)	Focus	General Durability	Safety Req'ments	Illumination (f-c)*
2D-Cell Mag Lite	Krypton Bulb	1.5	Yes	Adequate	Explosion-proof MIL-STD-810C	340
3D-Cell Mag Lite	Krypton Bulb	2.0	Yes	Adequate	Explosion-proof MIL-STD-810C	1100
4D-Cell Mag Lite	Krypton Bulb	2.4	Yes	Adequate	Explosion-proof MIL-STD-810C	1900
Justrite Headlamp #1904	Incandescent Bulb	1.9	Yes	Adequate	None indicated	1500

The following provides a summary of the results obtained from the laboratory and field evaluations:

* There are two different kinds of lights: inspection and work lights. Inspection lights (i.e., dynamic sources) must provide easy handling, for inspection normally demands frequent movement in and around the aircraft. In addition, the lights must provide a focused beam of light which can be controlled to reduce glare. Work lights (i.e., static sources) need not be as portable as inspection lights, for they are normally used in one place for a period of time (i.e., generally 30 minutes or more).

* The Mag Lites provide adequate light, durability, and focus control to reduce glare. They are also easily portable, which suits most inspection tasks. The light outputs and distributions of the Mag Lites increase with the size of the light (i.e., 2D to 4D), for the larger lights have more batteries; however they are also heavier. The focus ability of the Mag Lites provides either an intense focused beam, or less illumination over a larger area.

* The Justrite headlamp provides adequate light, and focus control to reduce glare, and produces a comparable amount of light as the 4D-Cell Mag Lite, although it is lighter and allows hands-free portability. However, it meets no additional safety requirements, thus possibly limiting its use in some environments. The actual weight of the lamp is less than the indicated weight, for the batteries are separated from the light source (0.3 lbs.).

* The Ericson Twin-tube #900-25 is not well suited for many inspection tasks, for the power cord reduces its portability and it does not provide a highly focussed beam. However, this light can serve as a small portable light source. It produces less light over a smaller area than the other portable lights, but gives off minimal heat and can fit into small access areas. It is very durable and meets OSHA and NEC safety requirements related to general electrical codes.

* The Ericson Portable lamp #1227 is a good static light source. It can be hung, using the provided strap or magnet, or placed (e.g., under a wing) in the work area for overall, heat-free light. Furthermore, these lamps meet OSHA and NEC safety requirements related to general electrical codes.

* The Fostoria PUL-500Q-HC provides a large amount of light over a large area. It can be used to illuminate large static work areas. However, it gives off heat, and thus could not be used for interior inspections or in small areas, limiting its use to open, exterior areas. In addition, it is UL listed for indoor/outdoor use, possesses up/down aiming control, is light-weight, and has a handle for easy portability and set-up.

* The color rendering characteristics of the standard incandescent lamps (i.e., Justrite headlamp #1904), krypton lamps (i.e., Mag Lites), and halogen lamps (i.e., Fostoria) are superior. The fluorescent lights generally provide adequate color rendering characteristics, dependent upon the chemical composition of the liner, and are more energy efficient, as opposed to incandescent lights.

6.0 RECOMMENDATIONS

Based upon the above evaluation of the visual environment and the selected sample of lighting sources, initial recommendations are presented. The task demands, the restrictiveness of the space to be inspected, the ambient light conditions, and the lighting requirements are considered (**Table 6**). Recommendations are advanced for the wheelwell area evaluated earlier, and only consider the lighting sources investigated during detailed field evaluation (Tables 4 and 5**).** Caution should be exercised in generalizing these recommendations to other task situations and light sources.

Table 6 Lighting Recommendations

Area	Task Demands	Space	Lighting Req'ments			Recommendations
			Illum. (f-c)	Focus /Aim	Handling	
Wheelwell	Inspect main landing gear, landing gear assembly, for corrosion and cracks. Inspect for security of joints, safety pin for shear, hinges of door for wear and play.	R	200	Yes Yes	Dynamic Static	2D,3D-Cell Mags Justrite Headlamp Ericson Twin-tube Fostoria PUL-500-HC Ericson #1227

For each task area, the task demands will dictate the required illumination, the focus/aiming, and the required handling. A majority of inspection tasks require dynamic sources, to allow for frequent movement in and around the area; whereas maintenance tasks may be adequately illuminated by static sources. Although inspection tasks are the primary focus in this study, recommendations will also be made for static sources, for they can be useful in contributing to the ambient light level in many areas, thus reducing reliance on personal lighting. As discussed previously, the ambient illumination levels in all the considered task areas were inadequate for satisfactory performance, thus there must be some reliance on personal or portable lighting in each area.

Inspection of the wheelwells require dynamic, focussed average illumination levels of 200 f-c. These areas are somewhat restrictive (R), thus requiring the smaller Mag Lites or Justrite headlamp for better handling. The Ericson Twin-tube and portable #1227 could be hung/placed in tight locations in these areas, while the Fostoria PUL-500-HC could be aimed up into these areas for general overall lighting. Based on the task demands and corresponding illumination requirements, it is observed that each of the recommended personal lighting sources furnishes the required illumination.

7.0 GUIDE FOR VISUAL ENVIRONMENT EVALUATION

A methodology by which to evaluate and design a visual environment may be advanced based upon the techniques employed in the above demonstration project.

Evaluate Existing Visual Environment. This includes the measurement of the ambient and task lighting conditions. In addition, task analyses should be performed in order to determine the task demands and associated operator requirements. In addition, personnel should be consulted to obtain additional information regarding the light characteristics and utilization and adequacy of the currently used lighting sources.

Evaluate Existing and Alternative Lighting Sources. Manufacturers' catalogs can be consulted to determine the current status of lighting source technology. These alternative sources, in addition to the sources currently being used, can be evaluated. Evaluations performed to date, including the present one, have used various criteria to judge visual environments (e.g., light output, glare, luminance, etc.). There needs to be standard criteria defined which allows visual environments in aircraft maintenance/ inspection operations to be evaluated in a consistent manner, and ensure that important components of the process are not over-looked. An attempt has been made to identify the most important components which need to be considered in the evaluation of an aircraft inspection/maintenance visual environment. The operator perceptions and other factors discussed earlier should be considered in the selection of adequate lighting sources.

Selection of Lighting Sources. Lighting sources can be selected based upon a comparison of the lighting requirements with the various lighting sources. An investigation of the existing visual environment (Step 1) will allow the determination of the lighting requirements based upon the task demands. These results can be directly compared with the capabilities of the various lighting sources (Step 2), to determine which lighting sources provide the most appropriate visual environment for each task analyzed.

Evaluate and Address General Visual Environment Factors. Based upon the operator perceptions and lighting design principles, factors needed in the design of an adequate visual environment can be identified. The assessment of these considerations (e.g., hangar maintenance) should result in additional improvements in the overall visual environment.

This methodology allows various light sources to be matched to different tasks, based upon consistent criteria. This methodology provides flexibility, for each practitioner can choose relevant criteria most important in their environment on which to base evaluation. The techniques utilized to assess the visual environment at the representative facility may be incorporated into a formal methodology and utilized to investigate visual environments and guide selection of lighting equipment at other aircraft inspection sites.

8.0 REFERENCES

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