Evaluating Dynamic ‘Landing Gear Unsafe’ Auditory Alerts as a Defense Against Habituation

Vincenzo Fasano

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EVALUATING DYNAMIC ‘LANDING GEAR UNSAFE’ AUDITORY ALERTS AS
A DEFENSE AGAINST HABITUATION

by

Vincenzo Fasano

A Thesis Submitted to the College of Aviation Department of Applied Aviation Sciences
in Partial Fulfillment of the Requirements for the Degree of
Master of Science in Aeronautics

Embry-Riddle Aeronautical University
Daytona Beach, Florida
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EVALUATING DYNAMIC LANDING GEAR UNSAFE AUDITORY ALERTS AS A DEFENSE AGAINST HABITUATION

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This Thesis was prepared under the direction of the candidate’s Thesis Committee Chair, Dr. Guy M. Smith, Associate Professor, Daytona Beach Campus, and Thesis Committee Member, Dr. Nickolas Macchiarella, Professor, Daytona Beach Campus, and has been approved by the Thesis Committee. It was submitted to the Department of Applied Aviation Sciences in partial fulfillment of the requirements for the degree of Master of Science in Aeronautics.

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Abstract

Researcher: Vincenzo Fasano

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Institution: Embry-Riddle Aeronautical University

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Auditory alerts are widely used in today’s daily routine. Unlike their visual counterparts, auditory alerts can be used to capture someone’s attention, even though the user is not within visual range. As beneficial as auditory alerts can be, it is possible to become habituated to alerts. Habituation is the elimination of a response as a result of continuous exposure to a stimulus. In this small-scale study, methods to reduce pilot habituation to the ‘landing gear unsafe’ auditory alert were investigated. Ten subjects executed eight non-precision instrument approaches that exposed the subjects to the ‘landing gear unsafe’ auditory alert for a prolonged period of time. Subjects were exposed to four different landing gear auditory alerts: (a) a constant alert over time (control), (b) an alert that changed in pitch over time, (c), an alert that changed in loudness over time, and (d) an alert that changed in duration over time. During the study, the researcher tracked whether the subjects complied with all required procedures; afterwards, subjects completed a questionnaire about their perceptions of the alerts. The results showed the alert that changed in pitch over time yielded the most accurate procedures. The questionnaire data also favored the alert that changed in pitch over time.
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Chapter I

Introduction

Auditory tones and alarms are an integral part of daily routine. Their common use can be attributed to their versatility. Unlike their visual counterparts, auditory alerts can be used to capture someone’s attention even though the user is not within visual range of the alert (Wickens, John, Yili, & Sallie, 2004). For example, if a microwave only provided a visual alert that the food was ready, a person in another room may not be alerted that the food was ready. On the other hand, if the microwave beeped as well, then people in another room would know that the food was ready, even if they couldn’t physically see the microwave. The same concept holds true with other auditory alerts such as fire alarms, car chimes, back-up sensors, etc. (Wickens et al., 2004).

Due to their versatility, auditory warning systems are widely used in aircraft flight decks as well. Some applications include ‘landing gear unsafe’ auditory alerts, stall warning horns, chimes accompanied with warning or alert messages, and terrain warnings (Wickens et al., 2004). As useful as these auditory alerts can be, they do have some problems that may render them non-productive. One such problem is in the properties of the sound itself. The pitch or the amplitude may not be ideal, so that detection by the crew may be difficult or the alert may become a distraction. Sometimes auditory alerts can be ambiguous, leading to confusion about which warning the alert is attempting to convey (Ulfvengren, 2000). The alerting system itself can malfunction as well, sometimes sounding an alert when it is not needed or not sounding the alert when it is needed. This problem may decrease the crew’s confidence in the alert (Wickens & Hollands, 2000).
This study investigated another common problem with auditory alerts: habituation. As with any stimuli, when exposed to a constant sound over a long period of time, habituation to that sound may occur where it is simply tuned out (Mackworth, 1969). This study specifically focused on pilot habituation on the ‘landing gear unsafe’ auditory alert. More detail was included on the properties of sound, research on ideal auditory alerts and their limitations, and habituation. The study itself investigated how ‘landing gear unsafe’ auditory alerts that changed over time helped in fighting pilot habituation to these alerts.

**Significance of the Study**

In recent years, there have been numerous incidents involving aircraft landing with the landing gear retracted. These incidents occurred despite requirements from the Federal Aviation Administration (FAA) for special pilot training for aircraft that are equipped with retractable landing gear. Furthermore, the FAA requires such aircraft to have a landing gear warning system in accordance with Title 14 of the Code of Federal Regulations (CFR) § 23.729:

> For landplanes, the following aural or equally effective landing gear warning devices must be provided: (1) A device that functions continuously when one or more throttles are closed beyond the power settings normally used for landing approach if the landing gear is not fully extended and locked. A throttle stop may not be used in place of an aural device. If there is a manual shutoff for the warning device prescribed in this paragraph, the warning system must be designed so that when the warning has been suspended after one or more throttles are closed, subsequent retardation of any throttle to, or beyond, the position for
normal landing approach will activate the warning device and (2) A device that functions continuously when the wing flaps are extended beyond the maximum approach flap position, using a normal landing procedure, if the landing gear is not fully extended and locked. There may not be a manual shutoff for this warning device. The flap position sensing unit may be installed at any suitable location. The system for this device may use any part of the system (including the aural warning device) for the device required in paragraph (f)(1) [the last paragraph] of this section. (Landing Gear Extension and Retraction Systems, 2012 ¶ f)

These measures may become ineffective during prolonged exposure, causing pilot habituation to ‘landing gear unsafe’ auditory and visual warnings.

**Purpose Statement**

The purpose of this study was to discover if the introduction of an auditory warning system that changes in pitch, loudness, or duration over time can increase the effectiveness of ‘landing gear unsafe’ auditory alerts, indicated by a reduction in pilot habituation resulting in a timely landing gear extension.

**Hypotheses**

H1: There will be a difference in effectiveness of the ‘landing gear unsafe’ auditory alarm between alarms with constant pitch and alarms that change in pitch over time for pilots with an instrument and multi-engine rating and trained in the Embry-Riddle Aeronautical University Standard Operating Procedures (Embry-Riddle Aeronautical University [ERAU], 2012).
H2: There will be a difference in effectiveness of the ‘landing gear unsafe’ auditory alarm between alarms with constant loudness and alarms that change in loudness over time for pilots with an instrument and multi-engine rating and trained in the Embry-Riddle Aeronautical University Standard Operating Procedures (ERAU, 2012).

