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Static and Motion-Based Visual Features Used by Airport Tower Controllers: Some Implications for the Design of Remote or Virtual Towers

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April 2011

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Contents

List of Abbreviations and Acronyms

A/C............................aircraft
ADSB.........................Automatic Dependent Surveillance Broadcast (aviation surveillance)
AGL ....above ground level
ARN...........................Stockholm-Arlanda Airport (Sweden)
ATC ....air traffic control
ATCO ....Air Traffic Control Office
ATIS ....Automated Terminal Information Service
AT-SAT ....Air Traffic Selection and Training
BOS............................Boston International Airport (Maine)
CAMI.........................Civil Aerospace Medical Institute
CATIII ....instrument landing Category III flight conditions (700' visible range AGL)
CERDEC....................Communications-Electronics Research Development and Engineering Center
DEN ....Denver International Airport (Colorado)
FAA ....Federal Aviation Administration
GTR ....Golden Triangle Regional Airport (Massachusetts)
IMC............................instrument meteorological condition(s)
JND ....just noticeable difference
JPDO..........................Joint Planning and Development Office
LGA ....LaGuardia Airport (New York)
NASA ....National Aeronautics and Space Administration
NATCA......................National Air Traffic Controllers Association
nm ....nautical mile
PHL............................Philadelphia International Airport (Pennsylvania)
SBA............................Santa Barbara Municipal Airport (California)
SFO ....San Francisco International Airport (California)
SID ....standard instrument departures
SJC.............................Norman Y. Mineta San Jose International Airport (California)
STARS ....standard terminal arrival routes
VFR............................visual flight rules

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Stephen R. Ellis and Dorion B. Liston

SUMMARY

Visual motion and other visual cues are used by tower controllers to provide important support for their control tasks at and near airports. These cues are particularly important for anticipated separation. Some of them, which we call visual features, have been identified from structured interviews and discussions with 24 active air traffic controllers or supervisors. The visual information that these features provide has been analyzed with respect to possible ways it could be presented at a remote tower that does not allow a direct view of the airport. Two types of remote towers are possible. One could be based on a plan-view, map-like computer-generated display of the airport and its immediate surroundings. An alternative would present a composite perspective view of the airport and its surroundings, possibly provided by an array of radially mounted cameras positioned at the airport in lieu of a tower. An initial more detailed analyses of one of the specific landing cues identified by the controllers, landing deceleration, is provided as a basis for evaluating how controllers might detect and use it. Understanding other such cues will help identify the information that may be degraded or lost in a remote or virtual tower not located at the airport. Suggestions are made regarding how some of the lost visual information may be displayed. Many of the cues considered involve visual motion, though some important static cues are also discussed.

Introduction

The visual cues necessary to fly and land an aircraft have been well studied over many decades (e.g. Gibson et al., 1955; Grunwald & Kohn, 1994). In particular, the degradation in piloting performance and the consequent need to reduce airport capacity due to bad weather is fairly well understood. (FAA 71010.65R, 2006). The present report outlines a complementary side of the airport capacity-safety trade-off. It identifies and quantifies some of the visual features and properties used by tower controllers to monitor and enable safe landing and maneuvering on or near airports. These features are especially interesting due to recent proposals for technology and procedures in which controllers work in towers without a direct view of their controlled space. Such towers are described alternatively as a remote or "virtual tower" (JPDO, 2007). Work in these towers would be supported by controller displays of information about aircraft and the airport environment.

In general, two types of displays can be considered: One would present a plan-view, map-like computer-generated display of the airport and its immediate surroundings (JPDO, 2007) similar to existing ASDE-x displays (Figure 1). An alternative would present a composite perspective view, possibly provided by an array of radially-mounted cameras positioned at the airport in lieu of a tower (Fürstenau, Möhlenbrink, Rudolph, Schmidt, & Halle, 2008), as shown in Figure 2. In either case, procedures and display techniques need to be developed which are cognizant of the current visual information used by controllers that may be lost.

Figure 1. ASDE-x airport map display.

The following discussion initially points out visual elements of the control task facing the tower evident in previous task analyses of tower operations (Paul, Zografos, and Hesselink, 2000; Werther, 2006). However, this earlier work appears to provide only very general descriptions of the specific visual features to which controllers attend. To the extent the visual functions that are important to the controllers are considered, they are generally limited to questions of detection, recognition, and identification. The following discussion will examine other visual features that go beyond these basic three elements and relate in specific ways to the individual decision processes tower controllers develop to do their job; in particular, we discuss the motion of the controlled aircraft. The preliminary conclusion is that tower controllers use visual features to provide predictive position information allowing them to use *anticipated separation* to effectively and safely merge and space aircraft, and to maximize airport capacity.

Figure 2. Out-the-window camera or synthetic vision display format.

Visual cues used by controllers are important for several reasons. First there is FAA interest in increasing airport capacity so that current operations under non-visual flight rules with reduced capacity may be modified to allow higher visual flight rules capacity during non-visual operations. For this purpose the currently used visual information needs to be provided by alternative means. Such "Equivalent Visual Operations" described FAA/NASA planning documents may be achieved with synthetic visual systems, i.e., (Kramer, Williams, Wilz, & Arthur, 2008) with replacement of direct tower camera or sensor views with visualized electronic position data. This replacement of the direct view, however, will not be fully successful and may be tragically misleading if the useful visual affordances provided by the real scene are not appropriately included or accounted for. Although Equivalent Visual Operations have primarily been considered from the pilot's viewpoint in terms of flight displays that use new sensor data for synthetic vision, it has a flip side for which synthetic vision or camera-based displays could be used to present useful visual information within a remote or virtual tower.

Significantly, this information need not be provided in the form of an image but could be provided in a more map-like plan view format and conceivably could even come along non-visual sensory channels, e.g. auditory or haptic. In fact, it could be based on data directly down-linked to ground displays from an aircraft indicating its state, i.e. spoilers deployed (Hannon, et al., 2008).

The visual environment in an airport tower may be illustrated by considering the view from a specific tower such as that of San Francisco International Airport (SFO) (Figure 3). Such tower views show significant perspective compression at the ~1 nm range to runways and taxiways, making commercial aircraft subtend small visual angles and posing viewing difficulties due to background visual clutter. Interestingly, during low visibility CAT III operations at SFO, airport operations may be conducted with the controllers never actually seeing the aircraft. Thus, since it is already possible for the controllers to continue many of their control tasks without visual contact, albeit with fewer aircraft, the idea of a remote tower may have some prima facie feasibility. But without visual contact, controllers must inform the pilot and those monitoring their communications that visual contact has been lost. Significantly, at the SFO tower where the parallel runways are ~750 feet apart, continued operation without visual contact is associated with a loss (~50%) of airport capacity[1]. In contrast, at an airport such as Arlanda, Sweden (ARN) with the parallel runways ~1 km (~3280 feet) apart, total loss of visual contact can have virtually no impact on capacity when the ground radar is fully functional[2]. Thus, there exist some operational examples of tower operation with total loss of visual contact. During low visibility operations it is not always necessary for the controller to maintain visual contact with the aircraft but for the aircraft to have enough forward visibility to safely maneuver the aircraft during ground taxi operations.

[1] Personal communication, ATCO, San Francisco International Airport, 7/7/2006.
[2] Personal communication, Tower Supervisor, Arlanda International Airport, 4/23/2007.

