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# **An Investigation into Landing Approach Visual Illusions**

A thesis  
submitted in partial fulfillment  
of the requirements for the Degree  
of  
Master of Social Sciences in Psychology  
at the  
University of Waikato

by  
**Natalie Beth Reynolds**

**The University of Waikato**

**2007**

## **Abstract**

This experiment was designed to examine aspects of human visual perception during approaches to a runway. The runway width illusion has commonly been reported to contribute to the dangerous tendency of pilots to fly low approaches to runways that are wide and high approaches to runways that are narrow. Attempts to prevent the runway width illusion have not attempted to identify the ideal location for an indicator of altitude. Thus the present experiment examined the effect of varying runway width and manipulated scenes in order to determine whether the runway width illusion was present and where participants were focusing their attention in the scenes. Thirty-two non-pilot participants and 3 pilots took part in the experiment and viewed static and dynamic scenes of runways that were narrow (30.48m), medium (60.96m) or wide (91.44m) at one of three viewing heights low (30.48m), medium (45.72m) or high (60.96m). After viewing scenes, participants were required to estimate their altitude and aim-point. The results of this experiment revealed that participants were fairly inaccurate at estimating altitude and were inclined to overestimate aim-point, however the data also indicated that there was a robust runway width illusion that was present across static and dynamic trials and in both altitude and aim-point data. The standard marking on the runway in an attempt to prevent the runway width illusion was not effective at preventing incorrect altitude estimations but did assist participants to estimate aim-point. It was also found that the objects that participants' most commonly reported using to estimate altitude in the visual scene were located in the lower segment of the scenes.

## **Acknowledgements**

I would like to give my thanks and gratitude to the participants, both pilots and non-pilots, who participated in this experiment. These participants gave me their time and their patience and this research could not have been completed without them. I owe a huge thanks to my supervisors Dr. Samuel Charlton and Dr. John Perrone for their constant support, guidance and assistance throughout the thesis and even prior to its commencement. I thank you both for your encouragement, reassurances, advice, time and belief that the research project I proposed was possible. I would also like to thank Rob Bakker for his patience and for the hours he spent designing my runway images. Without Rob I would not have had the scenes with which to run my experimental trials. I was a recipient of the FASS Masters Thesis Award and I would also like to thank the Faculty for awarding this scholarship to me.

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## INTRODUCTION

Landing an aircraft is a visually demanding task, not to mention one of the most dangerous phases of flight. Fifty percent of aviation accidents occur during the approach and landing phase of flight and thus landing is the most dangerous phase of flight (Kraft, 1978). Not only do the accident statistics indicate that landing is the most dangerous phase of flight, a wide range of researchers have also noted that landing is the most hazardous phase of flight (Beall & Loomis, 1997; Benbassat & Abramson; 2002; Benbassat, Williams & Abramson, 2005; Bricton, Ciavarelli & Wulfeck, 1969; Reardon, 1988; Smiley, 1958; Warren; 1988). These researchers have either directly or indirectly conducted research into landing. For example Smiley's hypoglycaemia research amongst pilots focused on the landing phase of flight as this study examined the element of flight that had a high exposure to risk, and thus the landing phase of flight was chosen for study (Smiley, 1958). Bricton et al., in a more direct study of landing examined the landing of aircraft onto aircraft carriers. It was reported that as the dimensions of the runway, and elements of the visual scene changed, pilots perceived it was more difficult to successfully land the plane without incident (Bricton, Ciavarelli & Wulfeck, 1969). In addition, it has further been reported that pilots' loss of control on landing was the second main cause of air crashes (Li, Baker, Lamb, Grabowski & Rebok, 2002). As can be seen from this research into landing, the final approach and touchdown phase of flight is the most dangerous phase of flight with a high exposure to risk and potential for loss of control.

Despite the advances made in aircraft technology, it appears that perceptual illusions in the landing phase of flight still present a problem. It was reported in 2001 that 80% of all aviation crashes are attributed to pilot error, but not necessarily during landing (Li, Baker, Grabowski & Rebok, 2001). However, although modern day flight is deemed to be a lot safer than the earlier days of flight, this same crash statistic was also recorded in 1942 when there were far fewer planes in the sky and at airports (Li et al., 2001). The statistics indicate that landing aids have not reduced the high instance of pilot error as much as first believed. Researchers had believed that with the advent of landing

aids e.g. a VASI (Visual Approach Slope Indicator) system, that there should have been a decrease in the incidence of crashes during landing due to the additional instrument support. However even with the introduction of landing aids, the pilot error statistic has not decreased, thus, due to the high levels of pilot error with respect to landing accidents, it has been assumed by researchers that landing incidents are commonly caused by misperceptions in a pilots visual field during landing (Kim, 2000).

When examining the presence of visual illusions in the landing phase of flight, it is necessary to understand the sub-tasks during landing. The goal of landing an aircraft is naturally to have the plane land safely on the runway and in order to achieve this, pilots must accomplish several sub-tasks. Firstly, a pilot has to align the aircraft with the runway on which they intend to land and this can be done visually, with instruments or a combination of both (Beall & Loomis, 1997). Secondly, the speed and altitude of the aircraft must be reduced in order to enable a stable path of descent to the runway (Beall & Loomis, 1997). In the final phase in landing, a pilot must complete the descent with a landing flare to bring the aircraft down safely on the runway (Beall & Loomis, 1997). A landing flare is the "transition from a controlled descent to actual contact with the landing surface and is also known as the flareout, roundout, or leveloff" (Benbassat & Abramson, 2002, p137). The landing flare is important for smooth and safe landings as the descent rate at touchdown is reduced which aids the steady and even descent of the aircraft (Benbassat, Williams & Abramson, 2005). Figure 1 provides a pictorial view of the various sub-tasks in the landing process. With regards to the approach angle, it should be noted that the approach angle is the angle between two lines: (A) A line that could be drawn from the plane's current position to the intended touchdown point, and (B) the line corresponding to the horizontal ground plane.

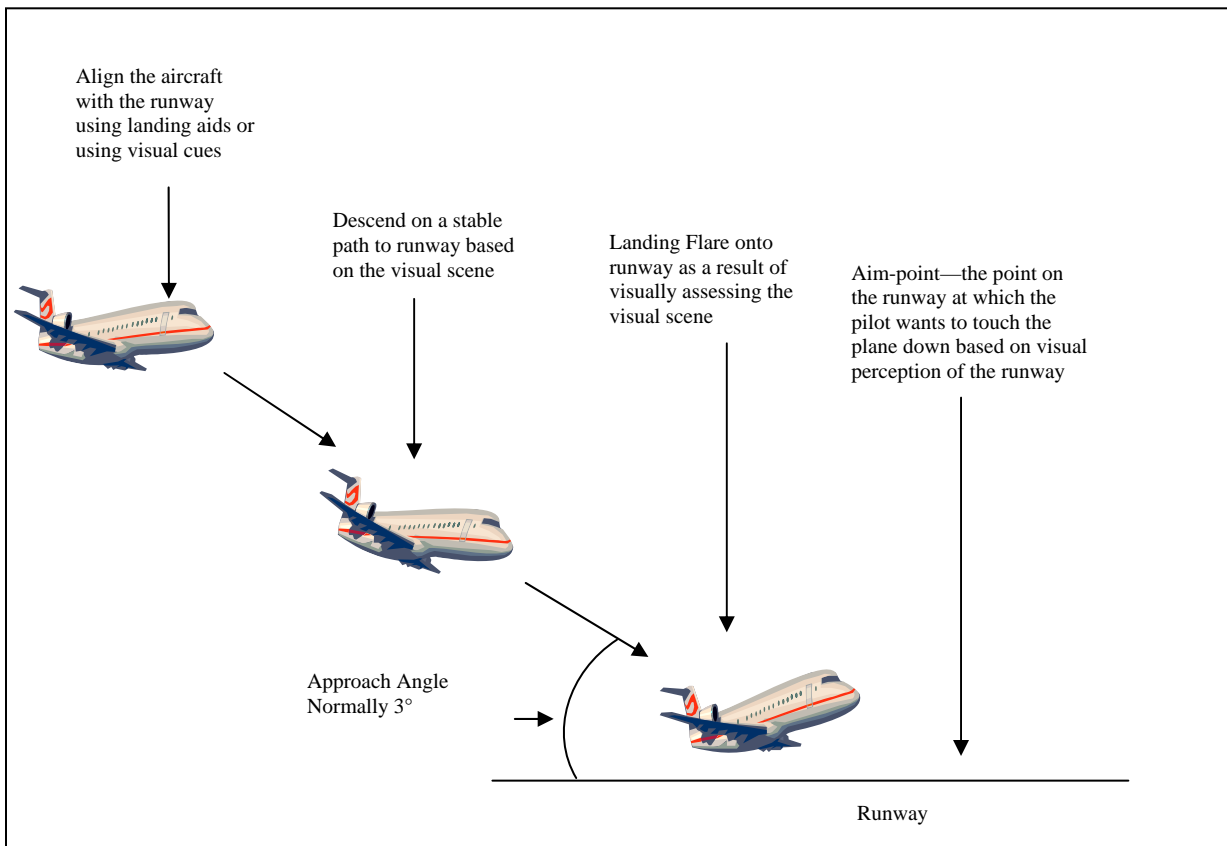


Figure 1: The four basic sub-tasks involved in the final approach and landing of an aircraft

The attempts made in the past to remedy pilot misperceptions of the runway, e.g. VASI systems, did not decrease the number of accidents as a result of runway and visual scene misperceptions during the landing phase of flight. Mertens and Lewis reported that “even with these Visual Approach Slope Indicators (VASI) systems in use, too many accidents continue to occur” (Mertens & Lewis, 1979, p991). As a result, it was concluded that misperceptions of the runway scene are responsible for a large number of accidents while landing, thus, with the focus on the various misperceptions in the visual scene, much research has tended to focus on visual cues that pilots use in the landing phase of flight. However, with new landing aids and systems, it is possible that this old argument is no longer valid since previous research findings were based on older navigation equipment rather than the new landing systems. In aviation landing vision research, the cues used in visual tasks have been divided into static and dynamic cues, and therefore two methodologies that focus on either static or dynamic cues. Static cues are aspects of the visual scene that relate to size and objects relative to each other in the

visual scene. In contrast, dynamic cues are based on the locomotion or movement of the objects relative to each other and the movement of the observer. The movement of the observer results in the retinal image motion that provides dynamic cues e.g. heading and depth perception. Representation of the static environment has received little methodological attention; however studies have shown that static information is as equally relevant to study as dynamic information in determining motion and heading (Hahn, Andersen & Saidpour, 2003). It has been established in the research literature that both static and dynamic scenes contain important cues for landing an aircraft and therefore both are worthy of research.

### **Static Cues**

If a snapshot of the runway image was taken at a given time in final approach, this would be a view of a static image (Edwards & Harris, 1974). The 2-dimensional static information on the pilot's retina is what pilots need to infer aspects of the 3-dimensional environment e.g. their distance from the runway, angle of their line of sight relative to the ground plane. Many of the early investigations into pilot misperceptions used a static view methodology which focused on the non-moving aspects of a visual scene. It is believed that in a static scene, visual cues such as the runway size, shape and angle of descent are available for pilots to determine altitude. Static views have also proven to be useful in judging depth, distance and approach angle. It should be recognised that static indicators of depth contain a different set of indicatory cues than dynamic cues, and that there are various static cues that are available for the detection of altitude and judgment of approach angle which can be analysed separately from dynamic cues (Best, Crassini & Day, 2002).

### **Horizon-Angle**

It is believed by many researchers that the horizon provides a very useful cue for judgments of altitude in a static scene. There are various theories about how pilots use the horizon to estimate altitude and the H-angle (horizon-angle) hypothesis is the most researched. Kraft believed that the angle between the horizon and the end of the runway had a significant effect on pilot's approach path and altitude (Kraft, 1978). In order to

reach this conclusion, Kraft examined 234 jet accidents and found that 82 of these accidents had occurred while pilots were on an approach path to land (Kraft, 1978). To further validate the findings from the crash reports, Kraft tested pilot's performance in a simulator with a night landing visual scene and had the pilot's altitude recorded at eight different intervals along the approach path (Kraft, 1978). During Kraft's examination of one particular landing crash, it was noted that pilots made reference to lights of a city underneath them, but also kept in view the lights of a city on the horizon ahead. The angle that is so often referred to as H-angle is the angle between an object ahead of the plane on the ground, and the horizon (Galanis, Jennings & Beckett, 1998; Lintern & Liu, 1991). Figure 2 presents a diagrammatic view of the H-angle and how the H-angle itself is actually the angle derived from the horizon, the distance to the runway and the aim-point on the runway.

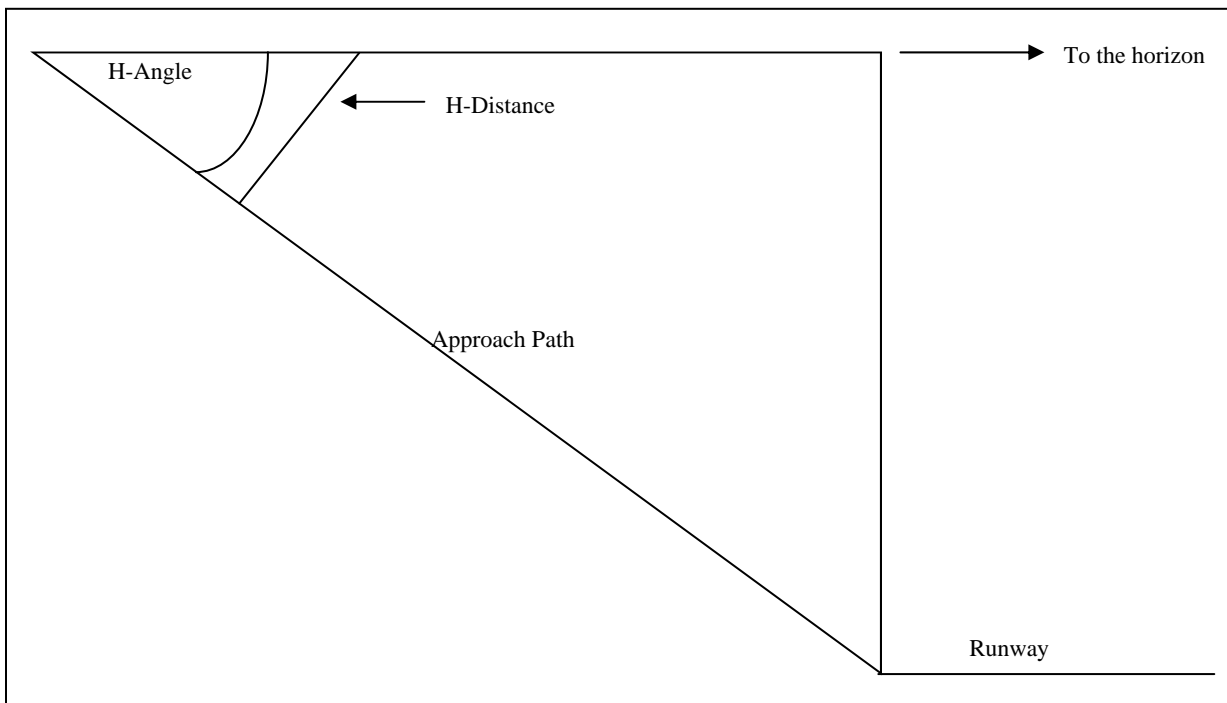


Figure 2: A diagram of the H-angle that depicts the angle between the horizon and the runway that pilots often use to judge their altitude. Without an estimate of the distance from the runway, a pilot cannot estimate their altitude from just the H-angle.

In a static image, it has been theorised that pilots are able to estimate altitude and approach angle based on the H-angle that emerges from the distance to the runway and the approach path. Thus pilots view the static angle between the horizontal plane of the scene and a distance to a point on the runway. However, despite the research support for pilots use of the H-angle, Riordan reported different results from Kraft when Riordan surveyed pilots and asked what information they used during a visual landing approach without a VASI (Kraft, 1978, Riordan, 1974). Riordan issued a questionnaire to 360 captains and first officers and asked each pilot to identify the visual cues or aspects of the visual scene that they used during approach to landing (Riordan, 1974). The survey included ranked choices of first, second and third for day and night landing approaches (Riordan, 1974). Questionnaire results indicated that few pilots mentioned the runway location relative to the horizon as a cue (Riordan, 1974).

Lintern and Liu, who conducted another study questioning the importance of the H-angle reported similar findings to Riordan (Lintern & Liu, 1991; Riordan, 1974). Lintern and Liu conducted research into the role of the horizon as a static cue and examined the implications of both implicit and explicit horizons (Lintern & Liu, 1991). Lintern and Liu believed that there was reason to question the H-angle hypothesis as pilots can often land with a limited visual scene and only a runway outline present with no other visual cues (Lintern & Liu, 1991). In their methodology, 8 male pilots aged 18 to 30 years with at least 100 hours flying experience took part in the experiment. In one trial run, Lintern and Liu presented four displays to participant pilots; a normal runway display, an augmented runway display, a display that depicted only aim-point and a fourth display with no glide-slope information (Lintern & Liu, 1991). Pilots were to make simulated approaches on a 4 degree glide-slope from a distance of 3078m from the runway threshold and line up with the runway to begin their descent. Other variables in this study included headwinds of 0, 5, 10 or 15 knots and the presence of an explicit or implicit horizon. At times, features of the natural environment e.g. perspective and compression gradients can form a functional specification of the horizon location; this is referred to as an implicit horizon. An explicit horizon, in contrast, is formed by the natural environment and is the formation of a 'true horizon'. From the results of this

study, Lintern and Liu reported that pilots were able to land without an explicit horizon, but the presence of an implicit horizon could influence the pilot's glide-slope (Lintern & Liu, 1991). Therefore, according to these research findings, pilots were able to monitor their glide-slope with the presence of the H-angle, involving an implicit or explicit horizon. Thus pilots would theoretically be able to monitor their glide-slope as a function of the H-angle (Galanis, Jennings & Beckett, 1998; Hasbrook, 1975). It should be noted that without an estimate of the distance from the runway, a pilot cannot estimate their altitude from just the H-angle. However, as can be seen from the research into the H-angle hypothesis, it is possible for pilots to identify an implicit horizon e.g. from cloud formation and distance to the runway, and use this to judge the H-angle. However, due to Riordan's results from the questionnaire, it is possible that pilots do not use the H-angle as much as commonly thought. It is also possible that pilots do make H-angle judgements in order to determine their altitude, but that this is an unconscious cognitive process that pilots do not realise they are performing.

### **Linear Perspective**

Another static cue that has been investigated is that of linear perspective. Linear perspective is a term that refers to the perception of depth as a result of line convergence on the pilots' 2-D retina. While linear perspective is the term commonly used for this phenomenon, the terms geometrical perspective and runway perspective are also used. Linear perspective is defined as "the apparent tapering in the direction away from the observer due to the apparent convergence of all sets of parallel lines which proceed towards a vanishing point on the horizon" (Riordan, 1974, p766). It should be noted that these angles that are perceived by the observer are the angles on the pilot's 2-D retina and not in the world. In the case of landing an aircraft, the linear perspective would relate to the convergence of the runway edges to a point on the horizon as a cue to indicate altitude. Another example of linear perspective in a different field from aviation is the convergence of railroad tracks that appear to converge into the distance. In the world, the railway lines appear parallel; however the image that appears on the retina makes the image appear as though the lines are converging. It is probable that pilots become

familiar with the view of the converging runway edges and use this as a cue to judge altitude.

Riordan's (1974) questionnaire to pilots regarding the visual cues they used in the absence of a VASI indicated that the majority of pilots in the study identified the subtended visual angle (a form of linear perspective) as the most important cue they used in landing. Measuring the subtended visual angle is a common method to examine visual acuity with respect to the angle that an object casts on the retina (Riordan, 1974).

Riordan suggested that there were three variables associated with runway perspective/linear perspective and these were: a) the size of the runway on the retina, b) the shape of the runway that the pilot perceives as a function of their altitude, c) the slant of the runway which is in direct reference to the size and shape of the runway (Riordan, 1974). Thus, pilots who focus on the shape, size and the location of the runway should be able to accurately estimate altitude and approach angle from a static image (Kim, 2000). It is proven to be mathematically possible to derive the angle of approach from linear perspective information. Perrone mathematically proved that it was possible to derive the approach angle from the convergence of the runway sides along with the estimated height of the runway (Perrone, 1980). Perrone's model of slant estimation was based on motionless test surfaces and therefore based on static estimations of slant from linear perspective. The method that Perrone used to derive a model of slant estimation was similar to the method used by Flock who proposed that it was possible to relate perspective cues e.g linear perspective, motion parallax and size perspectives (Flock, 1965).

### **Relative size of objects in the visual scene**

Pilots use of and familiarity with objects in the visual scene have been noted by various researchers (Gogel & Mertens; 1966; Mertens, 1981; Mertens & Lewis, 1983). Riordan reported that the apparent size of familiar objects along the approach path to landing was the second most important cue that pilots use to judge their altitude (Riordan, 1974). Research has tended to focus on familiarity with a scene, but the presence of specific reference points in a given scene has also been studied (Li, 2006). The

familiarity of a scene refers to the notion that pilots may become accustomed to the size of various objects in their environment and this allows pilots to judge their altitude as a result of their knowledge about certain objects in the environment. In Riordan's questionnaire to pilots, it was apparent that many pilots ranked the size of familiar objects in the terrain as an important cue they used to make a visual landing. For example, when pilots land on runways where the trees and objects in the environment are a different size to those that a pilot is accustomed to looking at, the pilot will often misjudge their altitude as a result of the difference in tree height.

Gogel reported that the intention of the observer, in this case the pilot, can modify the perceived depth between objects in a scene, and theorised that task-set could modify a pilot's perception of distance (Gogel, 1967). Task-set refers to the intention of the observer about what they perceive they are going to see in a scene e.g. if a person is set to perceive a person hiding in a photograph, the chances of a hidden figure being noticed is increased. In Gogel's experiment, participants were presented with a familiar object (a playing card) which appeared at different depths depending on the dominance of other non-familiar objects (a large grey square and a double-sized playing card) (Gogel, 1967). Gogel reported that under certain conditions, the participants' task-set or intention to identify the correct depth of the normal sized playing card modified the depth perceived between other objects in the scene i.e the grey square and the double-sized playing card (Gogel, 1967). Thus, when applying these experimental findings to flight, it appears that task-set or the way that a pilot wants to analyse a flight scene can have an effect on their perception of distance and height. Therefore, the presence or absence of various cues in a static scene that pilots are familiar with should have an effect on their ability to judge altitude correctly.

