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Unmanned Aerial Vehicles Human Factors

FY05 Funded Projects

Human Factors in the Maintenance of Unmanned Aircraft

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Abstract

The accident rate for UAVs is higher than for conventional aircraft. A significant proportion of these accidents are associated with human error. If UAVs are to be permitted to operate in the National Airspace System, it will be necessary to understand the human factors associated with these vehicles. Unlike conventional aircraft maintenance, UAV operators must ensure the reliability of an entire system that comprises the vehicle, the ground station, and communication equipment. At present, there have been no published studies of the human factor issues relevant to UAV maintenance. Twenty-two structured interviews were conducted with personnel experienced in the operation of small- to medium-sized UAVs. Information was gathered on critical UAV maintenance tasks including tasks unique to UAV operations, and the facilities and personnel involved in maintenance. The issues identified were grouped into three categories: hardware; software/documentation; and personnel issues. Hardware issues included the frequent assembly and disassembly of systems, and a lack of information on component failure patterns that would enable maintenance personnel to plan maintenance effectively. Software/documentation issues included the need to maintain computer systems, and difficulties associated with absent or poor maintenance documentation. Personnel issues included the influence of the remote controlled aircraft culture and the skill requirements for maintenance personnel.

Introduction

The history of unmanned aviation can be traced back at least as far as World War I (Newcome, 2004). Recent technological advances, including the miniaturization of components and other developments in the fields of electronics, navigation and telemetry, are creating new possibilities for Unmanned Aerial Vehicles (UAVs). Potential civil and commercial applications include: communication relay linkages, surveillance, search-and-rescue, emergency first responses, forest fire fighting, transport of goods, and remote sensing for precision agriculture (Herwitz et al, 2004; Herwitz, Dolci, Berthold & Tiffany, 2005).

There have been different views about the precise definition of UAVs (Newcome, 2004). For the purpose of this study, the definition provided by ASTM International was adopted. UAVs are here defined as "an airplane, airship, powered lift, or rotorcraft that operates with the pilot in command off-board, for purposes other than sport or recreation … UAVs are designed to be recovered and reused…" (ASTM, 2005).

Several different classification systems have been proposed for UAVs (ASTM, 2005; Joint Airworthiness Authories/Eurocontrol, 2004; CASA, 1998). UAVs range in size from micro vehicles measuring inches in size and ounces in weight to large aircraft weighing more than 30,000 pounds. In this study, the categorization system shown in Table 1 was used.

Figure 1. Two operators prepare a small-sized UAV for flight.

The weight categories encompass fixed-wing, rotorcraft and lighter-than-air vehicles. These vehicles have a range of propulsion systems including electric and gas powered engines. Cost, complexity and capability generally increase with weight. Our initial focus in this study was on the small- to medium-sized UAVs (weights ranging from 15 to 500 lbs.). The micro and mini, and larger UAVs will be examined in the next phase of this research.

Table 1. Size class groups for UAVs

ROA Class	Weight (lbs)	Range (miles)
Micro	Less than 1	1-2
Mini	1 - 15	A few
Small	15 - 100	100s
Medium	100 - 500	100s to 1,000s
Large	500 - 32,000	1,000s

Throughout the history of aviation, human error has presented a significant challenge to the operation of manned aircraft (Hobbs, 2004). Although UAVs do not carry an onboard human, operational experience is demonstrating that human error presents a hazard to the operation of UAVs (McCarley and Wickens, 2005). Given the fact that maintenance and ground support activities appear to be responsible for a growing proportion of airline accidents (Reason and Hobbs, 2003), this human factor element will be a critically important part of UAV operations.

To enable the operation of UAVs in the National Airspace System (NAS), it is necessary to understand the human factors of unmanned aviation. The objective of this study was to identify human factors that will apply in the maintenance of UAV systems. Maintenance was defined as any activity performed on the ground before or after flight to ensure the successful and safe operation of an aerial vehicle. Under this broad definition, maintenance includes assembly, fuelling, pre-flight inspections, repairs, and software updates. Maintenance activities may involve the vehicle as well as equipment such as the UAV ground control station.

The accident rate for UAVs is higher than that of manned aircraft (Tvaryanas, Thompson, & Constable, 2005). Williams (2004) studied US military data on UAV accidents. Maintenance factors were involved in 2-17% of the reported accidents, depending on the type of UAV. For most of the UAV systems examined by Williams, electromechanical failure was more common in accidents than operator error. In a study of US Army UAV accidents, Manning et al (2004) determined that 32% of accidents involved human error, whereas 45% involved materiel failure either alone or in combination with other factors. In contrast, Tvaryanas et al. and Williams found that a higher proportion of accidents involved human factors. These studies suggest that system reliability may be emerging as a greater threat to UAVs than it currently is to conventional aircraft. This trend may serve to increase the criticality of maintenance.

McCarley and Wickens (2005) reviewed the literature on human factors of unmanned aviation and identified a range of issues related to automation, control and interface issues, air traffic management, and qualification issues for UAV operators. At present, however, there have been no studies specifically focused on the maintenance human factors of UAV systems.

Methods

Twenty-two structured interviews were conducted with UAV users from civil and military operations as part of a qualitative study. Interviewees were asked a series of questions designed to reveal human factor issues associated with UAV maintenance. The interview questions are listed in Appendix A. Site visits were conducted to selected UAV maintenance facilities. A distinction was made between manufacturers who fly and maintain their UAVs, and customers who purchased UAVs. Of the sample group, 36% were manufacturers and operators of their own UAVs. All of the civil operators were conducting line-of-sight operations.

Results

Issues that emerged from the structured interviews are arranged in three sections based on the SHEL model (Hawkins, 1993). Hardware issues are human factors that relate to the interaction of maintenance personnel with the physical structures of the UAV system. Software/documentation issues concern the interaction of maintenance personnel with computer systems and written documentation. The last section deals with personnel issues including the skill levels of maintenance staff.

Hardware

Packing and transport. Operators reported that transport and handling damage “ramp rash” are significant issues due to the need to move and assemble UAVs. The handling of UAVs is similar to sailplanes that are typically moved in trailers. One UAV manufacturer actually used the maximum size of a UPS box as a point of reference for designing their UAVs. A Sports Utility Vehicle or van may be used for the smaller UAVs, but when wing spans start to exceed the dimensions of such a ground vehicle, then new packaging and human factors must be addressed.

Assembly. Small- and medium-sized UAVs are generally disassembled between flights for transport and storage. A particular concern is the frequent connection and disconnection of electrical systems, which can increase chances of damage and maintenance errors. One advantage of UAVs compared to conventional aircraft is that they are not generally stored outdoors where they would be exposed to threats from the elements.

UAV-specific elements. UAV systems may include unique components such as launch catapults, autonomous landing systems, sense-and-avoid instrumentation (ground-based or airborne) and flight termination systems (e.g. parachute release; engine kill).

Battery maintenance requirements. Batteries were noted as the cause of a high proportion of mishaps, both with the airborne and ground-based systems. Careful attention needs to be directed to battery charging/discharging cycles. In addition, some types of batteries (e.g., lithium polymer) can be dangerous if correct procedures are not followed.

Composite materials. UAVs tend to make extensive use of composite materials. Repair of these materials may require special expertise and equipment to deal with hazardous materials.

Distinguishing between payload and aircraft. In contrast to conventional aircraft, the payload on board a UAV is more likely to be integrated with the UAV structure and power supply. Maintainers may be expected to support the payload as well as the aircraft.

Salvage of UAV and associated hardware. UAVs often experience operational-related damage (e.g., hard landings; contact with water). Maintenance personnel will be required to make judgements about the reuse and salvage of components involved in such occurrences.

Repair work by UAV manufacturer. The small size of many components and the modular approach to many UAV designs enables operators to ship damaged components back to the manufacturer for repair. A trend was detected indicating that minor maintenance was performed by operators, but major repairs generally involved sending the UAV back to the manufacturer.

Absence of information on component failure modes and rates. The manufacturers of components used in small UAVs generally do not provide data on the failure modes of their components and the expected service life or failure rate of these components. This absence of information is particularly notable for components purchased from Radio Control (RC) hobby shops. In the absence of service life information, reliability-centered maintenance programs cannot be developed (Kinnison, 2004). For example, there is little information on the service life of servos designed for radio controlled aircraft, and now being used in UAVs (Randolph, 2003).

Recording of flight hours. UAVs do not generally have on-board meters that record airframe or engine flight hours. If this flight history information is not recorded by the ground station, the timing of hours flown must be recorded manually for maintenance purposes and inspection scheduling.

Lack of part numbers. Non-consumable UAV parts that can be removed and repaired (i.e., rotable components) generally do not have part numbers. Tracking the maintenance history of these components may become problematic, and may increase the risk of maintenance errors.

Unconventional propulsion systems. An increasing number of UAV designs propose the use of emerging technologies. Interviewees could not provide detailed information on the maintenance requirements of technologies such as fuel cells, solar power systems, and electric engines.

Fuel mixing. Unlike conventional manned aircraft, some UAVs require fuel to be mixed on-site. This task is typically performed by the UAV operator/maintainer rather than by dedicated refuelers. Human error during the handling of fuels may result in health and safety, and airworthiness hazards.