H3: There will be a difference in effectiveness of the ‘landing gear unsafe’ auditory alarm between alarms with constant duration and alarms that change in duration over time for pilots with an instrument and multi-engine rating and trained in the Embry-Riddle Aeronautical University Standard Operating Procedures (ERAU, 2012).

**Delimitations**

This study investigated pilot habituation only to the ‘landing gear unsafe’ auditory alert. It used this alert from the Diamond DA-42 L-360 multi-engine aircraft as the control and three other alerts that changed in pitch, loudness, and duration (derived from the control). In order to expose the subjects to a situation where they flew with the landing gear auditory alert sounding for a prolonged period, they were asked to execute multiple single-engine approaches. This study was different from a flight experience because there were few flight distractions such as traffic, extraneous communication, system failures (other than the initial engine failure), or hazardous weather.

**Limitations and Assumptions**

The most important limitation to this study was the number of subjects used. Due to availability of subjects and time constraints, this study involved only ten participants, thus categorizing it as a pilot study, a small-scale set of observations undertaken to decide how and whether to launch a full-scale project. Also, the equipment used for the study had limited realism, as the simulations of the aircraft used for this study were based on a
simulation not approved by the FAA to be used for official training. The hardware which included a yoke, rudder pedals, a full functioning throttle quadrant, landing gear handle, major switches, and communication equipment, was not specific to the aircraft that was simulated. Furthermore, the aircraft simulated was the Diamond DA-42 Next Generation model (NG) which is a little different from the desired model, the Diamond DA-42 L-360. The subjects were made aware of these differences and were allowed a trial run to become accustomed to them.

It was assumed that the participants would fly this device following all the applicable Federal Aviation Regulations (FARs) and Embry-Riddle Aeronautical University (ERAU) standard operating procedures (SOPs), as if they were flying the actual aircraft. The only difference between the simulated NG aircraft and the desired model (L-360), was the method in which power was set. It is assumed that the power settings provided to subjects prior to the study were studied and understood prior to commencing the study.

Definition of Terms

Circling Approach – An approach which requires the pilot to land on a runway that is oriented more than 30 degrees from the final approach course of that instrument approach (General Definitions, 2012).

Habituation – The elimination of a response as a result of a continuous exposure to the stimulus that originally elicited the response (Roeckelein, 2006).

Instrument Approach – A procedure which allows a pilot who is flying with no visual references to the outside environment to line up with the runway
and execute a controlled descent towards that runway (General Definitions, 2012).

Non-Precision Approach – An instrument approach that only has lateral guidance (General Definitions, 2012).

**List of Acronyms**

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<th>Description</th>
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<tr>
<td>AGL</td>
<td>Above Ground Level</td>
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<tr>
<td>CFR</td>
<td>Code of Federal Regulations</td>
</tr>
<tr>
<td>ERAU</td>
<td>Embry-Riddle Aeronautical University</td>
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<tr>
<td>FAA</td>
<td>Federal Aviation Administration</td>
</tr>
<tr>
<td>FAF</td>
<td>Final Approach Fix</td>
</tr>
<tr>
<td>FAR</td>
<td>Federal Aviation Regulation</td>
</tr>
<tr>
<td>FTD</td>
<td>Flight Training Device</td>
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<tr>
<td>GPS</td>
<td>Global Positioning System</td>
</tr>
<tr>
<td>HAT</td>
<td>Height Above Threshold</td>
</tr>
<tr>
<td>IAF</td>
<td>Initial Approach Fix</td>
</tr>
<tr>
<td>KAPF</td>
<td>Identifier for Naples Municipal Airport</td>
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<tr>
<td>MAP</td>
<td>Missed Approach Point</td>
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<tr>
<td>MDA</td>
<td>Minimum Descent Altitude</td>
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<tr>
<td>NG</td>
<td>Next Generation</td>
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<tr>
<td>PCATD</td>
<td>Personal Computer Aviation Training Device</td>
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<td>SOP</td>
<td>Standard Operating Procedure</td>
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Chapter II

Review of the Relevant Literature

Auditory alerts are widely used in today’s daily routine. There is a wide variety of auditory alerts ranging from alarm clocks, microwave beeps, car chimes, monitors for a patient’s vital signs, and fire alarms. These are just a few examples of auditory alerts that are encountered on a daily basis. Each is intended to report a system status, provide a reminder, or signify that something is abnormal.

Introduction to Auditory Display Systems in Aviation

The aviation industry is particularly dependent on auditory alerts, or “auditory displays” (Wickens et al., 2004). The FAA requires many auditory alerts for a wide variety of systems. For example, they require that an aircraft with retractable landing gear must have an oral warning advising the pilot that the landing gear is not down and locked for landing. This warning should activate when either one throttle is below a given power setting and/or when the flaps are set for landing. In general, if the airplane is configured for landing and the landing gear is not down, an oral alert is required to advise the pilot of such a situation (Landing Gear Extension and Retraction System, 2012). The pilot should not be able to silence the aural alert associated with the flaps (Landing Gear Extension and Retraction System, 2012).

Displays in general, whether auditory or visual, must be very carefully developed according to what their purpose may be. For example, a digital display is more appropriate for reading an exact figure, whereas an analog display may be more appropriate for noticing a trend at a quick glance (Wickens et al., 2004). There are thirteen principles of display design as described in An Introduction to Human Factors...
*Engineering* (Wickens et al., 2004). These principles are split into four categories: perceptual principles, mental model principles, principles based on attention, and memory principles (Wickens et al., 2004).

**Basic Principles of Sound**

For this study, it is essential to have a general understanding of sound. Sound is a stimulus received by the human hearing system (University of Winnipeg, 1999a). Physically, sound is a vibration or a compression and rarefaction of air molecules. This vibration is felt by the eardrum within the ear and interpreted by the brain. Sound can be described by a sine wave that has both amplitude and frequency. The amplitude is related to the sound’s loudness (typically measured in decibels) and the frequency of its pitch (University of Winnipeg, 1999b). A musician, for example, knows that sound frequencies are grouped into seven distinct pitches or notes. These notes are assigned letters from A to G and are equally spaced from the next. The range between an A to the next A is known as an octave since there are eight notes from A to A (A,B,C,D,E,F,G,A). These are known as simple frequencies which a trained musician can determine by listening to the sound (University of Winnipeg, 1999a). Humans can detect further details in frequency characteristics by being able to distinguish the difference between a C from a trombone and a C from a saxophone (Wickens et al., 2004).