### **Variations in runway width**

The importance of runway width is apparent from the early slant perception literature (Braunstein & Payne, 1969; Freeman, 1966; Perrone, 1980, 1982, 1984). The approach angle is a function of the width of the runway and the wider the runway the greater the convergence angle is for different slant angles. Any system that uses the

convergence angle of the runway sides without taking into account the length of the runway is susceptible to the runway width illusion. Due to the variance in the width of runways at different airports, pilots are required to adapt to differently sized runways. This is because pilots do not always fly to the same airport and depending on their flight plan they may have to land at a myriad number of different airports in the duration of one flight. As a result, pilots have to learn to adapt to the different visual scenes that are present when the objects in the visual field change. Errors associated with runway width differences can result in errors in altitude estimation and misjudgement of the distance from the plane to the landing threshold (Hasbrook, 1975). Put simply, when the runway is wide, this produces the illusion that the pilots are at a lower altitude, in addition to this, similar findings have been reported with regards to runway length variation (Ewing, 2001; Hasbrook, 1975; Mertens & Lewis, 1982, 1983). For example, when the runway is wide, pilots perceive that they are at a much lower altitude because the runway appears nearer to them and therefore they increase their altitude in order to land on the ideal aim-point on the runway. Because the pilot is on the correct approach path, and they increase their altitude with a wide runway, it greatly increases the chances of overshooting the runway. When a runway is narrow, pilots perceive that they are at an altitude that is too high, when they are on the correct approach path and therefore they lower their approach. Because the pilots' were on the correct approach path and they lower their altitude, this increases the chances of pilots undershooting the runway.

Mertens and Lewis conducted an influential study on the runway width illusion with 40 male pilots as participants. In their experiment, Mertens and Lewis had pilots do practice approaches on runways with widths of 100, 150, 200 and 300 feet, and in addition to this, runways were shown to pilots that were 3,000 to 9,000 feet long (Mertens & Lewis, 1982). Each flight completed by participants consisted of a takeoff and climb to a designated altitude, when the participants reached the required height, the simulator descended to an altitude between 1,100 ft and 2,700 ft and pilots were required to make a 'normal' landing. The component in this study that could be considered static was the participant's adjustment of a model to indicate their estimate of altitude (Mertens & Lewis, 1982). Thus in a moving image, Mertens and Lewis also used a static

component in order to complete their analysis of pilot perceptions of approach angle and altitude estimation thus demonstrating the relevance of the static methodology as a way to analyse flight data.

The illusion produced by variation in runway width has been the focus of various research papers. The runway width illusion is dangerous because the effects of the illusion can be experienced in both daylight and in the darkness of night. For example in the situation of a night-landing approach, Mertens and Lewis had pilots complete landings in a simulator and recorded their altitude between 1100ft and 2700ft (Mertens & Lewis, 1982). As a result of this experiment, Mertens and Lewis reported that on a wider runway, approaches were lowered, and on a narrow runway, approaches were higher (Mertens & Lewis, 1982). In addition to the research findings of Mertens and Lewis, Lintern and Walker also reported that manipulations to runway breadth had a significant effect on experienced pilots (Lintern & Walker, 1991). Lintern and Walker conducted a study into the effects of varying runway breadth with 8 pilots aged 18 – 30 years to participate in their experiment. Pilots were to make simulated approaches starting at 10,000ft from the runway threshold at a glide-slope that was  $0.5^{\circ}$  below the ideal glide-slope (Lintern & Walker, 1991). Pilots were instructed to fly until they achieved a  $4^{\circ}$  glide-slope and then begin their descent. Static angles to aim-point were recorded at various distances along the flight path as a way to analyse the path flown by pilots. Like Mertens and Lewis, Lintern and Walker also reported a significant effect of runway width and that lower approaches were being flown to the narrow runways (Lintern & Walker, 1991; Mertens & Lewis, 1982). Further research into the viability of the theory proposed by Mertens and Lewis and Lintern and Walker has demonstrated that pilots do respond to the various deviations that may occur in the glide-slope, however they may take some time to make a correction for the deviation (Galanis, Jennings & Beckett, 2001). These studies demonstrate that variations in runway width can cause pilots to alter their flight path and therefore fly dangerously low or high depending on the width of the runway. The runway width illusion is an important concept to consider when 50% of all aviation accidents occur during the approach and landing phase of flight (Kraft, 1978).

### **Pilot familiarity with runway appearance**

An important research finding in relation to varying runway width is that pilot familiarity with a certain runway shape can heighten the runway width illusion (Mertens, 1981, Mertens & Lewis, 1983). Mizumoto, Fujiwara and Utsugi conducted research into glide-paths of the visual approaches made by pilots using visual flight rules (Mizumoto, Fujiwara & Utsuki, 1977). From this study, it was reported that the perspective of the runway was important for pilots' estimation of altitude and glide-path (Mizumoto, Fujiwara & Utsuki, 1977). The evidence for pilot familiarity can be found in a study by Mertens & Lewis who reported that there was a general tendency to overestimate altitude when pilots landed on unfamiliar runways (Mertens & Lewis, 1983). To demonstrate the principle of familiarity, an experiment by Mertens and Lewis is important to examine, in a 1982 study, Mertens and Lewis established familiarity with runway width by having pilots fly 20 visual approaches and landings to a runway that was either 75ft, 150ft or 300ft wide (Mertens & Lewis, 1982). The effects of practice were then measured on five test runway widths of 75ft, 100ft, 150ft, 200ft and 300ft. Mertens and Lewis reported a significant main effect of practice runway width, however it should also be noted that the main problem associated with familiarisation with certain sized runway is that pilots become accustomed into acceptance of low altitudes if they are familiarised with a runway that is wide (Mertens, 1981, Mertens & Lewis, 1982). As a result, pilots accept these low altitudes as being acceptable and continue to make low approaches on wide runways thus increasing the chance of incidence.

Like runway size, pilots can also become familiar with terrain in their visual scene. Haber (1987) discussed the familiarity of the terrain surrounding an airport. Haber theorized that familiarity with terrain was derived from either direct experience flying over the terrain or from indirect experience e.g. being told that all fences in the vicinity are 2m in height (Haber, 1987). Therefore, pilots make decisions about the terrain based on their assumptions about the height of objects. Sanocki theorised that previous experience with a scene could develop into a representation of layout (Sanocki, 2003). As such, Sanocki developed a theoretical framework that was focused on the familiarity with spatial relations in a scene (Sanocki, 2003). Sixteen students took part in

the experiment and were required to observe photos that varied in layout and lighting (Sanocki, 2003). Sanocki's stimuli had a constant camera position and photo layouts that varied in orientation and arrangement (Sanocki, 2003). It was reported that prior experience with a scene can facilitate spatial relations and scene representation and subsequent processing of scenes will be affected. Sanocki's theory was confirmed by the fact that pictures of scenes facilitated the later processing of other similar scenes (Sanocki, 2003). Thus, knowledge or experience with a scene can affect the later interactions with a similar scene. Pilots have a lot of experience with the visual scene of the runway as their training involves hundreds of flight hours and therefore hundreds of landings. Sanocki's findings are consistent with Haber's claim that knowledge of the height of trees or buildings in a visual scene can influence pilots' landings at other airports (Haber, 1987, Sanocki, 2003).

While a visual scene can be viewed in many ways, there are two different types of representations that are used to describe how people conceptualise a scene. Egocentric representation is related to the observers' viewpoint and the absolute distance and location of objects relative to the observer (Andersen & Enriquez, 2006). Allocentric representation, in contrast, is based on landmarks and their positioning independent of the observer (Andersen & Enriquez, 2006). Andersen and Enriquez assessed the use of landmarks and scene layout and recruited 8 students who were naïve to the purposes of the experiment and completed a driving task with a stimulus display of a 200 dot pattern and 12 landmarks that were randomly located on the ground. Landmarks were projected outside the field of view and were static with no motion. Participants were told to maintain a fixed path of motion through the dots and were not informed about the landmarks. Andersen and Enriquez reported that layout of a scene was significant and an important finding of this study was that participants had greater sensitivity and accuracy when the landmarks were repeated and thus identical compared to when the landmarks were randomised. In addition to this, Andersen and Enriquez also reported that their subjects appeared to report an allocentric perspective of the visual scene (Andersen & Enriquez, 2006). This research shows that people do become accustomed to landmarks or certain objects in their visual field and do use them as 'anchor' or reference points in a

visual task in subsequent scenes, also people view landmarks as separate from their own position in a visual scene.

The testing of various shapes on the runway to guide final approach has been the subject of ongoing research. By having certain shapes on the runway, it is believed that these shapes could serve as a reference point for pilots (Kelly & Bliss, 1971). The principle behind various shapes on the runway was that even though the shape of the runway would change, the shape would stay constant and thus aid the pilots to stay on the correct flight path. Moert, Estes, Andrews and Olmos conducted a study into the effect of airport markings in enhancing pilot awareness about runway location (Moert, Estes, Andrew & Olmos, 2005). In a simulation study, twenty four general aviation pilots performed taxi operations using the simulator, the airport surface in these simulations were; changes to runway holding position markings on the taxiways, surface painted holding position signs, modified taxi centrelines and runway ahead labels (Moert et al., 2005). It was found in the simulator experiment that for transport pilots, who had more hours than other pilots in the research, the simple taxiway intersections with enhanced markings were detected earlier than those that did not have enhancements (Moert et al., 2005). Thus, in this experiment it appeared that there was a perceptual advantage for more experienced pilots. In addition to the twenty four pilots viewing taxiway enhancements, one hundred and twenty eight pilots completed feedback surveys about the enhanced markings they were presented with. The results showed that a majority of pilots preferred the enhanced markings more than the current markings and it was concluded that the enhanced runway markings would be useful for pilots who were unfamiliar with an airport, but aware of the new markings on the tarmac (Moert, et al., 2005). Moert et al. study indicates that there needed to be more research into runway markings and possible markings to enhance pilot perceptions during landing.

### **Effects of Texture**

It has been reported by various researchers that terrain and features in the surrounding environment can influence pilots decisions while landing aircraft. Haber reported five characteristics of terrain that affected pilots judgments of ground clearance

and these were; the degree that terrain is highly textured, ground elevations, visible detail on the ground surface and the presence of known size references on the ground e.g cars (Haber, 1987). However while some researchers conclude that detailed texture on the ground can influence pilots' decisions while landing, there are some researchers who do not view texture as being important in the simulation environment. Roessingh conducted research into the implications of low-fidelity experiences in flight training and in particular investigated the aerobic curves of trainee pilots who were practicing aerobic moves in a real aircraft. Trainees were assigned to one of three groups; no ground training, ground training with a standard PC-based simulator and ground training with a more advanced PC-based simulator (Roessingh, 2005). Roessingh hypothesised that aerobic skills that were learned in a low-fidelity simulator could have a positive transfer to the aircraft and stated that while performing aerobic moves such as the loop, only the line of the horizon on the ground was required, and thus only a low level of detail was required. After training some trainees in a high-fidelity aircraft and having other trainees receive preliminary training on a PC based simulator with low-fidelity it was concluded that there were no highly significant effects of simulator training and neither positive or negative transfer of flying skills to the aircraft (Roessingh, 2005). Thus it poses the question of whether a high-fidelity simulator would result in positive transfer or whether lower fidelity simulators are adequate for training.

It is interesting to note that in the research literature, there is very little research into the location that pilots fixate on during landing. The most obvious way of assessing pilots' eye movements during final approach is to use an eye-tracker. An eye tracker was used in a study by Fitts, Jones and Milton to determine which instruments pilots were most often using in the cockpit during an instrument landing approach (Fitts, Jones & Milton, 1950). However, this is quite an intrusive measure as the pilot has to wear the tracker while they are trying to fly, or while they are watching a visual scene. Therefore, an alternative method of analysis needs to be sought and one possible way to achieve this could be to change aspects of the environment and ask pilots whether they notice any changes in the environment while landing. The rationale behind this practice is that if a

person does not notice an object missing, they must not have been focusing their attention on it.

A number of studies have been conducted into the implications of texture changes in a visual scene. There have been studies into the effects of nested texture (texture that emerges as a function of altitude as opposed to constant texture), (Reardon, 1988); the role of ground texture in spatial judgment, (Flach, Hagen & Larish, 1992); the scene content, (Pausch & Crea, 1992); the properties of the visual scene that are relevant for low-altitude flight (Kleiss, 1995); global optical flow rate opposed to optical edge rate, (Larish & Flach, 1990); magnification of the runway scene (Lintern & Koonce, 1991); the different visual factors that influence low-altitude flight in different aircraft (Kleiss, 1996); the effect of scene content on landing (Lintern & Walker, 1991); the effects of varying scene detail on the transfer of skills from a simulator to real flight (Lintern, Taylor, Koonce, Kaiser & Morrison, 1997); the location of objects in the environment from an allocentric viewpoint (Sohn & Carlson, 2003); the effect of texture on slant estimation (Rosas, Wichmann & Wagemans, 2004). Lintern reported that texture gradients alone were not useful for judging an aircraft's descent (Lintern, 2000); Lintern and Koonce reported that high scene detail was associated with high approaches and low scene detail was associated with low approaches (Lintern & Koonce, 1991). As has been illustrated with the papers mentioned, research into the effects of texture is still a popular topic in the research literature.

### **Slant Estimation**

The detection of slant is highly important in the task of landing an aircraft. This is because pilots have to accurately perceive slant in order to descend and land on the runway. The detection of slant is done in the last few minutes of the flight and therefore can be considered a static cue. It has been reported that pilots check their glide-slope, a form of slant on average every 2 seconds (Milton, 1952). In the research literature, there are two types of slant that are referred to, the first is termed optical slant which is the observer's line of sight relative to the observation point (Kinsella-Shaw, Shaw & Turvey, 1992). The second type of slant is geographical slant which refers to the surface

inclination relative to the horizontal plane or other reference points (Gibson, 1950a). Both geographical and optical slant are important in the context of an aircraft landing, however many researchers often do not differentiate between the two. Gibson conducted a study into the perception of visual surfaces and tested the hypothesis that there would be no impression of slant when a textured image had the same density at all points (Gibson, 1950b). The hypothesis further predicted that an increase in texture density upwards in the visual field would result in a backwards slant and an increase in texture density downwards would result in a forward slant (Gibson, 1950b). Gibson tested this hypothesis by having observers sit and look through two screens (through eye holes) with one eye which was designed to simulate an observer looking through a camera. The observer viewed two different kinds of texture with the first texture consisting of an image with regular rectangular elements, while the other had an irregular pattern (Gibson, 1950b). Ten observers were paid to do the experiment and report on the apparent slant of the surface and it was confirmed that when slant does physically occur with the stimulus, the observers increased their judged slant. It was also found that regular structure to the texture provided a clearer impression of slant than a less regular structure (Gibson, 1950b). This research has implications for aviation landing surfaces as slant was best recognised when the surface that Gibson presented had structure and form (Gibson, 1950b) and thus this research proves that standardisation of a viewed surface contributes to correct estimation of slant and thus standard runway surfaces could aid in pilots estimating their slant more accurately.

### **Experimental findings on slant perception**

There has been varied research into the area of slant perception and while not all of this research has been specific to the field of aviation, various findings do posit implications for the field. With regards to slant, it appears that optical slant (observers line of sight relative to the observation point) is the most commonly referred type of slant. Research results tend to indicate that perspective is of more use to pilots' estimation of slant than the form ratio of vertical distance between features in the environment (Braunstein & Payne, 1969). This has implications for pilots landing aircraft when the runway is long or there is poor weather as they may not be able to see

the end of it. Because perspective is more useful than the Form Ratio, pilots will be relying more on the shape of the runway to guide them into land.

Perrone has produced various perceptual models to explain how pilots estimate slant (Perrone, 1980, 1982, 1984, 1992). Many of these models have been proposed with respect to the black-hole landing task, where pilots land with very limited visual cues at night. Perrone devised an algorithm for slant perspective that involved linear perspective whereas other models proposed include a model that separated optical slant from geographical slant and the perception of slant relative to distance from the observer (Perrone, 1980, 1982, 1984). There has also been research into texture gradients (Flock, 1964; Freeman, 1965); the size and spacing of texture elements in the visual field (Flock, 1964, 1965; Freeman, 1966); perceived slant for horizontal lines of varying length disparity (Gillam & Grove, 2004); the temporal aspects of slant that can be evoked from scale, shear, rotation or divergence (Van Ee & Erkelens, 1998); the effect of slant or occlusion in horizontal lines (Gillam & Grove, 2004). These research projects have been aimed at understanding slant perception rather than having a focus on aviation related topics. However, the research that has been conducted has contributed to the body of literature that grows annually on perception of slant. Slowly, as researchers understand more about slant perception in general, the findings can extend to the field of aviation to fill the void that exists regarding pilot perception of slant.

### **Summary**

In summary, there are various static cues that contribute to a pilot's ability to estimate altitude. The H-angle is the angle between the end of the horizon and a point on the ground (Kraft, 1978). With regards to the role that the horizon plays in landing, there have been varied findings in the research literature about the role of the horizon and while some researchers have reported that pilots make use of the horizon, other researchers have reported that the presence, or absence of the horizon does not have a significant impact on landings. Linear perspective is the perception of depth as a result of line convergence and this has been theorised by many researchers to have an effect on

landings. However, like the possible role that the horizon is said to have in landing, there have been varied research findings as to the role of linear perspective in landing.

The familiarity of various objects in the visual scene have been reported by pilots and researchers as being related to pilot errors during landing. Objects in the visual scene such as cars, trees and buildings have been reported as being used in a pilot's judgment of height. Texture in the visual scene is also thought to contribute to the judgment of altitude on landing. Furthermore, research into the runway width illusion has shown that varying runway widths can have an effect on the approach angles chosen by pilots. In addition to the possible variation in runway widths, it has also been reported that runway length can have an effect on approach angles chosen by pilots. Therefore, variation in runway widths can create the illusion of a high or low approach and as such pilots underestimate/overestimate their location with reference to the runway.

### **Dynamic Cues**

Dynamic cues are indicators that are related to the movement of the observer and objects in their visual field. In the field of aviation, this visual information serves to provide cues regarding the orientation of the observer relative to the runway. While static cues provide one set of cues for pilots to use during final approach, dynamic cues are only present in a moving scene. While static cues are important to examine in visual tasks, it is equally important to assess separately which dynamic cues are relevant to the landing phase of flight.

### **Optic Flow**

In landing an aircraft, one of the critical decisions that a pilot has to make is where to have the plane touchdown on the runway. The point on the runway at which a pilot wishes to land is called the aim-point and in order to aim and land correctly, the pilot needs to be approaching the runway at the correct angle and altitude. One method that Gibson used to assess the way a pilot chooses a point on the ground is with optic flow (Gibson, 1950a). The horizon is the point that Gibson termed the 'focus of expansion' and this is the point with no motion and from which all other optic flows on

the ground expand outwards (Gibson, 1950a). The focus of expansion in aviation is always in the direction that the pilot is heading therefore when a pilot is moving parallel to the ground and looking towards the horizon, the focus of expansion is the horizon. The aim-point, according to Gibson, is the point with no motion and from which all other optic flows on the ground expand outwards and the aim-point on the runway that a pilot aims for is called the 'focus of expansion' (Gibson, 1950a, 1950b, 1966, 1979). Choosing a safe aim-point is vital as any change in the intended touchdown point on the runway could result in the pilot overshooting or undershooting the runway (Hasbrook, 1975). Aside from Gibson and his abundance of research into optical flow, various other researchers have investigated the field of optical flow in aviation; Flach, Hagen and Larish, Flock (Flach, Hagen & Larish, 1992; Flock, 1964, 1965a).

Riordan has cast doubt on how much contribution the focus of expansion has on a pilot's ability to land (Riordan, 1974). Pilots are not consciously aware of optical flow as being part of their perception as they would not perceive what is occurring in the retina. People do not perceive radiating patterns of motion in the environment, but there is evidence to suggest both physiological and psychophysical that motion information from heading and aim-point estimation is used. Because pilots are unaware that they could be using optical flow as a cue in their judgment of altitude, they are unable to report that it was a cue they used to estimate altitude and approach angle. Any errors in judgments relating to aim-point can result in a serious accident, loss of life or extensive damage to both the aircraft and the runway.

### **Perception of Heading**

The first theory regarding the perception of heading was based on the concept of optical flow present in an observer's environment (Gibson, Olum & Rosenblatt, 1955; Gibson, 1950a, 1950b, 1966, 1979). Gibson proposed that during the movement of an observer in the environment, velocity vectors that Gibson termed the 'focus of radial outflow' were present (Gibson, 1950a). In particular reference to the perception of heading, it was stated that there was a centre of velocity that was termed the 'focus of expansion' and the focus of expansion was the point at which all other optical flows on

the ground flowed from (Li & Warren, 2000; Warren, Morris & Kalish, 1988). As a further investigation of Gibson's theory, mathematical models have also been proposed with Gibson's optic flow concept as a foundation (Gibson, 1950a; Perrone, 1992; Perrone & Stone, 1994). However many researchers have questioned the adequacy of Gibson's theory in explaining perception of heading (Cutting, Springer, Braren & Johnson, 1992; Johnston, White & Cumming, 1973; Van Den Berg, 1996; Van Den Berg & Brenner, 1993; Wann, Swapp & Rushton, 2000). Van Den Berg has investigated the role of the horizon in optic flow and examined the extent that heading direction estimates are affected by objects in the visual field (Van Den Berg, 1992). Van Den Berg reported that the horizon was essential for robust heading perception in the visual task (Van Den Berg, 1992). Also, recognisable points at infinity, like the horizon, appear to be essential components for good heading perception. Van Den Berg's study gives weight to Gibson's arguments of the focus of expansion being an important component of heading perception. There have been various models that have been tested and while one model may have good predictive power with one data set, given another data set, the predictive power may not be as great. It has been believed that there is a formula that pilots compute mentally while in flight regarding the angles of their descent. However, it has proven to be very difficult finding a model that accurately predicts more than one set of data. It also has to be acknowledged that human estimations of motion can come from a range of visual, vestibular, oculomotor and even possibly auditory stimuli which could make it even harder to propose a solid motion theory that is accurate (Stone & Perrone, 1997). This is one of the great mysteries of heading perception with respect to aviation as the errors made in final approach are not fully understood nor can be accurately predicted.