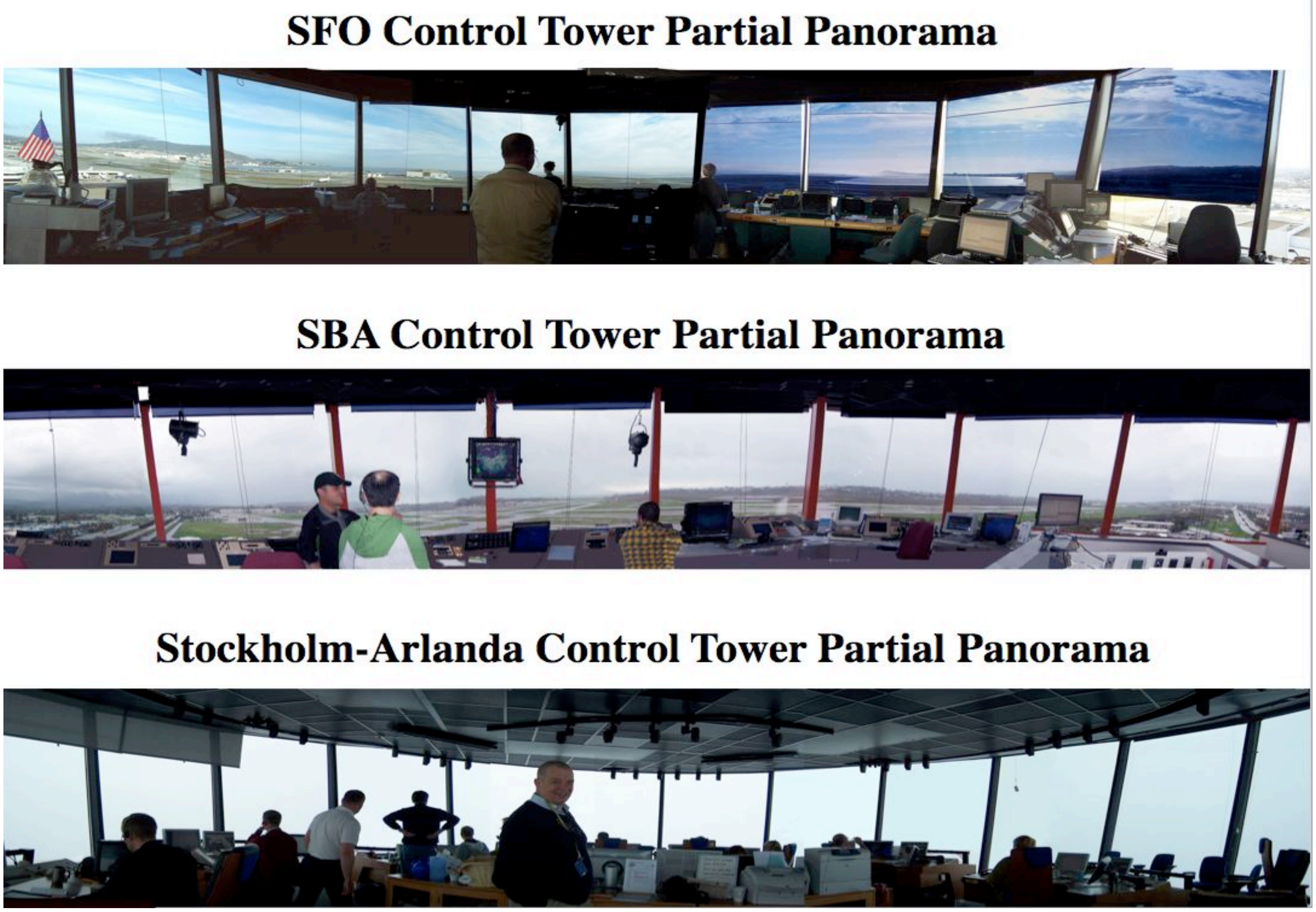

Figure 3. The range of visibility of the airport tower's immediate environments from unlimited visibility (San Francisco International, top) through partial occlusion due to low clouds (Santa Barbara Municipal, middle), to complete white-out (Stockholm-Arlanda, bottom).

SFO Operations

An analysis of the role of visual features in tower control can be developed from a more detailed discussion of operations for a particular airport, San Francisco International Airport (SFO). A sense of the overall strategy for some aspects of usual airport operation at SFO is best obtained from plan-view maps (See Figure 6 for SFO map). Aircraft are taxied from their gates to the southwest ends of runways 1L and 1R and launched in staggered pairs to the northeast. Departing aircraft are interleaved between aircraft landing on Runways 28 Left and 28 Right which also are treated as staggered pairs. Current winds, weather, and special operational requirements, of course, can significantly alter this pattern. For example, sometimes the longer 28 runways are needed for heavy, departing transpacific aircraft. Detailed descriptions of the alternative approach and departure procedures can be found in the Standard Instrument Departures (SID) and Standard Terminal Arrival Routes (STARS) associated with the airport but the local controller's responsibility for arriving traffic generally begins with radio contact before the aircraft crosses the San Mateo Bridge and ends for departing aircraft 1 nm beyond the end of the departure runway. By FAA rules, the local controller is generally responsible for aircraft entering and leaving the runways whereas the ground controllers handle, in a coordinated way, most of the taxiing to and from the gate. These two positions, in addition to that of the supervisor, are the ones that make the most use of the out-the-window information. The other two tower controller positions, Flight Data and Clearance Delivery, primarily use inside-the-tower information sources and voice communications.

Visual Information Used in the Airport Tower

The primary responsibility of the control tower is to ensure sufficient runway separation between landing and departing aircraft (FAA, 2006). A back propagating process may be used to understand the visual requirements supporting the tower controller's primary responsibility. This process first identifies the visual affordances that the controller's tasks involve. Affordances are the higher-level behavioral capacities that vision must support (Figure 4). Controllers, for example, must be able to identify the aircraft type, company, and flight status. They must control and recognize aircraft speed, direction, and position. They must establish a movement plan involving a succession of spatial goals. They must communicate this plan to the aircraft, coordinate it with other controllers and pilots as necessary, establish whether aircraft comply appropriately, and recognize and resolve spatial and other conflicts that may arise. These higher-level elements are supported visually by a number of visual functions: detection, recognition, and perception of the static and dynamic state of the aircraft. These functions are supported by still lower-level visual mechanisms: underlie luminance, color, control, position, and movement processing. These three levels of analysis provide a basis for describing the controller's visual task.

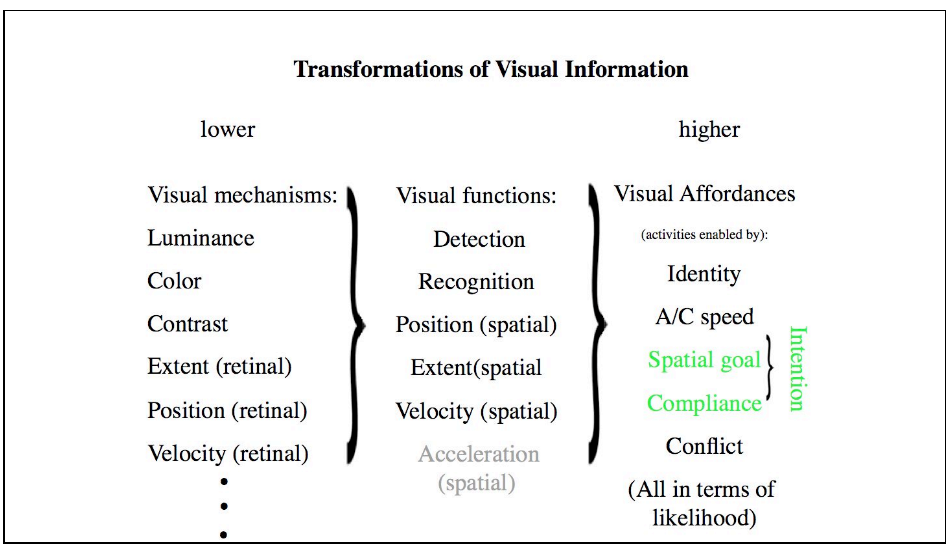

Figure 4. Description of the dependency of the high-level spatial information needed by controllers on progressively low and lower perceptual functions and visual mechanisms.

The tower controller's overall task has, of course, been analyzed within and outside of the FAA. It may be broken down into six different job subtasks: separation, coordination, control judgment, methods/procedures, equipment, and communication. Five of these subtasks involving vision have been identified by boldface type in Table 1 (Ruffner et al., 2003; FAA, 2006).

Table 1. Analysis of Tower Control Tasks*

Job Task	*Job Subtask*
1. Separation	**1. Separation is ensured and maintained at all times.** 2. Safety alerts are provided.
2. Coordination	**1. Performs handoffs/point-outs.** 2. Required co-ordinations are performed.
3. Control judgment	1. Good control judgment is applied. 2. Priority of duties is understood. 3. Positive control is provided. 4. Effective traffic flow is maintained.
4. Methods/procedures	**1. Aircraft identity is maintained.** **2. Strip posting is complete/correct.** 3. Clearance delivery is complete/correct and timely. 4. Letters of Agreement (LOAs)/directives are adhered to. 5. Additional services are provided. 6. Rapidly recovers from equipment failures and emergencies. **7. Scans entire control environment.** 8. Effective working speed is maintained.
5. Equipment	1. Equipment status information is maintained. 2. Equipment capabilities are utilized/understood.
6. Communication	1. Functions effectively as a radar/tower team member. 2. Communication is clear and concise. 3. Uses prescribed phraseology. 4. Makes only necessary transmissions. 5. Uses appropriate communications method. 6. Relief briefings are complete and accurate.

** Tasks inherently involving visual information are printed in* ***bold****.*

The assurance and maintenance of spatial separation is, of course, a visual task regardless whether separation is determined by radar or direct view. Handoffs and point-outs are also intrinsically dependent upon vision, though the need for the controller to adopt the pilot's spatial frame of reference to direct attention toward objects and aircraft is also a significant cognitive task. Control judgment, being essentially a mental and cognitive issue, does not have an intrinsically visual component. But its connection with maintenance of effective and efficient traffic flow does emphasize the critical importance of time in traffic control. Three general methods and procedures directly involve vision: (1) establishment and maintenance of aircraft identify; (2) posting and correct annotation of flight strips; and (3) continual scanning of the entire control environment. Associated with these methods is the admonition to work quickly and to rapidly recover from errors or off nominal conditions. Because each tower environment is to some extent unique, the specifics of procedures differ from tower to tower. All control techniques are, of course, consistent with the regulations cited and described in the FAA air traffic control *(Order 7110.65R)* but unique procedures and heuristics are passed on to future controllers by onsite training. The specific visual features tower controllers use can frequently be found in these locally developed heuristic rules.