Software/documentation

Extensive use of computers. Virtually all UAV systems rely on laptops as the basis for flight control. Given the importance of computer components, several UAV owners require maintenance personnel to have an understanding of software and the capability to make software updates.

Autopilot software management. Maintenance personnel may need to update UAV autopilot system software, and then verify and clearly document the software versions being operated.

Availability of flight history data. UAV ground stations commonly record flight history such as engine performance. These data are useful for evaluating performance and identifying anomalous conditions. UAV maintenance personnel will require the ability to interpret such data.

Lack of maintenance documentation. Several operators reported that UAVs were delivered with operating manuals, but no maintenance manual or maintenance checklists. As a result, the operators had to develop their own maintenance procedures and documentation. The need for well-prepared documentation is highlighted by the fact that several customers purchased UAVs without technical information such as wiring diagrams.

Poor standard of maintenance documentation. In cases where a UAV was delivered with maintenance documentation, maintenance personnel were sometimes dissatisfied with the quality of documentation. For example, UAV maintenance documents rarely, if ever, conform to the ATA chapter numbering system. In the course of the interviews, examples were given of poor procedures including poorly conceived Fault Isolation Manual (FIM) documents. One of the most common recommendations was the need to keep careful log books that document all tasks performed on the UAV.

Personnel issues

Complacency. Aware that there is no human on board the aircraft, there is a potential for maintenance personnel to become complacent, particularly with regard to deviations from procedures.

Model aircraft culture. The most commonly cited skill sought for UAV maintenance was experience with RC planes. Such personnel, however, do not necessarily reflect a mainstream aviation background. Some RC hobbyists may be accustomed to operating without formal procedures or checklists.

Lack of direct pilot reports. UAV maintenance personnel do not receive log book entries describing problems detected by an on-board pilot during flight. For manned aircraft flights, the pilot's log book entries are an important source of information for maintenance personnel (Munro, 2003). Although flight history may be recorded in the UAV ground control station and reports may be made by the ground-based UAV operator, these reports will not contain any information on a pilot's direct sensory experience of the aircraft's flight performance.

Operator and maintainer may be same person.
A primary attraction of UAV technology is the ability to operate the vehicle with a small number of multi-skilled individuals. For small UAV operations, maintenance tasks tend to be performed by the operator.

Need for wide skill set. Small operators expect maintenance personnel to possess skills in a wide range of fields, including electrical and mechanical repairs, software, and computer use. Given the potential risk of electromagnetic interference (EMI), another fundamental requirement is an understanding of radio transmission, wireless communication, and antenna electronics.

Discussion

A key finding was that UAV maintenance requires attention not just to the aircraft, but to the entire system, including the ground control station, wireless communication links, sense-and-avoid instrumentation, and, in some cases, specialized launch and recovery equipment.

This study identified tasks that are unique to UAV maintenance, representing new challenges for maintenance personnel. These tasks include transport and assembly of the vehicle and associated systems, and pre-flight ground tests necessitated by the assembly of the aircraft at the flight location. The work of a UAV maintenance technician involves a broader range of tasks than those involved in the maintenance of conventional aircraft.

The diversity of UAV systems is typical of the early development stage of any new technology. The scope of maintenance activities ranges from repairing a small military UAV with duct tape to major work on complex vehicles necessitating return to the manufacturer. The maintenance requirements for a 5 oz. micro air vehicle cannot be equated with those for a 32,000 lb. Global Hawk.

The interviews conducted thus far have been confined to manufacturers and operators of small- to medium-sized UAVs. The conclusions reached apply to these sectors of the industry.

The ability to ship components or even entire aircraft to the manufacturer for maintenance will have significant impact on the way maintenance is performed. It appears that major maintenance or major checks will be performed by the manufacturer, while the operator will attend to routine preventative maintenance and minor corrective maintenance. An increased trend towards modularity and "repair by replacement" may enable maintenance to be performed by personnel with a lower level of expertise than would be required if components were repaired in the field.

Human factors in conventional aircraft maintenance include time pressure, insufficient knowledge and skills, procedure design and coordination difficulties (Hobbs and Reason, 2003). The maintenance of UAVs involves not only these issues, but also additional challenges. The reliance on laptop computer for UAV operations means that the support and maintenance of a computer system and associated software is now an airworthiness task. As a result, human-computer interaction and computer system knowledge will be important human factors considerations for UAV maintenance personnel.

Several findings related to information management. Issues such as the lack of maintenance documentation, the poor quality of existing documents, a lack of formalized checklists and the absence of parts numbers are potential error-producing conditions.

Cultural issues also were identified as a potential area of concern. Many UAV maintenance personnel have a background in RC aircraft , and they may bring expectations and norms that differ from those in conventional aviation.

The driving force behind the UAV industry is affordability and the need to minimize the number of personnel involved in UAV operations.

This driving force creates a pressure as well as an incentive to staff UAV operations with a small group of individuals. Although the trend towards modularity will reduce the need for complex maintenance in the field, the view was expressed that maintenance personnel will nevertheless require a wide range of skills. Key skills widely cited by the interviewees included knowledge of electrical and mechanical systems, radio communication, and an understanding of software upgrades and documentation.

During the interview process, it became apparent that there are two schools of thought regarding the maintenance of UAVs. One view is that the aircraft and control station must be maintained at the same standards as conventional aircraft. The other view is that small and medium-sized UAVs comparable in size to RC planes can be maintained to a different standard than conventional aircraft.

The next phase of this study will provide more attention to the extremes of the UAV industry as defined in Table 1 (i.e., micro, mini, and large UAVs). In future reports, specific attention will be given to the knowledge and skills required to perform UAV maintenance, the facilities required, and human factors training requirements.

References

ASTM. (2005). *Standard terminology for unmanned air vehicle systems*. F2395-05. ASTM International: West Conshohocken, PA.

Civil Aviation Safety Authority, Australia (1998). *Civil Aviation Safety Regulation Part 101.F*.

Hawkins, F. (1993). *Human factors in flight*. Ashgate: Aldershot, UK.

Herwitz, S.R., Dolci, R.J., Berthold, R.W. & Tiffany, G.C. (2005). Chemical sensing from a low-flying UAV: data for first responders during a staged terrorist event. *Proceedings of Department of Homeland Security Partnering Conference*, Boston, MA

Herwitz, S.R., Johnson, L.F., Dunagan, S.E., Higgins, R.G., Sullivan, D.V., Zheng, J., Lobitz, B.M., Leung, J.G., Gallmeyer, B.A., Aoyagi, M., Slye, R.E., & Brass, J. (2004). Demonstration of UAV-based imaging for agricultural surveillance and decision support. *Computers & Electronics in Agriculture* 44: 49-61.

Hobbs, A. (2004). Human factors, the last frontier of aviation safety? *International Journal of Aviation Psychology* 14: 335-341.

Joint Airworthiness Authorities/Eurocontrol. (2004). *UAV Task Force Final Report: A Concept for European Regulations for Civil Unmanned Aerial Vehicles (UAVs).* Retrieved April 13, 2005 from http://www.jaa.nl/news/news.html

Kinnison, H. A. (2004). *Aviation maintenance management*. McGraw Hill: New York.

Manning, S, D., Rash, C. E, LeDuc, P. A., Noback, R. K., & McKeon, J. (2004). *The role of human causal factors in US Army unmanned aerial vehicle accidents.* USAARL Report No 2004-11. US Army Aeromedical Research laboratory, Fort Rucker, AL.

McCarley, J. S. & Wickens, C. D. (2005). *Human factors implications of UAVs in the National Airspace*. Technical Report AHFD-05-05/FAA-05-01. Prepared for Federal Aviation Administration, Atlantic City International Airport, NJ. Contract DTFA 2004-G-032

Munro, P., (2003). *Reporting discrepancies: Informational needs of airline mechanics and pilots.* Unpublished Masters Thesis, San Jose State University, San Jose, CA.

Newcome, L. R. (2004). *Unmanned Aviation: A brief history of unmanned aerial vehicles*. AIAA: Reston, VA.

Randolph, R. (2003). Some very interesting facts about servos. *Flying Models* (October).

Reason, J. & Hobbs, A. (2003). *Managing maintenance error: A practical guide*. Ashgate: Aldershot, UK.

Tvaryanas, A. P., Thompson, B, T., & Constable, S, H. (2005). *U.S. military UAV mishaps: Assessment of the role of human factors using HFACS*. Paper presented at Human Factors of UAVs workshop, Mesa, AZ, May 25-26.

Williams, K.W. (2004). *A summary of unmanned aircraft accident/incident data: Human Factors implications*. U.S. Department of Transportation, Federal Aviation Administration, Office of Aerospace Medicine, Washington, DC. Technical Report Publication No. DOT/FAA/AM-04/24.

Appendix A: *Interview structure.*

1. Provide a general description of vehicle and operations.

2. Who performs maintenance?

3. What are the key maintenance tasks? Ground support tasks?

4. Are there maintenance tasks unique to unmanned aircraft? Are these tasks different to those in maintenance of RC aircraft?

5. Are there particular maintenance problems associated with your operation?

6. Special facilities needed?

7. What qualifications, skills and training are needed to perform maintenance? If you were advertising for a UAV maintenance person, what skills and experience would you be looking for?