There have been theories proposed by researchers seeking to confirm or deny the adequacy of optical flow in explaining aviation landing errors. Also, in viewing what researchers in other fields study, it is possible to extrapolate their ideas into the field of aviation to assess what viability the theories of other disciplines can offer aviation research. For example, in the case of heading estimation in the context of curvilinear motion, theories include retinal-image and extra-retinal models that have been proposed

(Banks, Ehrlich, Backus & Crowell, 1995). In a study by Warren, Morris and Kalish, it was stated that retinal flow refers to changes of light on the retina as a result of eye movements (Warren, Morris & Kalish, 1988). Warren et al. had proposed that there were two types of information that were available in optical flow and these were exterospecific, which related to the 3D structure and motion of objects in the environment, and propriospecific information regarding the direction of heading and the direction of locomotion. In studies of dynamic landing cues, there have been various studies that suggest possible variables that are used for perception of heading. Van Den Berg and Brenner (1993) concluded that when depth range was reduced, subjects underestimated heading as relative to the stationary point, and that heading perception that used sources other than optic flow were more robust. Other researchers have reported that in order to analyse the possible contributions of these cues, it is best to conduct an analysis of global optic-flow rather than a local and constrained analysis of motion (Di Luca, Domini & Caudek, 2004). Other topics in heading estimation research include way-finding with various sources of local information in retinal flow and path flow in cluttered environments (Cutting, 1996; Cutting, Vishton, Fluckiger, Baumberger & Gerndt, 1997); accuracy of heading and path judgments over curved or straight paths (Wilkie & Wann, 2006).

### **Runway Size**

The shape and size of the runway can be considered both a dynamic and static cue to the landing of an aircraft. Errors associated with runway width differences can result in errors in altitude and the distance judgements from the plane to the landing threshold (Hasbrook, 1975). The illusion that pilots experience, due to variations in runway dimensions, results in pilots perceiving their approach altitude to be too high when the runway is long and narrow and in contrast, pilots perceive their approach to be too low when the runway is wide and short. The width of the runway can be considered a dynamic cue as pilots retain a visual of the runway during final approach, and therefore the size of the runway constantly changes the closer pilots fly to the touchdown point (Mertens, 1978a, 1978b, 1979). Thus, as the shape of the runway changes while a pilot is in motion approaching the runway, the runway width illusion is a dynamic cue.

Mertens and Lewis conducted a study into the runway width illusion with a focus on the visual effects or illusions that resulted from final approach to the runway (Mertens & Lewis, 1982). Five different runway widths were used in this experiment; 75ft, 100ft, 150, 200 and 300 ft wide and participants were familiarised with a designated runway width that was either 75ft, 150ft or 300ft (Mertens & Lewis, 1982). The task of the participants was to fly a 'normal' glide-slope during the approach to landing and touch down upwind of the runway threshold by about 1,000 ft (Mertens & Lewis, 1982). The findings of this experiment indicated that lowered approaches were made to narrower runways and practice on narrow runways raised approaches to wider runways (Mertens & Lewis, 1982). This was a dynamic experiment due to the fact that the participants had to 'fly' the simulator and land in the runway scene and there was no viewing of a static scene of the image.

### **Perception of Aim-point in Landing**

There has been limited research into the predictions of aim-point in a landing task. With the limited research there are only three main studies that were concerned with aim-point estimation in an aircraft landing tasks. Reardon, Ahumada and Acree all conducted research into aim-point estimation in an aircraft landing task (Acree, 1981; Ahumada, 1983; Reardon, 1988). Reardon (1988), conducted research into aim-point estimation in conjunction with a nested texture variable. Nested texture is a term that refers to texture which changes in accordance with the pilot's altitude as opposed to texture that remains constant regardless of altitude (Reardon, 1988). It was interesting to note that in this experiment Reardon used both pilots and non-pilots for the trials (Reardon, 1988). The runway size was 150 x 1500 ft and there were four types of texture used: no texture, dots that were randomly positioned in a grid pattern, and x-patterns (Reardon, 1988). The texture was either nested (changed and emerged as a function of altitude), or remained constant throughout the trial. The simulated trials began at either 110ft or 230 ft and continued until an altitude of 50 ft was attained and then the display froze. At this point participants were given a mouse to move a cursor onto their proposed aim-point on the runway and after they had indicated their aim-point, the participants rated their confidence in their aim-point estimates on a three point scale. Overall, the participants

underestimated their aim-point by an average of 20 ft and it was concluded that when there was no texture, as in the wire frame condition, the participants aim-points were estimated short of the actual aim-point (Reardon, 1988). As the complexity of texture increased, the aim-point was perceived as being further down the runway (Reardon, 1988). It is important to note that the nesting of texture had no effect compared to constant texture and participants tended to underestimate their aim-point with the 5 degree slope, whereas they overestimated their aim-point with a 15 degree slope. Across the different textures, it was found that the 15 degree path angle resulted in more accurate predictions than the 5 degree angle. It was found that the more texture that appeared on the display led to more accuracy with a 5 degree flight path (Reardon, 1988).

Acree (1981) researched pilots' responses to errors in aim-point estimation. The goal of Acree's experiment was to obtain responses of pilots to deviations in altitude and deviations of aim-point from the nominal touchdown point (Acree, 1981). Subjects viewed a video, which was black and white, of approaches to a runway model measuring 60m x 2400m. There were five pilot participants in this study, and all the participants had various experience in military jets and civil aircraft (Acree, 1981). The glide-paths were 3 degrees with deviations of  $\pm 0.5$  and  $\pm 1$  degree and the starting ranges were 900m and 1800m. The subjects in the experiment estimated the glide-path as being too high or low with respect to the normal glide-slope as being 'long' or 'short' on a +10 - -10 with reference to the nominal touchdown point (Acree, 1981). It was reported by Acree that aim-point estimates were nonlinear with a low sensitivity of 0.24 and it was seen that there was reduced sensitivity at the extremes of the stimuli shown to participants (Acree, 1981). It was also reported that glide-path was a strong influence on aim-point estimates. Aim-point estimates were therefore estimated to be further up the runway with an increased approach angle (Acree, 1981).

Ahumada (1983) experimented with aim-point estimates and discriminability. Ahumada planned to have a single row of lights on a display that stretched out from the participants with a measure of aim-point estimation and investigated whether random or uniformly positioned lights were beneficial in a landing situation (Ahumada, 1983).

Participants were required to view a display with a row of lights on it. There were either 20 or 60 lights, and the lights were either random or uniformly positioned. The initial altitude that a participant viewed was either 719 or 1790 units, and the time to landing was either 3.75, 7, 15 or 30 seconds (Ahumada, 1983). When the display stopped, participants had to place a cursor on their estimation of aim-point and all the variables were held constant except for the glide-slopes which were displayed in 2 blocks. The glide-slope blocks were 2, 3, 4, 5 and 6 degrees or degrees of 8, 9, 10, 11 and 12. Ahumada reported an interaction between approach angle estimates and aim-point as for steeper glide-slopes, the aim-point estimation by participants was overestimated and with shallower glide-slopes, participants mostly underestimated aim-point (Ahumada, 1983). It was reported that the overall mean of deviation from actual aim-point was  $0.4^\circ$ , that is, there was a tendency for participants to overestimate aim-point location. Time to touchdown was also significant and when there was more rapid motion in the visual field, participants tended to overestimate aim-point as higher up the runway (Ahumada, 1983). With regards to random versus uniform dot patterns, it was found that participants had better discriminability with the random distribution (Ahumada, 1983). Ahumada believed that this last finding could have been due to the fact that randomness prevented the dots from blending together into a single line (Ahumada, 1983).

### **Summary**

In summary, optic flow is a dynamic cue related to the perception of aim-point which is the point with no motion and which all other optic flows on the ground expand outwards from (Gibson, 1950a). Gibson termed the point at which a pilot aims to land on the runway the 'focus of expansion' (Gibson, 1950a). The faster that objects 'stream' past a pilot the lower they are, the slower that objects 'stream' past the pilot, the higher they are. With regards to the runway width illusion, as the shape of the runway changes while a pilot is in motion, the width of the runway can pose as a cue for estimating altitude. Perception of heading is also important to the landing of an aircraft and due to the lack of aviation related research and there has been varied research with respect to the perception of heading.

### **Previous aids for landing**

The runway width illusion has been the subject of many decades of research and has been recognised by aviation researchers and pilots alike. Attempts to alleviate the problems associated with the runway width illusion have been to use landing aids to assist in the descent to landing. Landing aids such as the Visual Approach Slope Indicator (VASI) and the Precision Approach Path Indicator (PAPI) have become commonplace in most aircraft. These systems have been constructed and utilised in the belief that the number of crashes as a result of misperceived approaches should decrease (Li et al, 2001). However, with the reported prevalence of pilot error, it is evident that even with the aid of automation in the cockpit; there has not been a significant reduction in the number of accidents during landing. Therefore although researchers believed that the problems associated with landing would cease with the introduction of new automated aids, it appears that these aids were not sufficient to prevent errors. The Civil Aviation Authority requires that pilots maintain the runway image in their visual field while landing and therefore researchers need to focus on the perceptual problems associated with landing an aircraft. Part of the problem of navigation and landing aids could be to do with the fact that many pilots prefer to use their visual judgments rather than rely on landing aids in the cockpit. There are various accident reports that state the landing aids were flashing to indicate a dangerously low approach, however pilots ignored these in favour of their own judgments. By this, it is meant that pilots ignored the landing aids that are commonly used and prefer to use their own judgments about approach angle and land using various visual cues. For example, in 1996, a Canadian Airlines 767 crashed as a result of an extremely low landing. It was discovered that the visual landing aid system had indicated a low landing with a red line on the display. However, even though the instrument indications were red, therefore indicating a low landing, the captain and co-pilot ignored the red indications and continued on the flight path that they were on, the path that ultimately resulted in the plane being damaged (Rossier, 2002). Thus, while landing aids may be widely used, pilots may not always accept the indications of the aid.

A further attempt to aid pilots in landing have been attempts to add markers on the runway as an indication of approach angle. Triangles in particular have been used in trials to determine if markings on the runway could be used to guide a pilot into land. It was believed that triangles would lose their shape and not look much like a triangle if pilots were approaching at an incorrect angle. Thus, the triangles were designed so that pilots on the correct glide-path would correctly perceive a triangle on the runway, and if they were approaching too high or too low, the triangle would not be a clear shape but appear skewed. Thus, in addition to aids in the cockpit, cues outside the cockpit on the runway tarmac have been tested also.

### **The focus of this research**

Previous research into static cues has found that pilots should be able to monitor their angle and rate of descent based on the H-angle (angle between the horizon and the end of the runway). A static cue that is not related to angles is the convergence of parallel lines in a scene, also called linear perspective and by viewing how parallel lines e.g. the sides of the runway, recede towards the horizon appears to be a useful cue available to pilots in judging altitude in a scene. In addition to linear perspective, the relative size of objects in the visual scene appears to be a fairly important cue that pilots use to estimate their altitude from a static image. Pilots appear to become familiar with the size, shape and even location of objects in their visual field. As a result of this, objects in the scene that pilots are familiar with and therefore know the relative size of, can be useful in judging altitude. Although there have been varied research results, the texture of the runway scene appears to be useful to pilots in judging altitude.

In contrast to the research into static cues, the cues associated with dynamic scenes are related to movement. Optic flow and the focus of expansion are two terms that are used to describe the focus point in the scene, and thus the point from which all flows on the ground expand outwards. The focus of expansion and the aim-point in the scene are very important dynamic cues used by pilots when estimating correct descent angles and altitude. The perception of heading is important to pilots as an available dynamic cue as it appears that optic flow, along with other objects in the environment e.g.

the horizon provide pilots with dynamic cues sufficient to determine heading. Relative motion parallax is a dynamic cue that relates to the rate of speed and movement of objects in the visual field. Thus, the speed that objects move past pilots as they descend to the runway on final approach is a dynamic cue to indicate altitude. The dynamic cues mentioned are different from the static cues as the static cues are not present when there is motion in the visual field and dynamic cues are not present in a static image. However, a dynamic cue that is similar to one of the static cues mentioned is the changing size of the runway as a pilot descends. Pilots become accustomed to viewing the runway as they descent, and thus learn to recognise what looks like a good landing and one that looks too low. Thus, as with the static cue related to runway shape and width being useful to judging altitude, the changing size of the runway as a pilot descends in dynamic conditions is also useful for determining altitude. A further cue that is available to pilots in dynamic conditions is their ability to judge slant as in order to ensure that they are on the correct flight path as pilots' often check the slant of the ground surface as well as the slant of the plane relative to the ground. Judgement of slant involves processing of motion and therefore is a vital dynamic cue to a safe landing. In addition to judgement of slant and heading is the ability of pilots to estimate aim-point. The ability of a pilot to judge aim-point depends on their ability to detect their altitude from cues in the environment and respond to these cues by making sure that their flight path is in accordance with what they can see in the visual scene.

In the present research, both static and dynamic cues were used in order to combine the two lines of previous research as there are few research projects that have employed both static and dynamic cues in the visual scenes. Also of importance is a comparison of altitude estimation and aim-point measures in order to examine how the different measures provide different insights into pilot errors during landing. Further, a comparison of participants' subjective impressions regarding the cues they used to judge altitude and aim-point were assessed with regards to the observed efficiency of these cues in contributing to accurate altitude and aim-point judgments. Finally, the potential for a standardised runway marking to increase the accuracy of landing judgments and overcome runway illusion effects associated with varying runway widths were explored.

## **Experimental Aims and Structure**

The structure of this research was a within-subjects experiment with blocks of static and dynamic landing scenarios presented in simulations. There were 66 scenes in total that the participants viewed with 33 static scenes and 33 dynamic scenes. The factorial design of this experiment was a  $2 \times 3 \times 3 \times 2$  with 2 trials (static and dynamic), three different viewing heights, three different runway widths and scenes with a standard runway marking and some without. While there were various components to this research, there were two main aims of the experiment. Firstly, this experiment aims to contrast the effects of dynamic and static cues with respect to the runway width illusion. The effectiveness of the research design was to incorporate both the static and dynamic visual and motion cues. Secondly, this experiment aimed to investigate the potential to overcome the runway width illusion by using a standard runway marking. The marking on the runway was an attempt to provide a solution to the well documented runway width illusion. Other general aims of this research were to investigate the influence of environmental texture on altitude and aim-point estimates.

## **Method**

### **Participants**

Thirty-two participants were recruited from the University of Waikato to take part in this experiment. These participants were students from different departments at the University of Waikato who had no experience in flying aircraft and participated for course credit and/or a petrol voucher. The participants were comprised of 15 males and 17 females who ranged in age from 17 years to 42 years with the approximate average age being 23 years. These participants were different nationalities with 5 Asian participants, 1 Indian, 1 Norwegian and 25 New Zealand European/Maori. In addition to the 32 non-pilot participants, there were also 3 pilots who participated in the study. These pilot participants were recruited from a local flight training centre, and the only requirement was that they had at least 20 hours flying time. The three pilots ranged in age from 40 to 21 and were all European males.

### **Apparatus**

The study was conducted using custom-made software that displayed realistic simulations of airport approaches on a 76.2 cm LCD display screen at a resolution of 2560 x 1600 pixels. As shown in Figure 3, participants' sat with their heads supported by a chin rest in order to keep their eyes at a fixed distance (69cm) from the screen and remain at the correct viewing height. The horizontal field of view was 49.76° and the vertical field of view was 32°. See Figure 4 for a diagram representing a top and side view of the participants' field of view. Trials were run in a dark room with the only source of light coming from the computer screen and a small lamp to enable the researcher to record the data.



Figure 3: The apparatus used in the experiment

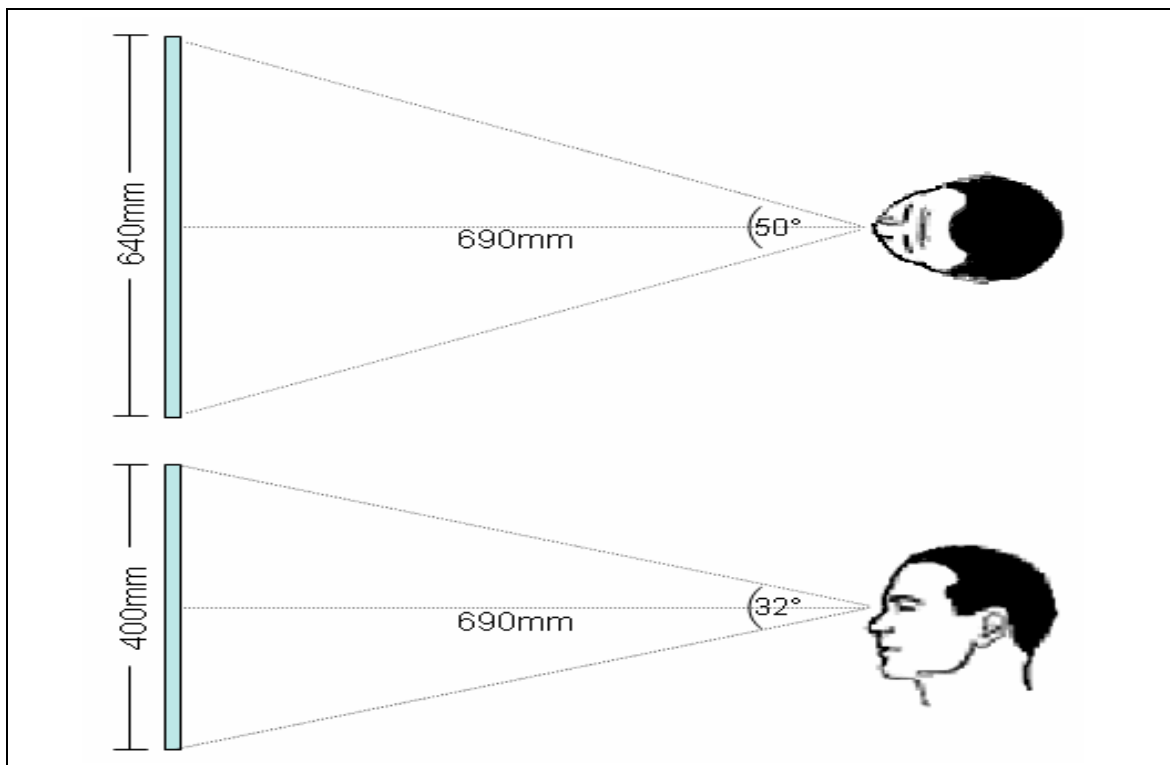


Figure 4: A top and side view of the participants' field of view during the experiment.

## **Simulation Scenarios**

The airport approach simulations consisted of both static and dynamic visual scenes viewed from three different approach angles. The approach scenes contained a detailed runway scene with no auditory information associated with any of the simulation scenarios. The simulator scenes were based on an aerial photograph of the airport in Hamilton, New Zealand which was modelled in three-dimensions. For example, airport buildings, vehicles, trees and fences were located in the model to accurately represent the airport as shown in Figure 5. The image shown on the screen was a computer generated 3-D scene. The scenarios were created by moving a camera view through the three-dimensional model at three approach altitudes at a downwards approach angle of  $3^\circ$  (an angle typical of civil aircraft) landing at the airport. The speed of the simulated aircraft (the view from the camera) through the model scene was 70 knots per hour (36 metres per second). The dynamic scenarios contained a 10 sec video (360m) of the approach to the model airport. The dynamic scenes began 1232m from the start of the runway and ended 872m before the start of the runway. It should be noted that the camera angle during the  $3^\circ$  descent was kept parallel to the ground in the three-dimensional simulation (parallel to the runway) and therefore the horizon appeared halfway up the screen. While the camera angle remained at  $3^\circ$ , there were several methodological choices possible, e.g. the aim-point could have been fixed and the approach angle could have been varied. However this approach was used for reasons of simplification in designing the simulated scenes. Figure 6 shows the three viewing heights at the beginning of the dynamic scenarios (49.24m, 64.54m and 78.8m) and at the end point (30.48m, 45.72m and 60.96m). The middle viewing height was designed to represent the ideal approach trajectory for landing on the runway at the ideal altitude, whereas the highest approach altitude would overshoot the start of the runway and the lowest altitude would touch down more than 200m short of the runway. The static simulation scenes consisted of the end frames of each of the 10 sec dynamic simulations.

Three different runway widths were depicted in the simulation scenarios; narrow (30.48m), medium (60.48m) and wide (91.44m) as shown in Table 1. In all scenes, the runway length was constantly at 8000m. Markings on the runway were in accordance

with the New Zealand Civil Aviation Authority (CAA) guidelines and included a dashed centre line on the runway and a group of vertical stripes at the start of the runway (touchdown strip) (New Zealand Civil Aviation Authority, 1993). Runway centre line markings consisted of a series of white dashes 36m in length with gaps of 24m between them. As per the CAA guidelines, the number of vertical stripes at the start of the runway varied according to the width of the runway. The narrow runway required 8 stripes while the medium and wide width runways required 16 stripes each. It must be noted that the width of the stripes on the narrow runway were made slightly smaller than the markings on the medium and wide runways in order to appear clear while still looking realistic. In addition, two versions of each runway were created, one with the standard runway markings, and one with an additional white rectangle painted on the runway before the required touchdown zone stripes. The white rectangle was an inverted trapezoid that measured approximately 15.24m by 15.24m, and as such, when viewed from the middle altitude it appeared to be a rectangle with 90° angles on the screen. Viewed from the other altitudes, the marking appeared trapezoidal and was intended to provide participants with a cue that the approach was either too high or too low (and therefore overcome the runway width illusion). An example of a narrow runway containing the painted landing cue is shown in the lower panel of Figure 5. The simulation scenarios thus contained each of the three runway widths shown from three viewing heights, with runway with and without the landing cue (a 3x2x2 design).

In addition to the three-way factorial comparison described above, several different versions of scenarios containing the medium runway width were developed to identify which features of the scene were used by participants to judge their altitude. Five additional versions of each scene containing the painted landing cue were created: 1) no tower or airport (the scene was complete except for the fact that the tower building and airport building were removed), 2) no buildings (the scene was complete except for the fact that apart from the tower and airport building the scene had no buildings present), 3) no cars (the scene was complete apart from the absence of the red car, the Ute and the truck), 4) no trees (the scene was complete apart from the absence of the line of trees on the left side of the scene), and 5) no buildings nor trees (the scene was complete with the

airport and tower buildings but lacked all other building and the line of trees on the left side). Thus, as shown in Table 1, a total of 33 dynamic and 33 static simulation scenarios were developed. Finally, it should be noted that the dynamic scenarios contained two vehicles that drove past the runway. These vehicles were designed to move away from the runway in order to prevent participants perceiving that they might collide with these vehicles should they continue on to land. In the dynamic scenes, the red car and the orange truck start moving together on the road in front of the runway. However, the red car moved left along the road away from the runway, and the truck moved right along the road away from the runway and red car.