The overall tower control process has been formally analyzed and modeled including visual and nonvisual components (Alexander et al., 1989, Werther, 2006). For example, the MANTEA notation (Zografos & Hesselink, 2000) has been applied to analyze controller activity in the tower. Some of the elements identified in the MANTEA analyses are, in fact, visual but the visual components are only described in very general terms such as "visualize runway," "visualize meteo," etc. These descriptions only identify the sensory modality used to gather the information and are a general description of the content of the visual information but they say nothing specific about the actual visual viewing conditions or about the specific visual stimuli. This feature is common in other more recent and more sophisticated task analyses of visual features seen from the tower. Even the recent modeling done with Petri nets (Werther, 2006) does not identify specific visual stimuli but is more concerned with estimates of time required for the precision with which various visual sub-functions may be executed and to the logical conditions and consequences associated with the functions.

The FAA has done some analysis of the specific visual performance expected from tower controllers. The work primarily focuses on the controller's surveillance function and has been based on visual performance models developed for the military by CERDEC at Ft. Belvoir (e.g., Vollmerhausen & Jacobs, 2004). These models primarily are intended to predict the probability of visual detection, recognition, and identification of known targets. *Detection* refers to users' ability to notice the presence of a particular object. *Recognition* refers to their ability to categorize the object into a general class such as a tank, light aircraft, or truck. *Identification* refers to their ability to determine the specific type of object, i.e., an Abrams tank, a Cessna 172, or a Ford refueling tanker. More modern similar visual performance models do not require the same amount of calibration techniques to determine model parameters for specific visual targets and specific users (Watson, Ramirez, & Salud, 2009).

The CERDEC analysis, which predicts specific object perception from towers of various heights during a variety of atmospheric conditions and object distances, has been incorporated into a web tool to help tower designers ensure that specific architectural and site selection decisions for new towers will meet FAA requirements (Figure 5). Significantly, this tool focuses only on the surveillance function and does not address the aspects of visual motion that tower controllers use for the information, separation, and safety tasks.

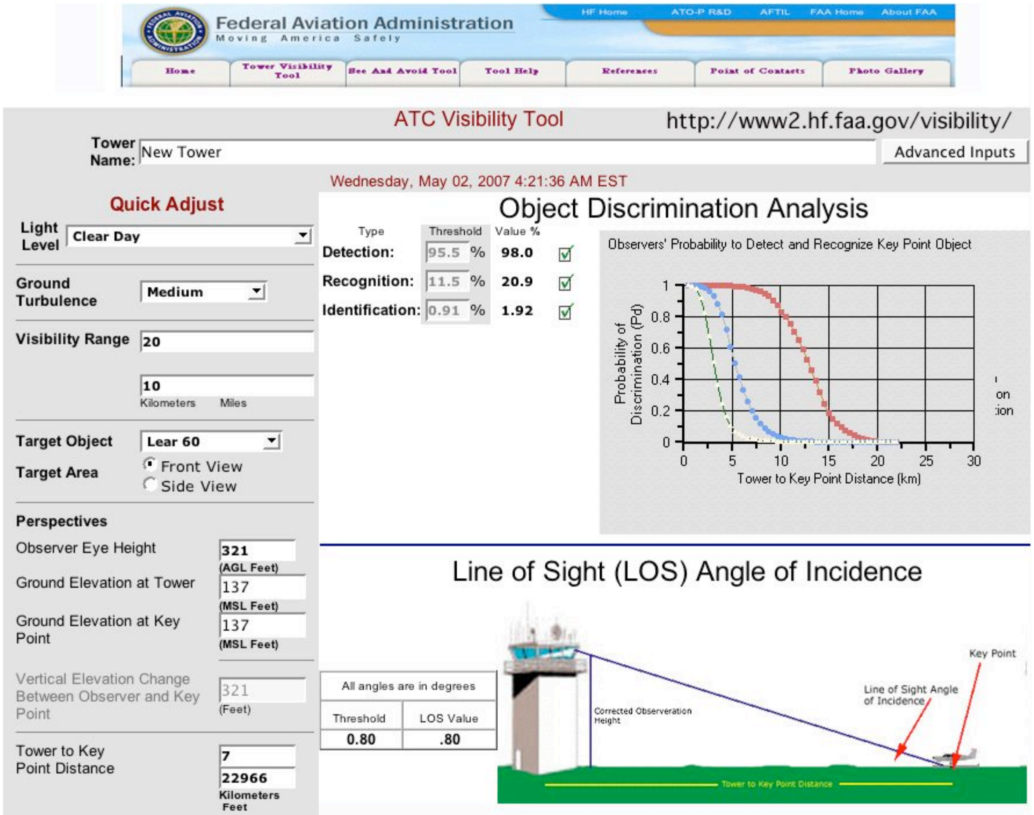

Figure 5. The web interface to the FAA's tower design analysis tool that may be used by municipalities and others to test tower designs ultimately intended for FAA analysis and approval. Note website indicated in the upper right.

In order to understand the details of the visual features used in tower control it is first necessary to identify the range within which controllers use visual information. We can use the example of SFO. Informal voluntary discussions and structured interviews with ten active controllers and supervisors who work at this tower were analyzed for the physical locations identified as points where various types of visual references are used while controlling approaching or departing aircraft. These discussions, which were considered preliminary work, were conducted with the knowledge and approval of the SFO tower manager, his chain of command, and the local NATCA representative. All primary notes were taken without personally identifying markings and transcribed into secondary statistical summaries or grouped data so as to preserve the anonymity of the respondents. Primary notes were thereafter discarded.

These reported points where useful visual information could be seen primarily to include positions where visual contact with the aircraft is first or last were considered to be helpful. These positions, marked in Figure 7, include those for which aircraft come under or leave tower control, where they pass important ground references, or where visual contact provides other useful information. The points were determined independently from each of the controllers in response to the question "When you are in the Local controller position, where are the aircraft when you usefully observe them visually, what visual aspects of the aircraft do you observe, and why?" Controllers could designate more then one point of interest for departing and more than one for arriving traffic; only two controllers took this option. One point represents nine controllers' overlapping responses identifying approximately the same location about 1 nm beyond the end of the departure Runway 1.

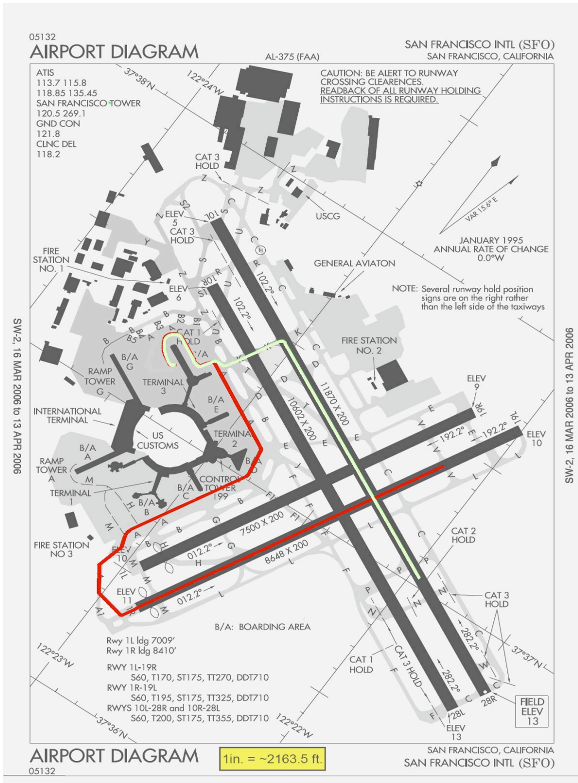

Figure 6. SFO airport diagram showing typical movement paths for United Airlines, departures (dark/red paths) and arrivals (light green/paths).

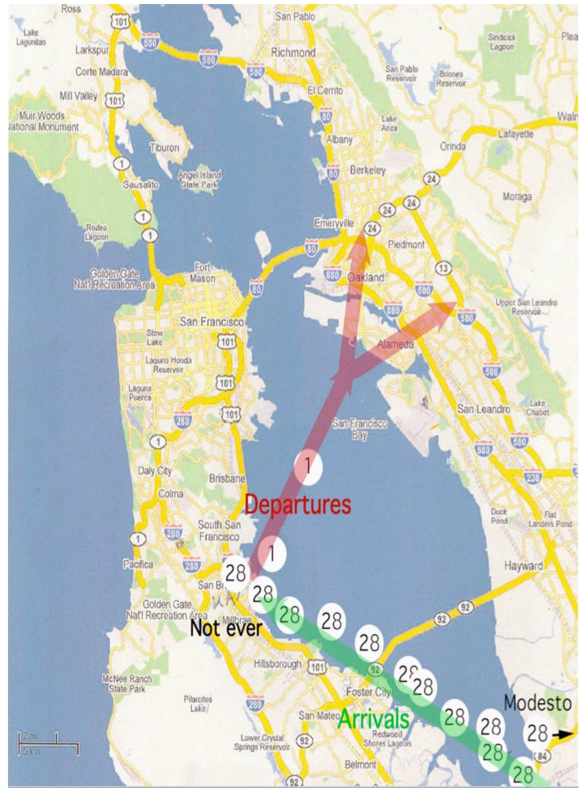

Figure 7. The first and last positions where SFO controllers report useful visual information with regards to landing (Runway 28) and departing aircraft (Runway 1). The arrows show idealized, most common approach paths (transparent green) to the west and departure paths (transparent red) to the north.

