How High Is High Enough? Quantifying the Impact of Air Traffic Control Tower Observation Height on Distance Perception

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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 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. (quote from an FAA employee, 2004)"*

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

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Methods

Object Discrimination Analysis

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

The overall objective of this metric 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: The model assumes that

(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.

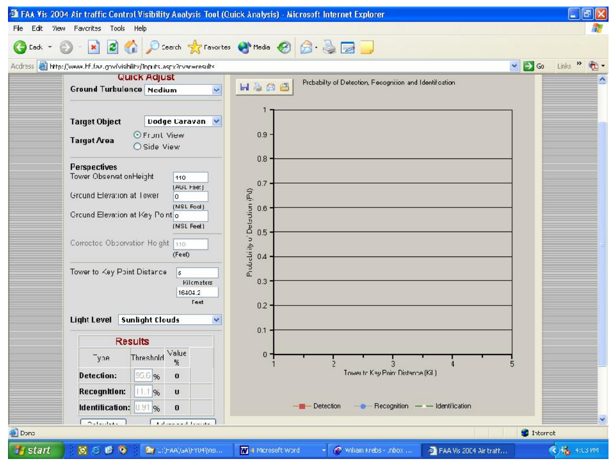

Figure 1. *Object discrimination tool graphical user interface. Users enter tower height and distance to calculate air traffic control tower specialists' detection and recognition of an airport surface object.*

Procedure: From the graphical user interface select an object, specify tower height and key point distance, specify ground turbulence, and specify the outside illumination level. Key point distance is defined as the distance between an observer in 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 grade seven or greater air traffic control towers in the national airspace system. Key point was defined as the most distant runway threshold from the air traffic control tower for each airport. The object selected was a front-view of a Dodge Caravan minivan set at 33% contrast. Illumination was specified as 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 system.*

Line of Sight Angle of Incidence Analysis

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.

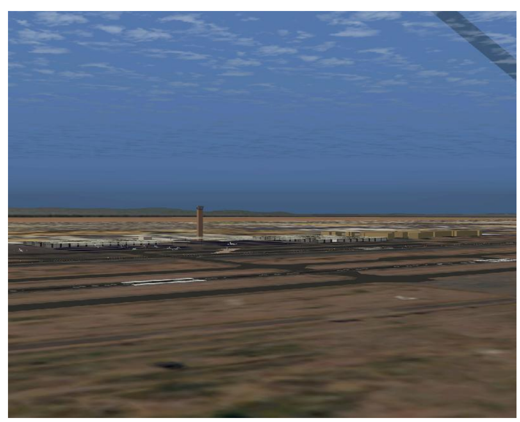

Figure 2. *Simulated air traffic control tower scene generated by the Federal Aviation Administration William J. Hughes Technical Center Airway Facilities Tower Integration Laboratory.*

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. 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 the proportion of "yes" responses for response 2 or greater to Z scores, and 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).

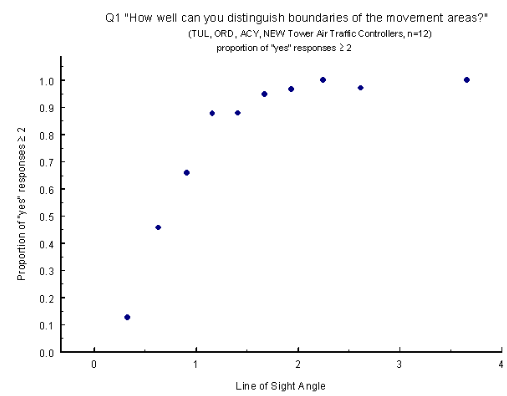

Figure 3. *Illustrates observers' proportion of "yes" responses for response of 2 or greater for question 1: "How well can you distinguish boundaries of the movement areas?"*

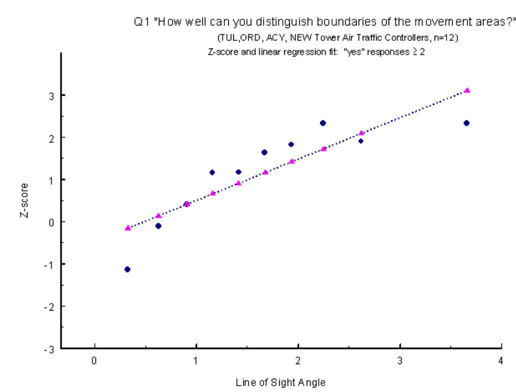

Figure 4. *Converting the proportion of "yes" responses for response 2 or greater to Z scores, and then fitting a linear line showed that 50% of the observers reported 0.481 degrees as the preferred line of sight angle of incidence.*

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).

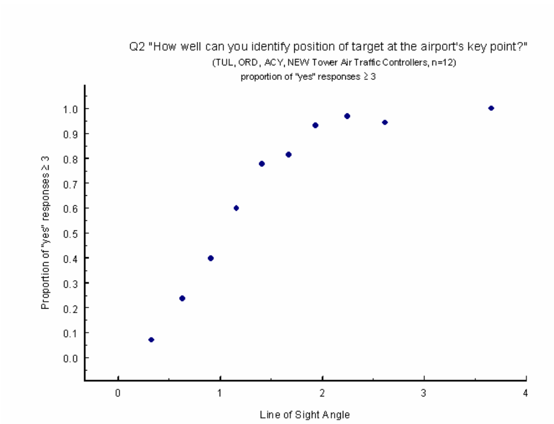

Figure 5. *Illustrates observers' proportion of "yes" responses for response of 3 or greater for question 2: "How well can you identify the position of an object relative to the airport's key point?"*

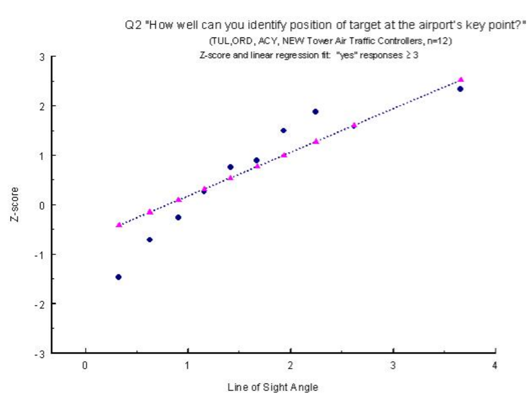

Figure 6. *Observers reported 0.799 degrees as the preferred line of sight angle of incidence for a response of 3 or greater.*

The minimum line of sight angle of incidence is set at 0.799. The higher value was selected because 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 and location. To assist the decision team, the analyses could be plotted to illustrate percent improvement of air traffic control tower specialists' recognition 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

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

Acknowledgements

Sponsored by Federal Aviation Administration, Human Factors Research and Engineering Division. Also, sponsored by Bill Kaplan, Federal Aviation Administration, Terminal Facilities.

Thanks to Scott Iwamoto, Kathy Peterson, Dave Cloutier for their never ending support in allowing us to participate in the air traffic control tower siting process, and a special thanks to Bill Vaughan for providing access to the William J. Hughes Technical Center Airway Facilities Tower Integration Laboratory. We also thank John Aschenbach, Rodman Bourne, Roger Bawgus, and Bernie Garbowski in their assistance with the simulation data collection, and Rob Heckart and Doug Norvell for placing the tower visibility tool on the website.

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