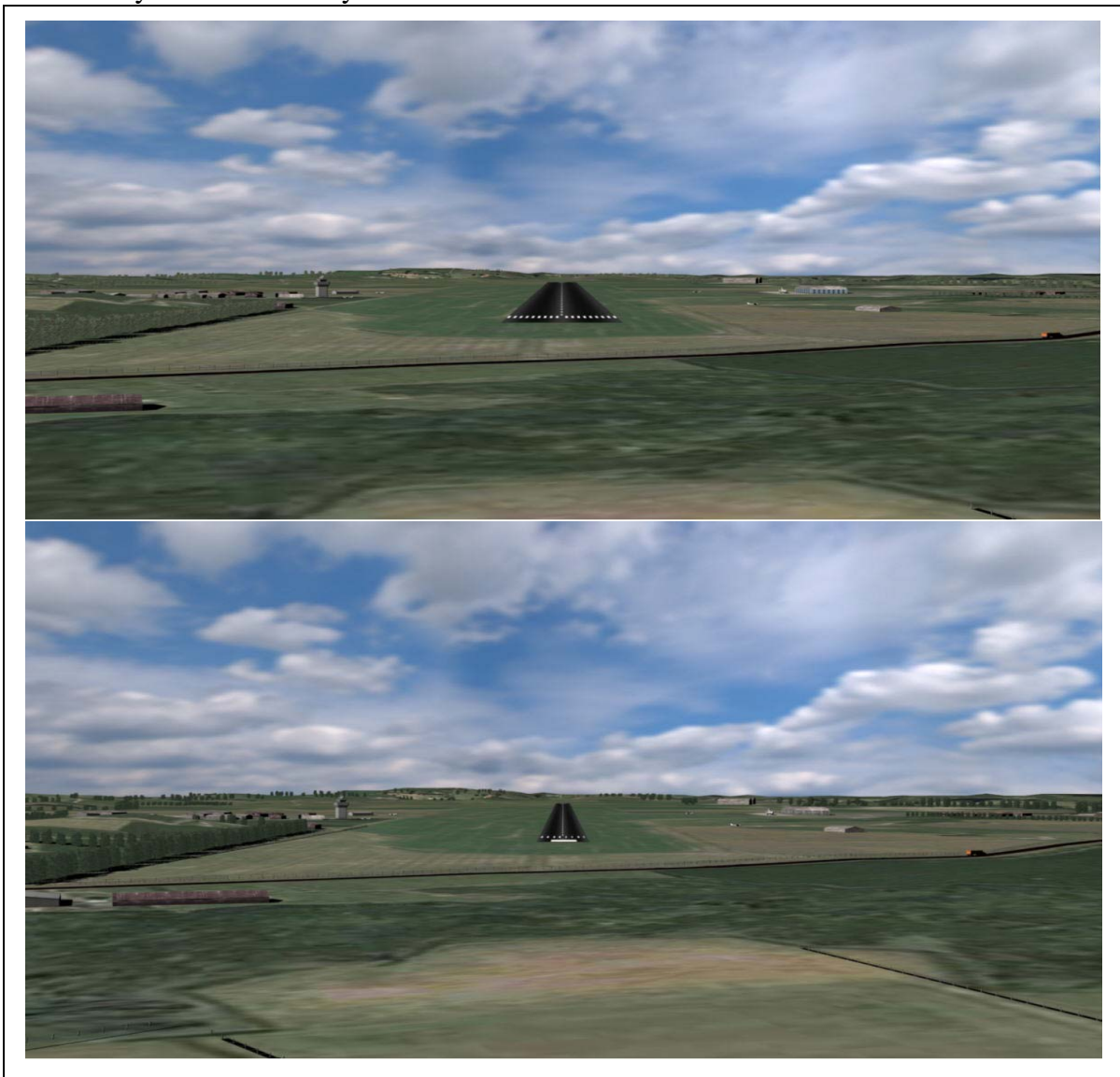


Figure 5: Example scenes from the simulation scenarios shown to participants. The top panel shows the wide runway viewed at the middle altitude and the bottom panel shows the narrow runway with the added runway marking viewed from the middle altitude

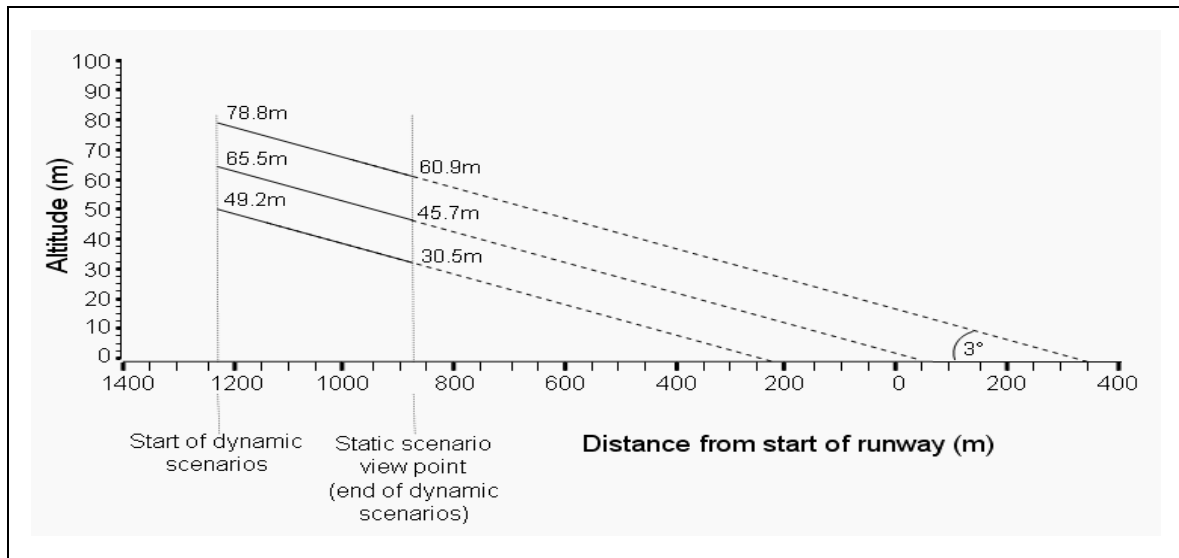


Figure 6: Start points, end points, and viewing altitudes for the simulation scenarios.

<b>Table 1: Diagram of the Different Scenes Viewed By Participants with the Differences in Viewing Height and Runway Width</b>			
	High Viewing Height 60.96m (200ft)	Medium Viewing Height 45.72m (150ft)	Low Viewing Height 30.48m (100ft)
Narrow Width 30.48m (100ft) Static – Altitude estimates Dynamic – Altitude and Aim-point Estimates	9 Standard Runway Scenes 9 Scenes with additional runway marking	9 Standard Runway Scenes 9 Scenes with additional runway marking	9 Standard Runway Scenes 9 Scenes with additional runway marking
Medium Width 60.96m (200ft) Static – Altitude estimates Dynamic – Altitude and Aim-point Estimates	9 Standard Runway Scenes 9 Scenes with additional runway marking <b>Scene Manipulations</b> <i>No cars</i> <i>No trees</i> <i>No tower and airport</i> <i>No buildings</i> <i>No trees or buildings</i>	9 Standard Runway Scenes 9 Scenes with additional runway marking <b>Scene Manipulations</b> <i>No cars</i> <i>No trees</i> <i>No tower and airport</i> <i>No buildings</i> <i>No trees or buildings</i>	9 Standard Runway Scenes 9 Scenes with additional runway marking <b>Scene Manipulations</b> <i>No cars</i> <i>No trees</i> <i>No tower and airport</i> <i>No buildings</i> <i>No trees or buildings</i>
Wide Width 91.44m (300ft) Static – Altitude estimates Dynamic – Altitude and Aim-point Estimates	9 Standard Runway Scenes 9 Scenes with additional runway marking	9 Standard Runway Scenes 9 Scenes with additional runway marking	9 Standard Runway Scenes 9 Scenes with additional runway marking

## **Procedure**

On arrival, participants were given a written description of the experimental requirements (See Appendix B). Participants were then informed verbally about the proceedings of the experiment and given a consent form to complete. Those participants who required prescription lenses were asked to wear them. When participants first sat down and put their head on the chin rest, the display screen presented the same written instructions that the participants had read previously. When the participant was comfortably seated, the researcher asked if they were ready to begin the experiment, and when they indicated that they were ready, the researcher clicked on the spacebar on the keypad to show them a practice static scenario. All 33 static scenarios were shown prior to the 33 dynamic scenarios, and each trial started with 5 practice trials. During these practice simulations, participants were asked to report their estimated altitude verbally and the researcher wrote down this estimation on data collection sheets (see Appendix C). There was no feedback given to the participants on how accurate their estimations were. After the practice trials, the participants were given time to ask any further question regarding the workings of the trial, again no feedback was given regarding performance on the practice trials. After each static runway scene, the participants were asked to report their altitude based on what they could see in the scene. There was no time limit and participants could take as long as they needed to tell the researcher what height they thought they were at, thus the participants' trials were self-paced. The order in which the various simulation scenarios (combinations of viewing altitude, runway width, markings & features) were presented to each participant was randomly assigned. In the dynamic trials, the procedure was similar to the static trials, participants viewed each 10sec approach video and then reported their altitude. When the participants had completed their altitude estimate a crosshair indicator appeared in the centre of the screen and the participants were asked to indicate where their estimated aim-point was on the display screen by moving a mouse and locating the point with the crosshairs.

Each participant viewed all 66 scenarios and produced 66 altitude estimates (from each static & dynamic scene) as well as 33 aim-point estimates (from the dynamic trials). Thus, there were a total of 99 judgements required from each participant, as well as the

short questionnaire on completion of the simulations. The total experiment took approximately 45 minutes for each participant to complete and then participants were asked if they would fill in an 'end of trial' questionnaire (see appendix D). This questionnaire asked participants to note what cues they used in order to judge their aim-point and altitude, how influential runway width variations/runway markings were in determining their altitude and were finally asked to identify any objects they noticed absent in some scenes. On completion of the simulations and questionnaire, participants were given a petrol voucher for their participation in the study and the full details of the experiment were revealed to them. The participants' were asked if they wanted to know the end results of the research and if they did wish to know the results, their contact emails were obtained in order to send them a summary of research findings.

## Results

The effects of runway width, viewing height, and runway marking, as well as the differences between the amounts of detail present in the scenarios, were assessed with a series of repeated-measures multivariate analyses of variance (MANOVA). The results of the analysis for each task type (static and dynamic) are presented in the following sections.

### Static Scene Judgments

In the 3x3x2 MANOVA analysis of the static trials, it was found that there were statistically reliable effects of runway width [Wilks' Lambda = .691,  $F(2, 30) = 6.69$ ,  $p < 0.01$ ], viewing height [Wilks' Lambda = .564,  $F(2, 30) = 11.595$ ,  $p < 0.001$ ], and a significant width x height interaction [Wilks' Lambda = 0.618,  $F(4, 28) = 4.32$ ,  $p < 0.01$ ]. There was no main effect of runway marking [Wilks' Lambda = .927,  $F(1, 31) = .895$ ,  $p > 0.001$ ], or other higher-order interactions indicated by the MANOVA. As can be seen in Figure 7, scenes with the narrow runway resulted in higher estimated altitudes and higher viewing heights also produced higher estimated altitude thus illustrating an example of the runway width illusion. It was interesting to note that participants' estimates of altitude for medium and wide runway widths were fairly similar but notably different from the estimates of altitude made by participants for scenes with a narrow runway. Figure 8 presents the difference between the average altitude estimate and the actual altitude being viewed. As can be seen from Figure 8, altitude estimates were much higher for the narrow runway thus illustrating an example of the runway width illusion where participants estimate higher altitudes on runways that are narrower than runways that are wider.

Post-hoc comparisons using a Bonferoni adjustment for experiment-wise error rate showed that the narrow runway was significantly different than the medium runway ( $p < 0.05$ ) and the wide runway ( $p < 0.01$ ), but that the medium runway and the wide runways did not differ reliably ( $p > 0.05$ ). Similarly, the low viewing height, 30.48m (100ft), was significantly different than the medium viewing height (45.72m) ( $p < 0.01$ )

and the high viewing height (60.45m) ( $p < 0.001$ ), but the latter two heights did not differ significantly ( $p > 0.05$ ).

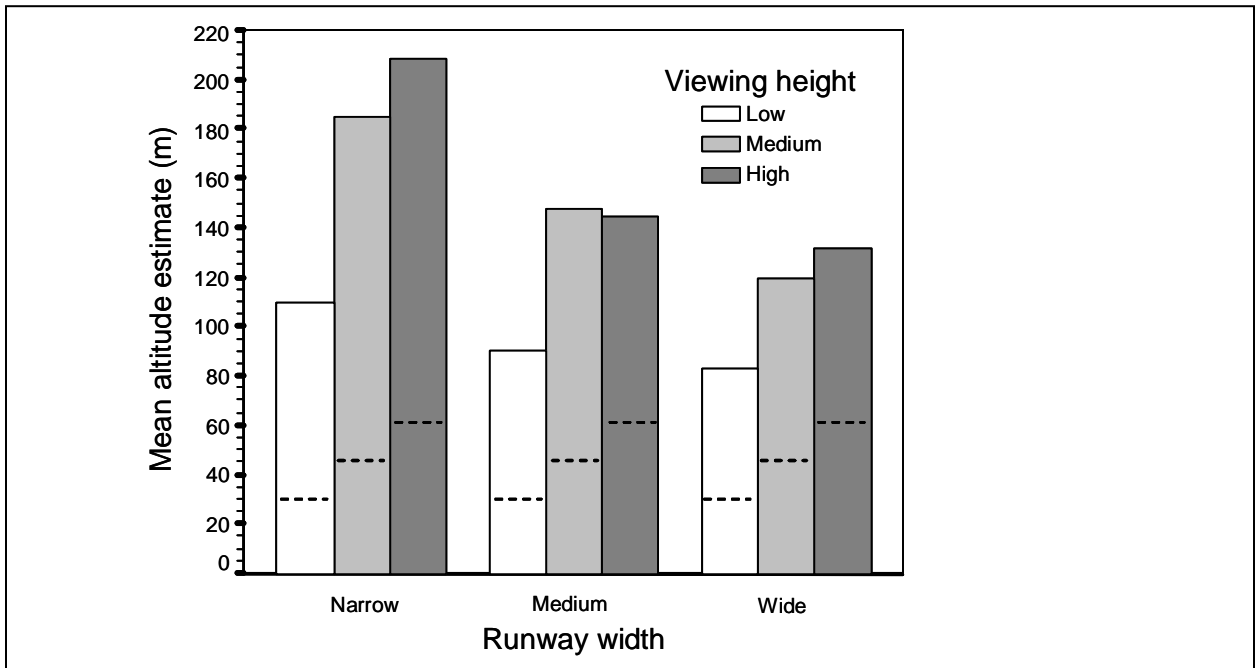


Figure 7: Participants' altitude estimates as a function of runway width and viewing height. Dashed lines indicate the actual altitude for each runway width.

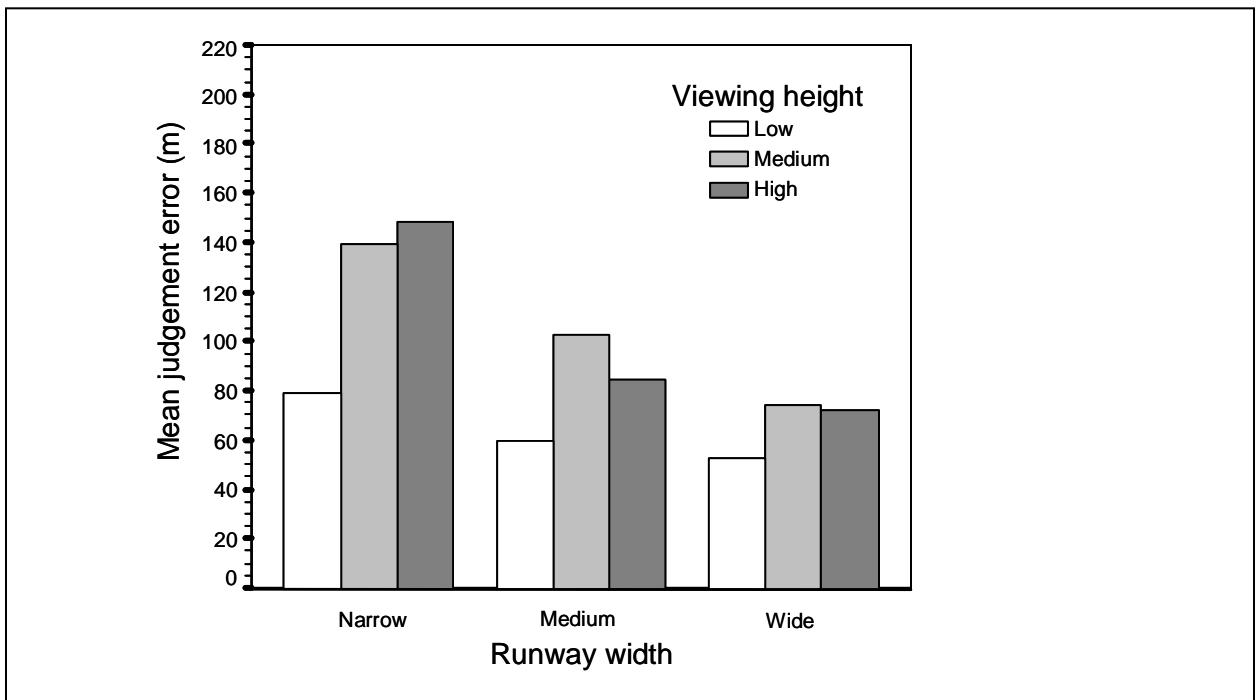


Figure 8: Participants' altitude judgement errors as a function of runway width and viewing height.

### Dynamic Scene Judgments

Another 3x3x2 MANOVA was used to investigate the altitude judgements in the dynamic scenes. The MANOVA indicated that there were statistically reliable effects of runway width [Wilks' Lambda = .656m F (2, 30) = 7.87, p<0.01] and viewing height [Wilks' Lambda = .496, F (2, 30) =15.25, p < 0.001]. There was no main effect of runway marking [Wilks' Lambda = .981, F (1, 31) = .59, p > 0.01], or other interactions indicated by the MANOVA. As can be seen in Figure 9, scenes with the narrow runway resulted in higher estimates of altitude and higher viewing heights also produced higher estimates of altitude. The narrow runway width resulted in higher altitude estimates on average.

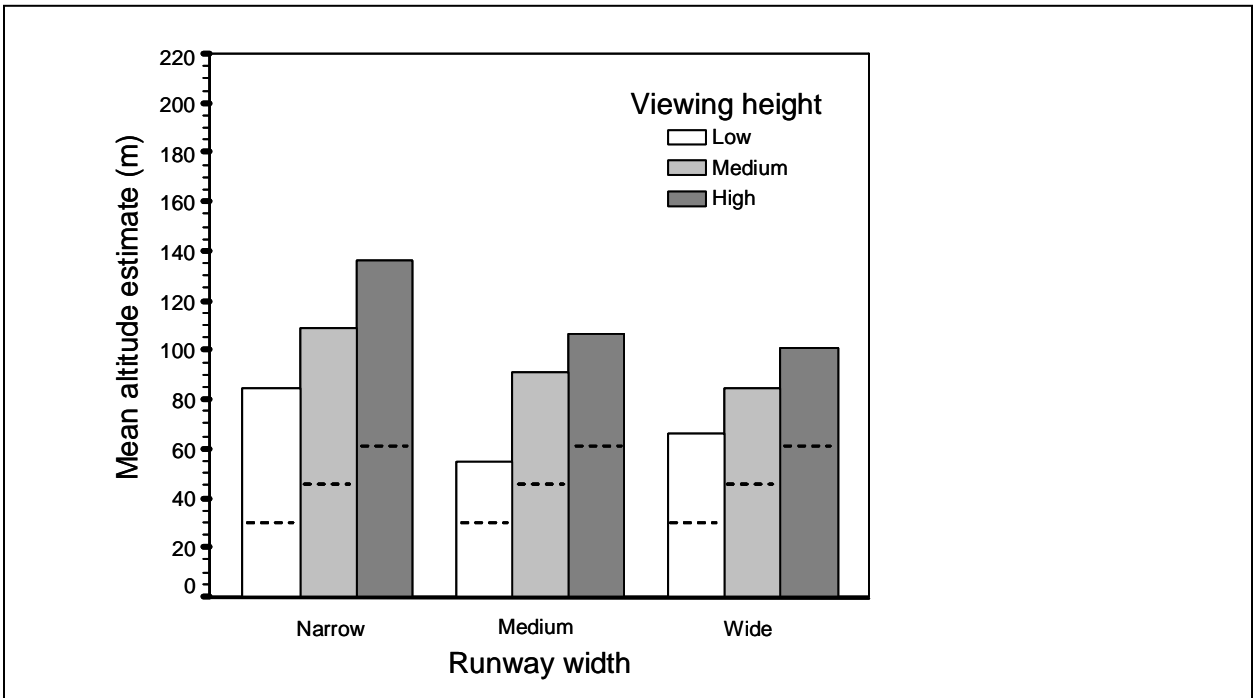


Figure 9: Participants' altitude estimates as a function of runway width and viewing height. Dashed lines indicate the actual altitude for each runway width.

Figure 10 displays the difference between the average estimated altitude for each viewing height and runway width, and the actual altitude. As can further be seen in Figure 10, there is a difference between the narrow runway and the wide runway, but the medium and wide runway resulted in similar error rates.