In general, it is apparent from the distribution of points that controllers' visual attention is much more spatially distributed to the aircraft approaching the 28LR runways and rather abruptly drops off about 1 mile off the end of the usual departure runways 1LR. These observations refer to the most common aircraft flow at SFO but suggest the generalization that the local controllers' visual attention to approaching aircraft is distributed over a much larger area than that corresponding to departing aircraft. A likely reason for this is that departing traffic is handed off to approach/ departure control at 1 nm beyond the end of the runway and generally not thereafter of concern to the tower.

A significant aspect of the controllers' remarks concerning when they first start paying visual attention, or when they last pay attention, to aircraft is that they rarely mentioned the aircraft's visual motion[3]. One reason is that for the viewing angles and distances to the aircraft approaching and departing SFO, this motion is very small in terms of degrees per second. Often the azimuth rate is on the order of much less than 0.25°/second and rarely more than 0.5°/second. The visual accelerations are even much smaller and difficult to see because of atmospheric haze, thermal effects, and the visual range being beyond 5 miles. Visual rates of motion are more important for closer aircraft on or just seconds away from being on the runways or taxiways.

Probably the most obvious need for visual contact by controllers in the tower is to immediately note unusual events that are not detected by electronic sensors such as radar. Examples could be heavy bird activity or an aircraft leaking fuel onto a taxiway. But there are a wide variety of other visual features that controllers use on a more regular basis when aircraft are close enough for the visual motion to be more easily noticed. Discussions with controllers have provided a list of some that are used (Tables 2 and 4).

A tabulation (Table 2) of the visual features mentioned in the discussions with each of the SFO controllers shows the relative frequencies with which different features were mentioned. These discussions used a "cognitive walk-through" technique in which the controllers were asked to imagine representative approaching, departing, and taxiing aircraft under a variety of visual conditions and to report what they looked for visually to assist their control tasks. The consequent discussions were guided by the elements outlined in the Appendix. The most frequently mentioned features were relative motion between landing or departing aircraft and obstacles that could be on the runway. The first of these features is probably prominent because SFO has intersecting runways commonly used for takeoffs and landings. An assessment of all of the features mentioned, however, shows what may be a more general element. Seven of the 13 features identified in the interviews note that the feature helps the controller anticipate future activity. This information provides insight into pilot intent, knowledge, and likelihood of aberrant behavior. These predictive cues help the controller with the short term trajectory planning needed for *anticipated separation* and helps them allocate their attention to pilots either unfamiliar with the airport or maneuvering in unexpected ways.

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[3] Visual motion is defined as the angular rate of change of the line of sight angle to an aircraft from the tower.

Table 2. Visual Features Identified by Interviews with 10 SFO Tower Controllers*

Feature	*Xs Mentioned*	*Commentary*
1. Relative visual motion used to verify interleaving or takeoffs and landings.	5	Controllers **verify their predicted** separation of coordinated landing and approaching A/C by monitoring relative motion with respect to some stationary, visible direction of an object such as an airport light.
2. Visual check obstacles or A/C for runway clearance.	5	Obstacle checks include ground vehicles, aircraft, birds, and people.
3. Taxiing with 'authority' helps attention allocation.	4	Fast and 'confident appearing' A/C motion allows controllers to distribute their attention to pilots who appear unfamiliar land hesitant to maneuver so as to **anticipate** problems they may create.
4. Aircraft attitude/altitude predicts 'Go Around'.	4	Controllers like to be able to **anticipate** 'go arounds' by observing A/C attitude and altitude as various approach 'gates.'
5. Visual speed, acceleration, or turn used to anticipate taxiway selection.	4	Controllers mentally integrate speed and acceleration (including turn rates) to **anticipate** future taxiways that might be used to complete A/C's movement to for from gate.
6. Coordinate/crosscheck visual and radar.	4	A large amount of time is spent crosschecking visual separation during approach and departure with radar information during VFR conditions.
7. Visible wing dip predicts turn.	3	Visible banking given a quick **prediction/confirmation** that A/C is turning in conformance with clearance.
8. 'Mike and a mile' rule for interleaving takeoffs and landings.	3	**Predictive rule:** A/C needs to be rolling across taxiway Mike on RW1 with matched landing A/C on RW28 at 1 nm final for the required separation to be obtained.
9. Engine smoke and heat confirms takeoff roll start	2	Modern A/C don't smoke much and have cooler exhaust.
10. Onset of navigation lights or strobe predicts coming dynamic change.	2	Appearance of these lights allows controller to **anticipate** call from a/C requesting clearances and instructions.
11. Visual resolution of motion and position better at airport than radar.	1	Near the tower (<1–2 nm) the visual display of the real world has many more 'pixels' than associated radar displays.
12. Visual check done on tail for A/C company.	1	
13. Check landing gear.	1	This check is done so automatically by controllers that it wasn't mentioned due to focusing of the interview on visual features for separation.

* Boldface marks out the predictive aspect of specific visual features

Visual Features at SFO and Other Airports

In order to examine the generality of the visual features and produce a list as complete as possible, structured anonymous interviews were conducted with controllers from an additional seven airports. Because we were not able to obtain timely agreement from the national NATCA office for the participation of line controllers, these additional discussions were limited to supervisory personnel. Anonymity was maintained since all written notes were taken without personally identifying markings and formal questionnaires were not used. To ensure anonymity, original notes were transcribed into statistical or grouped secondary notes and the originals were thereafter discarded, ensuring that no personally identifiable information was recorded or could be reconstructed post hoc. In all cases, tower visits to U.S. airports were conducted with the knowledge and approval of the specific tower's manager and FAA headquarters. In addition to that of San Francisco International Airport (SFO), U.S. airport towers that were visited were: Boston International (BOS) MA; Golden Triangle Regional (GTR) MS; Santa Barbara Municipal (SBA) Santa Barbara, CA; and Norman Y. Mineta San Jose International (SJC), San Jose, CA. Supervisory controllers from Denver International (DEN) Denver, CO, LaGuardia Airport (LGA), New York City, NY, and Philadelphia International (PHL) Philadelphia, PA were included in the multi-airport analysis. They visited the first author at NASA Ames Research Center and provided information regarding the nature and location of visual features used by controllers while viewing airport diagrams and regional maps. The tower at Stockholm-Arlanda (ARN) in Sweden was the only foreign airport tower visited but was not included in any quantitative analysis. Table 3 gives a summary of the airport towers considered and the personnel interviewed.

Table 3. Airport Tower Environments Discussed and Evaluated

Airport Tower Environments Discussed	*Number of Controllers or Supervisors*	*Notes*
Stockholm (Arlanda) ARN	1	Discussions were held but visual features from the ARN tower were not analyzed.
Boston International (BOS)	3	Supervisors only.
Denver International (DEN)	1	Supervisor only without airport view.
Golden Triangle Regional (GTR)	1	Supervisor only.
La Guardia International (LGA)	1	Supervisor without airport view.
Philadelphia International (PHL)	1	Supervisor without airport view.
Santa Barbara City (SBA)	2	Supervisors only.
San Jose International (SJC)	3	Supervisors only.
San Francisco International (SFO)	11	One supervisor, 10 controllers.
Total	24	

Figures 8 and 9 illustrate how the visual velocity of aircraft viewed from the tower could be determined for moving aircraft at or near the airport and those that were farther away in the airport vicinity but still visible. Figure 10 provides a breakdown of various classes of features as 14 general categories that were used to organize the features. Counts on the numbers in each category give an idea of their relative frequency of mention. At this stage of investigation no systematic attempt was made to determine the relative operational importance or frequency of use of the various features. Investigations are currently underway in collaboration with Jerry Crutchfield of the Civil Aerospace Medical Institute (CAMI) to determine the frequency of use and criticality of the visual features that have been identified[4]. (Also see van Schaik, Roessingh, Lindqvist and Fält, 2010.) In particular, the high frequency of mention of the points of first and last useful visual contact are undoubtedly an artifact of their mention in the structured interview as an example of the kind of visual information being sought. The point of the investigation was to collect as broad a range of visual features as possible for further analysis in subsequent studies that are presently underway.

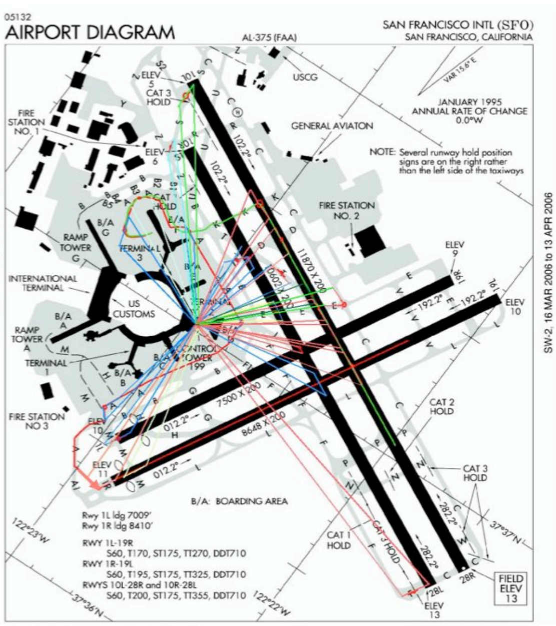

Figure 8. Lines of sight from the San Francisco International Airport (SFO) tower to positions on the airport where the visual motion was analyzed. Simple geometry allows calculation of rates of change of lines of sight from the tower to aircraft from knowledge of tower and aircraft position and aircraft velocity.