There are three different types of sounds: noise, tones or alarms, and speech (Wickens et al., 2004). Noise is typically undesirable, often causing high levels of stress during prolonged exposure. Tones and alarms are either pleasant sounds such as music or they can be sounds that have a specific meaning such as an alarm clock in the morning. Auditory alarms are widely used in everyday application such as a microwave beep or a
more specific applications, such as a stall warning horn on the flight deck. Auditory displays are so popular because the human auditory system is the only sense that is omnidirectional. This means that not only can the auditory system pick up the sound, but it can also detect where it is coming from (Wickens et al., 2004).

**Auditory Display Design**

The first step in designing a good auditory display (or alarm) is to make sure that the user will be able to initially perceive it (Bliss, Freeland, & Millard, 1999). An aircraft’s flight deck has a plethora of auditory alarms designed to warn pilots of abnormal or potentially dangerous situations. In certain scenarios, these auditory alerts can be counterproductive, as they may distract the pilots by creating sensory overload (Bliss et al., 1999). For example, while an alarm must be loud enough to be heard over ambient noise, it should not be at such a high decibel (db) level as to be distracting or even harmful. Similarly, the alarm’s pitch should be different from the pitch of other sounds on the flight deck, but should not be too high as to distract the user from the task at hand. Alarms may also be so ambiguous that the pilot is not sure what the alarm truly means (Bliss et al., 1999). A constant tone can be either a stall warning horn or a ‘landing gear unsafe’ auditory alarm. There has been considerable research on the auditory alerting systems in the present day flight deck, their shortcomings, and how they can be augmented to better serve their purpose (Bliss et al., 1999).

**Initial Perception**

Perception of displays accounts for five out of the thirteen principles of display design that Wickens et al. (2004) lists in *An Introduction to Human Factors Engineering*. The first principle is to make the display as visual or audible as possible. Secondly, a
display should lead to absolute judgment. For example, if a tone sounds in the flight
deck, the crew should be able to determine what the nature of the alert is without having
to reference any other sources. The third principle is the idea that a display should trigger
a top-down mental process. An example of such a process widely used in aviation is a
checklist, where things have to be done in a specific order. The idea is that if a tone
sounds, the user should know exactly what he or she needs to do and in which sequential
order. One of the most important principles describes initial display perception and is
known as redundancy gain. A traffic light is a redundant display since both the color and
position of the illuminated light are an indicator of the required action. In the auditory
world, this may include a tone whose meaning is linked to specific sound and direction
from where it is emitting. Finally, the last principle states that a display should have
discriminability (Wickens et al., 2004). This requirement is often not met, as many flight
deck auditory alarms tend to be ambiguous.

In general, the biggest challenge with auditory alarms is that they must be
designed in a fashion to allow the operator (pilot) to sense the alarm but not to be
overstimulated (Wickens et al., 2004). Visual alerts need to have the same balance, but
unlike auditory alerts, they can be more easily ignored in the case when they are
overbearing. The idea is that one can close his or her eyes but not his or her ears. For
this reason, auditory alerts can be more effective than their visual counterparts, but also
more intrusive if not designed well (Wickens et al., 2004).

**Effectiveness of Auditory Alarms**

There are some prerequisites that auditory alarms should meet to increase their
effectiveness. As a minimum, they must be louder than the surrounding ambient noise
(Wickens et al., 2004). Research suggests that the alarm be at least 30 db above the ambient noise so the operator can detect it. By the same token, an alarm should not be above the danger level of around 90 db. If the ambient noise level is already very high, then it may be better to have an alarm at the same decibel level but at a completely different frequency or pitch. As important as it is for an auditory alarm to capture the operator’s attention, it is paramount that it does not startle him or her. It is also imperative that an alarm does not disrupt any other tasks that the operator is required to complete or overpower any voice communication that is required to complete the task (i.e., communications between crew members or air traffic control). Lastly, an auditory alarm should be informative. It should cue the listener to what went wrong and ideally should prompt the course of action required in order to correct the problem (Wickens et al., 2004).

In order to catch the pilot’s attention, auditory alerts can often be relatively loud and/or high pitched (Ulfvengren, 2000). Alarms activate on the flight deck during an abnormal or emergency situation where pilot workload is already relatively high. Consequently, auditory alarms can actually become counterproductive, as they may distract pilots, ultimately leading to silencing or ignoring them altogether. Furthermore, many auditory alarms can be ambiguous, since they do not indicate the exact nature of the abnormal situation unless the pilot looks for some visual cues to match the auditory alarm. For example, a continuous beeping auditory alarm could either be a ‘landing gear unsafe’ warning horn or a traffic alert (Ulfvengren, 2000).

There has been considerable research on creating more natural alarms. According to Ulfvengren (2000), an auditory alert should provide information to the
operator using sounds found in the natural environment. These sounds should allow the operator to distinguish between a normal and abnormal situation without having to use any other sensory cues. Also, if using verbal auditory alerts, the voice should sound clear and natural. Natural auditory alarms can significantly reduce warning ambiguity and flight crew confusion. Furthermore, natural alarms are less intrusive to human cognition therefore reducing sensory overload during abnormal procedures (Ulfvengren, 2000).

**Ineffective Auditory Alarms**

If the alarm is not properly designed, there can be many errors associated with the initial detection of the alarms ranging from not hearing the warning to not believing it at all. An alarm that is often not heard or missed is considered to be unreliable. For example, an auditory warning that makes a single beep could be more unreliable than one that beeps continuously, since it has a higher chance of going undetected by the flight crew. Some auditory alarms are activated even if there is no abnormal situation present. These false alarms decrease crew confidence in the warning and therefore pilots will dismiss them. This phenomenon is known as the *cry wolf effect* since the auditory warning continues to activate even when there is nothing abnormal, therefore reducing flight crew compliance. Auditory alarm reliability and compliance is key to their effectiveness, for a lack of either one will prevent flight crews from initially detecting them (Wickens & Hollands, 2000).