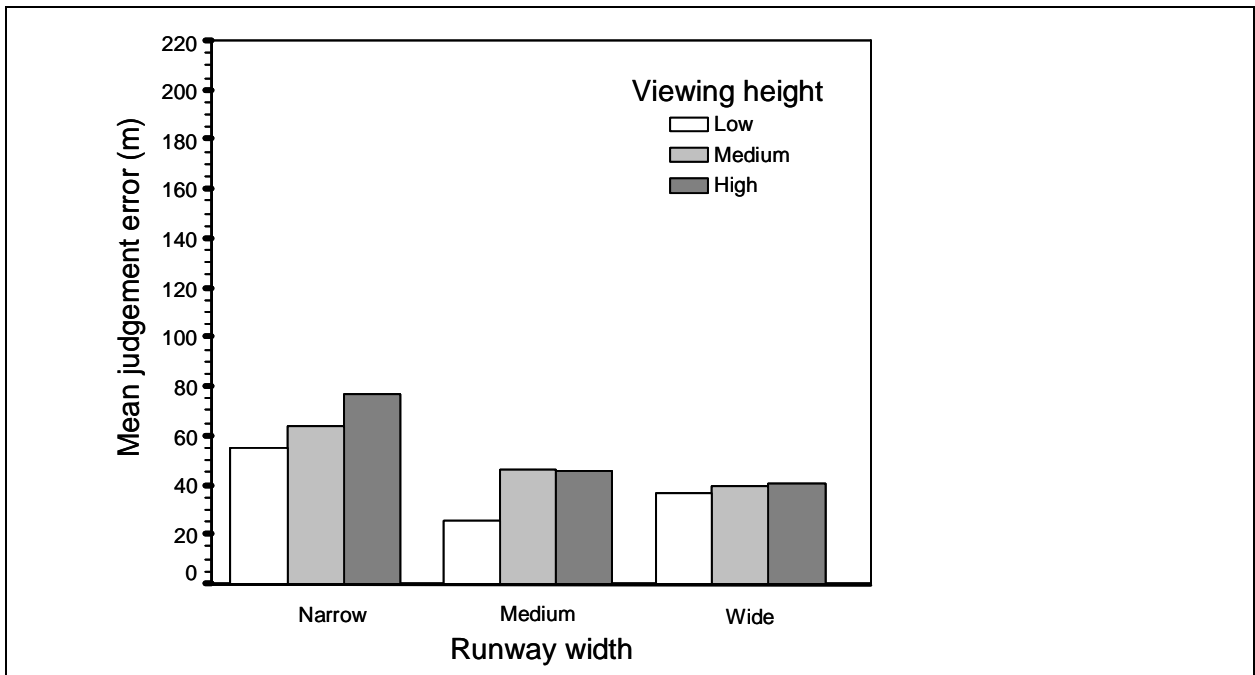


Figure 10: Participants' altitude judgement errors as a function of runway width and viewing height.

Post-hoc pairwise comparisons using a Bonferoni adjustment for experiment-wise error rate showed that the narrow runway was significantly different than the medium runway ( $p < 0.05$ ) and the wide runway ( $p < 0.001$ ), but that the medium runway and wide runway did not differ significantly ( $p > 0.05$ ). In contrast, the viewing heights all differed significantly from each other. The low viewing height differed significantly from the medium viewing height ( $p < 0.001$ ). Similarly, the low viewing height differed significantly from the high viewing height ( $p < 0.001$ ). The medium viewing height differed significantly from the high viewing height ( $p < 0.05$ ). It can be seen in the graphs that participants were inaccurate in estimating altitude in both trials, and the error rates were most consistent across the different viewing heights and the wide runway.

### Comparison of Static and Dynamic Trials

An important feature of the research method was that it incorporated both static and dynamic trials. Therefore a  $2 \times 3 \times 3 \times 2$  MANOVA was carried out in order to compare static altitude estimates with dynamic. There was a significant difference between static and dynamic trials [Wilks' Lambda = 0.220,  $F(1, 31) = 8.727$ ,  $p < 0.05$ ]. The MANOVA

indicated that across the two trials there were statistically reliable effects of runway width [Wilks' Lambda = 0.780,  $F(1, 31) = 8.727$ ,  $p < 0.05$ ] and viewing height [Wilks' Lambda = .588,  $F(2, 30) = 10.521$ ,  $p < 0.001$ ]. There was also a significant height x width interaction [Wilks' Lambda = 0.636,  $F(4, 28) = 4.006$ ,  $p < 0.05$ ], and of runway width x runway marking [Wilks' Lambda = .279,  $F(2, 30) = .699$ ,  $p < 0.05$ ]. Across the two tasks, the additional runway marking was not significant ( $p > 0.05$ ). Importantly, there were no higher-order interactions with trial type (static vs dynamic) indicating a consistent pattern of results across both sets of stimuli. As can be seen from the graphs, the altitude estimates produced during the dynamic trials were lower overall and more accurate than the estimates produced in the static trials.

### **Analysis of aim-point estimates**

In the dynamic trials, participants were required to estimate their aim-point on the runway. In the aim-point data, it was found that there were 15 outliers (data points that are not impossible but are highly improbable) in the data set (McBurney, 2001). These outliers were removed and replaced with column averages so that they did not skew the data in any direction. The aim-point estimates were reported in world coordinates rather than in terms of visual angle as this was how most heading experiments have reported their errors. A 3x3x2 repeated measures MANOVA was used to analyse the aim-point data. The MANOVA results indicated that there was a significant effect of viewing height [Wilks' Lambda = .449,  $F(2, 30) = 18.393$ ,  $p < 0.001$ ], and a significant width, altitude and marking interaction [Wilks' Lambda = .697,  $F(4, 28) = 3.045$ ,  $p < 0.05$ ]. There was not a significant effect of runway width ( $p > 0.05$ ) or additional marking ( $p > 0.05$ ). Figures 11 and 12 display the average distance away from the ideal aim-point that participants estimated. Figure 11 depicts the average distance from the ideal aim-point for scenes when the additional runway marking was present and Figure 12 depicts this average distance when the additional runway marking was absent.

Figures 11 and 12 indicate the average distance of estimated aim-point away from the ideal aim-point and the actual aim-points are indicated with a line. As can be seen from the graphs, when the additional runway marking was present, in the low viewing

altitude condition, participants were fairly accurate in estimating that they would undershoot the runway when viewing the narrow runway. However, participants were inaccurate when they viewed the wide runway and indicated that they would land further up the runway. When the additional runway marking was not present, participants were inaccurate at estimating they would not undershoot the runway when at the low viewing height except when viewing the wide runway. However, when viewing the low viewing height, participants were fairly accurate at indicating that they would undershoot the runway which is a contrast to the estimations made when the runway marking was present. The above differences between the two graphs demonstrate why there was a width x height x marking interactions found in the data.

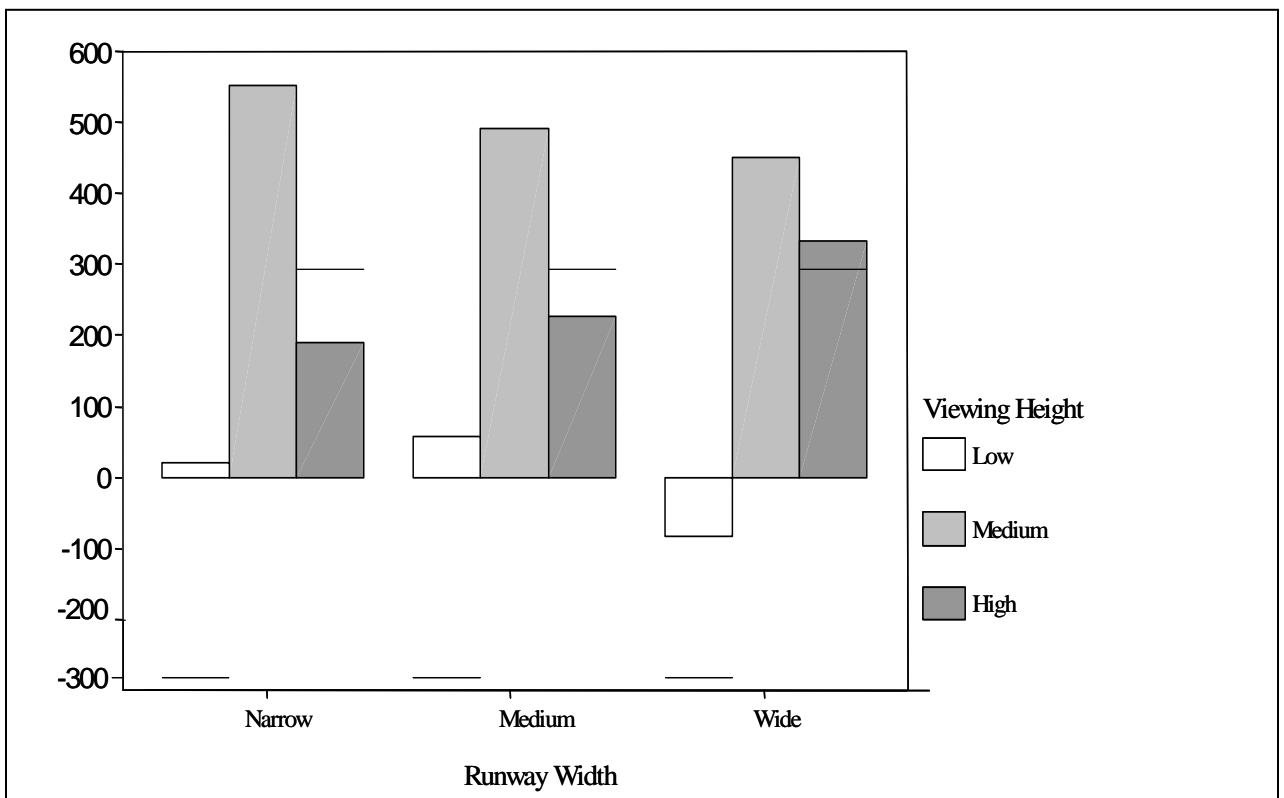


Figure 11: Average aim-point judgements for standard runways with no painted landing cue. Lines indicate the actual landing point for each viewing height.

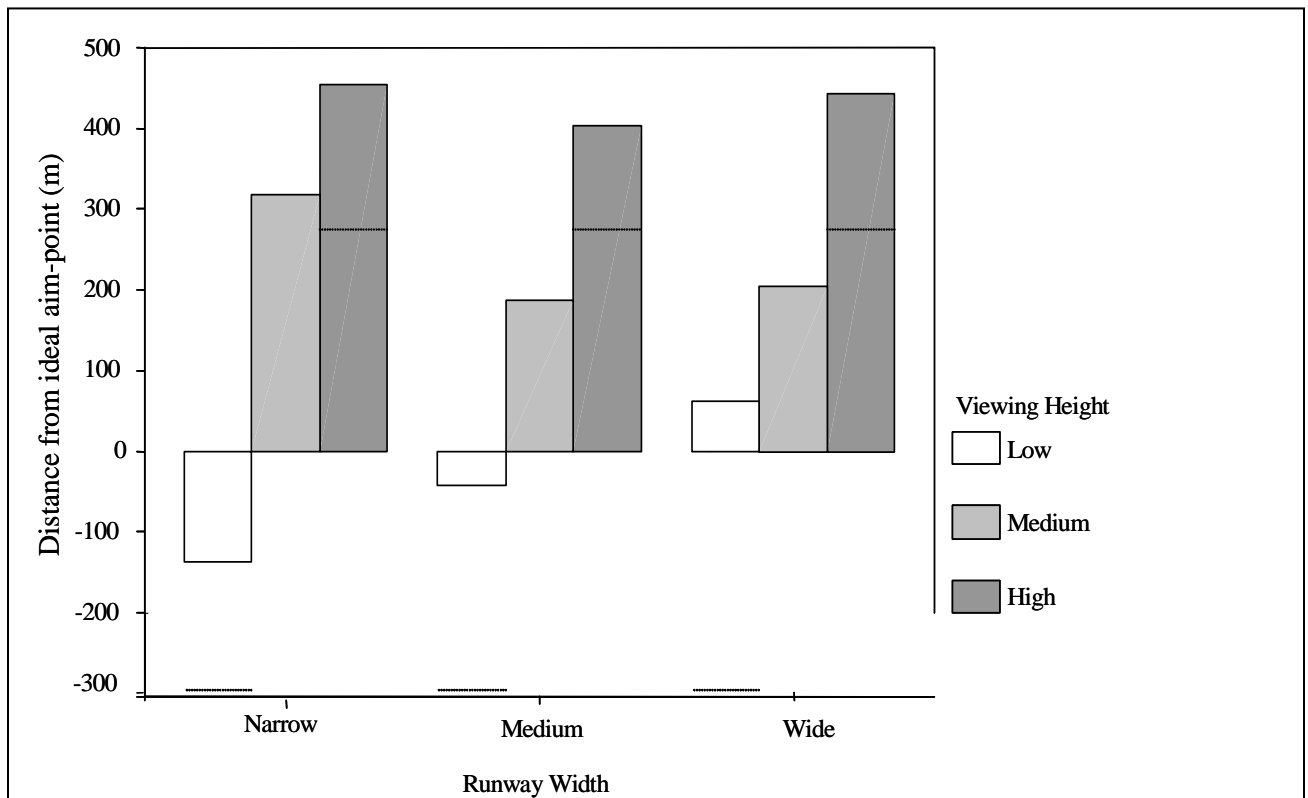


Figure 12: Average aim-point judgements for additional runways with the painted landing cue. Lines indicate the actual landing point for each viewing height.

Post-hoc comparisons using a Bonferroni adjustment for experiment-wise error rate showed that there was no significant difference between the narrow runway and the medium runway ( $p > 0.05$ ). There was also no significant difference between the medium runway and the wide runway ( $p > 0.05$ ). Thus, aim-point estimations were not affected by changes in runway width as altitude estimates were in both static and dynamic trials. In contrast, there were significant differences between the different viewing altitudes. There was a significant difference between the low viewing height and the medium viewing height ( $p < 0.001$ ). There was also a significant difference between the low viewing height and the high viewing height ( $p < 0.05$ ). However, there was not a significant difference between the medium viewing height and the high viewing height ( $p > 0.05$ ). This is an interesting result, as with participants' estimation of altitude, all heights differed significantly from each other in the dynamic task.

## Visual Scene Manipulations

As part of the factorial design there were various scene manipulations in order to assess where participants' were focussing their attention in the visual scenes. There were five different scene manipulations; no cars, no buildings, no trees, no trees or buildings and no tower/airport building and all of these scenes contained runways with the additional standard runway marking. For all these scenes participants were required to estimate their altitude and their aim-point. A 3x6 MANOVA was used to analyse the data as the MANOVA compared the five types of scene manipulations with full scenes. In the static trials, the MANOVA revealed that there was a statistically significant difference of viewing height [Wilks' Lambda = .618,  $F(2, 30) = 9.271$ ,  $p < 0.01$ ], but no significant difference due to scene manipulation [Wilks' Lambda = .951,  $F(5, 27) = .279$ ,  $p > 0.05$ ], or height x scene interaction [Wilks' Lambda = .517,  $F(10, 22) = 2.053$ ,  $p > 0.05$ ]. Post-hoc comparisons using a Bonferoni adjustment for experiment-wise error rate showed that the low viewing height was significantly different to the medium viewing height ( $p < 0.05$ ). There was also a significant difference between the low viewing height and the high viewing height ( $p < 0.05$ ). However there was not a significant difference between the high viewing height and the medium viewing height ( $p > 0.05$ ). See Figure 13 for the mean altitude estimate of each scene with manipulations in relation to other manipulations.

As can be seen in Figure 13, the different altitudes that participants viewed runway scenes from did impact on their estimations of altitude as was found in the MANOVA. Participants' estimates were highest when they viewed the scenes from the high viewing height and were lowest when scenes were viewed from the low viewing height. Also, across the low viewing height participants made more consistent altitude estimates which were not apparent across the medium and high viewing heights. Thus, the low viewing height appeared to skew participants estimates to lower altitudes whereas the high viewing height appeared to skew the altitude estimates to higher altitude estimates.

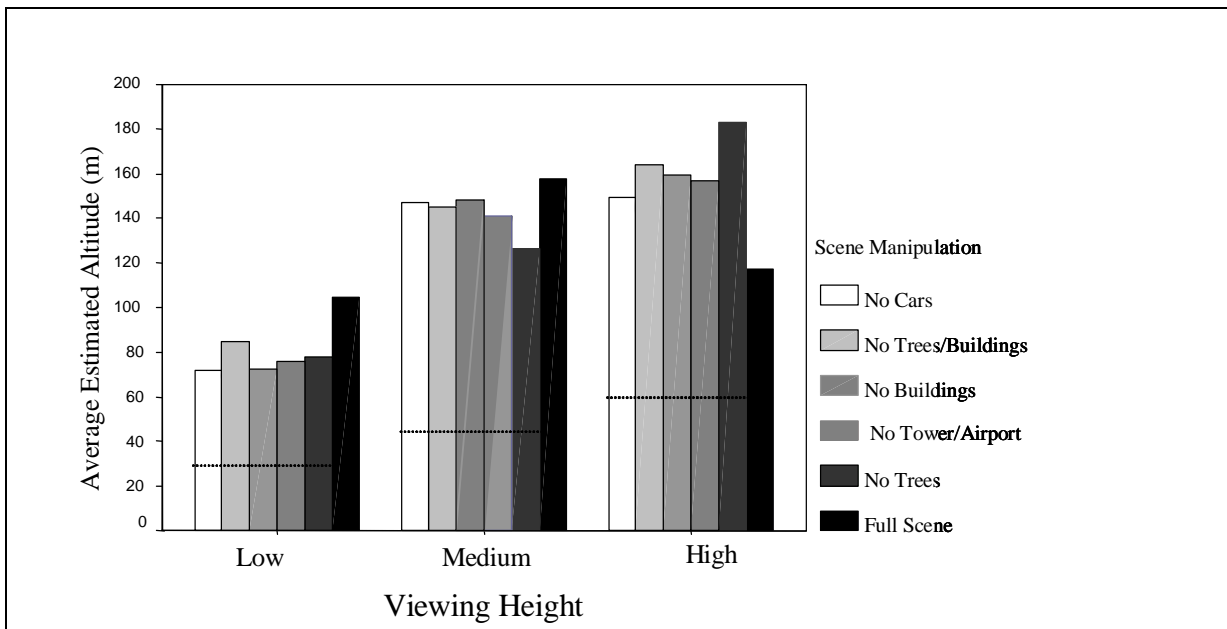


Figure 13: Mean altitude estimates made by participants as a function of different scene manipulations and viewing heights in static trials. Dashed lines indicate the actual altitude for each viewing height.

In order to investigate the data from the dynamic scenes, a 3x6 MANOVA was conducted. The MANOVA indicated that there was a statistically reliable effect of viewing height [Wilks' Lambda = .484,  $F(2, 30) = 16.017$ ,  $p < 0.01$ ], but no main effect of scene manipulation [Wilks' Lambda = .761,  $F(5, 27) = 1.697$ ,  $p > 0.05$ ], or height x scene interaction [Wilks' Lambda = .752,  $F(10, 22) = .725$ ,  $p > 0.05$ ]. Post-hoc comparisons using a Bonferoni adjustment for experiment-wise error rate revealed that the low viewing height was significantly different from the medium viewing height ( $p < 0.01$ ), and that the low viewing height was significantly different from the high viewing height ( $p < 0.01$ ). The high viewing height was also significantly different from the medium viewing height ( $p < 0.01$ ). With regards to the five different scene manipulations, there was no significant difference between the five different scene manipulations ( $p > 0.05$ ). In addition to this, there was no significant difference between each of the five different scene manipulations and the full scenes with no manipulations viewed at each of the three viewing heights ( $p > 0.05$ ). Figure 14 represents the average altitude estimates made by participants across different scene manipulations in dynamic trials. As can be seen in the graph, in the full scenes with no manipulations, participants' average estimates between

the medium viewing height and the high viewing height were the same. However, in the trials with scene manipulations, the estimated altitudes at these heights were variable and there is no other data set which produced this same pattern. As in the static trials, the high viewing height resulted in higher altitude estimates and low altitude estimates were made for the low viewing height. When comparing Figures 13 and 14, it can be seen that participants were more accurate at estimating their altitude in dynamic trials as was the case in the scenes without manipulations.

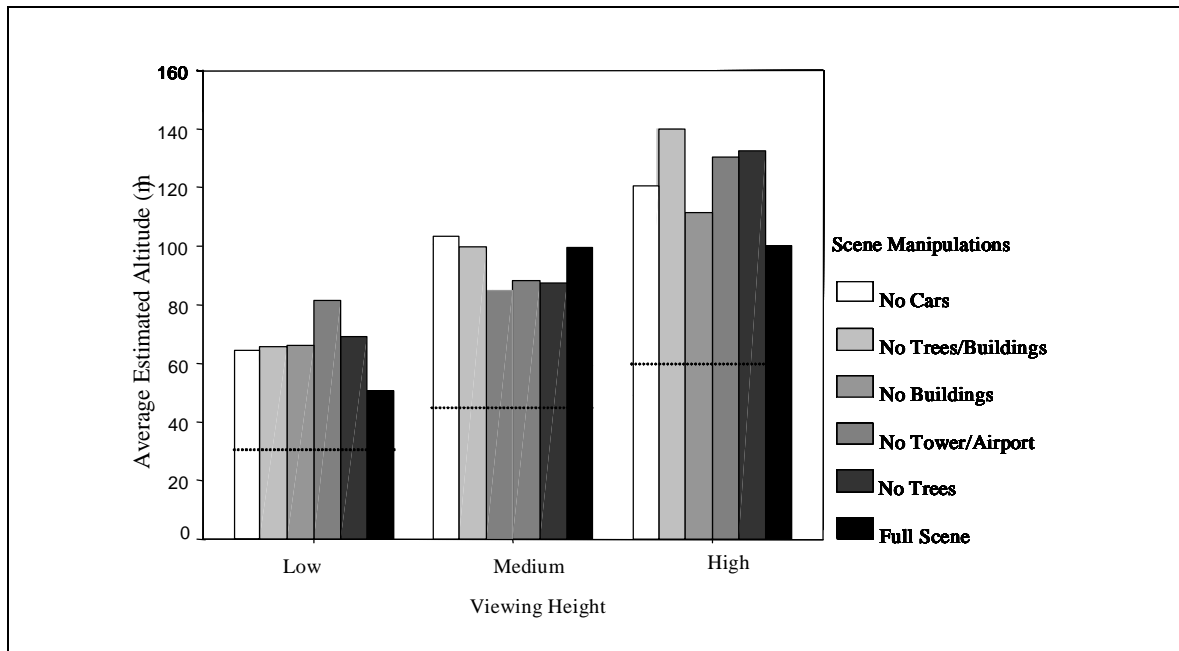


Figure 14: Mean altitude estimates made by participants as a function of different scene manipulations and viewing heights in dynamic trials. Dashed lines indicate the actual altitude for each viewing height.

In the dynamic trials, participants made aim-point estimates in the scenes with manipulations. A 2x6 MANOVA was conducted in order to analyse aim-point data across different scene manipulations. The MANOVA indicated that there were statistically reliable effects of height [Wilks' Lambda = 0.221,  $F(2, 30) = 52.904$ ,  $p < 0.01$ ], and scene manipulation [Wilks' Lambda = 0.708,  $F(4, 28) = 2.885$ ,  $p < 0.05$ ], but no significant height x scene interaction [Wilks' Lambda = 0.715,  $F(8, 24) = 1.195$ ,  $p < 0.34$ ]. Bonferroni adjustment for experiment-wise error rate showed that there was no significance between any of the other scene manipulations ( $p > 0.05$ ). See Figure 15 for a

graph displaying the average aim-point estimates for each viewing height and scene manipulation. As can be seen from the graph, participants were fairly inaccurate at estimating their aim-point at all viewing heights. It is interesting to note that the only scene that resulted in an underestimation of aim-point was the scene with no tower or airport when viewed at the low viewing height. It should also be noted that with the full scenes, participants' average aim-point estimate was further up the runway when viewing the scene from the medium viewing height rather than the high viewing height, as is the pattern in scenes with manipulations. One possibility that there are differences between the three viewing heights could be simply the result of participants estimating their touchdown point in terms of the visual angle on the screen rather than as a point that would appear in the world. For points closer to the horizon, as in the high viewing height condition, a small heading error angle can result in a large error of distance along the ground. Likewise, for the low viewing height, the same heading error angle would translate to a smaller error along the ground.