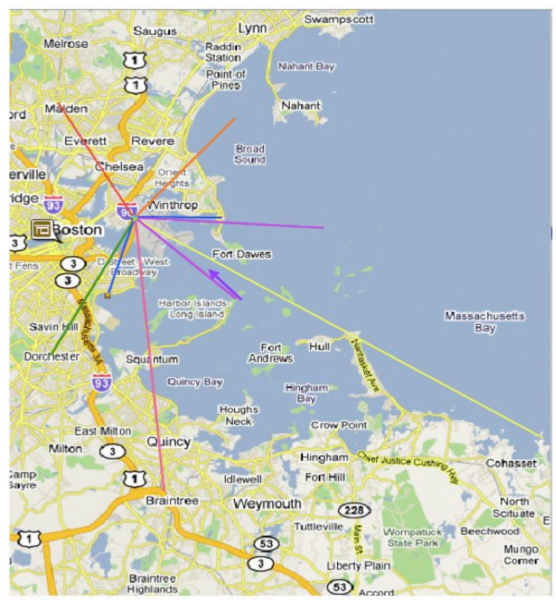

Figure 9. Lines of sight from the Boston Logan International Airport (BOS) tower to positions in the airport region where the visual motion of moving aircraft were analyzed.

[4]The project is called Concurrent Validation of AT-SAT for Tower Controller Hiring (CoVATCH). AT-SAT stands for Air Traffic Selection and Training test battery.

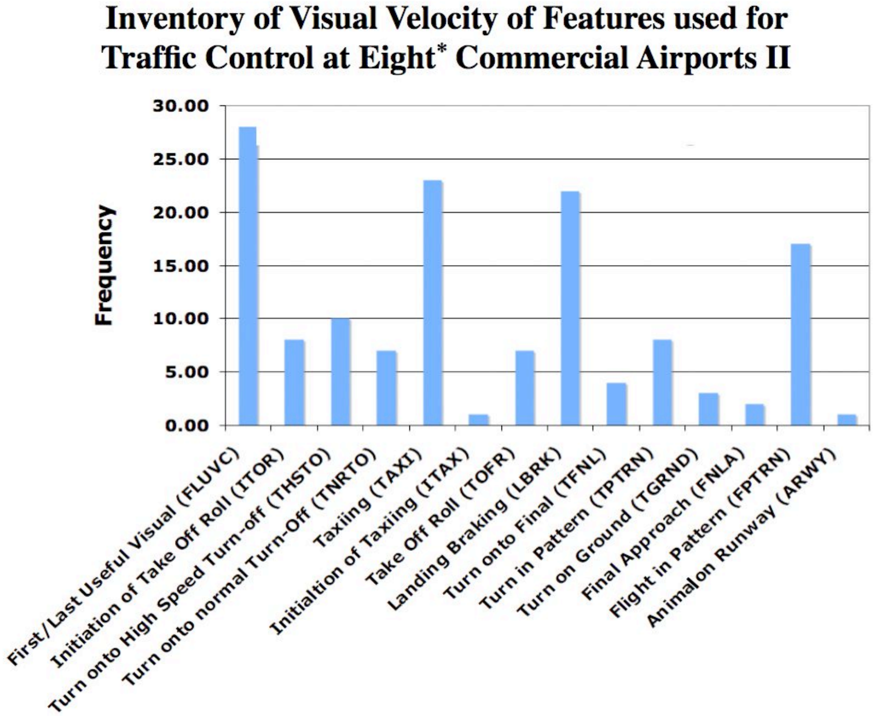

Figure 10. Inventory of visual velocity for features used for traffic control.

When a controller identified a visual feature, its location was plotted on an appropriate map. Afterwards, the direction of flight and speed was determined from the appropriate airborne traffic pattern or ground path. Simple geometric analysis was then possible to determine the apparent visual rate of the aircraft as seen from the tower at the time the visual feature would have been noted. Because actual aircraft speed was not actually measured, speed was estimated from typical rates mandated by approach procedures or estimated by controllers and pilots familiar with the airport and typical air and ground aircraft motion. Some reflection on the geometry shows, however, the aircraft speed to have a comparatively small influence on visual motion. Its impact is dwarfed by the effect of relative direction of flight. An aircraft flying directly towards the tower can have virtually 0°/second visual velocity! The relative direction of flight used for analyses was determined from the interviewees and the typical patterns of motion at and around the airport if the original notes did not include the needed information. Once the approximate visual velocity associated with each visual feature was determined, a spectrum of visual velocities associated with each of the 14 feature categories could be determined. These are shown in Figure 11 and summed to give an overall total. These spectrums of visual velocity for each of the categories of features reflect some of the physical aspects of each category. The first and last useful visual contact rates are slowest because these are in general the farthest from the tower. Visual rates during landing deceleration are high because the aircraft are generally closer to the tower yet still moving relatively fast compared to taxiing.

For the purposes of the present inventory the most important aspect of the distribution of motions is not its shape or arithmetic mean but its mode and range. As can be seen in Figure 11, the vast majority of visual rates are less than 1°/second with the mode at a small fraction of a degree/second. These visual rates are quite slow compared to those typically studied in visual psychophysics. If a concept of operations for a remote or virtual tower is to include visually presented targets that provide the information that controllers currently pick up from aircraft motion, then the display techniques need to be able to represent this range of slow motion for visual cues that controllers currently use. It is important to note that the useful presentation of aircraft motion therefore benefits significantly from the use of very large format displays. To the extent that the display scales down visual motion due to screen size, the displayed visual rates, which are already very slow, could well become imperceptible and require special signal processing to be operationally useful. An example of such processing could be the computational detection of the slow motion and its denotation by introduction of or changes in visible symbology. A second important caveat is that the visual rates are not seen in isolation but have a temporal context; in fact, the change in visual velocity itself can be an important cue which is identified for some visual features in Table 4 and discussed in more detail in the final section.

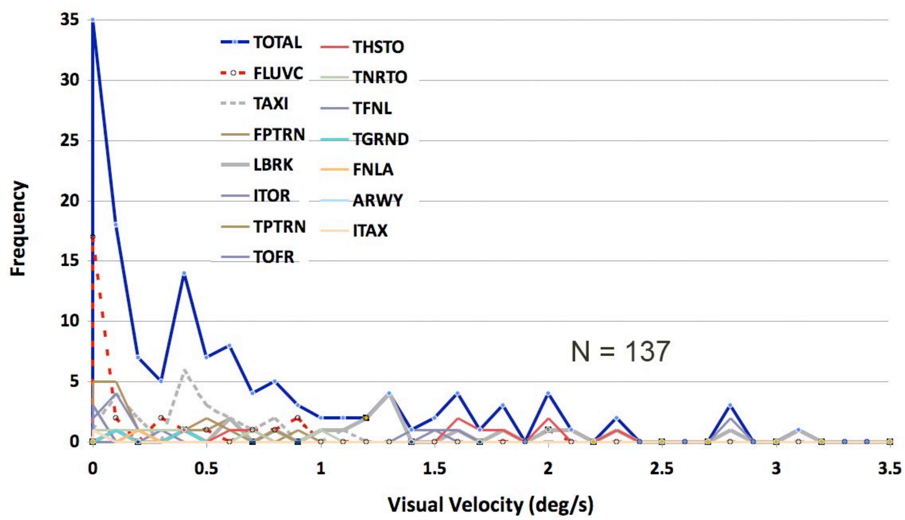

Figure 11. Visual velocities associated with each of the feature categories.

Table 4 provides a summary of all the visual features identified from discussions with controllers from all analyzed airports. It lists the identified visual feature, the information the feature provides the controller, and suggests some general information support characteristics that would be necessary to provide equivalent information on alternative displays that might be used in a virtual or remote tower: (1) a map-like display that could be driven by ground radar or other comparable positions information, e.g. ADSB; and (2) an image-like display that resembles the out-the-window view from a tower and could be driven by airport cameras or other sensors and computer graphics providing synthetic vision (Figures 1 and 2).