The above concepts refer to errors in the initial detection and perception of a stimulus, but do not address what may happen with continuous exposure over time. It is clear that the initial perception of a stimulus, such as sound, is psychological in nature and varies from person to person (Helander, 2006). For example, a librarian may find the
sound of an aircraft to be very annoying, but a pilot may find it very pleasurable. This same idea applies to how people perceive sound over time. According to Helander (2006), studies show that people living in Rome, Italy can tolerate a 10 dB greater noise level than people in Stockholm, Sweden. This phenomenon is linked to the idea that stimulus vigilance level decreases with time of exposure (Figure 1).

![Figure 1: Vigilance degradation over time. Reprinted from A Guide to Human Factors and Ergonomics (p. 91), by Helander, M. 2006, Boca Raton, FL: Taylor & Francis Group, LLC.]

**Human Memory and Auditory Alerts**

Stimulus detection in general can be traced back to how human memory works. One model of human memory has these three categories: the sensory register, the working memory, and the long-term memory (Wickens & Hollands, 2000). The sensory register is a subconscious process which filters stimuli from all five senses, allowing only the important ones to go through into the working memory. For example, consider a student listening to a professor presenting very important information in a cold
classroom. The student’s sensory register will filter all of the auditory and visual stimuli into the working memory as they are very important, but it may block the cold stimulus as it is not pertinent at the moment. Perhaps, if the professor decides to stop lecturing, therefore stopping the auditory and visual stimuli, the student’s sensory register will allow the cold stimulus to pass through into the working memory, and the student may suddenly detect that it is cold in the classroom, although he/she may have been in there for the past hour (Wickens & Hollands, 2000).

The example above would suggest that whether a stimulus is detected or not is determined by a subconscious process within the sensory register (Wickens & Hollands, 2000). After detecting a stimulus, a meaning must be given to it. For example, if the professor in the above example is lecturing but the student is not giving any meaning to the words that he is speaking, then that auditory stimulus is only noise rather than meaningful communication. The assignment of meaning to a stimulus is known as perception. It is very important to note that different people may assign different meaning to the same stimulus, therefore perceiving it differently. This concept applies to any stimuli received from any of the five senses (Wickens & Hollands, 2000).

There is considerable amount of research that attempts to link vigilance with the working (or short-term) memory. Successfully performing tasks that require a high level of vigilance puts a significant load on the working memory (Caggiano & Parasuraman, 2004). However, it is unclear whether there is a link between the working memory and the level of vigilance while performing that task (Caggiano & Parasuraman, 2004). Vigilance can also be thought of as sensitivity to a given target over time. Such sensitivity appears to decline more noticeably when the activity involves successive tasks
that require high levels of cognitive efforts. On the other hand, simultaneous tasks are more resistant to sensitivity decrement over time (Caggiano & Parasuraman, 2004). Regardless of the complexity of the activity, if it were to be repeated many times, there is a clear indication that vigilance will decrease. This decrement is caused by the fact that a continuously repeated activity leads to a subconscious evaluation that strong vigilance is no longer required (Caggiano & Parasuraman, 2004).

**Vigilance**

Vigilance can be categorized into six different paradigms (Wickens & Hollands, 2000). Two such paradigms include the free-response and inspection paradigms. The free-response paradigm involves a stimulus that can occur at any time with no set interval. On the other hand, the inspection paradigm involves a stimulus that occurs on a regular interval, such as a ‘landing gear unsafe’ auditory alert. Also there are the successive and simultaneous paradigms. Successive tasks require memorization of the stimulus to be compared later with successive stimuli. Conversely, a simultaneous task has all the required information available when the original stimulus is presented (Wickens & Hollands, 2000). This helps to explain the earlier idea that vigilance is more likely to decrease when performing successive tasks due to higher use of the working memory (Caggiano & Parasuraman, 2004). The last two vigilance paradigms are the sensory and cognitive paradigms. In sensory paradigms, the stimulus is detected by one of the five senses. The cognitive paradigm has to do with stimulus induced by mental activities such as evaluating someone’s paper (Wickens & Hollands, 2000).
Habituation

Along the same lines as vigilance decrement, there is the idea of habituation of sustained attention (Mackworth, 1969). This concept has to do with continuous exposure to constant stimuli over time. Mackworth (1969) explains that continuous exposure to a given stimulus can also lead to sensitivity decrement of that stimulus. There are many other terms such as desensitization and adaptation which describe this concept. Regardless of the term, the idea is that the response of a sensory system is reduced due to steady stimuli (McBurney & Balaban, 2009). It is important to note that, in the case of habituation or adaptation, when the stimuli are first exposed to sensory systems, they are processed and therefore the body notices the stimuli exist. This suggests that sensory systems have time-sensitive properties (McBurney & Balaban, 2009). Research indicates that the rate at which response decrement occurs as a result of a continuous stimulus is exponential (“Experimental Physiology,” 2009).

Habituation does not occur only with physical stimuli. It may also occur with psychological or emotional stimuli (“Pornography,” 2010). In other words, a stimulus that may trigger an emotional response, such as the previous citation, will most likely yield a reduced response with increased exposure over time. The more the citation appears in the following text, the smaller the psychological response that it will induce. In an article entitled Pornography Not Vehicle for Sexual Liberation (2010), the Daily News attributed the increase in violence in pornography to this idea of psychological and emotional habituation. They claim that regular patrons of this industry over time start to lose the emotional response that they crave, forcing the industry to change the stimuli enough to prevent this habituation (“Pornography,” 2010). In summary, the Elsevier’s
Dictionary of Psychological Theories proposes the most complete definition of habituation. They define it as “the elimination of a response as a result of a continuous exposure to the stimulus that originally elicited the response” (Roekelein, 2006, p. 262).

Summary

There is considerable amount of research on initial detection of an auditory alert in aviation. It is important that an alert is set at the correct amplitude so that the flight crew will detect it without being startled or distracted by it (Wickens et al., 2004). The frequency of the alert is also important in initial detection because one that is too low in frequency will not be heard and one that is too high in frequency will be distractive (Ulfvengren, 2000). Research is not definitive whether a tone or natural voice would be the most efficient alert in initial detection. Human psychology also has an important role in the initial detection of an auditory alert. For example, if an alert continuously activates when there is nothing abnormal, then sooner or later, the flight crew will lose faith in the alert; when it activates, they will dismiss it as being a false alert (Wickens & Hollands, 2000).