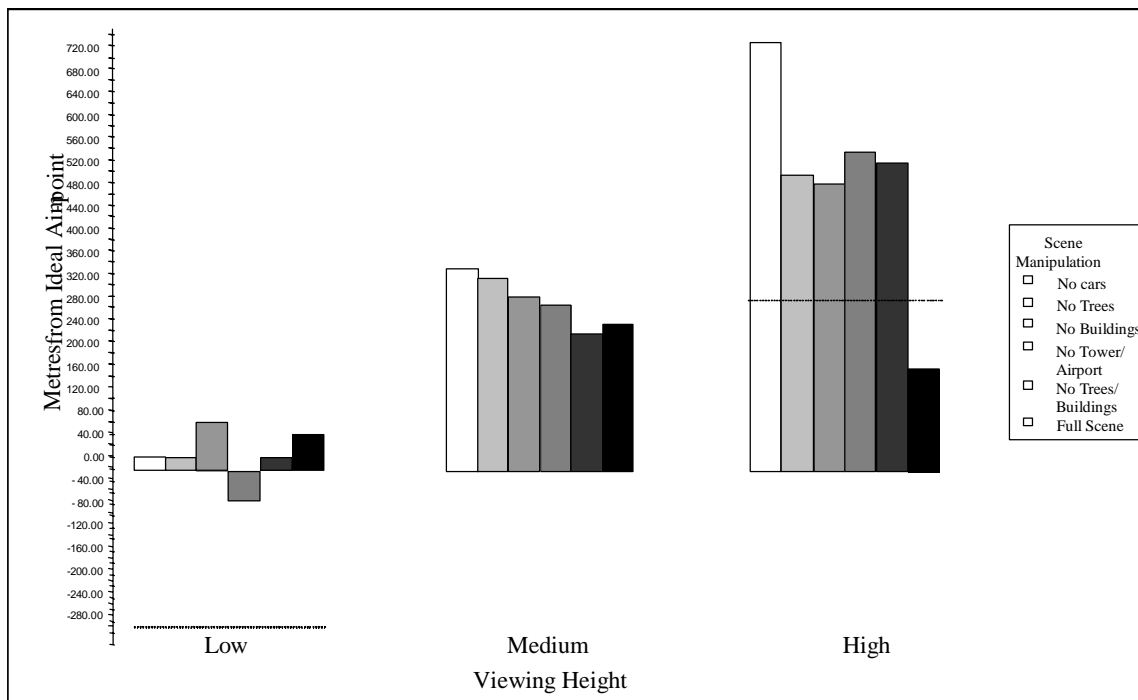


Figure 15: The average distance from the ideal aim-point that participants estimated their aim-point to be across different scene manipulations. Lines indicate the actual aim-point.

**Participants' response to the visual scene** After the participants had completed the experiment and agreed to complete the questionnaire, they were asked whether they noticed runway width changes. Twenty-nine out of 32 participants (90.6%) reported that they noticed runway width changes and participants who had noticed changes to the width of the runway were asked to rate what impact the changing width had on their estimation of altitude. Participants were given a scale of 1 to 10 with 1 being of no importance and 10 having an extremely significant impact and the resulting median rating was a 7 out of 10. Participants were also asked what impact the additional runway marking had on their estimations of altitude. 18 out of 32 participants (56.2%) of participants reported that they noticed changes in the markings on the runway. The median rating given by participants for the additional runway marking was 2.

Participants were asked to identify what objects or aspects of the visual scene they used to aid their altitude estimation. See Figure 16 for a graph that represents the objects people used and the percentage of participants that used each object. As can be seen from the graph, the objects that most participants used to judge altitude were the vehicles. There were three vehicles in the runway scene with one red car on the road with an orange truck and a white Ute. The second object type most commonly used were buildings in the runway scene that were present in most, but not all the scenes. Thirdly, fences were used to judge altitude by a large group of people. It is interesting to note that there were a greater number of people who reported using the vehicles to judge their altitude rather than relying on objects in the scene that were more constant e.g. buildings. See Figure 17 is a runway test scene that is included to identify the objects that most participants reportedly used to estimate altitude. It is interesting to note that the objects commonly reported by participants as being useful in their judgement of altitude are actually located in the foreground of the visual scene. Many participants reported after completing the experiment that if the image was divided up into four equal squares, they focussed on the two lower segments rather than the screen as a whole whereas other participants reported that they would use one square segment to estimate altitude.

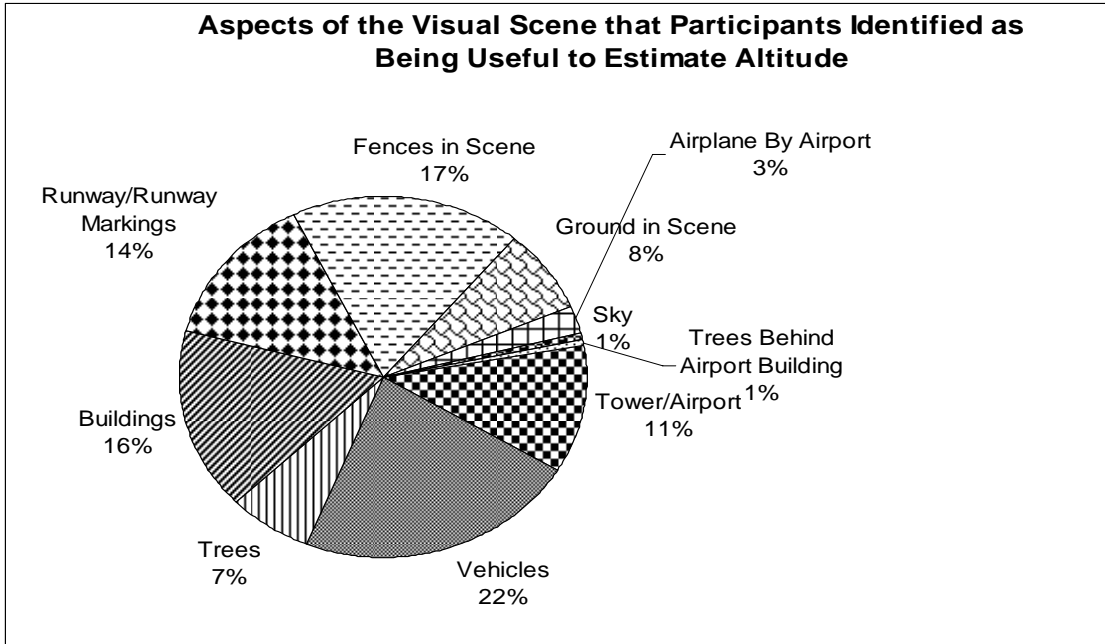


Figure 16: Aspects of the Visual Scene that Participants' reported using to estimate altitude and the percentage of participants that used them.

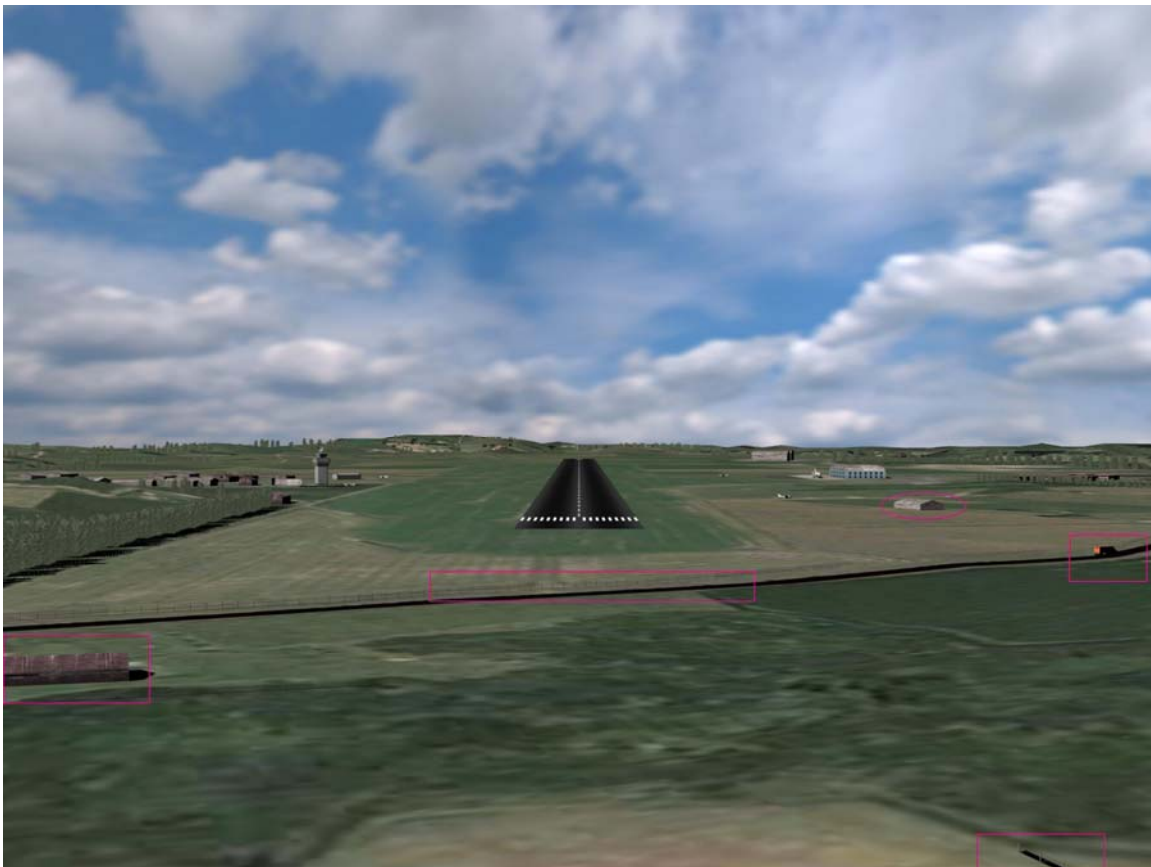


Figure 17: The most common objects in the visual scene that participants reported they were using to estimate altitude.

In the questionnaire, participants were also asked whether they noticed any changes in scene detail. Twenty-nine of the 32 participants (90.6%) reported that they noticed changes in scene detail. Participants were then asked to record what changes in detail they noticed by circling aspects of the visual scene and recording anything else they saw in the experiment that was not present in the picture given. Vehicles and buildings were the objects most commonly reported by participants as changing in the scenes with the tower, airport and trees also being reported to change. In addition to the objects reported missing in the scene, the following changes to scene detail were also mentioned; 3% reported the airplane by the airport missing, 10% reported the runway, and its markings changed, 5% reported that the ground in the scene changed, 7% reported changes to a road in the scene and 10% reported that the fences changed. It is interesting to note that these identified elements of the scene were reported to change as none of these changes occurred at all. The second most commonly reported change in scene detail were the buildings which were present in some scenes and not in others. See Figure 18 for the location of these changes in scene detail. Using vehicles to judge altitude meant that participants used variable aspects of the scene in order to judge their altitude as the vehicles moved. As a result of this, most participants were judging their altitude off objects that were not stable and consistent.

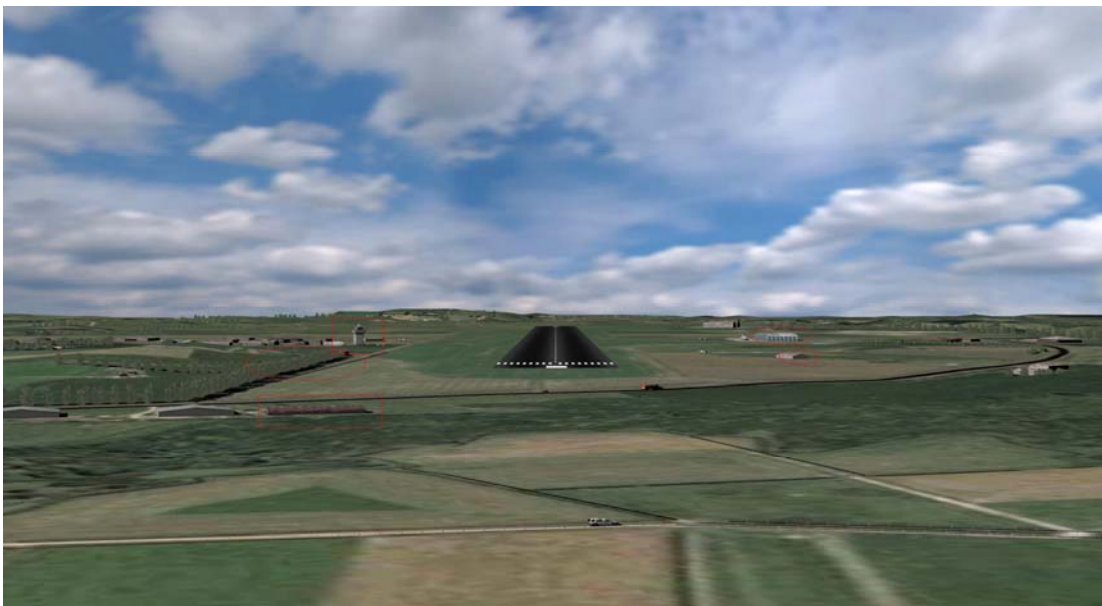


Figure 18: The most common objects in the visual scene that pilots reported they were using to estimate altitude.

## Pilots' Data for Comparison with Non-Pilots

**Pilots' responses to static scene.** Figure 19 shows the average altitude estimates in the static trials from the three pilots tested. The pilots showed good agreement in their estimates for the wide runway but not for the narrow runway. Overall the pilots were more accurate with their altitude estimations than non-pilot participants. As can be seen in the graph, pilots' estimates of altitude were highest when viewing runways from the high viewing height and were more accurate when viewing runways from the low viewing height which was also typical of the non-pilots' data. It appears from the graph that there was a runway width illusion amongst pilots that was especially apparent when scenes were viewed from the high viewing height. This finding was similar to the non-pilots data, as the runway width illusion also appeared in the non-pilots data particularly when comparing the scenes viewed from the high viewing height to the scenes viewed from the low viewing height as is the case with the pilots' data. Overall the pilots were more accurate at estimating altitude than non-pilots who greatly overestimated their altitude and typical of the runway width illusion, lower estimates of altitude were made for wide runways as was typical in both groups.

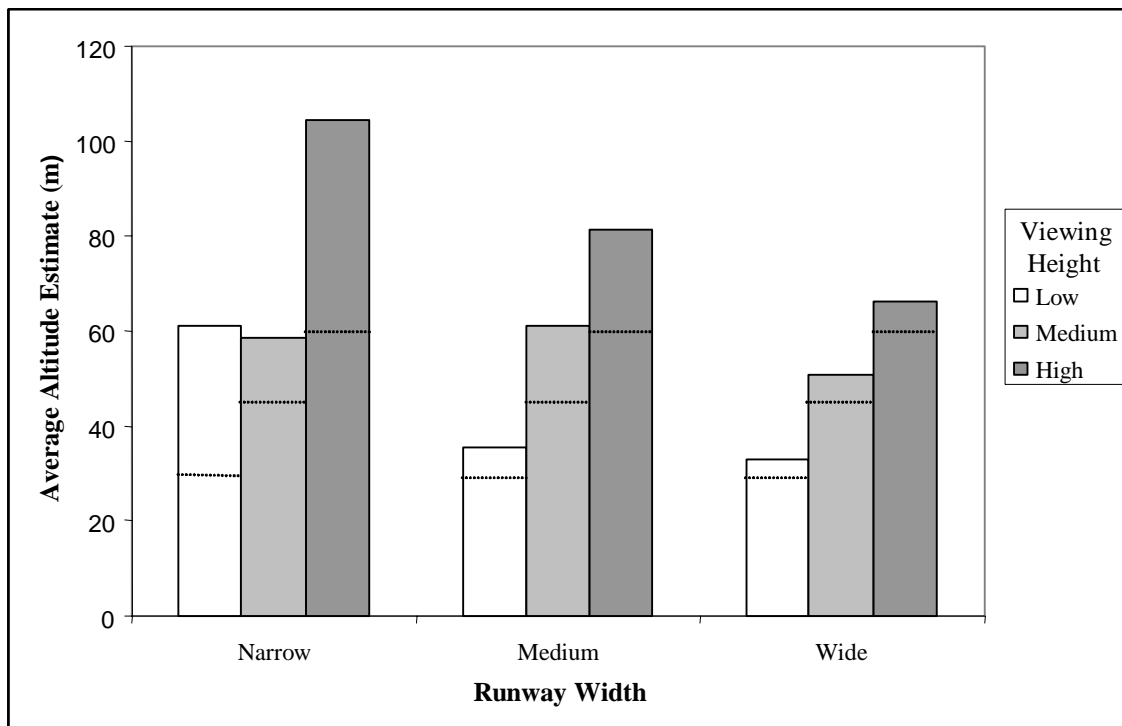


Figure 19: Average altitude estimates made by pilots across different runway widths and different altitudes in static trials. Dashed lines indicate the actual altitude.

**Pilots' responses to dynamic scene** Figure 20 displays the average altitude estimate made by pilots over different runway widths in the dynamic trials. As can be seen from the graph, the results for the dynamic trial were different to the results obtained in the static trial. Although the sample size (3 pilots) did not permit statistical comparison, the figure shows that the patterns were different to the non-pilot participants. Firstly, the magnitude of error was smaller amongst pilots as the altitude estimations made by pilots' were more accurate than the data collected from non-pilots as can be seen by the dashed lines which indicate the actual altitude. Non-pilots estimates of altitude were highest for the narrow runway, whereas in the pilots' data there is no width that is salient as having the highest altitude estimates. Secondly, the runway width illusion is not present in the pilots' data whereas in the non-pilots' data, the illusion was present and showed the same pattern as the estimates made in static trials with the highest estimates being made for the narrow runway. In the pilots' data estimates made for the narrow runway were slightly lower when viewed at the medium and low viewing heights than the estimates made for the medium and wide runways, which was contradictory to what was predicted by the runway width illusion. The runway width illusion predicted that altitude estimates made when viewing narrow runways would be higher than when viewing wide runways, however this does not present itself in the pilots' data. Thus, while the runway width illusion was present in both static and dynamic data for non-pilots, the illusion was only present in the static data amongst pilots. As can be seen when comparing Figures 19 and 20, pilots' were more accurate at estimating altitude in the dynamic trials which was the same finding with the non-pilot participants.

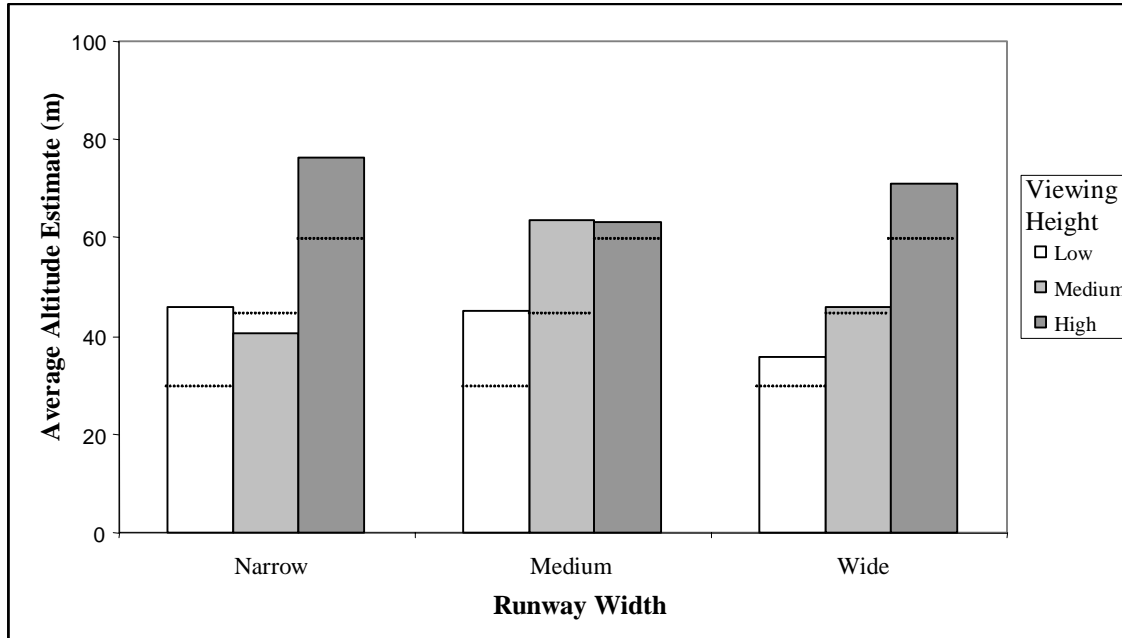


Figure 20: Average altitude estimates made by pilots across different runway widths and different altitudes in dynamic trials. Dashed lines indicate the actual altitude.

**Analysis of pilot's data for static scenes with manipulations.** Figure 21 displays pilots' average altitude estimates over different scene manipulations to a runway of medium width viewed at all three altitudes. In static trials, pilots' most accurate altitude estimates were made when viewing scenes at the low viewing height. It is interesting to note that in the scenes where there were neither buildings nor trees present and no cars, pilots greatly overestimate their altitude at the high viewing height whereas between the other manipulations there was a trend that was similar trend to the results for the full scene. The results from the pilots' data are similar to non-pilots in the fact that both groups overestimated their altitude when viewing scenes from the high viewing height. However, when viewing scenes from the low viewing height, pilots' were fairly accurate at estimating altitude relative to all scene manipulations. Overall it can be seen that pilots are more accurate at estimating their altitude than non-pilots in static trials.