Unmanned Aircraft Pilot Medical and Certification Requirements

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ABSTRACT

A research effort was undertaken to establish unmanned-aircraft pilot medical and certification requirements. The effort consisted of a review of relevant literature, a summary of potential unmanned aircraft applications, a review of proposed applications by members of RTCA SC-203, the convening of a panel of subject matter experts, and interactions with groups engaged in the process of establishing unmanned aircraft pilot guidelines. The results of this effort were a recommendation and justification for use of the Class III medical certification and recommendations regarding the training and testing of unmanned -aircraft pilots.

INTRODUCTION

The rapidly expanding commercial Unmanned Aircraft (UA) industry presents a challenge to regulators whose task it is to ensure the safety of the flying public as well as others who might be injured as a result of an aircraft accident. The military has used unmanned aircraft for several decades with various levels of success. Within the last few years, commercial UA operations have increased dramatically. Most of these operations have concentrated on surveillance and advertisement, but several companies have expressed an interest in using unmanned aircraft for a variety of other commercial endeavors.

Although the term "unmanned aircraft" suggests the absence of human interaction, the human operator/pilot is still a critical element in the success of any unmanned aircraft operation. For many UA systems, a contributing factor to a substantial proportion of accidents is human error (Williams, 2004). The FAA needs guidance to assist in the decision of who will pilot UA and what type of training will be required. Research may be required: to investigate the effects on pilot performance of different types of console display interfaces; to determine how UA flight mission profiles affect pilot workload, vigilance, fatigue, and performance; to determine whether prior flight experience is important to operate a UA; to determine whether new opportunities present themselves in terms of the inclusion of persons with handicaps that were previously excluded from piloting aircraft but would not have difficulty with UA; and to investigate medical and physiological standards required to operate a UA.

To assist in developing guidance, an effort was begun to study UA pilot medical and certification qualifications. The approach consisted of several steps. First, a literature review of existing research on UA pilot requirements was conducted. Second, analyses of current and potential UA commercial applications and of current and potential UA airspace usage were completed. The third step in the process was the assembling of a team of subject matter experts that reviewed currently proposed UA pilot medical and certification requirements and made recommendations regarding how those requirements should be changed or expanded. This information, along with the other efforts, was used to develop preliminary task analyses of the unmanned aircraft piloting task. This paper is a summary of this effort.

UA Pilot Requirements Literature Review

The first task was to conduct a review of literature related to the development of UA pilot requirements. The literature fell into just a few basic categories. Many of the papers were recommendations regarding the development of requirements (e.g., DeGarmo, 2004; Dolgin, Kay, Wasel, Langelier, & Hoffman, 2001; Reising, 2003). The paper by Weeks (2000) listed current crew requirements for several different military systems. Finally, some of the papers were a reporting of actual empirical research addressing some aspect of pilot requirements (Barnes & Matz, 1998; Fogel, Gill, Mout, Hulett, & Englund, 1973; Schreiber, Lyon, Martin, & Confer, 2002).

The research by Fogel et al. (1973) was especially interesting because it was one of the earliest attempts to address the issue of UA pilot requirements. In the study, three groups of pilots were recruited to fly a simulation of a Strike remotely piloted vehicle. The first group consisted of Navy attack pilots with extensive combat aircraft experience. The second group consisted of radio-control aircraft hobbyists. The third group was composed of non-pilots with no radio-control aircraft experience. The results showed that, even though the Navy pilots were better than either of the other two groups, the other groups showed significant improvement in flight control over the course of the sessions, leading the authors to state, "It is hypothesized that a broader segment of relatively untrained personnel could be brought up to the required level of skill with short time simulation/training provided they meet some minimum selection criteria" (Fogel, et al., 1973, p. 75). It should be noted that the control interface consisted of a joystick for controlling the aircraft (but no rudder pedals), with very little in the way of automation for simplifying the control task. However, the researchers did compare two types of flight control systems, with the joystick either directly controlling (simulated) aircraft surfaces or a more sophisticated control system where the joystick commanded the aircraft performance (bank and pitch) directly. The authors concluded that the performance control joystick was superior for aircraft control, regardless of the level of pilot experience.

The research by Schreiber et al. (2002) looked at the impact of prior flight experience on learning to fly the Predator UAS. Seven groups of participants were used in the study, ranging from no flight experience to prior Predator flight experience. Results showed that the group with no flying experience performed significantly worse than the other groups, while the group with previous Predator experience performed significantly better. This finding was expected. However, an unexpected finding from the study was that participants with various levels and types of non-Predator flight experience all performed relatively the same with the Predator system. The authors concluded that any type of flight experience with an aircraft with similar handling characteristics to the Predator was beneficial for flight training on the Predator system. The authors pointed out, though, that the study looked only at stick and rudder skills, and not at more general types of flight skills such as communication and airspace management. In addition, the study did not address whether other types of training, such as simulator training, would also be useful for the transfer of Predator flight skills.

While it might be possible to establish whether a certain type of training or experience is more effectively transferred to a particular UA system, such as the Predator, these studies have not answered the question of whether manned aircraft time is required to be a successful pilot of an unmanned aircraft. We know that certain systems, such as the U.S. Army Hunter and Shadow systems, are successfully flown by pilots with no manned-aircraft experience. However, once these systems begin flying in populated airspace, there is a question of whether a lack of manned-aircraft experience within the airspace might degrade the effectiveness of the pilot and the safety of the flight. Research is needed to address this issue.

UA Applications and Airspace Usage

For a summary of UA applications and airspace usage issues, please reference the technical report (Williams, in review).

Summary of Meeting on UA Pilot Medical and Certification Requirements

On July 26th, 2005, a meeting was held at the FAA Civil Aerospace Medical Institute (CAMI) in Oklahoma City, OK. The purpose of the meeting was to assemble a diverse group of subject matter experts, from industry, academia, the FAA, and the military, to discuss Unmanned Aircraft (UA) pilot medical and certification requirements.

Attendees included representatives of several groups currently working on the development of standards and guidelines for UA. There were representatives from NASA Access 5, ASTM F38, RTCA SC-203, and SAE-G10 at the meeting. In addition, Dr. Warren Silberman represented the FAA Airmen Medical Certification Division and the Office of Aviation Medicine in regard to the medical certification requirements discussion.

Because the meeting was for only one day, an attempt was made to focus the discussion as much as possible by providing a draft standard that was developed by the Flight Standards Division (AFS-400). In particular, two paragraphs from the draft UA standards were reviewed and discussed extensively during the meeting. These two paragraphs are shown below.

6.14 **Pilot/Observer Medical Standards**. Pilots and observers must have in their possession a current third class (or higher) airman medical certificate that has been issued under 14CFR67. 14CFR91.17 regulations on alcohol and drugs apply to both UA pilots and observers.

6.15 **Pilot Qualifications**. The intent of this paragraph is to ensure that UA pilots interacting with ATC have sufficient expertise to perform that task readily.

6.15.1 Pilots must have an understanding of Federal Aviation Regulations applicable to the airspace where the UA will operate.

6.15.2 If the UA is operating on an instrument flight plan, the UA pilot must have an instrument rating.

6.15.3 Pilots flying UA on other than instrument flight plans must pass the required knowledge test for a private pilot certificate as stated in 14CFR61.105 (or military equivalent) for all operations beyond visual line-of-sight and for all operations conducted for compensation or hire regardless of visual proximity.

6.15.4 Pilots requiring instrument ratings will be certificated pilots of manned aircraft.

6.15.5 Equivalent military certificates and training are acceptable in all cases.

In the end, it was decided that not enough was known about these aircraft to make an accurate assessment of all of the risks involved. Because of this, the decision was reached by the group that the original suggestion of a class III medical certification was good, with use of the existing medical waiver process for handling exceptions (e.g., paraplegics). This decision is also supported by the factors identified above that mitigate the severity of pilot incapacitation. However, there was some additional discussion that some applications might require a class II or I medical certification because of the increased risks involved. Imposing different certification requirements, though, would require a clearer specification of pilot certification levels and UA classes. The class III medical certification statement was believed to apply to many, if not all, existing commercial and public UA endeavors (public endeavors would include border patrol applications). The question thus arose as to what types of pilot certification would require a stricter medical certification. Since the document was viewed as certainly undergoing revisions in the future, no wording changes were suggested at this time for paragraph 6.14.

A complete summary of the meeting can be found in the technical report (Williams, in review).

Identification of Knowledge, Skills and Abilities

One final effort undertaken in the research this year was the development of a set of knowledge, skills, and abilities required by the UA pilot. Several groups are working on the development of pilot KSAs, including NASA Access 5 and SAE-G10. The KSAs that have been developed are very similar across the groups because they rely heavily on manned aircraft tasks.

There are, however, three areas that have been identified that distinguish manned from unmanned aircraft. These areas will be important during the development of training and test standards for these systems. The areas are 1) activities and information related to the data link, 2) activities and information related to the task of detecting, sensing, and avoiding aircraft, and 3) activities and information related to the handoff of control during the flight.

Data link issues cut across the entire flight, from pre-flight planning until recovery of the aircraft. It is important that the pilot have an understanding of the conditions that affect the data link during the flight, and be prepared to take appropriate action if the data link is lost. During pre-flight, the pilot should be aware of the weather conditions that will occur during the flight and understand how those conditions will affect the data link. The pilot must also know which portions of the flight might be susceptible to interference or blockage of the data link due to natural barrier or broadcasting. There should also be contingency plans during each leg of the flight in case of a loss of data link. During the flight, there should be procedures for attempting to re-establish the data link if it is lost, and for notifying others, such as air traffic control, if the data link cannot be re-established.