Much of this research does not include how alerts should be designed to keep the flight crew’s attention over time after initial detection. There is a considerable amount of unrelated information on the phenomenon of habituation or adaptation to stimuli over time. It is widely accepted that, when exposed to a continuous stimulus over time, one will begin to tune it out (Mackworth, 1969). The rate at which this habituation happens is exponential over time until habituation is so high that it is as if the stimuli never existed (“Experimental Physiology,” 2009). Unfortunately, there is a lack in research as to how this phenomenon may apply to continuous exposure to auditory alerts in aviation.
Chapter III

Methodology

Research Approach

This was a comparative study with a quasi-experimental design, comparing the effectiveness of the current ‘landing gear unsafe’ auditory alarm system (constant steady pitch and steady loudness) with one that changes in pitch, loudness, or duration over time.

Design and procedures. Pilots trained by ERAU, with a minimum of a private pilot certificate with instrument and multi-engine ratings, were asked to conduct a non-precision instrument approach with one engine inoperative in a multi-engine Personal Computer Aviation Training Device (PCATD). The PCATD software was based on Microsoft Flight Simulator 9 and modeled a Diamond DA-42 NG aircraft with a fully functioning G-1000 panel. Pilots were required to use ERAU’s SOPs to fly a non-precision instrument approach with one engine inoperative (i.e., a single engine non-precision approach). This type of approach requires the landing gear to be held in the retracted position until landing is assured (ERAU, 2012), allowing the ‘landing gear unsafe’ auditory alert to sound for a prolonged period of time. The pilots were directed to repeat a non-precision approach (GPS RWY 05) eight times into the Naples, Florida, Municipal Airport (KAPF). Two approaches included a standard ‘landing gear unsafe’ auditory warning system and were used to yield the control data. Two approaches involved a change in alarm pitch; two involved a change in alarm loudness; and two involved a change in alarm duration, to yield the experimental data. These alarms were generated by a computer recording of the actual alert in the DA-42 aircraft. The subjects
executed two approaches for each of the four alarms: one straight approach and another circling approach. The circling approach required the subjects to hold the landing gear in the retracted position for a longer period of time while also providing the extra distraction of the circling procedure. The order of these approaches was randomized for each subject. Subjects were video-recorded from behind to verify instrument indications and landing gear switch position.

Each approach was initiated at N 25 degrees 57.85 minutes latitude and W 81 degrees and 54.61 minutes longitude. The initial heading was 020 degrees, 2,000 feet altitude and 100 knots of airspeed. Before each approach, the subjects set up the GPS Runway 05 approach in the G-1000. On commencement, the researcher instructed the subjects to descend to the initial approach altitude and cleared them for the approach. Either the number one (left) or number two (right) engine failed after three minutes elapsed. The clouds were set at 100 feet above the minimums for the approach. Each subject took an average of one and a half hours to conduct eight approaches with a 20-minute break after the first four approaches. Subjects were compensated at $7.67 per hour.

**Apparatus and materials.** This study used a PCATD based on Microsoft Flight Simulator 9. The PCATD was configured as a DA-42 NG aircraft with a fully functioning G-1000 panel. The visual was displayed on a 15 inch flat screen monitor. The subject was provided with rudder pedals, a yoke, basic switches (including lights, flaps, landing gear, boost pumps, and magneto switches), a radio stack, and a full functioning throttle quadrant.
Population/Sample

Pilots trained by ERAU with a minimum of a private pilot certificate with instrument and multi-engine ratings were recruited. The sample was self-selected. The researcher sent out an e-mail to all ERAU flight students and posted a message on ERAU’s flight department scheduling system in order to inform potential subjects of the requirements and compensations for the study. No detail was provided about the purpose of the study, as that may have skewed the results.

Data Collection Device

Data were collected by the researcher through direct observation (Appendix B) and an end-of-experiment questionnaire, as illustrated in Appendix C. Subjects had their own spreadsheet assigned to them and their respective identification number was recorded on the “Subject #” line on top of the spreadsheet. The spreadsheet was designed to keep track of which approach the subjects were executing (straight in or circling approach). The subjects executed one of each (straight in or circling) for each alert type (standard, changing pitch, changing volume, and changing duration) for a total of eight approaches. The type of ‘landing gear unsafe’ alert variable was used to record which type of alert (standard, changing pitch, changing loudness, or changing duration) the subjects heard on a particular approach. The descent checklist completed variable was used to record whether the subjects fully completed the descent checklist prior to being established on the final approach course. The descent final items checklist variable tracked whether the subject completed the descent checklist final items at 1,000 feet above minimum descent altitude (MDA) according to ERAU procedures. The gear up callout at the FAF variable was used to record whether the subjects made the required
callout at the final approach fix (FAF) on an engine-inoperative approach: “gear up, holding gear.” The *busted MDA* variable was used to record whether the subjects descended below MDA without the required prerequisites, for any reason. According to ERAU procedure, subjects are required to be stabilized with the landing gear extended by the time they reach 200 feet height above touchdown (HAT). If that was not the case, ERAU procedures required a missed approach to be executed. The next two variables on the spreadsheet were designed to track whether the subjects followed the above procedures. The *gear up landing* variable was used to record whether the subjects forgot to extend the landing gear altogether, landing with the landing gear up. The last variable, *comments*, was designed to allow the researcher to add relevant comments.

The end-of-experiment questionnaire was designed to collect further data concerning the subjects’ opinions about the effectiveness of the different types of ‘landing gear unsafe’ auditory alerts. This questionnaire was given to subjects immediately after they finished all of their approaches. Question 1 was based on a 9-point Likert scale to determine if the subjects felt that distractions on an instrument approach may have led them to forget to extend the landing gear. Questions 2 through 4 asked the subjects to evaluate each of the three test alerts (the changing pitch, loudness, and duration) effectiveness using the same Likert scale as Question 1. Question 5 asked the subjects to rank the four different types of auditory alarms by their perceived effectiveness on a scale of 1 through 4 (1 was the least effective and 4 was the most effective). Question 6 was designed to be open-ended to collect opinions about any other ‘landing gear unsafe’ auditory alerts which the researcher did not include in the study but
may also be effective. These comments could initiate a discussion on any recommendations for further research.