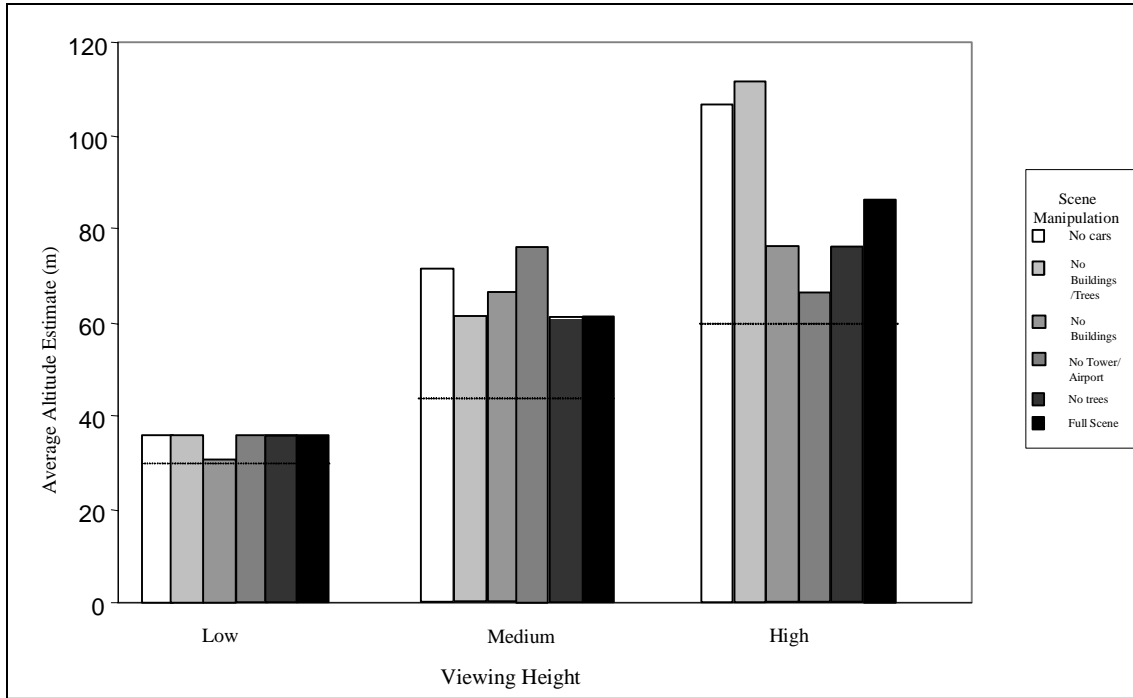


Figure 21: Average estimates of altitude made by pilots as a function of different scene manipulations and the three viewing heights in the static trial. Dashed lines indicate the actual altitude.

**Analysis of pilots' data for dynamic scenes with manipulations.** Figure 22 displays pilots' average altitude estimates relative to different scene manipulations in the dynamic trial. As can be seen in Figure 22, pilots' overestimated their altitude when viewing scenes from the high altitude that had; no manipulations, no tower nor airport and no buildings or trees. Pilots were fairly accurate at estimating their altitude when viewing runways from the low altitude, but it is interesting to note that in scenes with no manipulations and no trees viewed at the medium altitude, pilots overestimated their altitude significantly from the other data values in at this height. Contrary to the non-pilots' data, there were several scene manipulations at the medium and high viewing heights where pilots' underestimated their altitude. This finding is different to the findings from the non-pilots data as non-pilots consistently overestimated their altitude across all three viewing heights, whereas the pilots' data was more variable. A similar finding between the two groups was that there was more consistent altitude estimates

made when viewing the low altitude and this finding was found in both non-pilots' and pilots' data.

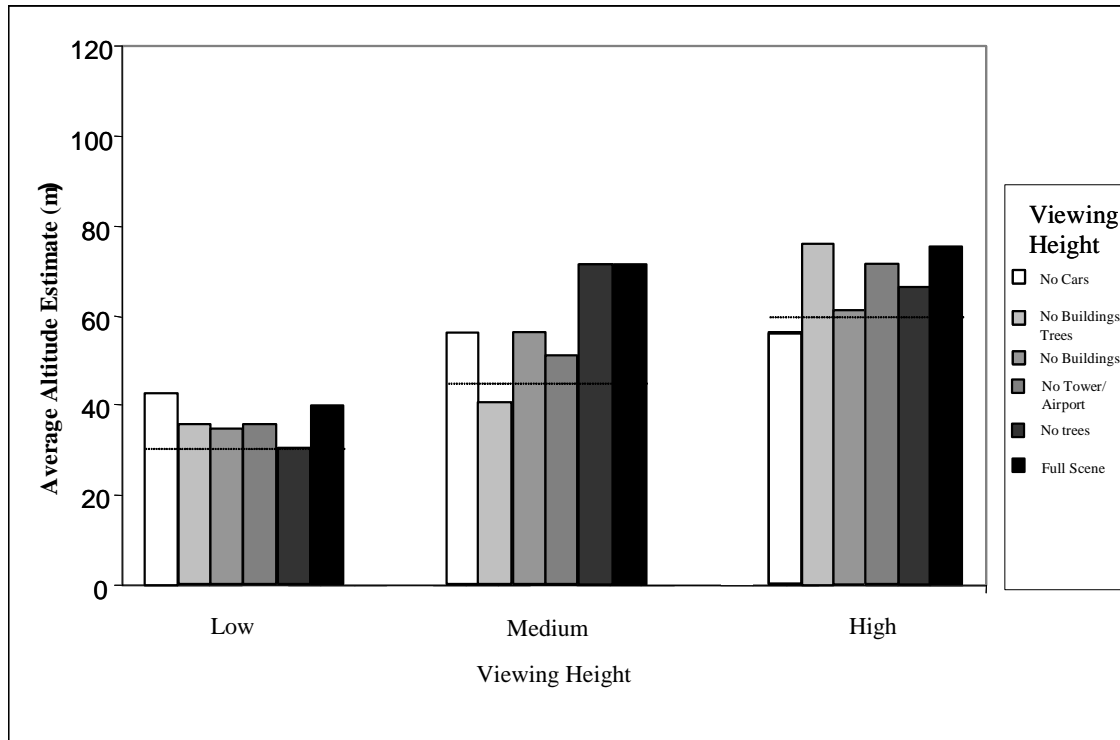


Figure 22: Average altitude estimates made by pilots relative to scene manipulations and viewing height in the dynamic scenes. Dashed lines indicate the actual altitude at each viewing height. .

**Analysis of pilot's estimates of aim-point.** Figure 23 represents the average aim-point estimate made by pilots across the different viewing heights and scene manipulations. As can be seen from the graph, pilots correctly estimated that the actual aim-point was further down the image before the runway when they viewed scenes from the low viewing height. Similarly, when viewing scenes from the high viewing height, they correctly estimated that the aim-point was further up the runway. It is interesting to note that pilots, who reported in their questionnaire that they most often used the tower to estimate their altitude, greatly underestimated their aim-point when viewing a scene from the medium viewing height when there was no tower/airport present. In the full scenes, pilots were most accurate at judging their aim-point when viewing a scene from the

medium viewing height. It is interesting to note that those pilots estimated their aim-point to be on the ground before the runway, whereas non-pilots were more inclined to estimate their aim-point to be further up the runway. Pilots appear to be more accurate at estimating aim-point than non-pilots because they appear to be able to differentiate when an aim-point is further up or down the runway. It is very interesting to note that pilots almost correctly estimated their altitude when viewing the full scene from the low altitude whereas non-pilots were generally inaccurate across all scenes and heights. It should be noted that the medium viewing height is the ideal flight path and altitude for an aircraft to located and thus the sort of flight path that pilots should have been familiar with. However the data for the medium viewing height is not consistent and appears to differ depending on scenes being viewed. Overall it appears that when the pilots' viewed scenes from the low viewing height, they were most inclined to correctly estimate aim-point further down the runway and when they viewed scenes from the high viewing height they were inclined to estimate aim-point further up the runway

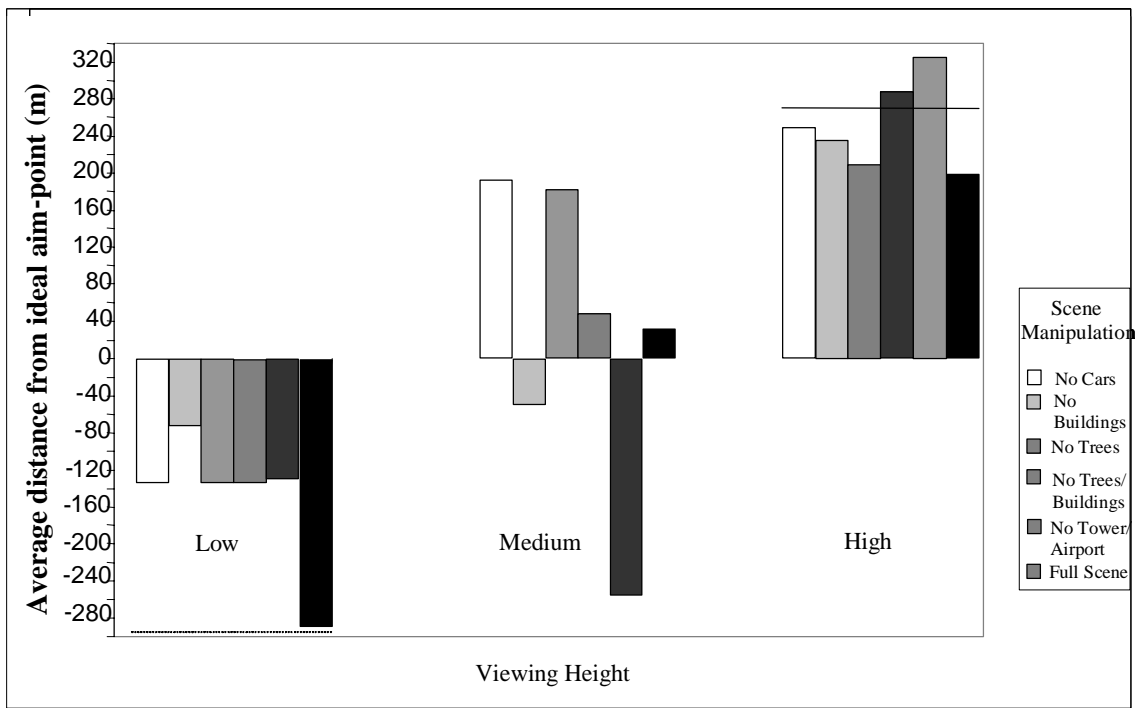


Figure 23: Pilots' average aim-point estimates relative to five different scene manipulations and three different viewing heights. Lines indicate the actual aim-point.

**Pilots' Response to the Visual Scene.** The pilots who participated in this study also completed the questionnaire. With regards to the varying runway width, all the pilots in this study reported noticing the runway width differences and were asked to rate the importance of the varying width on their estimation of altitude with 1 being of no importance and 10 having an extremely significant impact. The median rating of the pilots' responses was a 9 and thus pilots perceived that the changing runway width was more important than the non-pilots. Two out of the three pilots reported that they had noticed the additional runway marking and the median rating given by pilots' for the impact of this marking was 4 which is more importance than the non-pilots rated the marking. With regards to the objects that pilots used to estimate their altitude, the four objects mentioned were; the aircraft control tower, the airport building, the plane by the airport and the trees. Thus, pilots reported using quite different objects to non-pilots and in particular used objects that one would have to become familiar with the size of. With regards to the changing runway visual scene, only two of the three pilots reported that they noticed changes in scene detail. The object most commonly reported by pilots as being used to judge altitude was the aircraft control tower and the other objects reported were also the buildings in the scene and the trees. It is interesting to note that the pilots who did notice scenes changes predominantly noticed the tower missing in the airport scenes. Compared to non-pilots, relatively few non-pilots noticed the changes to the aircraft tower in the scenes. It is also interesting to note that out of every change that pilots noticed in the scene was actually one of the scene manipulations, whereas a minority of non-pilots reported changes that never occurred e.g. in the fences. This could possibly be that the pilots predominantly used certain objects e.g. the tower/trees that were coincidentally modified in the chosen scenes.

## Discussion

This experiment was intended to research the runway width illusion which has been reported by pilots and researchers alike. In this experiment, participants viewed scenes of a simulated landing at three different viewing heights and with three different runway widths. During these simulations, participants were required to make judgments of altitude in both static and dynamic trials and they were also required to estimate aim-point in the dynamic trials. The results of this experiment indicated that the runway width illusion was a robust phenomenon as it was present in both static and dynamic trials even across the different cues present in each trial. In addition to the illusion being present in altitude estimations across static and dynamic scenes, the illusion was also present in aim-point data. A further finding in this research was that participants' were more accurate with their altitude estimates in the dynamic trials than they were in the static.

This research aimed to combine previous research into pilot perceptions, and misperceptions of the runway by having both a static and a dynamic trial. While other research has tended to focus on either a static or dynamic methodology, the results from this experiment indicated that there was a difference between the static and dynamic methodologies, as has been reported by various researchers (Best, Crassini & Day, 2002, Hahn, Andersen & Saidpour, 2003). Static visual information in a runway scene is typically thought of as being the runway size, shape and angle of descent whereas dynamic information is related to the motion of the visual scene. In the current experiment, participants were asked in the experimental questionnaire what cues they had used to estimate altitude. However, participants were not specifically asked what cues they had used to estimate altitude in the static trials and what cues they had used in the dynamic trials. If participants had been questioned about what cues they had used to estimate altitude and aim-point, it would have been possible to conclude or refute the belief that participants were using different cues and perhaps a different method to estimate their altitude across static and dynamic trials. If this experiment was to be

repeated, it would be advantageous to question participants about what cues they used to estimate altitude.

The results from this experiment indicated that there was a robust runway width illusion phenomenon which was consistent with previous research into illusions associated with runway width (Ewing, 2001; Kraft, 1978; Lintern & Walker, 1991; Mertens & Lewis, 1982). It is interesting that the findings from this experiment regarding the difference between the three runway widths were consistent across both the static and dynamic trials. There have been various researchers who have documented the runway width illusion as being present in static research results (Ewing, 2001; Hasbrook, 1975; Lintern & Walker, 1991; Mertens & Lewis, 1982). Researchers like Mertens and Lewis (1982) and Lintern and Walker (1991) also reported the runway width illusion as being present in dynamic trials. A similarity between Lintern and Walker's research and this experiment was that Lintern and Walker (1991) had a similar independent variable with three runway widths (narrow, standard and wide) however glide-slope was used as the dependent variable rather than altitude and aim-point estimations. In a similar experiment, Mertens and Lewis (1982) also measured approach angles to analyse the approaches flown by pilots to runways of different widths. This present research further demonstrates the robustness of the runway width illusion as the illusion has been found to be present across altitude estimations, glide-slope and approach angle measurements.

While past research has found evidence of the runway width illusion in glide-slopes and approach angle measures, the runway width illusion was present in the aim-point data of this experiment. Analysis of the aim-point data revealed that there was an interaction between runway width, viewing height and additional marking. When the additional runway marking was present, participants underestimated their aim-point at the low viewing height with the narrow and medium runways. However, when the additional runway marking was absent, participants overestimated their aim-point for the narrow and medium runways at the low viewing height, but underestimated their aim-point for the wide runway at the low height. The above differences in the data account for the interaction between runway width, viewing height and additional marking that was found

in the data analysis. The current experiment has added to the previous literature into aim-point as the results have revealed that not only can variations in glide-slope affect perceptions of aim-point, but variations in runway width can also affect aim-point accuracy. However, it should be noted with regards to aim-point that the concept of an aim-point is foreign amongst non-pilots. This is because none of the participants had been in the cockpit of an aircraft and therefore it was difficult to know if all the participants knew what was meant by the term aim-point. It was explained to all participants in a simple manner, and all participants' were asked if they knew what was required of them when they needed to estimate their aim-point, however it is still difficult to know whether the participants did actually know what was meant by the concept. During the five practice trials at the start of the dynamic experiment, participants' had an opportunity to practice estimating their aim-point before they had to estimate aim-point in the actual experimental scenes. However, it is possible that some participants were still not sure exactly what they were meant to do when they estimated their aim-point. However, it should be noted that in a landing task, previous research has shown that naïve observers can estimate their heading direction accurately when presented with a field of dots at different depths.

In the aim-point data, it was interesting to note that in the scenes with manipulations, there were differences between the three viewing heights and the different scene manipulations. With regards to the differences between the five different scene manipulations, the scene with no cars and the scene with no trees or buildings were marginally different from each other however these were the only two manipulations out of the five that were marginally different at all from each other. The marginal difference between the scene with no cars and the scene with no trees or buildings is interesting because the vehicles and buildings were the objects that most participants' reported as using to estimate their altitude. Thus it appeared that the participants estimation of aim-point was affected when the two main objects that participants' mostly reported using to judge their altitude were missing in the scene. From previous research it has been reported in previous research that aim-point is affected by texture and the level of detail present in a flight scene (Reardon, 1988). In Reardon's (1988) experiment it was

reported that when there was a lack of texture, participants estimated their aim-point as being closer to the start of the runway and as the level of texture increased, aim-points were estimated further down the runway. While Reardon's experiment focussed on aim-point and texture, there has been little research into the errors generally associated with judging aim-point. Previous research into aim-point has revealed that participants accuracy in estimating aim-point was associated with steep and shallow glide-slopes and when there were shallow glide-slopes; participants mostly underestimated their aim-point and overestimated aim-point for steeper glide-slopes (Ahumada, 1983). Acree (1981) reported similar results to Ahumada (1983) with regards to different glide-slopes affecting participants estimation of aim-point. Thus it is difficult to compare the results of the current experiment with the research literature as there has been limited research into aim-point.

An important component of this research was to examine the differences, if any between static and dynamic visual images. As has been stated, there was a difference between static and dynamic images, and participants' estimations of altitude were more accurate in dynamic trials. There are several possible reasons that participants' were more accurate in dynamic trials. Firstly there could be an effect of order as the dynamic trials were presented after the static trials. Thus there may not have been a difference in the cues available in the dynamic scenes but was just an order effect. If this research was to be replicated, there should be a sub-group in the sample of participants who would view the dynamic scenes before the static scenes. A second possible reason that dynamic trials were more accurate than static could be due to the fact that the motion cues present in dynamic scenes provided participants with better quality cues than in the static scenes and thus resulted in more accurate altitude estimates. This is interesting to note as participants could clearly discriminate between the three different heights in the dynamic trials, but in the static trials, participants could not discriminate between the medium viewing height and the highest viewing height. A possible reason that participants did not notice the difference between the medium and high runway heights could be due to the differences that existed between the static and dynamic cues present in the scenes. It could be that in the dynamic scenes, there were certain cues present with the motion that

enabled participants to discriminate between the three viewing heights. One study in the literature that investigated the effects of altering the simulation start approach was a study by Mertens and Lewis who investigated the effects of altering approach conditions. Mertens and Lewis (1983) manipulated approach angle at the start of a flight sequence that pilots had to fly and land and it was found that there was a significant effect of starting angle with distance from the runway and therefore the angle at which pilots had to start controlling the model affected their later approach angles. Thus, even though the pilots' in Mertens and Lewis' experiment should have been able to determine their altitude from their starting approach and therefore fly a constant approach angle, the starting angle affected their ability to fly a safe flight path (Mertens & Lewis, 1983).

In this experiment, although the main population consisted of non-pilots, there were also three pilots who participated in this study. When viewing the altitude data collected for both pilots and non-pilots, it is obvious that there are differences between the two groups. In an analysis of pilot's data in static trials, it was found that pilots' estimates of altitude at the high viewing height were highest for narrow runways and lowest for the wide runways as was predicted by the runway width illusion. It should be noted that there were only three pilots and as a result of this, there was not enough data to obtain data that can be generalised but it can be seen that pilots' who have been trained in an aviation environment would have been informed about the runway width illusion. In the dynamic trials, there were different results for the high viewing height than were present in the static trials. It was found that pilots average altitude estimate was highest for the narrow runway width, the lowest average altitude estimate was made for the medium runway and the altitude estimation for the wide runway was between the average estimates for the medium and wide runways. However at the low viewing height, the data was consistent with research literature into the runway width illusion (Ewing, 2001; Kraft, 1975; Lintern & Walker, 1991; Mertens & Lewis, 1982). However, as it has been noted previously, there were only three pilot participants' and therefore the data gathered is not generalisable.

When comparing pilots and non-pilots, the element of familiarity with the runway scene is worth consideration. Various research findings have reported that there is an element of familiarity that pilots have with the runway scene (Gogel & Mertens, 1966; Li, 2006; Mertens, 1981; Mertens & Lewis, 1983). Previous research has reported that pilots may become familiar with the runway scene and therefore become familiar with the view of the runway at various altitudes when landing. Mertens and Lewis reported that there was a general tendency of pilots to overestimate approach angles when they landed on unfamiliar runways as they were not familiar with the size of the terrain (Mertens & Lewis, 1983). In this experiment, non-pilots would not be familiar with what a runway looks like from different altitudes, a scene that pilots would be familiar with, and therefore the estimations of altitude that participants made were overestimated in both static and dynamic trials that was possibly due to unfamiliarity. Thus, the findings in this experiment are consistent with previous research by Hasbrook, Ewing and Lintern & Walker who reported an element of familiarity with different runway sizes and altitudes amongst their participants (Ewing, 2001; Hasbrook, 1975; Lintern & Walker, 1991). With regards to viewing height, pilots' average altitude estimate was highest for the high viewing height and the lowest altitude estimate was for the low viewing height. Thus, pilots appeared to be able to discriminate between the different viewing heights, however as there were only three pilots, it was not possible to conduct parametric statistics and comparisons to confirm or deny this claim. It is still interesting to note that the average altitude estimates made by pilots for each of viewing heights are still slightly over-estimated. In the dynamic trials, there were similar findings to the static trials as pilots' lowest estimated altitude was for the low viewing height, and the highest estimated altitude was for the high viewing height. Also, like the static trials, average altitude estimates in dynamic were over-estimated. The differing results between participants and non-pilots thus suggests that familiarity may be involved in altitude estimation.

From the questionnaire results, it should be noted that there were a number of participants who reported they did not notice the runway width changes. Of the 32 non-pilot participants in the experiment, 9.4% reported that they did not notice changes to the

runway width. There are two possible reasons that non-pilot participants did not notice changes in the runway width; the fact that the changing width was implicit or due to the illusion itself. The changing width of the runway could have been processed by participants at an unconscious level and may therefore be implicit. Because participants were not aware that they were processing the changing width of the runway they were unable to report that they had noticed changes when they were asked in the questionnaire. Alternatively, some participants may not have noticed changes in runway width due to the fact that the runway width illusion was very strong. Thus, when the runway was wide, participants perceived they were lower and when the runway was narrow, participants perceived that they were higher and therefore did not realise that the runway width was changing. These were the two most likely reasons that participants did not notice changes to runway width.