There should be established procedures for detecting, sensing, and avoiding other aircraft during the flight. These procedures might begin before the flight, with the notification of other traffic that an unmanned aircraft will be flying in the airspace. The limitations of whatever method is in place for detecting other aircraft should be well understood. Also, the procedures for avoiding aircraft should be understood and practiced before they have to be used.

The handoff of control during a flight will be a common occurrence for a great many UA systems. Control handoff can occur in a variety of ways. Each method introduces the possibility of human error and has been the cause of a variety of UA accidents (Williams, 2004).

SUMMARY AND CONCLUSIONS

There were two goals for the research that was conducted. The first was a specification of the medical requirements for UA pilots. The second was a specification of the certification requirements for UA pilots.

The establishment of medical requirements for UA pilots was based on an analysis of the method for establishing the medical requirements of other occupations, including manned aircraft pilot. Rather than suggesting the creation of a new medical certification for UA pilots, it was decided to use an existing pilot medical certification. There were several reasons supporting this decision, including the bureaucratic difficulty in establishing a new certification level and the problems associated with training medical examiners who would be asked to assess whether pilots successfully met the new requirements.

Given that an existing medical certification was to be used, the question of which level of certification should be required was then based on the perceived level of risk imposed by the potential incapacitation of the UA pilot. The third class medical certification was judged to be the most acceptable based on the idea that there were several factors that mitigated the risk of pilot incapacitation relative to manned aircraft. First, factors related to changes in air pressure could be ignored, assuming that control stations for non-military operations would always be on the ground. Second, many of the current UA systems have procedures established for lost data link. Lost data link, where the pilot cannot transmit commands to the aircraft, is functionally equivalent to pilot incapacitation. Third, the level of automation of a system determines the criticality of pilot incapacitation, since some highly automated systems (e.g., Global Hawk) will continue normal flight whether a pilot is present or not.

The specification of certification requirements for UA pilots should be based on a task analysis of the UA piloting task and a specification of the knowledge, skills, and abilities needed for the task. While several groups have been working on completing such a task analysis, the work is still ongoing. Therefore, it is not possible at this time to reach definitive conclusions regarding certification requirements for UA pilots.

The available research on pilot qualifications shows that, while manned-aircraft experience is beneficial for piloting some UA systems (Schreiber et al., 2002), basic stick-and-rudder skills can also be mastered by those without flight experience (Fogel et al., 1973). This, of course, makes sense since even pilots with manned-aircraft experience had no flight experience at some point in their career. The question in regard to whether or not manned-aircraft flight experience should be a prerequisite for UA pilots centers on whether there is any learning that occurs during manned-aircraft flight training that would not be adequately addressed during training with an unmanned aircraft. One possibility is the idea of "shared fate". The fact that the pilot does not share the fate of the aircraft might lead to differences in decision-making during a flight (McCarley & Wickens, 2005). Another possibility, though one that has not been addressed experimentally, is that a full understanding of the three-dimensional aspect of the aircraft in the airspace cannot occur without experience in the airspace. Research is required to address this issue.

An analysis of the types of applications expected for UA indicated that airspace usage might be neatly divided between applications that use only Class G airspace and those that use other classes. Those that use only Class G airspace, with the exception of flights within restricted areas such as military areas of operation, were limited to line-of-sight from the pilot. Those that utilized other classes of airspace were always beyond-line-of-sight. This distinction (line-of-sight vs. beyond-line-of-sight) might be a useful way to classify types of unmanned aircraft for purposes of airworthiness ratings as well as pilot ratings.

Finally, while both training and test standards should be structured similarly to manned aircraft training and testing, they should include areas that are unique to the piloting of unmanned aircraft. Three areas that were identified as unique were data link issues, detect, sense, and avoid issues, and control handoff issues. The development of training and testing standards will require that these issues be addressed completely.

REFERENCES

Barnes, M.J. & Matz, M.F. (1998). Crew simulations for unmanned aerial vehicle (UAV) applications: Sustained effects, shift factors, interface issues, and crew size. *Proceedings of the Human Factors and Ergonomics Society 42nd Annual Meeting*, 143-7.

DeGarmo, M. (2004). *Issues concerning integration of unmanned aerial vehicles in civil airspace*. Mitre Corporation Report # MP04W0000323.

Dolgin, D., Kay, G., Wasel, B., Langelier, M., & Hoffman, C. (2001). Identification of the cognitive, psychomotor, and psychosocial skill demands of uninhabited combat aerial vehicle (UCAV) operators. Downloaded from URL http://forum.nomi.med.navy.mil/articles/safeucav/ on 3/10/2005.

Fogel, L.J., Gill, R.S., Mout, M.L., Hulett, D.G., & Englund, C.E. (1973). *Principles of display and control design for remotely piloted vehicles.* Decision Science, Inc. second semi-annual technical report on Contract #N00014-72-C-0196, Project # NR 196-119/11-29-71 455.

McCarley, J.S. & Wickens, C.D. (2005). *Human factors implications of UAVs in the national airspace*. University of Illinois Institute of Aviation Technical Report (AHFD-05-5/FAA-05-1). Savoy, IL: Aviation Human Factors Division.

Reising, J.M. (2003). The role of operators in uninhabited military vehicles: A NATO perspective. *Proceedings of the 12th International Symposium on Aviation Psychology*, Dayton Ohio, April 14-17, 988-92.

Schreiber, B. T., Lyon, D. R., Martin, E. L., & Confer, H. A. (2002). *Impact of prior flight experience on learning Predator UAV operator skills* (AFRL-HE-AZ-TR-2002-0026). Mesa, AZ: Air Force Research Laboratory, Warfighter Training Research Division.

Weeks, J.L. (2000). *Unmanned aerial vehicle operator qualifications (AFRL-HE-AZ-TR-2000-0002)*. Mesa, AZ: Air Force Research Laboratory, Warfighter Training Research Division.

Williams, K.W. (2004). *A summary of unmanned aircraft accident/incident data: Human factors implications.* U.S. Department of Transportation, Federal Aviation Administration, Office of Aerospace Medicine, Washington, DC. Technical Report Publication No. DOT/FAA/AM-04/24.

Williams, K.W. (in review). *Unmanned aircraft pilot medical and certification requirements*. U.S. Department of Transportation, Federal Aviation Administration, Office of Aerospace Medicine, Washington, DC. Technical Report.

UAV See and Avoid Systems: Modeling Human Visual Detection and Identification

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The FAA seeks to characterize the ability of UAV viewing systems to support target detection and identification. Existing system evaluation methods require expensive and time consuming subjective experiments. We hope to replace those experiments with the Spatial Standard Observer, a simple model of human detection and discrimination. This report describes progress on two elements of this project: simulation of an existing subjective data set using the Spatial Standard Observer (SSO), and development of a web-based application for demonstrating SSO-based visibility calculations. Preliminary results indicate the utility of both elements.

Introduction

The FAA seeks to compile and review the characteristics and performance of existing optical/digital viewing systems that could be used to enhance the human UAV operator's ability to see-and-avoid potential conflicts with other manned and unmanned aircraft. The systems will be characterized by their performance characteristics: field-of-view, field-of-regard, modulation transfer function, focal point, and lens quality, as well as bandwith and compression. This comparison will be used to determine the ability of these systems to allow detection of static images of differing sizes, at a range of distances in, variety of visibility conditions, i.e., sense-and-avoid.

In this context there is a need to supplement the Army's target acquisition model with a human vision model to predict observers' probability of detection and recognition of aircraft and other targets. In the current Army target acquisition model, these tasks are associated with particular values of N50 for particular image sets and classes, which are obtained by expensive and time consuming subjective experiment. We propose to create and evaluate a tool for computing N50 from a given image set and given classifications, thus obviating the need for subjective measurements. The predicted N50s would be entered in the Army's target acquisition performance model, Night Vision Thermal Imaging System Performance Model (NVTherm), to determine the effects of camera field-of-view, camera field-of-regard, camera modulation transfer function, opposing aircraft size, contrast, distance, and atmospheric conditions on observers' detection and recognition of an aircraft[1].

We have developed a model called the Spatial Standard Observer (SSO) that allows predictions of visual detection and discrimination of foveal spatial targets (Watson & Ahumada, 2004). The goal of this project was to assess the feasibility of using the SSO to compute N50 values for target image sets.

The first effort in this project has been to simulate the results of a recent psychophysical experiment that estimated N50 for a set of military vehicles[2]. A second concurrent effort has been the development of a prototype tool for calculation of the visibility of manned or unmanned aircraft under specified viewing conditions.

Target Identification Model

Here we describe the development and evaluation of a model to predict image and object identification. We begin with a description of the experiment whose data will be modeled.

Psychophysical Experiment

The experiment has been more extensively described in another report[2]. Here we provide a brief summary. The experiment consisted of two parts, using visible and infrared imagery respectively.

In each part of the experiment, the source images consisted of 144 digital images, of 12 "objects" in 12 "aspects." An illustration of two of the objects and three of the aspects are shown for the visible and infrared imagery in Figure 1. Each object is a particular military vehicle, and each aspect is a view of that vehicle. The twelve aspects are approximately the same from vehicle to vehicle. Of the twelve aspects, eight are views from an elevation of seven degrees, while the remaining four are from 0 degrees.