**Instrument validity and reliability.** The variables collected in this study were proxy variables for the dependent variable of ‘landing gear unsafe’ auditory warning habituation. Proxy variables were used since this study attempted to measure a psychological phenomenon (auditory warning habituation), not directly measurable. These variables were validated by the researcher, a professional in the field.

**Treatment of the Data**

**Descriptive statistics.**

*Measured variables.* All of the measured variables in this study were nominal in nature. The data from these variables were described in tables.

*Questionnaire variables.* The end-of-study questionnaire included four questions with a Likert scale. The data from Questions 2 through 4 were described in a table that included the mean, standard deviation, maximum values, minimum values, and the number of subjects. The survey also included a question which asked the subjects to rank the types of ‘landing gear unsafe’ warnings on an ordinal scale. Question 5 was described in a figure.

**Hypothesis testing.** For all three hypotheses, the dependent construct was effectiveness of the ‘landing gear unsafe’ auditory alert. This construct was defined as the number of correctly executed procedures for each alarm type. The independent variable for H1 was the constant alert versus the alert with changing pitch; the independent variable for H2 was the constant alert versus the alert with changing loudness; and the independent variable for H3 was the constant alert versus the alert with changing
duration. All three hypotheses were tested with a Chi-Square. Refer to Appendix C for the table outlining the details for incorrectly executed procedures for each alert type.

For end-of-experiment questionnaire Questions 2 through 4, a Likert (interval) variable, all three hypotheses were tested with an ANOVA. For Question 5, all three hypotheses were tested using a Friedman test.

**Qualitative data.** The qualitative responses from Question 6 were evaluated. Selected qualitative responses were used in Chapter V to clarify and enrich the discussion and conclusions of the study.
Chapter IV

Results

Descriptive Statistics

**Observed data.** Ten subjects were asked to execute eight (8) instrument approaches in a PCATD simulating a Diamond DA-42 multi-engine aircraft. All these approaches included an engine failure three minutes into the scenario. ERAU (2012) procedures prescribe that the throttle of the inoperative engine is to be retarded to idle as a means of verifying which engine is inoperative. This will trigger the ‘landing gear unsafe’ auditory alert, if the landing gear is in the retracted position. During the eight approaches, subjects were exposed to four (4) different auditory alerts including the standard one currently in the aircraft (the control). The other three were auditory warnings which changed over time in their pitch, loudness, or duration.

During each approach, the researcher tracked whether the participant correctly completed a series of eight ERAU procedures which were required during the approach. The procedures included completing the descent checklist, completing the descent final items, making the gear-up callout at the FAF, doing the GUMP checklist (a memory aid to remind the pilots to configure the aircraft for landing, including extending the landing gear), whether they descended below the MDA, whether the landing gear was down by 200 feet, whether a missed approach was executed, and whether they had a landing gear up landing (refer to Appendix B). Table 1 describes the percentage of procedures that were correctly executed during exposure to each ‘landing gear unsafe’ auditory warning.
Table 1

*Descriptive Statistics on Correctly Executed Procedures for Each Alarm Type*

<table>
<thead>
<tr>
<th>Alarm Type</th>
<th>Number Correct</th>
<th>Number Incorrect</th>
<th>Percent Correct</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>133</td>
<td>27</td>
<td>83%</td>
</tr>
<tr>
<td>Pitch</td>
<td>152</td>
<td>8</td>
<td>95%</td>
</tr>
<tr>
<td>Volume</td>
<td>145</td>
<td>15</td>
<td>91%</td>
</tr>
<tr>
<td>Duration</td>
<td>143</td>
<td>17</td>
<td>89%</td>
</tr>
</tbody>
</table>

**Questionnaire data.** After having executed all eight approaches the subjects were given an end-of-experiment questionnaire to measure their perceptions of each ‘landing gear unsafe’ auditory alert (refer to Appendix C). Question 1 ("A distraction, such as an engine failure during the approach and landing phase of flight, could contribute to my forgetting to extend the landing gear") was general in nature and intended to be used for qualitative analysis. Although this question was not used for hypothesis testing, it still yielded descriptive statistics. Figure 2 illustrates these statistics.

![Figure 2. Responses to Effects of Distractions, Question 1.](image)
Questions 2 through 4 asked the subjects to rate the effectiveness of each of the auditory warnings which changed over time using a Likert scale. Figures 3 through 5 illustrate the number of subjects who selected a given number on the Likert scale on Questions 2 through 4.

Figure 3. Responses to Changing Pitch Alert, Question 2.

Figure 4. Responses to Changing Loudness Alert, Question 3.
Figure 5: Responses to Changing Duration Alert, Question 4.

The descriptive data for questionnaire Questions 2 through 4 is included in Table 2.

Table 2

Descriptive Statistics For End-of-Experiment Questionnaire, Questions 2-4

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>Mean</th>
<th>Std. Deviation</th>
<th>Std. Error</th>
<th>Lower Bound</th>
<th>Upper Bound</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pitch</td>
<td>10</td>
<td>7.80</td>
<td>.79</td>
<td>.25</td>
<td>7.24</td>
<td>8.36</td>
<td>7</td>
<td>9</td>
</tr>
<tr>
<td>Loudness</td>
<td>10</td>
<td>6.70</td>
<td>2.21</td>
<td>.70</td>
<td>5.12</td>
<td>8.28</td>
<td>1</td>
<td>9</td>
</tr>
<tr>
<td>Duration</td>
<td>10</td>
<td>6.50</td>
<td>1.72</td>
<td>.54</td>
<td>5.27</td>
<td>7.73</td>
<td>4</td>
<td>9</td>
</tr>
</tbody>
</table>

Table 2 illustrates that the ‘landing gear unsafe’ auditory alert that was considered by the subjects to be most likely to remind them to extend the landing gear was the one with changing pitch. This follows the trend from the observed data where the alert with
changing pitch yielded the most correctly-executed procedures followed by the alert with changing loudness and then the alert with changing duration. This trend can be further noticed in the means chart, Figure 6.