A component of this experiment was dedicated to the investigation of where participants were focusing their attention in the visual scene. It had been reported by various researchers that terrain and features in the environment can influence pilots' decisions in the landing of aircraft, and thus could be utilised in an attempt to overcome the runway width illusion. The questionnaire at the end of the experiment asked participants what aspects of the visual scene they used to judge their altitude. Participants' most commonly reported that they used the vehicles in the scene to estimate their altitude. The second most common item in the scene that was reportedly used by participants to judge altitude were the buildings in the scene. The most common building that was reportedly used was the barn in the paddock on the left in the end frames. It is interesting to note that participants most commonly reported using vehicles to estimate their altitude. Vehicles in the dynamic scenes were highly variable in the sense that they moved and were never still for participants to compare the size of a particular vehicle to other aspects of the visual scene. The fact that participants used variable aspects of the scene to judge their altitude could explain why participants were not very accurate at judging their altitude. However, while this is one possibility, there are many other possible reasons why participants' were inaccurate with their altitude estimates. It is interesting to note that most participants' reported using items in the scene that they were

familiar with which is consistent with the research literature. In an overview of the three pilots that took part in the experiment, it can be seen that the objects they reported using to judge altitude were different to the objects that non-pilots reported as commonly using e.g. the aircraft tower, planes by the airport. Objects such as the tower and plane by the airport in the visual scenes would be objects that pilots would be familiar with and would see on a regular basis while flying. A non-pilot in contrast would not be familiar with how high the aircraft tower was or how large a plane appears when viewed from different altitudes. Thus, familiarity with the runway scene does appear to impact on decisions made by participants when landing.

Haber (1987) theorised that familiarity with terrain surrounding an airport could influence perceptions of landing. The main problem associated with familiarisation of the runway scene is that pilots become accustomed into accepting low approach angles if they are familiarised with wide runways. These research findings are consistent with the research by Sanocki (2003) and Andersen & Enriquez (2006). Haber (1987) theorised that familiarity with terrain could affect judgments of height relating to the height of objects in the visual scene. Sanocki (2003) similarly developed a theoretical framework derived from the notion that familiarity with a scene could affect future judgments about a scene. Sanocki reported that prior experience with a scene could affect later processing of scenes. Similarly, Andersen and Enriquez (2006) reported that landmarks or anchor points could be found in a scene that could later act as reference points in a visual task. Thus, the research findings in this experiment can be related to past research where it is possible for participants to establish anchor points that they could become familiar with in order to establish altitude in the runway scenes.

A further manipulation in this experiment was to delete certain objects in the visual scene to determine whether participants noticed them missing. This was done to validate the objects that participants most commonly reported using. 90.6% of participants reported that they noticed changes in scene detail, thus some participants never noticed that there were changes in the visual scene. Of the participants who noticed changes, the changes most commonly reported were the vehicles and the various

buildings being removed from the scene and some participants also noticed the trees and tower/airport building being removed. It was interesting to note that the objects that participants most commonly reported using to judge their altitude were in the lower segment of the scene however the objects that participants commonly reported as changing were the objects surrounding the runway. This finding posits the idea that participants may look at objects on the ground to estimate height, but still maintain a focus on the runway. While this is one possibility, the meaning of this finding is not totally clear. It was also interesting to note that there were some scene detail changes recalled that had not changed at all. With the high percentage of participants noticing changes to the vehicles in the scene, and commonly reporting that it was the vehicles in the scene that were mostly used to judge altitude, it can be assumed that most participants were focusing on items that they were most familiar with which is consistent with previous research. Participants would know the average size of a car, a truck or a farm Ute, and therefore it is likely that this could have largely been the reason that these items were so commonly used and therefore obviously absent in some scenes. It is also interesting to identify what objects pilots commonly reported missing from the scenes. The aircraft tower was the most commonly reported object missing in the scene, followed by sheds, the trees and the airport building. In the static scenes, it was found that pilots were inclined to overestimate their altitude when there was no tower/airport present from the medium viewing height. In the dynamic trials, pilots underestimated their altitude when viewing scenes with no tower/airport or no buildings/trees at the medium viewing height. Thus, the presence or absence of objects that pilots used in estimating altitude had an impact on their ability to accurately estimate altitude. None of the pilots' reported that there were changes in the visual scene that were not actually manipulations.

In the research literature, there were few studies that had scene manipulations that were similar to the manipulations used in this experiment. As such, the results are hard to compare with the present experiment with most research into texture focusing on the instruments that pilots use in flight, and where pilots focus their attention in the cockpit (Fitts, Jones & Milton, 1950). Andersen and Enriquez (2006) conducted research into the use of landmarks and the layout of a visual scene and it was reported that participants

in their experiment used an allocentric perspective (participant viewed a scene and their positioning independent of landmarks in the scene). The study by Andersen & Enriquez (2006) reported results that are consistent with this present study as participants were not affected by the absence of objects in their visual field, and therefore likely viewed their positioning independent of landmarks in the scene. This is consistent with the findings in the current experiment with regards to the fact that there was no significant difference between the various scene manipulations. Comparisons between static and the dynamic trials revealed that there was statistical significance between all three viewing heights and with regards to scene manipulations there was no significance between any of the scene manipulations. Thus, the perceived height of the viewer was significant in the scenes, but the actual aspects of the scene that were present or absent (the manipulations) were not significant. Further aviation research is needed into the presence of absence of objects in the visual field in order to draw more definitive conclusions about landmarks and layout of the visual scene.

It was hypothesised that the runway width illusion would be present in this experiment and therefore an additional runway marking was placed on the runway in an attempt to overcome the illusion. This marking was a standard size (50ft x 50ft), however participants in the experiment were not informed about the size and shape or even the purpose of the marking. This marking was based on the rationale that a standard sized shape would signal any change in runway width, and therefore pilots, and non-pilots would be alerted to the fact that the runway width was changing and therefore alter altitude judgments due to this variation. The results from this experiment revealed that there was no significant effect of additional runway marking and thus, the standard shape on the runway had no effect on participants' estimation of altitude. Only 56.2% of participants reported that they noticed changes in the runway markings and therefore nearly half of participants did not notice any runway marking changes. As has been stated previously, this finding could be due to the implicit properties of the runway or the illusion itself. In the experiment, participants were also asked to rate the importance of runway width their estimation of altitude and of the 18 participants who reported runway marking changes, only 4 participants rated the importance of the marking in their altitude

judgments over 5 (moderately to very influential), thus, more participants rated the additional marking as having little effect on their judgment of altitude. It can be concluded that the additional runway marking had little influence on participants' conscious effort to estimate altitude.

In the research literature, there has been limited research in the area of additional runway markings to guide pilots' descent. Kelly and Bliss (1971) conducted an experiment into the effects of triangles on the runway believing that having additional shapes on the runway could serve as a point of reference for pilots. Moert, Estes, Andrews and Olmos (2005) reported that changes made to taxiway intersections resulted in these intersections being detected earlier than the traditional markings on taxiways. It was reported casually by most participants after they learned the details of the standard runway marking that if they had known that it was a standard size, they would have used it more often. It was also reported by participants that the marking had more effect on estimation of aim-point rather than altitude estimate and most participants reported that the standard runway marking was more useful when judging aim-point rather than altitude. Thus, if participants had been told of the dimensions of the runway marking, it may have been of more use to them in judging altitude more correctly. Although the additional runway marking had no effect in this experiment, additional information gathered can be used to refine the marking. There are four main possibilities about why the standard runway marking did not influence participants' estimations of altitude. Firstly, it could be that non-pilot participants are not familiar with runway markings in general and therefore did not notice when there was an additional shape on the runway. Secondly, the runway and markings on the runway were not greatly reported by participants as being used to judge altitude, therefore participants may have been focussing on other objects in the scene e.g. vehicles and trees rather than looking at the runway thus participants would not see the additional marking. Thirdly, in aim-point estimates, there was a difference between runways viewed with a standard marking and those without, therefore the standard runway marking may have had implicit properties and participants had unconsciously used it to estimate their aim-point but had not consciously processed the shape. It should also be noted that it was not certain that the

shape of the additional marking (a square) was the optimum shape to use and further research is required into the possible usefulness of other shapes. Lastly, it is possible that the shape was too small and perhaps a larger shape would have had a greater effect.

As a result of the findings of the research, it is possible to posit a more effective marking for testing in future research. In the experiment, participants commonly reported using objects in the lower segment of the image and therefore further research could focus on testing objects in the lower segment of the simulated scenes in order to guide a pilots' descent onto the runway. It is possible that the square marking that was used in this experiment was the incorrect shape and that perhaps a triangle, diamond or another shape would be more effective to use as a marker. Indeed previous research into landing on aircraft carriers experimented with triangles to guide pilots into land and therefore there needs to be further research into which shape would be most effective in aiding pilots to estimate altitude and glide-slope. It was interesting to find that buildings were one of the most commonly reported objects by pilots and participants in this study as being used to estimate altitude and therefore it is possible to identify what kind of objects could be placed in the visual scene to aid pilots in landing. Further research could focus on the viability of having a standard shaped building or a tree beside the runway or in the lower segment of the scene that pilots are informed about located in the same place at each airport. Although there appears to be a vast abundance of research possibilities arising from the standard marking in this experiment, it should also be considered that the main population in this experiment were non-pilots and therefore the location in the scenes that they appeared to be focussing may differ from where a population of pilots may focus. Therefore further research does need to be conducted into the location that pilots focus in the visual scene.

### **Limitations of the Study**

There are several main limitations that were present in this study. Firstly, as can be seen from the research literature, and the current experiment, familiarity with the visual scene is an important component to be considered in a study involving altitude estimates. Non-pilots do not have any form of familiarity with a runway scene, and

therefore the results that were obtained from non-pilots can only be considered tentative results. This experiment should be replicated with pilots rather than non-pilots as they are the sort of participants' required in order to fully investigate the landing phenomenon. Pilots' have a lot of experience with landing and as a result the data obtained from a sample of pilots would give more definitive results. Secondly, many participants' remarked after the experiment that if they had been informed about the standard runway marking, they would have used it more. Therefore, if this experiment was to be replicated, the experimental design could incorporate a group in the sample that were informed about the standard runway marking, and then it could be determined whether knowledge of the shape would enhance its influence. Thirdly, the differences present between static and dynamic trials required further investigation. The difference between the two trials could be due to the fact that static scenes were viewed first and the dynamic scenes were viewed second by all participants'. Therefore if this experiment was to be replicated, an experimental group should be assigned to viewing dynamic scenes first and static scenes second in an attempt to determine whether the order of presentation influences the results.

## **Summary**

The intention of this experiment was to investigate the runway width illusion in altitude and aim-point estimates and possible ways to overcome this illusion. The experimental design uniquely combined previous research methodologies in aviation perception research as this experiment included both static and dynamic trials. This research also aimed to determine where participants were focussing their attention in the runway scene and in order to do this, aspects of the runway scene were removed and participants were questioned whether they could report changes in scene detail and runway width. Consistent with previous research, the results of this experiment revealed that there was a robust runway width illusion that was present across both static and dynamic trials and altitude and aim-point data with dynamic trials resulting in more accurate estimations of altitude. In an attempt to overcome the runway width illusion in this experiment, a standard square runway marking was placed on the runway, the results indicated that although the marking did not alert participants to the different runway

widths, it still influenced participants estimations of aim-point. This research was successful in identifying what objects participants used to estimate their altitude in the visual scene and where participants were focussing their attention in the runway scene.

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**Appendix A:** The poster that was used to inform psychology students about the existence of the experiment.



## **Participants Wanted for Aviation Psychology Research**

This study is being done to investigate perception of the runway environment in the landing phase of flight. Participants will be required to complete several tasks on a simulated landing trial. You do not need to have any experience flying an aircraft. The main focus of the research is to explore perception of the environment during the landing phase of flight.

Participants will be rewarded with a petrol voucher for their efforts. 1% course credit can also be claimed for students of PSYC102.

If you are interested, you can contact the researcher on [nbr1@waikato.ac.nz](mailto:nbr1@waikato.ac.nz), or you can sign up in the research folder on the desk of the Psychology Office.

**Researcher:**  
**Natalie Reynolds**

**Research Supervisor:**  
**Dr Samuel Charlton**

**Appendix B:** The standard introduction and information sheet that participants read when they first arrived at the experiment.



## **Welcome to the Aviation Landing Experiment**

Welcome to the aviation landing experiment! This experiment was designed to further understand the perceptual properties associated with the landing of an aircraft and in particular the visual perception of the scene. In this experiment, you will view a total of 66 images. 33 of these images will be static (not moving) and 33 will be dynamic (moving scenes). In the static trials, you are required to estimate your altitude from where you perceive the ‘plane’ is in the scene down to the ground in the scene. In the dynamic trials you will be required to estimate your altitude and also your aim-point (where you perceive you would touchdown on the runway if the scene were to keep moving). Each dynamic trial is 10 seconds in duration and as such you are required to watch each of the scenes until they stop moving. After the scene has stopped moving, a cross-hatch will appear on the screen and to estimate aim-point, you will be required to move the mouse so that the cross-hatch appears at the point that you perceive the ‘plane’ would land if the scene kept moving. However, as the screen will go blank after you have clicked the mouse to indicate your aim-point it is best if you estimate your altitude before you click the mouse so that you do not forget your altitude estimate. After the experiment there is a quick questionnaire to complete and you will receive your voucher/course credit.

You are free to leave at any time without explanation and will continue to receive the voucher and/or course credit.

Thank you for taking part in this experiment.

Natalie Reynolds.

**Appendix C:** The recording sheets used by the researcher to record the altitude estimates made by participants for each runway scene.

**Static Scenes**

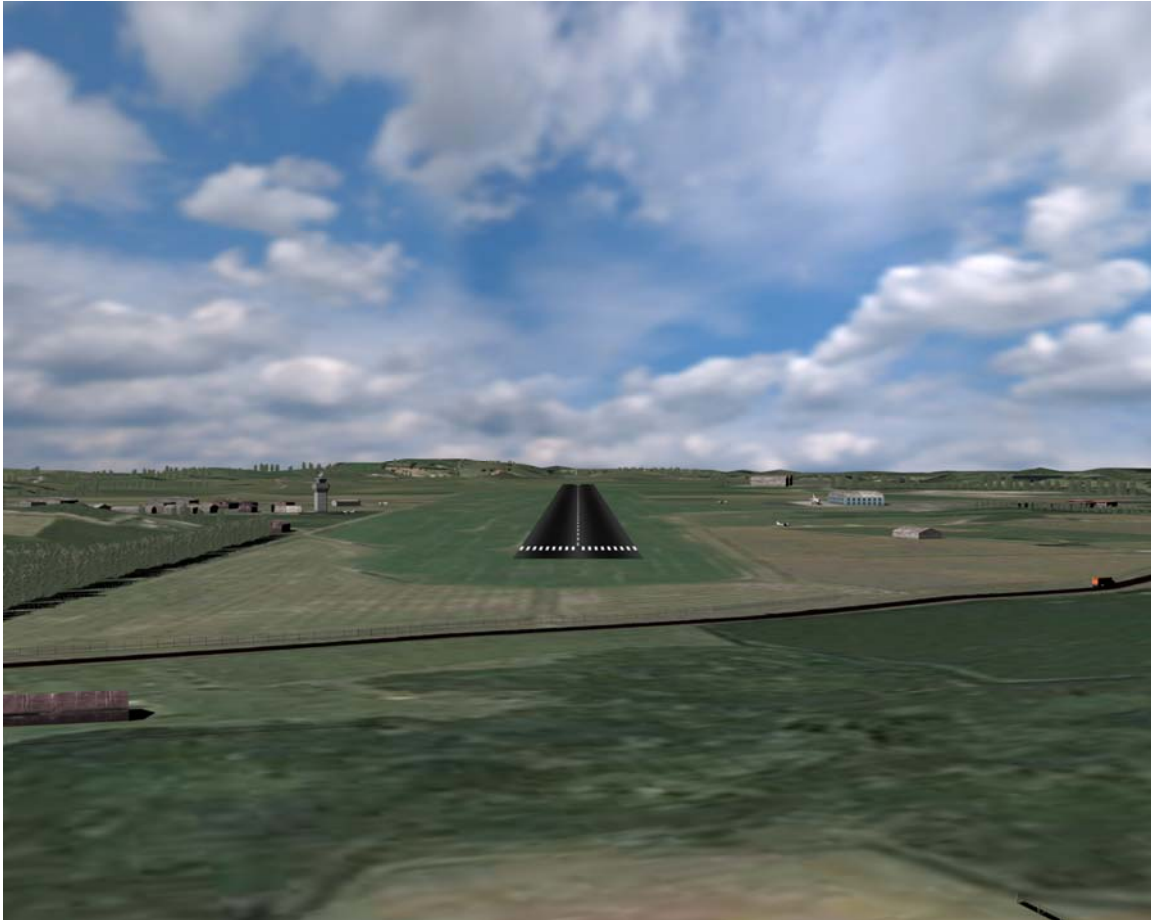
Trial Scene 1	
Trial Scene 2	
Trial Scene 3	
Trial Scene 4	
Trial Scene 5	
Trial 1	
Trial 2	
Trial 3	
Trial 4	
Trial 5	
Trial 6	
Trial 7	
Trial 8	
Trial 9	
Trial 10	
Trial 11	
Trial 12	
Trial 13	
Trial 14	
Trial 15	
Trial 16	
Trial 17	
Trial 18	
Trial 19	
Trial 20	
Trial 21	
Trial 22	
Trial 23	
Trial 24	
Trial 25	
Trial 26	
Trial 27	
Trial 28	
Trial 29	
Trial 30	
Trial 31	
Trial 32	
Trial 33	

## Dynamic Scenes

Trial Scene 1	
Trial Scene 2	
Trial Scene 3	
Trial Scene 4	
Trial Scene 5	
Trial 1	
Trial 2	
Trial 3	
Trial 4	
Trial 5	
Trial 6	
Trial 7	
Trial 8	
Trial 9	
Trial 10	
Trial 11	
Trial 12	
Trial 13	
Trial 14	
Trial 15	
Trial 16	
Trial 17	
Trial 18	
Trial 19	
Trial 20	
Trial 21	
Trial 22	
Trial 23	
Trial 24	
Trial 25	
Trial 26	
Trial 27	
Trial 28	
Trial 29	
Trial 30	
Trial 31	
Trial 32	
Trial 33	

**Appendix D:** The questionnaire that participants completed at the end of the experiment.

## Aviation Questionnaire



Please circle the object(s) that you used to judge your altitude

If there were any other objects that you used to judge your altitude that are not present in this scene, please describe them below.

.....  
.....  
.....  
.....  
.....  
.....  
.....  
.....  
.....



Did you notice that the runway width varied over different scenes?

- Yes
- No

**If yes;**

What impact did this have on your altitude estimation with 1 being no effect at all and 10 being an extremely significant impact an impact on your altitude estimation?

1	2	3	4	5	6	7	8	9	10
---	---	---	---	---	---	---	---	---	----

What method did you use to judge your altitude when you noticed the varying runway width?

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.....

Did you notice the standard runway marking?

- Yes
- No

To what extent did this change your method to judge your altitude based on the standard runway marking with 1 being no change at all and 10 being an extreme change in the method of altitude estimation?

1	2	3	4	5	6	7	8	9	10
---	---	---	---	---	---	---	---	---	----

**If yes;**

What method did you use to judge your altitude when the standard runway marking was present?

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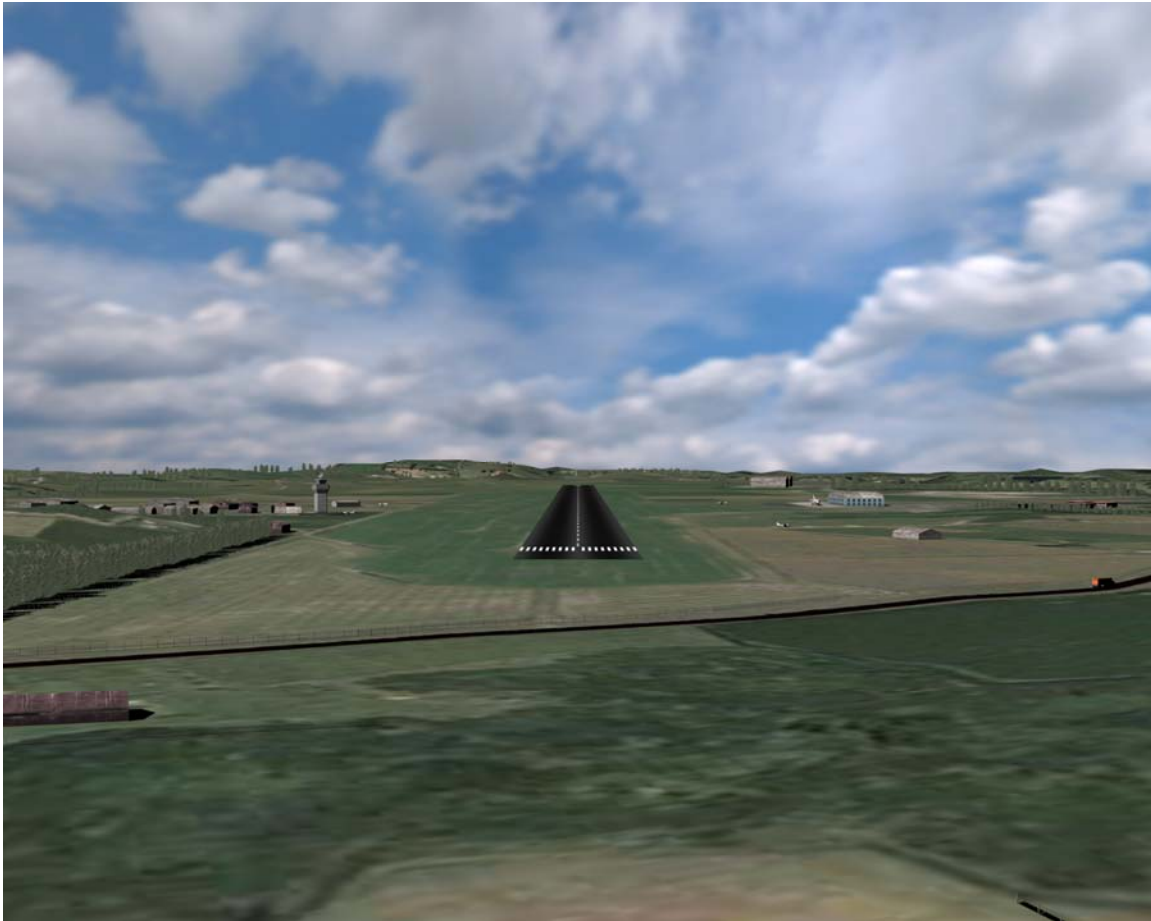
.....

Did you notice any changes in scene detail?

- Yes
- No

**If yes;**

Please circle the elements in the scene below where you noticed changes in scene detail.



If you noticed any changes in scene detail that are not present in this scene, please note these below.

.....  
.....  
.....  
.....  
.....  
.....  
.....