Table 4. Visual and other Perceptual Features that Aid Tower Air Traffic Control			
Visual Feature	*Visual Information Provided*	*Corresponding Decision Support Information and Display Techniques for Map-like Displays*	*Corresponding Decision Support Information and Display Techniques for Out-the-window Image-like Displays*[5]
Status			
1. A/C is prepositioned with an anticipatory rotation for a turn while holding short of a taxiway or runway.	Pilot is correctly expecting to be cleared for a specific turn.	Current and static A/C orientation should be shown on electronic map.	Visual resolution of display should be sufficient for user to recognize A/C pose at crossing points.
2. A/C type.	Predicts likely ground acceleration, e.g. the difference between turbine vs. constant speed propeller A/C determines separation techniques used.	A/C type should be indicated by icon shape or data tag to relieve controller memory load.	High resolution visual image required to support existing visual performance requirements for tower design.
3. Dust up or thermal optical distortion from thrust.	Applied power can confirm compliance with take-off or other clearances that require engine spool-up.	Down-linked indications from A/C of engine spool up should be displayed on A/C icon.	Evidence of spool up should be visible on display or A/C icon associated with the power up should be displayed based on down-linked information.
4. Smoke, spray from wheel indicates ground contact and touchdown point.	Touch down point, landing likely unless a touch-and-go is planned. Helps to identify likely taxiway to be used to exit runway.	Down-linked information from wheel sensors indicating touchdown should be displayed on A/C icon to indicate touchdown point.	Visual evidence of wheel contact should be visible or down-linked information from wheel sensors indicating touchdown should be displayed on A/C icon.
5. Navigation lights being turned on.	Call to tower is imminent, usually to the Clearance Delivery Controller at a big tower.	Down-linked information regarding cockpit A/C start up (i.e. before engine start) should be displayed (e.g. A/C icon first appears on display on startup before pilot calls tower).	Navigation lights when A/C is in the gate should be visible. Down-linked information regarding cockpit A/C start up (i.e. before engine start) should be displayed if visibility is insufficient, example, e.g. A/C icon first appears on display on startup before pilot calls tower.

[5] Synthetic vision or image type displays can in general also be augmented with computer generated icons or data tags in what would be called an augmented reality display. In contrast to an electronic map display, the choice to use an image type display could be based on a minimal sensor system using only cameras so as to as to keep costs and computational overhead low.

6. A/C relation between A/C attitude and altitude.	The visual relationship between A/C attitude and altitude predictive of pilot intent such a landing or executing a missed approach.	A/C pitch attitude should be displayed geometrically or numerically for comparison with speed display with short delay < ~1 sec.	Pitch attitude and speed need to be perceivable on display with short delay < ~1 sec.
7. Reflected "lights" on the water. Visible reflections of A/C light off ground features such as bodies of water or a runway surface that confirm normal or indicate deviant flight path.	At some airports reflections of landing lights off surfaces like water can independently confirm normal lateral position and orientation of landing A/C; such information is similar to pilot reports of passing the Outer Marker.	Indication of A/C passing over "virtual" markers along approach route and outer or inner marker shown on display, possibly sourced from data down-link.	Visual fidelity of image of approaching A/C should include large specular reflection of landing lights.
8. A/C mechanical status, gear, flaps, spoilers, reversers.	Confirms appropriate aerodynamic status of A/C. Confirms intention to land. Can be used to indicate onset and intensity of braking, predicting the A/C deceleration profile.	Down-linked data from A/C should provide data for display of status of gear, flaps, spoilers, and reversers to confirm commitment to landing.	Aerodynamic configuration of A/C should be visually evident or enhanced by graphic overlays based on down-linked data.
9. Weather conditions immediately at airport (e.g. fog, rain, water on runway).	Cross check pilot reports, provide weather information, determine VFR/IMC status, determine airport approach/departure patterns, provide input for ATIS.	Map symbology should include weather icons and/or text indications based on down-linked A/C or airport sensor information.	Weather should be visually apparent on display or presented by overlaid icons and text based on down-linked or airport sensor information.
10. Weather conditions near airport (e.g. ceiling, RVR, Outer and Middle Markers).	Cross check pilot reports, provide weather information, determine VFR/IMC status, determine airport approach/departure patterns, provide input for ATIS.	Map symbology should include weather icons and/or text indications based on down linked or airport sensor information.	Weather should be visually apparent on display or presented by overlaid icons and text based on down-linked or airport sensor information.
11. First/last visual acquisition. The position where an approaching aircraft is normally first usefully visible or where visibility is typically lost for a receding aircraft.	Confirm location of radar contact, spacing w/r to A/C in pattern.	Display A/C icon corresponding to initial and final radar contact.	Provide sufficient visual contrast and resolution to allow visual contact at times and positions comparable to view from a real tower.
12. Movement during taxi.	Verify compliance with taxi clearance and/or detect violation.	A/C motion and position need to be observable. Note: Because of reduced display size and map scale, the physical motion on the display may be below perceptual thresholds.	A/C motion and position need to be observable. Note: Because of reduced display size, the physical motion on the display may be below to perceptual thresholds.

13. Animal obstructions or intrusions.	Need to issue obstruction warning, modify approach, departure, or ground movement. Could be as small as a snapping turtle or as large as a bear.	Airport sensor data (e.g. motion sensors or cameras) should be used to provide timely displays of obstruction locations and movements.	Visual displays should have sufficient resolution and contrast to match out-the-window views. Airport sensor data (e.g. motion sensors or cameras) could alternatively be used to provide timely iconic or text overlays.
14. Birds, flocks, large birds.	Need to issue bird activity warning, modify approach, departure, ground movement.	Airport sensor data (e.g. motion sensors or cameras) should be used to provide timely iconic and/or text displays of obstruction locations and movements.	Visual displays should have sufficient resolution and contrast to match out-the-window views. Airport sensor data (e.g. motion sensors or cameras) could alternatively be used to augment display to provide timely iconic or text warning overlays.
15. Inanimate obstacles on runway/taxiway.	Need to issue obstruction warning, modify approach, departure, ground movement, possible communication with user-operated vehicles.	Airport sensor data (e.g. motion sensors or cameras) should be used to provide timely iconic and/or text displays of obstructions locations and movements.	Airport sensor data (e.g. motion sensors or cameras) should be used to provide timely iconic and/or text displays of obstacles or displays making them visually detectable.
16.Unexpected/unanticipated event.	Visual observation of event requiring nonstandard/ emergency procedures.	Not handled well without sensors designed for unanticipated dangers; consequently rare but dangerous events could be missed.	High visual fidelity wide-field-of-view surveillance with high sample rate and low latency required for unanticipated events, which likely have a visual component.
Acceleration/Deceleration			
17. A/C beginning visual acceleration of takeoff roll.	Confirms compliance with Clearance to takeoff.	Detection of onset of takeoff roll by low latency motion sensors, Down-link from A/C or other sensors would be needed to provide information with delays comparable to current view of the A/C. Note: Physical size of map display will make initial A/C motion harder to see than direct out-the-window view (see text). A discrete onset of motion signal on the map, such as making the A/C symbol double-bright, would greatly assist controllers.	High resolution, bandwidth, low latency view of A/C starting takeoff roll is required for visual confirmation of compliance. Such a display could provide information for equivalent to the current out-the-window view.

18. A/C landing deceleration reportedly sensed to anticipate use of high-speed turnoff.	Predicts length of landing roll and, indirectly, the turnoff and taxiways used after exiting the runway.	Down-link from A/C or other sensors would be needed to provide information with delays comparable to current view of the A/C. Note: Physical size of map display will make initial A/C motion harder to see than direct out-the-window view. Consequently, a ground speed data tag should be associated with the landing A/C. It could be removed at the end of the landing roll.	High resolution, bandwidth, low latency view of A/C starting takeoff roll is required for visual confirmation of compliance. Such a display could provide information for equivalent to the current out-the-window view allowing controllers to use current perceptual speed estimation techniques. Large visual displays would need to be used to present rates of visual angles comparable to current visual contact.
19. A/C pitching after main gear touch down.	Predicts use of aerodynamic braking, length of landing roll, and indirectly the taxiway to be used to exit runway.	Down-link from A/C or other sensors would be needed to provide information with delays comparable to current view of the A/C. A visual indication on the landing A/C icon of nose wheel contact could provide comparable information.	High resolution, bandwidth, low latency view of A/C landing A/C is required for visual confirmation of pitch down. Large visual displays would need to be used to present rates of visual angles comparable to current visual contact. Current specifications for tower design provide adequate visual requirements for the visibility of A/C pitch that could be adapted for remote/ virtual towers.
20. A/C pitching after landing braking.	Predicts landing, length of landing roll, taxiway to be used to exit runway and related to assigned gate.	Down-link from A/C or other sensors would be needed to provide information with delays comparable to current view of the A/C. A visual indication on the landing A/C icon of nose wheel contact could provide comparable information.	High resolution, bandwidth, low latency view of A/C landing roll is required for visual detection of pitching. Since this pitch cue is smaller than that at touch down its visibility on out-the window displays should be verified.