![Means chart for responses to end-of-experiment questionnaire, Questions 2-4.](image)

**Figure 6.** Means chart for responses to end-of-experiment questionnaire, Questions 2-4.

Question 5 asked the subjects to rank each of the ‘landing gear unsafe’ auditory alerts on a scale from 1 to 4 where 1 was the least effective and 4 was the most effective. The descriptive data for questionnaire Question 5 is included in Table 3

### Table 3

*Descriptive Statistics For End-of-Experiment Questionnaire, Question 5*

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>Mean Rank</th>
<th>Std. Deviation</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>10</td>
<td>1.80</td>
<td>1.03</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>Pitch</td>
<td>10</td>
<td>2.80</td>
<td>1.23</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>Loudness</td>
<td>10</td>
<td>3.00</td>
<td>0.82</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>Duration</td>
<td>10</td>
<td>2.30</td>
<td>0.95</td>
<td>1</td>
<td>4</td>
</tr>
</tbody>
</table>
On Question 5, there was a slight deviation from the prevailing response trend. The auditory alert that had the highest average rank by the subjects was the alert that changed in loudness over time, and the alert that changed in pitch over time was ranked slightly lower. The alert that changed in duration over time was ranked the lowest among the test variables, which is in line with previous trends. As anticipated, the control variable was ranked the lowest by the subjects.

**Hypothesis Testing**

**Observed data.** A Chi Square was used to test the null hypothesis: There will be no difference in effectiveness of the ‘landing gear unsafe’ auditory alarm between alarms with constant pitch and alarms that changed in pitch over time for pilots with an instrument and multi-engine rating and trained in Embry-Riddle Aeronautical University Standard Operating Procedures. The Chi-Square test rejected the null hypothesis $\chi^2 (1, N = 10) = 11.58, p = .001$.

A Chi-Square was used to test the null hypothesis: There will be no difference in effectiveness of the ‘landing gear unsafe’ auditory alarm between alarms with constant loudness and alarms that changed in loudness over time for pilots with an instrument and multi-engine rating and trained in Embry-Riddle Aeronautical University Standard Operating Procedures. The Chi-Square test rejected the null hypothesis $\chi^2 (1, N = 10) = 3.95, p = .047$.

A Chi-Square was used to test the null hypothesis: There will be no difference in effectiveness of the ‘landing gear unsafe’ auditory alarm between alarms with constant duration and alarms that changed in duration over time for pilots with an instrument and multi-engine rating and trained in Embry-Riddle Aeronautical University Standard
Operating Procedures. The Chi-Square test failed to reject the null hypothesis $\chi^2(1, N = 10) = 2.64, p = .105$.

**Questionnaire data.** The questionnaire did not include a question for the subjects to rate the effectiveness of the constant (control) ‘landing gear unsafe’ auditory alert; therefore, Questions 2 through 4 were used to test the following null hypothesis: There will be no difference in effectiveness of the ‘landing gear unsafe’ auditory alarm among alarms with changing pitch, loudness, and duration over time for pilots with an instrument and multi-engine rating and trained in Embry-Riddle Aeronautical University Standard Operating Procedures. An ANOVA was conducted to test this null hypotheses. Table 4 shows the results.

<table>
<thead>
<tr>
<th></th>
<th>Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between Groups</td>
<td>9.80</td>
<td>2</td>
<td>4.90</td>
<td>1.73</td>
<td>.19</td>
</tr>
<tr>
<td>Within Groups</td>
<td>76.20</td>
<td>27</td>
<td>2.82</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>86.00</td>
<td>29</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The threshold for significance for this study was preset at .05. Table 4 shows that there was no statistically significant difference among the three ‘landing gear unsafe’ auditory alerts which change over time. Although the descriptive statistics from Table 2 for these three questionnaire questions would suggest otherwise, according to the ANOVA test, the null hypothesis failed to be rejected. The descriptive statistics indicate
that the alert with changing pitch had a noticeably higher average score, compared to the other two alerts.

The data from questionnaire Question 5 was used to test the following null hypothesis: There will be no difference among the rankings of the effectiveness of the constant, changing pitch, changing loudness, and changing duration ‘landing gear unsafe’ auditory alarms for pilots with an instrument and multi-engine rating and trained in Embry-Riddle Aeronautical University Standard Operating Procedures. A Friedman Test was used to test this null hypothesis. The results are illustrated in Table 5.

Table 5

<table>
<thead>
<tr>
<th>Friedman Test for End-of-Experiment Questionnaire, Question 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>( N )</td>
</tr>
<tr>
<td>Chi-Square</td>
</tr>
<tr>
<td>( df )</td>
</tr>
<tr>
<td>Asymp. Sig.</td>
</tr>
<tr>
<td>Exact Sig.</td>
</tr>
<tr>
<td>Point Probability</td>
</tr>
</tbody>
</table>

The Friedman Test also did not yield any statistically significant differences among the rankings given to the control alert and the test alerts. Thus the null hypothesis failed to be rejected. As was the case with the other questionnaire questions, the descriptive statistics for questionnaire Question 5 indicates a noticeable difference among the control auditory alert and the test alerts.
Chapter V
Discussion, Conclusions, and Recommendations

Discussion

**Observed data.** Although this was a small-scale study with only ten participants, the data collected appears to follow a specific trend. The data observed during each of the 80 single-engine instrument approaches executed during the course of this study indicates an overall noticeably higher number of correctly followed procedures when the subjects were given a dynamic ‘landing gear unsafe’ auditory alert that changed over time compared to one that did not. In particular, the alerts that changed in pitch and loudness over time resulted in the highest increases in correctly followed procedures, compared to the alert which was constant over time. The alert which changed in duration over time also had a greater number of correctly followed procedures compared to the constant alert.

**Questionnaire data.** The end-of-experiment questionnaire also indicated a trend in favor of the dynamic landing gear auditory alerts that changed over time compared to the constant alert. This survey was designed to collect both quantitative and qualitative data concerning the subjects’ perceptions of the effectiveness of each alert. The first and last questions (Questions 1 and 6) were qualitative in nature, whereas Questions 2 through 5 were quantitative. The first question asked the subjects whether they thought a distraction such as an engine failure during an instrument approach would increase their chances of forgetting to extend the landing gear. All of the subjects answered this question with a 6 or above, indicating that they believed that a distraction would contribute to forgetting to extend the landing gear.
Questions 2 through 4 were quantitative in nature and asked the subjects to rate the effectiveness of each dynamic ‘landing gear unsafe’ auditory alert that changed over time on a Likert scale, where a score of 1 was least effective and a score of 9 was most effective. Because there was no question that asked the subjects to rate the effectiveness of the alert that was constant over time, the data from these three questions could not be used to test the research hypotheses since they stated there was no difference between the alerts that change over time (the test variables) and the one that is constant (the control variable). These three questions were used to compare the three test variables to each other. As a result, a new null hypothesis was created: there will be no difference in effectiveness among the ‘landing gear unsafe’ auditory alerts with changing pitch, loudness and duration over time. After running an ANOVA, statistical significance was not achieved. As a result, the null hypothesis failed to be rejected. The descriptive statistics appeared to show noticeable differences among the three dynamic landing gear auditory alerts suggesting that a full-scale study may produce significant results.