These source images were blurred with Gaussian kernels of 6 possible scales,

$$G(\mathbf{x}) = Exp\left(\frac{-\pi|\mathbf{x}|^2}{scale^2}\right) \tag{1}$$

The scales ranged from 5 to 30 pixels in steps of 5. This yields a total of 6 x 144 = 864 images for each image set (visible or infrared). The six levels of blur are illustrated in Figure 2.

Identification experiments using trained human observers were run separately on each level of blur. Each observer viewed a subset of 144 images of one type (visible or infrared), consisting of 2 aspects for all 12 objects in all 6 blurs. The two aspects were chosen in a quasi-random fashion. The observers were previously trained on identification of these vehicles, using different images. On each trial, the observer attempted to identify the object. The percent correct was recorded. The results are shown in Figure 3.

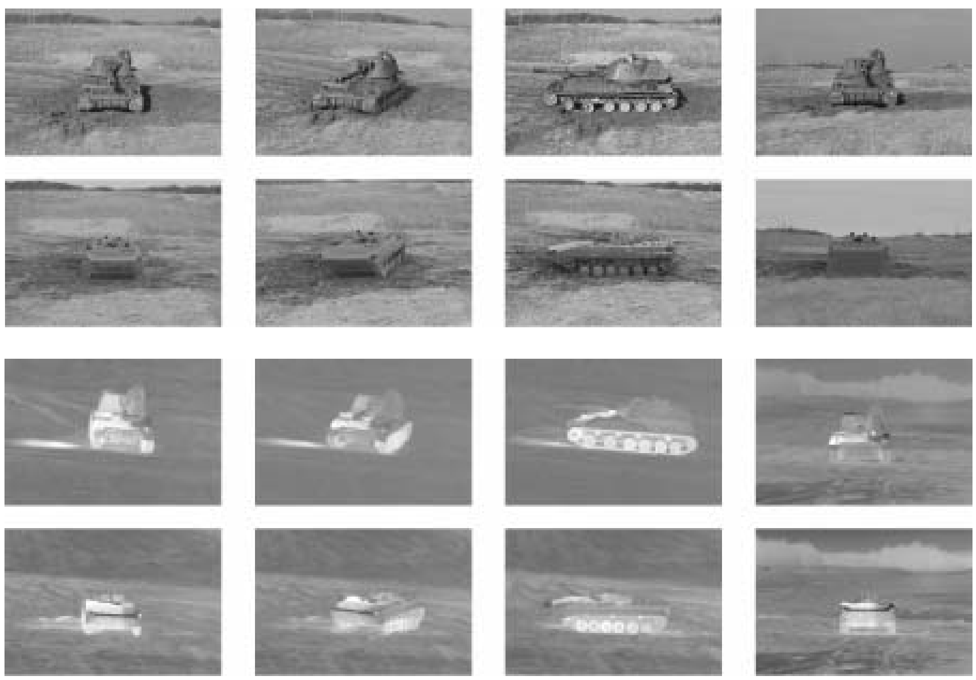


Figure 1. Example images. Two objects (rows) and four aspects (columns) are shown for both the visible and infrared image sets. The last aspect shows an example of the 0 degree elevation.

Figure 2. Examples of the six levels of blur applied to one image of each type (visible and infrared).

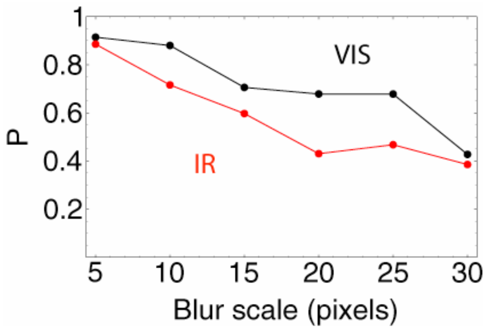


Figure 3. Percent correct identification as a function of blur scale for visible and infrared targets.

Model

The first model we have considered is a simple image classification machine operating on the basis of a normalized correlation matching rule. This model computes a set of N discriminant functions, where N is the number of possible images (in this case, N = 144). One discriminant corresponds to each candidate image, and the model selects the image with the largest discriminant.

The matching is assumed to occur in a "neural image" space, which is reached by transforming the image. The transformation consists of a conversion to contrast and filtering by a contrast sensitivity filter (CSF). The CSF is derived from our Spatial Standard Observer (SSO), a simple model of foveal contrast detection[3].

The templates consist of the transformed images. If the presented transformed image is written s (for sample), then the discriminant for image i is given by

$$d_i(s) = s g_i \tag{2}$$

where t_i is the normalized template. It is not necessary to divide by the norm of s, since it is the same for all discriminants.

Each transformed image can be expressed as a product of its normalized form and its energy

$$g_k = e_k t_k \tag{3}$$

Thus if image k is presented,

$$s = e_k t_k + n \tag{4}$$

where n is a neural noise image (noise in the neural image space). Then

$$\begin{aligned} d_i(s) &= (e_k t_k + n) g_i \\ &= e_k t_k g_i + n g_i \end{aligned} \tag{5}$$

We can divide through by e_k without changing the ranking of the discriminants,

$$\begin{aligned} d_i(s) &= t_k g_i + \frac{n g_i}{e_k} \\ &= \rho_{i,k} + \frac{n g_i}{e_k} \end{aligned} \tag{6}$$

where $\rho_{i,k}$ is the correlation (dot product) between each pair of neural images.

If the noise is white and normally distributed with standard deviation σ, then the second term in this expression will be a normally distributed random variable with standard deviation σ/e_k. So finally, each discriminant will be be a normal random variable distributed as

$$d_i(s) = \text{Normal}\left(\rho_{i,k}, \frac{\sigma}{e_k}\right) \tag{7}$$

To simulate performance of this model, we simply pick a noise σ, and generate N discriminant values for a number of trials T for each of N sample images. On each trial, the image selected is the largest discriminant, and from these results we can compute percent correct (we can also generate confusion matrices). We compute both percent correct image identification and correct object identification. The performance of the model is controlled by a single parameter: σ, the standard deviation of the "neural noise" added to the sample neural image. In Figure 4, we plot the percent correct for image identification and object identification for images blurred by 30 pixels.

As expected, increasing noise reduces performance. The red and green lines in the figure show the asymptotic guessing performance expected given the numbers of images and objects, and the larger values of noise reach these asymptotes.

Another question of interest is whether the image and object identification performance can be related by a simple guessing model: is the object identification performance what would be expected by assuing that if the model does not pick the correct image, that it then guesses among th other images. In that case the percent correct object identification (P_O) can be computed from the percent correct image identification (P_I) as

$$P_O = P_I + (1 - P_I)\frac{N-1}{N^2-1}. \quad (8)$$

This prediction is shown by the gray curve in Figure 4. Clearly, in this example, the object identification is better than would be expected from this prediction. We call this the "object advantage" (OA). The OA is negligible at 5 pixels blur, but increases to a max of about 0.13 at 30 pixels. Without an aperture (see below), it is about the same for VIS and IR. With an aperture, it is smaller for IR than for VIS. Possible sources for the OA are: background (without aperture), object color (for visible), and overall object size. We will return to this point later.

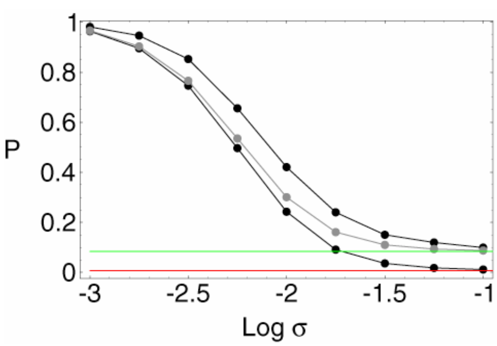
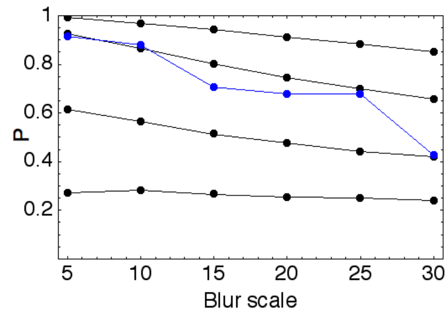


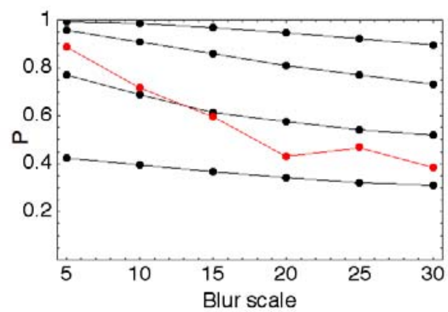
Figure 4. Percent correct image (lower black curve) and object (upper black curve) identification for various levels of the noise standard deviation. These results are for visible targets at blur scale = 30 pixels. Green and red lines indicate predicted guessing performance. The gray curve is object identification predicted from image identification using a guessing model (see text).