21. A/C pitching during initiation of takeoff (especially B757).	Confirms compliance with Clearance to Takeoff.	This information is redundant with the indication of onset of takeoff roll (see above).	High resolution, bandwidth, low latency view of A/C starting takeoff roll is required for visual detection of pitching. Since this pitch cue is smaller than that at touch down, its visibility on out-the window displays should be verified.
22. Banked wing predicts turn faster than change in A/C position.	Confirms compliance with Clearance.	Aircraft symbol or data tag needs to indicate A/C pose.	High resolution, bandwidth, low latency view of A/C banking is required for visual detection of pose.
23. A/C initiating turn onto taxiway, especially cue from nose wheel angle.	Confirms clearance to turn onto taxiway, nose wheel angle predicts turn.	Down-link from A/C or other sensors would be needed to provide information with delays comparable to current view of the A/C. A visual indication on the landing A/C icon of nose wheel angle and A/C pose w/r to taxiway and runway could provide comparable information.	High resolution, bandwidth, low latency view of A/C taxiing is required for visual detection of pose and nose wheel position.
24. Timing of visible plume effects of thrust reversers and spoilers, Note: These cues are distinct from the visibility of the mechanical deployment of these devices.	Predicts landing deceleration, length of landing roll, taxiway to be used to exit runway and related to assigned gate.	Down-link from A/C or other sensors would be needed to provide information with delays comparable to current view of the A/C. A visual indication on the landing A/C icon of deployment of thrust reversers could provide comparable information.	High resolution, bandwidth, low latency view of A/C landing roll is required for visual detection of deployment of reversers and spoilers (see text).

Speed			
25. Visual deviation of glide path seen as relative motion against stationary reference. Relative motion of an A/C seen against stationary ground references, allowing its glide path to be more easily perceived.	Confirms correct approach/ departure paths.	Graphical display of flight path against a ground-referenced map could provide some comparable visual information but the 3-D element would require an AGL-based altitude data tag for the A/C icon.	High-resolution visual image required based on existing visual performance requirements for tower design.
26. Relative motion of visually overlapping targets. Relative motion of visually, partially overlapping objects that allows them to be perceptually separated (e.g. two aircraft along approximately the same line of sight). This cue is especially helpful at night when A/C are seen as light patterns.	Breaks visual clutter, aids perceptual separation of otherwise confusing objects.	Relative motion can also be displayed on a map but the sampling rate degrades and delays motion perception. De-clutter algorithms can be employed to remove clutter. The usual plan-view format minimizes clutter due to perspective compression seen from a tower.	High resolution, bandwidth, low latency view of visually overlapping A/C and background is required for visual judgment of relative motion. Current specifications for tower design provide adequate visual requirements for the perception of relative motion (see text).
27. Relative motion of A/C on crossing trajectories with respect to a fixed ground reference such as a lamp pole.	Confirms correct approach/ departure paths, allows estimation of safe passing through runway intersections such as those at SFO.	Stationary ground reference symbols should be introduced to map displays to make the relative motion of moving symbols easier to perceive.	High resolution, bandwidth, low latency view of visually overlapping A/C and reference objects is required for visual judgment of relative motion (see text).
28. A/C speed during taxi, "Taxing with authority."	Speed indicates level of pilot familiarity with airport and likelihood of clearance conformance, improves distribution of controller's attention, unusually slow speed indicates need for special attention.	Ground speed data tags should be associated with A/C symbols. If such data tags are not provided, the physical map size needs to be large enough that high and low speed taxiing can be distinguished by controllers.	High resolution, bandwidth, view of taxi area required for visual judgment of motion. The physical size of the display needs to be sufficient for discrimination of high and low visual rates of taxiing (see text).

Sound[6]			
29. Sound of takeoff power.	Confirms compliance with takeoff clearance.	Directional sound cues provided by 360° radially-mounted directional microphones should be provided within a remote tower.	Directional sound cues provided by radially-mounted directional microphones should be provided within a remote tower.
30. Sound of engine run-up.	Preparing for takeoff.	Directional sound cues provided by 360° radially-mounted directional microphones should be provided within a remote tower.	Directional sound cues provided by radially-mounted directional microphones should be provided within an remote tower.
31. Loud unexpected sound.	Attention directed to source; possible explosion, bomb, attack etc.; important adjunct to visual information.	Directional sound cues provided by 360° radially-mounted directional microphones should be provided within an remote tower.	Directional sound cues provided by radially-mounted directional microphones should be provided within a remote tower.
Additional Observation			
32. General surveillance.	Some airport towers are strategically placed so as to provide useful, excellent visual surveillance outside of the airport and relevant airspace.		The field of regard may be usefully made larger than that needed for A/C control for airports where general surveillance is needed (e.g. Boston, Logan).

[6] In discussions of visual features used to aid control, many controllers spontaneously mentioned the importance of sound cues, so we have included them in this table.

A better understanding of exactly how some of these cues can be used can come from examining them quantitatively. In the next section an example of such analysis is presented with respect to landing deceleration at SFO.

Deceleration during Landing at SFO

In order to analyze the deceleration of aircraft landing at SFO, digital video images were recorded of the initial braking after touch down. Recordings of a wide variety of landing aircraft were made to examine a wide range of decelerations. The 45 observed and reported aircraft included 747-400s, a variety of models of 767, 757, 737, A319, A320, CRJs, and small twin turboprops. The weather was clear with light winds from the west. The landing data from all the aircraft have been aggregated since there was no intention to make a more detailed analysis by type but rather to understand the range of visual rates and visual decelerations that would be visible from the airport tower.

The following analysis begins to determine the magnitude of this visually sensed deceleration and how it could be used by controllers. Through this process we identify one of the dynamic visual features used in traffic control from the airport tower: the change in speed evident during a single glance a controller might make towards a decelerating landing aircraft[7]. In thinking about what specific aspects of the visual stimulus to which the controllers might be attending, it is helpful to remember that perceptual discriminations of commonly experienced magnitudes of sensory quantities such as velocity are fairly well described by Weber's Law, which states that the just noticeable difference (JND) is a constant proportion of the quantity's magnitude. This so-called Weber fraction is roughly constant for a variety of psychophysical parameters but under the best conditions is ~6 % for changes in velocity viewed within a typical 0.5-second time period. For stimuli with random mixtures of spatial frequencies, i.e. mixtures of contours of different sizes, the JND grows to about 7.5%. Very significantly for the very slow visual velocities less than 1 degree/second such as those commonly seen from the control tower for landing and departing aircraft, the JND can climb up to ~10% (McKee, Silverman, & Nakayama, 1986).

It is therefore important to understand that controllers may not be directly sensing the visual velocities per se even though they may claim to do so. They may, in fact, develop alternative viewing strategies allowing them to translate speed into displacement during relatively fixed time intervals, thus making the detection of unusual rates of change easier. Additionally, alternative visual cues to quantities such as deceleration could be used. For example, aircraft pitch while moving along the ground could be equally well a clue to the onset or offset of braking.

It is not so much the visual aspect of the visual information that is important as it is the fact that the information revealed by vision is relevant, real, direct, unmediated, immediate, and continuous that makes it the best basis for the best possible anticipation of future action. This is why the visual input could be critical. Replacements for it need to capture the same predictive, informational features as suggested in Table 4.

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[7]During normal vision, people make from 3–5 fixations per second (Rayner & Castelhano, 2007). However, when studying some aspect of an ATC image, fixations duration can increase but rarely grow longer than approximately 1.3 s (e.g. Remington, Lee, Ravinder, Matessa, 2004). Consequently, a reasonable constraint for modeling the duration of a controller's glance would be to insure that they are 1.3 s or less.

In order to begin to analyze the visual features actually present in real landings in more detail, we have initially focused on the deceleration profile of aircraft landing on the 28 Left and 28 Right runways at SFO. Controllers report that they use their sense of degree and timing of this specific deceleration to anticipate which taxiway would be needed for the aircraft to exit the active runway. Their decision is time critical during heavy runway use since landing aircraft are staggered in pairs and interleaved with departures on crossing runways 1R/1L.

We made 15 frame/second video recordings at 1024 x 768 resolution of the braking phase of 45 aircraft landing on 28L and 28R and processed the recordings to measure changes in visual velocity. We used a custom MatLab© image processing technique that isolated the moving contours across a set of two frames and averaged them to localize the aircraft and provide their screen velocity in degrees per second. Using the viewing geometry described in Figure 12, we have recovered the aircraft braking profile and computed the changes in its visual velocity as viewed from the control tower by re-projecting the movement, as it would have been seen from the tower. Thirty of these velocity profiles (low pass filtered with a 1Hz cutoff) are shown in Figure 13.