Object Identification vs Blur Scale

The results for image identification can also be plotted as a function of blur scale, as shown in Figure 5. The value plotted is percent correct object identification (as in the upper curve in Figure 4), and each curve is for a different noise sigma. The figure also includes (blue and red curves) the data from the human observers. No attempt has been made at this point to find the best fitting value of noise σ, but it is clear that a value of around -2.25 yields a rough approximation to the human data for visible images, and -2 for infrared images.



A



B

Figure 5. Simulated percent correct object identification as a function of blur scale for several different values of neural noise (Log σ = -2.5, -2.25, -2., -1.75). The blue and red curves are the human data. A) visible, B) infrared.

Removing the Background

As noted above, object identification performance is better than expected from the guessing model, which indicates that on average different aspects of one object are more similar (as images) than are aspects of another image. This could be due in part to the object background, which is nearly constant from aspect to aspect. To test this we have computed results for images with the background removed. Aperture images defining the object area were provided by the U.S. Army Night Vision and Electronic Sensors Directorate. The apertured image was constructed as image * aperture + 2048 * (1 - aperture). An example of the construction of one apertured image is shown in Figure 6.

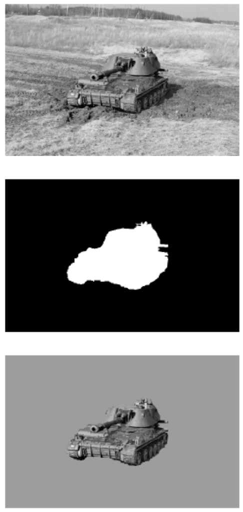


Figure 6. Construction of an apertured image. A) Original image, B) aperture, C) apertured image.

The model results obtained using the apertured images are shown in Figure 7. Overall, performance is somewhat better than for the original images. The visible image performance for –Log σ = –2.25 is now closer to the data, while the infrared data lie between Log σ = -2.5 and -2.25.

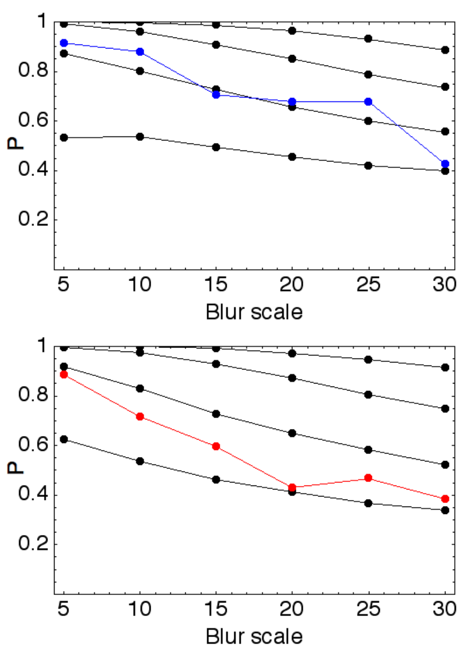


Figure 7. Object identification performance vs blur scale for apertured images. Details as in Figure 5.

Visible vs Infrared

One purpose of the original psychophysical experiment was to determine the relation between N50 for visible and infrared images of similar objects. If the N50s were the same, that would allow the same metric to be used regardless of the iamge type. However, in that experiment the estimated N50s differed by about 50% (7.5 visible, 11.5 infrared)[2].

Figure 8 compares model results for visible and infrared. A short summary is that performance is somewhat better for infrared than for visible, but that this advantage largely vanishes with apertured images. Recall that human performance is slightly lower for infrared, so this consititutes a small discrepancy between model and data.

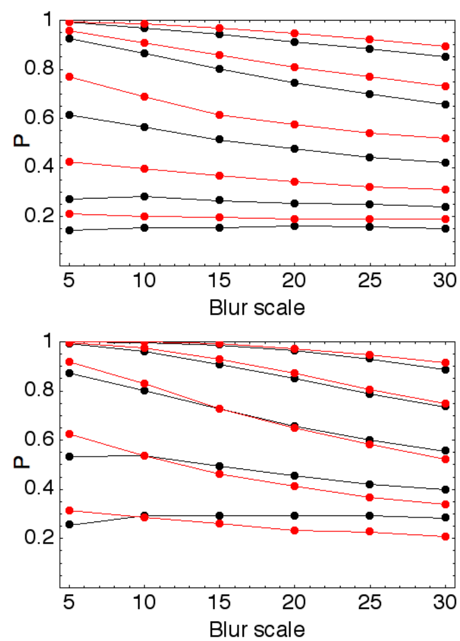


Figure 8. Object identification performance vs blur scale for visible (black) and infrared (red) images. A) Original, B) apertured. Other details as in Figure 5.

Summary

A very simple identification model incorporating the Spatial Standard Observer can generate performance similar to human data for both visible and infrared imagery. Some discrepancies remain, notably the slightly steeper decline with blur, and the poorer performance with infrared imagery, found in the human results. We hope to investigate these matters further in the second stage of this project.

Future work on this part of the project will include alternative SSO-based models, as well as other human data sets[4]. We hope to understand better the reasons for infrared vs visible performance. We also want to work with aircraft rather than tank images.

Visibility Calculator

In a second part of this project, we have begun development of a prototype application to predict visibility of aircraft targets as they might be seen from a UAV. Conversely, the tool could be used to predict visibility of the UAV from another aircraft. A screen shot of the prototype application is shown below.

The tool allows the user to select an aircraft, as well as various viewing parameters. The tool then computes the visibility of the aircraft, expressed in units of JND. The tool is currently online and operational at the URL shown in the figure.

The tool operates by computing a rendered image from a selected 3D model. The rendered image is then processed using the current version of the Spatial Standard Observer (SSO). The tool is implemented using webMathematica, an extension of the Mathematica language[5]. The current version of the prototype is only a proof of concept, and must be augmented by realistic optical and atmospheric effects, and must be calibrated in both geometric and photometric aspects. We plan to accomplish these augmentations in the second phase of this project.

Acknowledgments

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References

1. Vollmerhausen, R.H. and E. Jacobs, *The Targeting Task Performance (TTP) Metric A New Model for Predicting Target Acquisition Performance*, Modeling and Simulation Division Night Vision and Electronic Sensors Directorate U.S. Army CERDEC Fort Belvoir, VA 22060.

2. Driggers, R.G., et al., *Fifty-percent probablity of identification (N_{50}) comparison for targets in the visible and infrared spectra*, US Army Night Vision and Electronic Sensors Division (NVESD).

3. Watson, A.B. and A.J. Ahumada, Jr., *A standard model for foveal detection of spatial contrast.* Journal of Vision, in press.

4. Moyer, S., et al., *Cycle Criterion for Fifty-Percent Probability of Identification for Small Handheld Objects*. 2005, US Army CECOM, RDEC Night Vision and Electronic Sensors Directorate Ft. Belvoir, VA.

5. Wolfram, S., *The Mathematica Book*. 5th ed. 2003, Champaign, IL: Wolfram Media.

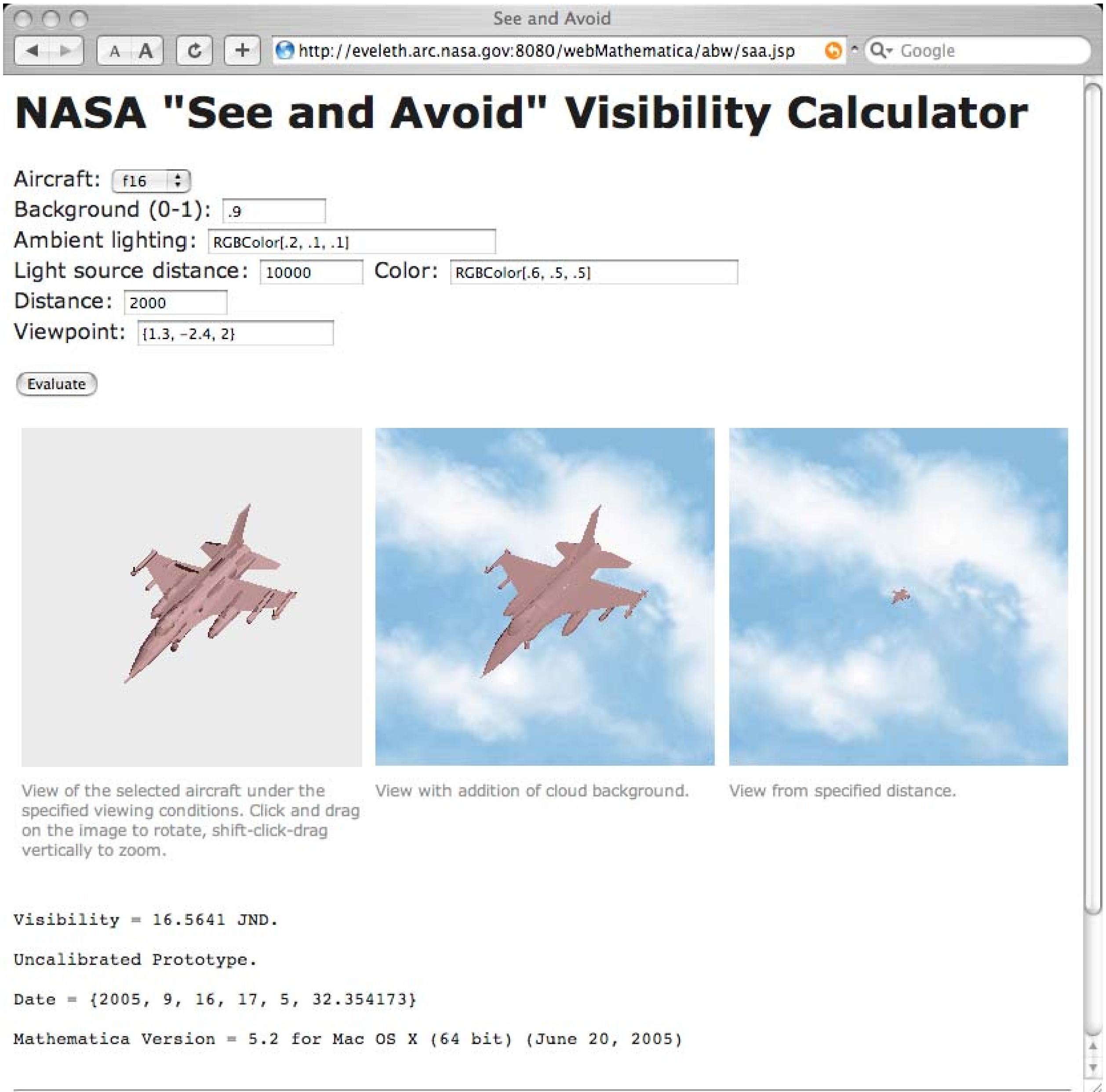

Figure 9. Screen shot of web-based visibility tool.

HOW HIGH IS HIGH ENOUGH? QUANTIFYING THE IMPACT OF AIR TRAFFIC CONTROL TOWER OBSERVATION HEIGHT ON DISTANCE PERCEPTION

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Each year the Federal Aviation Administration (FAA) builds approximately seven air traffic control towers in the national airspace system. Each airport has unique surface and airspace characteristics, but all airports must determine the location and height of the new air traffic control tower (ATCT). These two factors impact cost and safety, therefore the FAA must develop a quantitative means in measuring what improvement in ATCT visibility can be gained by increasing tower height at different locations on the airport surface. Two metrics were developed (Object Discrimination, Line of Sight Angle of Incidence) to assess the impact of tower height on distance perception. The two metrics are fairly robust and easy to use to assess the impact of tower height on air traffic control tower specialist distance perception.

Introduction

"The air traffic control tower siting process must take into consideration criteria relating to the safety of air traffic operations for each site. The optimum height and location is the result of balancing many requirements and considerations, based on the current approved Airport Layout Plan (ALP). The goal of this process is to maximize operational performance and safety when siting an ATCT. (6480.xx, page 3)".

A Federal Aviation Administration employee requested assistance in determining a proposed tower height. The employee's request stated:

> *"I've been asked to justify a certain height at a new tower. I've tried to explain to the Terminal Business folks that this place needs a taller tower because of line of sight problems, heat wave distortion, night time glare from lighting that surrounds the airport, and a parallax type of problem when watching aircraft approaching the airport for landing on closely spaced parallel runways. (FAA employee, 2004)"*

The Federal Aviation Administration William J. Hughes Technical Center Airway Facilities Tower Integration Laboratory tower cab simulation allows air traffic control tower specialists to assess the impact of a proposed tower height and location on an airport surface. The AFTIL can simulate real-world scenes to assess the physical attributes of the tower cab relative to the airport surface and how that may affect visibility, such attributed include cab orientation, tower look-down angle, look across line-of-site, mullions, look-up angle for missed approaches, movement and non-movement areas; unobstructed views. The diversity of the AFTIL has tradeoffs; specifically to depict a real-world scene in a 360^0 tower cab simulation spatial resolution of the generated scene is sacrificed due to amount of computer processing required to generate a scene. In normal mode, the AFTIL image generated scene is equivalent to 20/80 visual acuity which is more than sufficient to address the most of the tower siting criteria. However, the AFTIL can not address the impact of tower height on an air traffic control tower specialists' detection of a distant object.

The objective of this study was to develop, test, and validate a set of human performance metrics to assess the impact of tower height on air traffic control tower specialist distance perception. The human factors metrics as well as the AFTIL simulation will be used to site a tower at an airport.

Methods

Object Discrimination

Question: What improvement in detecting or recognizing a distant object can be gained by increasing tower height or decreasing tower distance from the object?

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The overall objective is to provide the FAA with a user-friendly software tool that provides quantitative information on the impact of ATCT height on aircraft visibility. The tool includes drop-down windows for user input as well as graphical chart windows for results output. The primary output of this tool is probability-of-discrimination (detection and recognition) curves as a function of observation range and tower height. The tool draws from four well-developed and empirically-validated functions and models: The U.S. Army Night Vision Laboratory's Standard Target Transfer Probability Function (using modified Johnson's discrimination criteria), Barton's model for the human eye's Contrast Transfer Function, Kopeika's atmospheric (optical) turbulence modulation transfer function, and Tatarski's atmospheric-index-structure-parameter height-scaling model. In addition, the algorithms and routines include two enhanced-accuracy features that account for: the impact of turbulence on a downward-slanting optical path, and the effect of distance between the point of optical path integration and the observer (the "shower curtain" effect).

Model Assumptions:

(a) Detection is defined as the ability to notice the presence of an object on the airport surface without regard to the class, type, or model (e.g., an object such as an aircraft or vehicle). The observer knows something is present but cannot recognize or identify the object.

(b) Recognition is defined as the ability to discriminate a class of objects (e.g., a class of aircraft such as single engine general aviation aircraft).

(c) The object (aircraft or vehicle) size is taken to be the square root of the frontal or side cross-sectional area of the object (e.g., wing span x height).

(d) Modified Johnson's criteria is used for the number of optical cycles required for a 50% probability of success in object discrimination (N50).

(e) All observations are made with the unaided eye.

(f) The observer is assumed to be at the specified tower height while all objects (e.g., aircraft, vehicles) are taken to be at the ~ 3 ft (1 m) height.

To account for the impact of atmospheric (optical) turbulence on the downward-slanting optical path, an average/effective refractive-index-structure-parameter *scaling factor* was calculated. This *scaling factor* was derived by taking the line integral of the Tatarski height scaling equation over the downward-slanting optical path.

Object Discrimination Tool: The tool (figure 1) can be found at http://www.hf.faa.gov/visibility.

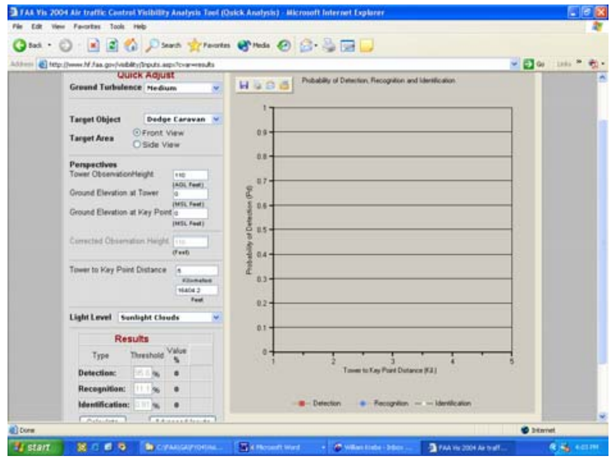

Figure 1. Object discrimination tool graphical user interface. Users enter tower height and distance to calculate air traffic control tower specialists detection and recognition of an airport surface object.

Procedure: From the graphical user interface select object, specify tower height and key point distance, specify ground turbulence, and specify outside illumination level. Key point distance is defined as the distance between the air traffic control tower and object of interest on the on the airport surface.

Results: Probability of detection and recognition values were calculated for one hundred and ninety five level seven or greater air traffic control towers in the national airspace. Key point was defined as the most distant runway threshold from the air traffic control tower for each airport. The object was a front-view of a Dodge Caravan minivan set at 33% contrast. Illumination was sunlight clouds and ground turbulence was dependent upon geographical location.

Based on the 195 air traffic control tower sample, criterion was set at 1½ standard deviations below the sample mean (i.e., better than 6.7% of the sample) which is equivalent to 95.5% for detection and 11.5% for recognition (table 1).

Observation Capability Requirements	Observation Description	Front View Probability Criteria Minimum
Detection	Ability to notice the presence of an object on the airport surface without regard to the class, type, or model (e.g., an object such as an aircraft or vehicle). The observer knows something is present but cannot recognize or identify the object.	95.5%
Recognition	Ability to discriminate a class of objects (e.g., a class of aircraft such as single engine general aviation aircraft).	11.5%

Table 1. Probability of discrimination detection and recognition criterion values based on one hundred and ninety five level seven or greater air traffic control towers in the national airspace.

Line of Sight Angle of Incidence

Question: What improvement in the controller's viewing perspective can be gained by increasing the observer's line of sight angle of incidence to the airport surface at key distance points?

Observers: Twelve tower-rated air traffic control specialists, age 26-59 years, were recruited from four different tower airport facilities. Average air traffic control tower experience was 17.4 years. All observers had normal or corrected-to-normal visual acuity, and had normal color vision. All observers granted informed consent prior to participation. All observers were naïve to the experimental hypothesis.