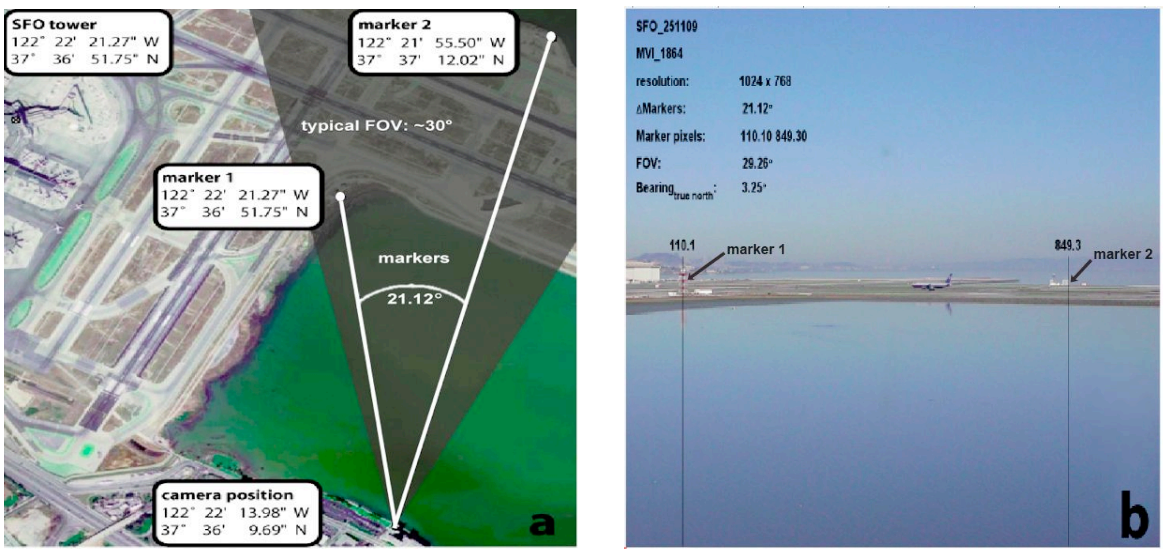

Figure 12. Camera parameters and view at SFO. Markers at known ground positions determined from Google™ Earth ground images were used in combination with the known geometry of the runway to convert line of sight angles to aircraft from the camera position into position along the runway and thereafter into line of sight angles from the airport tower and thereafter into visual velocities as seen by controllers.

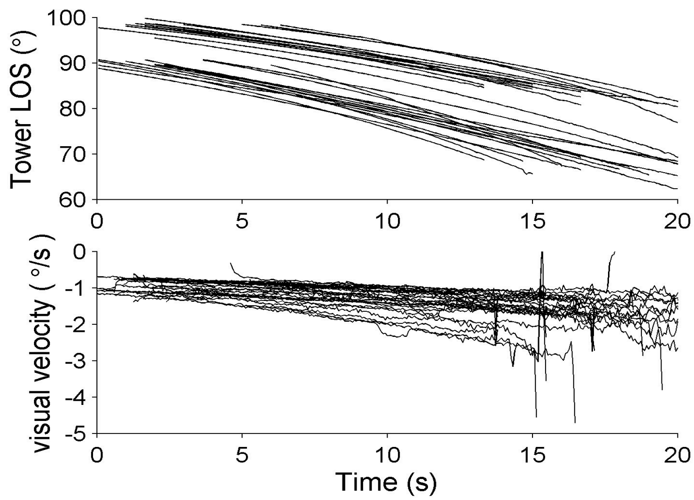

Figure 13. Line of sight for A/C at SFO.

Because of the noise present in our current recording technique, we were unable to obtain velocity and acceleration values with acceptable noise levels. We were, however, able to obtain a directly recorded braking deceleration profile[8] for another A319 aircraft landing on Runway 28L from the same company, comparably loaded and flying in the same wind and weather conditions as one of the aircraft we had recorded visually. Since we knew the touchdown points for these two A319 landings, we've combined the two trajectories to produce what we believe to be a fairly accurate landing profile as seen from the tower (Figure 14).

The deceleration profile in Figure 14 shows the aircraft approaching and passing the tower as it decelerates. In fact, during the approach the visual velocity actually increases during the deceleration because of the decreasing distance between the aircraft and the tower. It is clear from the deceleration profile that there are several phases of braking due to deployment of the thrust reversers, spoilers, and mechanical brakes and further data collection and processing needs to be done to more precisely identify these periods. However, the very smooth velocity plot in Figure 14 (third panel from top) already shows that the amounts of velocity change in the braking within any short time window 2 seconds or less are well less than the ~6% usual Weber fraction for a just noticeable difference of midrange psychophysical quantities such as perceived speed. This level is defined by convention to be that difference in a sensory quantity that can be detected correctly 75% of the time and is therefore not evidence of a very strong sensory stimulus[9]. This observation leads to some skepticism that the controllers are detecting velocity change per se because controllers would likely wish to be more certain regarding their judgments than 75% correct. Accordingly, they may have developed a strategy to detect speed change by some other means, perhaps by comparing displacement for approximately equal time periods. Such a timing strategy might be evident in eye tracking records of controllers judging aircraft deceleration. Of particular interest will be future

[8]The aircraft's deceleration was recorded just after touch-down using a arm rest stabilized iPhone in Airplane Mode running an application called Motion Data with sampling rates at 30 Hz.

analyses and experiments to determine how well the controller's sense of aircraft deceleration can be maintained with airport imagery spatially degraded by pixilation and sensor noise, and temporally degraded by low sampling rate. The sampling rate issue has been addressed by research currently being prepared for publication (Ellis, Fuerstenau, & Mittendorf, 2011).

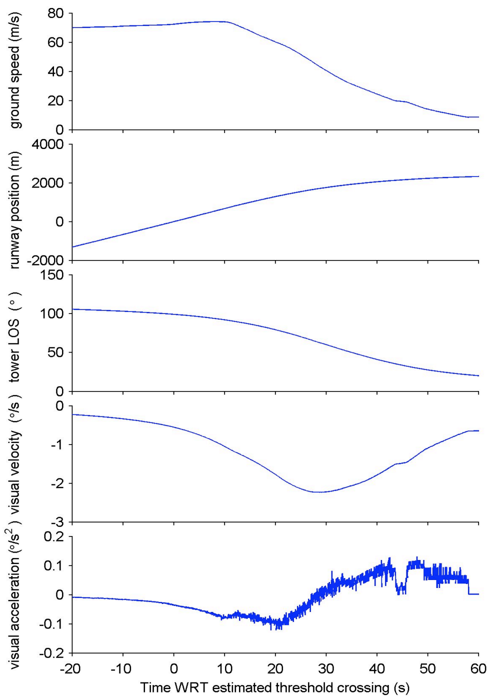

Figure 14. Line of sight changes.

Conclusions

1. Airport tower controllers use visual features observed during aircraft operations to provide information beyond simple detection, identification, and recognition of aircraft.

2. Twenty-eight useful visual features have been identified from discussions with 24 controllers and supervisors. Some involve the static pose of the aircraft of interest but many of the most useful involve aircraft motion, especially aircraft acceleration and deceleration.

3. The visual features provide predictive or lead information regarding future aircraft position, pilot intention, and pilot airport familiarity that enable controllers to appropriately distribute their attention during operations and to anticipate possible conflicts.

4. The very slow rates of visual motion in terms of subtended visual angle suggest that the change in velocity reported by controllers is not directly sensed but must be observed by learned viewing strategies developed from tower experience.

5. Directional aircraft sounds audible in the tower are also used to assist operations.

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Appendix: Structured Interview Form

The following outline was used to structure the interviews with tower managers, supervisors, and controllers in order to elicit the visual features they observe in the course of tower operations. This structure was primarily intended to spark a conversation about visual information used during operations during different kinds of aircraft flows. Discussions were generally held in rooms with a clear view of ongoing tower operations. The cues were generally collected with respect to the Ground Controller and the Local Controller positions.

Raw notes were taken during each individual discussion with the information transferred to notations made on airport and regional maps on which notes from multiple discussants were cumulated. The primary notes were then discarded to preserve controller anonymity.

The sequence of the outline was usually used, but discussions were not restricted to following it.

Discussion Topics/Activities for Structured Interviews

1. Airport immediate surroundings
   a. Draw approach and departure paths into and out of airport for different flows/time of day/weather conditions.
   b. Note points of initial and final useful visual contact: comment on with respect to lighting, specific visual conditions.
   c. Imagine A/C flowing past visual references along the approach paths, identify important behaviors, controller rules of thumb useful for conformance monitoring.
   d. What information and or procedures would be lost if out-the-window vision is lost?

2. Airport
   a. Draw approach and departure paths into and out of airport for different flows/time of day/weather conditions.
   b. Note points of initial and final useful visual contact: Comment on with respect to lighting, specific visual conditions and other useful visual reference points.
   c. Imagine A/C flowing past visual references along the approach paths, identify important behaviors, controller rules of thumb useful for conformance monitoring.
   d. What information and or procedures would be lost if out-the-window vision is lost?

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14. ABSTRACT
Visual motion and other visual cues are used by tower controllers to provide important support for their control tasks at and near airports. These cues are particularly important for anticipated separation. Some of them, which we call visual features, have been identified from structured interviews and discussions with 24 active air traffic controllers or supervisors. The visual information that these features provide has been analyzed with respect to possible ways it could be presented at a remote tower that does not allow a direct view of the airport. Two types of remote towers are possible. One could be based on a plan-view, map-like computer-generated display of the airport and its immediate surroundings. An alternative would present a composite perspective view of the airport and its surroundings, possibly provided by an array of radially mounted cameras positioned at the airport in lieu of a tower. An initial more detailed analyses of one of the specific landing cues identified by the controllers, landing deceleration, is provided as a basis for evaluating how controllers might detect and use it. Understanding other such cues will help identify the information that may be degraded or lost in a remote or virtual tower not located at the airport. Some initial suggestions how some of the lost visual information may be presented in displays are mentioned. Many of the cues considered involve visual motion, though some important static cues are also discussed.

15. SUBJECT TERMS
Visual cues; airport tower; operations

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