Apparatus: Federal Aviation Administration William J. Hughes Technical Center Airway Facilities Tower Integration Laboratory's (AFTIL) nine Quantum 3D "Alchemy" image generators (IGs) drove nine, six-foot vertical by eight-foot horizontal rear-projection screens arranged in a 360^0 circular pattern to simulate an air traffic control tower cab environment. The diameter of the simulation floor plan is 24'. Each rear-projector, Epson "PowerLight" model 9100, had a pixel resolution set at 1280 (horizontal) by 1024 (vertical) pixels with a field-of-view of approximately 20^0 (horizontal) by 15^0 (vertical). To increase resolution of the visual simulation, three of the nine rear-projection screens were used in the test. Observers were positioned 24' from the most distant screen thereby allowing a resolution of 64 pixels per degree. The base of the screens is approximately 30 inches from the floor to allow an average standing observer's eye-height to be centered on the screen. Software used to model the simulation were AutoCad, MultiGen-Paradigm, PhotoShop, and other graphic simulator tools to generate vehicle ground and air routes for the airport. Frame rate was fixed at 30 frames/second.

Airport Display: The AFTIL tower simulation displayed a realistic depiction of an airport surface using panoramic photographs and computer graphics (figure 2). The visual simulation contained terrain features, hangers, terminals, runways, taxiways, as well as dynamic surface and airborne aircraft and other ground surface vehicles.

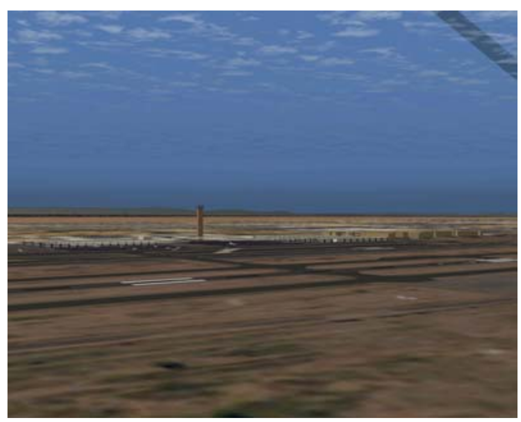

Figure 2. Simulated air traffic control tower scene generated by the Federal Aviation Administration William J. Hughes Technical Center Airway Facilities Tower Integration Laboratory.

Eight ATCT simulations were created: Cahokia/Saint Louis Downtown (CPS), Fort Wayne International (FWA), New York/La Guardia (LGA), Memphis International (MEM), Morriston Muni (MMU), Minneapolis-Saint Paul International (MSP), Oshkosh/Wittman Regional (OSH), and Richmond

International (RIC). At each airport, a critical key point was selected. Observers were informed on the location of the key point. All simulations were displayed during day illumination.

<u>Procedure:</u> The observer was exposed to fifty experimental dynamic scenes: five of eight ATCT simulations and ten tower observation heights (table 1). In each trial, observers performed common air traffic control tower visual tasks at different tower heights. The observer's task was to visually scan a designated distant "key point" on an airport surface and rate the ability to (1) distinguish boundaries of the movement areas and (2) identify position of target at the airport's key point. The distant "key point" was an MD-80 located on the airport surface. Prior to entering the tower cab simulation, the experimenter familiarized the observer to a 6-point Likert rating scale and the response criteria for each question. At the beginning of each block of trials, observers were afforded several minutes to familiarize themselves with the airport layout and location of the distant key point. At the completion of the familiarization, the observer's eyes were occluded and the first experimental tower height was selected. The experimenter then instructed the observer to open his or her eyes and respond to both questions. Within each block of trials, tower height was randomly assigned without replacement. At the completion of the tenth tower height, the next ATCT scene was presented and the same procedure was repeated. ATCT scene order was randomly assigned across observers. Reaction time was not recorded.

<u>Results:</u> Calculate the height of the observer in the tower according to the formula:

$$H_O = (H_C - (P_E - T_E)),$$

where, H_O is height of observer; H_C is controller eye height; P_E is ground elevation of key point Above Mean Sea Level; T_E is ground elevation of tower Above Mean Sea Level. Controller eye height is defined as five feet above cab floor height.

Compute the Line of Sight angle at which the observer's view intersects with the airport surface at the key point.

Line of Sight angle = ArcTan (height of observer/distance between key point and tower)

Based on the responses of twelve observers and several other air traffic tower controller specialists, the minimum level of performance for question 1 (*How well can you distinguish boundaries of the movement areas?*) was response 2 (*Can discriminate boundaries of most of runways and taxiways; but provides no distance information*). Figure 3 illustrates observers' proportion of "yes" responses for response of 2 or greater. All observers reported a response of 2 or greater when towers line of sight angle of incidence was 1.5 degrees or greater. Converting proportion of "yes" responses for response 2 or greater to Z scores then fitting a linear line showed that 50% of the observers reported 0.481 degrees as the preferred line of sight angle of incidence (figure 4).

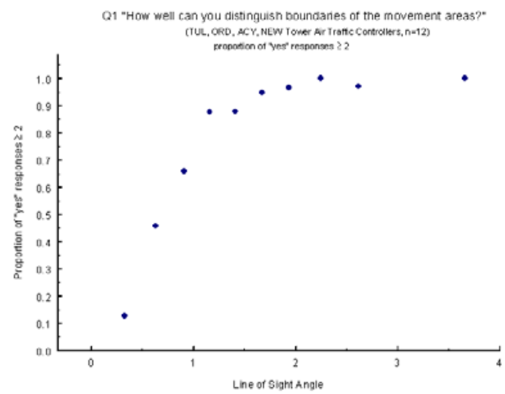

Figure 3. Illustrates observers' proportion of "yes" responses for response of 2 or greater for question "*How well can you distinguish boundaries of the movement areas?*"

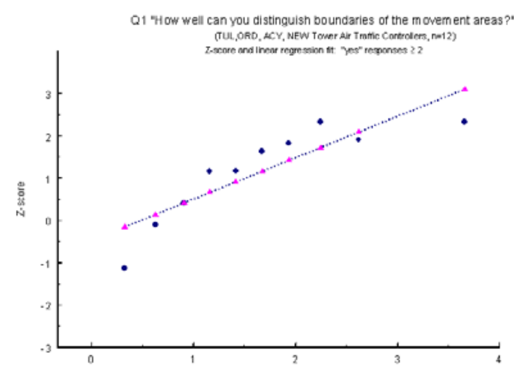

Figure 4. Converting proportion of "yes" responses for response 2 or greater to Z scores then fitting a linear line showed that 50% of the observers reported 0.481 degrees as the preferred line of sight angle of incidence.

For question 2 (*How well can you identify the position of an object relative to the airport's key point?*), the minimum acceptable response was 3 (*Able to determine that object position is in general vicinity of key point, but unable to estimate distances of object within movement area*). Figure 5 and 6 illustrate observers' responses for a response of 3 or greater and linear fit to Z scores, respectively. Fifty percent of the observers reported 0.799 degrees as the preferred line of sight angle of incidence (figure 6).

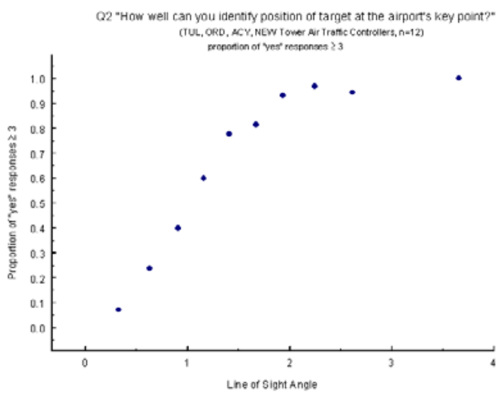

Figure 5. Illustrates observers' proportion of "yes" responses for response of 3 or greater for question "*How well can you identify the position of an object relative to the airport's key point?*"

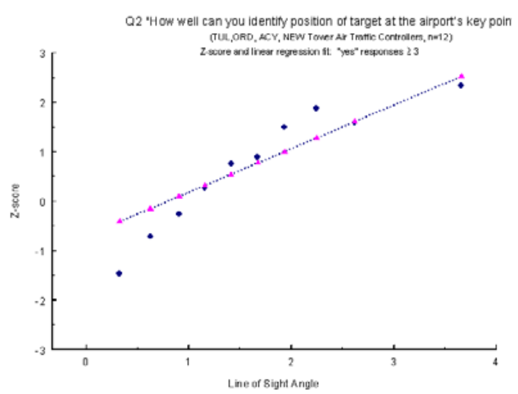

Figure 6. Observers reported 0.799 degrees as the preferred line of sight angle of incidence for a response of 3 or greater.

The minimum line of sight angle of incidence is set at 0.799. The higher value was selected due to question 2 was reported as the more important task of an air traffic control tower specialist.

Conclusions

The analyses performed may assist air traffic requirements in determining future air traffic control tower heights. To assist the decision team, the analyses could be plotted to illustrate percent improvement of air traffic control tower specialists' recognition or identification of an aircraft by tower height expressed in dollars per linear foot. Of course, there are many factors that determine tower height and location but the analyses described above may provide air traffic requirements additional quantitative data to assist in their decision.

References

Federal Aviation Administration (November 10, 1972). Department of Transportation, Federal Aviation Administration Publication Order #6480.4, Airport Traffic Control Tower Siting Criteria.

Federal Aviation Administration (in preparation). Department of Transportation, Federal Aviation Administration Publication Order #6480.xx, Airport Traffic Control Tower Siting Process.

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