Question 5 asked the subjects to rank the four ‘landing gear unsafe’ alerts on a scale from 1 to 4 where 1 was the least effective and 4 the most effective. Because the control ‘landing gear unsafe’ alert was included in the rankings, the results from Question 5 could be used to test the research hypotheses. A Friedman Test was conducted but it did not yield any statistically significant differences among the four alerts.

Question 6 asked the subjects to describe any other ‘landing gear unsafe’ alerts, not included in this study, which they believed may be more effective than the standard one. Although this qualitative question gave the subjects freedom to suggest alerts other than auditory ones, most suggested additional auditory alerts. Many suggested including
an alert in spoken language instead of a tone which may alert the pilot that the landing gear is still up (i.e., “check gear”). As discussed in Chapter II of this study, there have been instances where such alerts have been used, but they do not change over time and therefore are still susceptible to habituation. One subject mentioned that if the avionics in the aircraft had a function for the pilot to set the minimums for the approach (the aircraft used in this study had such a function), then there could be an alert in spoken language to alert the pilot that the landing gear was still retracted when the pilot descended 100 feet below the minimums set in the aircraft’s avionics. This would be in addition to the normal ‘landing gear unsafe’ auditory alert. Along the same idea, another subject suggested that a bell sound could be used to remind the pilot to extend the landing gear at 1,000 feet above ground level (AGL), 500 feet AGL and again every 100 feet AGL thereafter with the landing gear still retracted. This would require a radar altimeter to measure the aircraft’s altitude above the ground. Another suggestion was made to have an alert which changed in pitch every time a configuration change was made, alerting the pilot that the landing gear was still in the up position. One subject suggested having a combination of more than one of the landing gear alerts included in this study.

Of the non-auditory ideas, one subject suggested that a light which changes over time may be helpful as well, perhaps one whose flashing gets faster over time. Another subject thought that a vibration may be helpful in reminding the pilot that the landing gear is not correctly configured for landing.

Conclusions

From the descriptive statistics of both observed and questionnaire data, it is apparent that there was an increase in ‘landing gear unsafe’ auditory alert effectiveness
between one that is constant and one that is dynamic (changing over time). The observed data showed practical differences in effectiveness by the number of correctly executed procedures during a single-engine instrument approach. Although all three alerts that changed over time yielded more correct procedures, compared to the constant alert, only the changing pitch and loudness alerts were noticeably different. This could suggest that the alert which changes in duration may be too similar to the constant alert, therefore also susceptible to habituation. Even though the ‘landing gear unsafe’ auditory alert is specifically designed to remind the pilot to extend the landing gear, it can also remind the pilot to perform other procedures as well. This was apparent in the observed data. Regardless of the type of alert, none of the subjects forgot to extend the landing gear, but other procedures were forgotten, most often with the constant alert and the changing duration alert.

The survey data was used to evaluate the effectiveness of the ‘landing gear unsafe’ auditory alert, as perceived by the subjects. Using these data, a comparison was made between the three dynamic alerts (changing pitch, loudness, and duration). The alert that changed in pitch over time was perceived to be the most effective alert. The descriptive statistics for questionnaire Question 5 (which asked the subjects to rank all four alerts), yielded a slightly higher average rank for the alert that changed in loudness compared to the alert that changed in pitch. It is possible that the subjects perceived the alert that changed in pitch over time to be the most effective at fighting habituation but also the more distracting. This alert may have diverted too much of the subjects’ attention to itself, therefore making it harder to concentrate on other tasks. When it came to ranking all four alerts, the subjects most likely felt that the alert that changed in volume,
changed enough over time to prevent habituation, but not so much as to create a
distraction.

**Recommendations for Further Studies**

Since this was a small-scale (pilot) study, it would be recommended to conduct
this study again as a full-scale project with at least 30 subjects to achieve possible
statistical significance. In this new study, using an FTD of the Diamond DA-42 L-360
aircraft rather than a PCATD of a DA 42-NG may enhance the results. Using the DA-42
NG model forced the subjects to learn new power settings since the NG model has
different engines from the L-360 model.

Using an FTD instead of a PCATD would allow the subjects to interact with a
realistic and full-functioning representation of the flight deck of the DA-42 aircraft,
rather than interacting with a generic panel of a multi-engine aircraft. Furthermore, the
FTD can be programmed with the different test landing gear auditory alerts instead of
requiring those alerts to be generated by a separate PC. This would alleviate the
researcher’s workload since he will no longer have to observe when subjects reduced the
throttle or extended the landing gear in order to determine when to activate or deactivate
the ‘landing gear unsafe’ auditory alert. The auditory alert was not generated by the
PCATD itself.

The design of the study could be changed slightly so that the malfunction during
the profile was not associated with the engine, but rather with the landing gear. During
the present study, none of the subjects actually forgot to extend the landing gear. The
possibility of one of them actually forgetting to extend the landing gear was slim,
compared to a study with 30 or more subjects. Another possibility is that these subjects
received primary training in an aircraft with retractable landing gear; this training stresses extending the landing gear on approach and checking multiple times that the landing gear is in fact down and locked before touchdown. A few subjects in the current study extended the landing gear late, indicating that they forgot initially but then remembered. It is hard to determine whether they remembered because of the auditory alert or because they did a final check and realized that the landing gear was not yet extended.

Another study, where the landing gear malfunctions when the subject extends it so that one or more landing gears do not extend and lock, may reduce the uncertainty of this study. If the subject is habituated to the alert, then it is as if it were not sounding at all, meaning that landing gear extension depends solely on pilot memory. As discussed previously, pilot memory to extend the landing gear is very reliable, but what happens if the pilot extends the landing gear and it is not completely down and locked? The auditory alert will still sound, but the pilot may become habituated to it. Intellectually, pilots determine that they extend the landing gear when they physically move the landing gear handle to the down position; this conclusion could persist, even when the system indicates otherwise. This scenario would be another useful study to further understand pilot habituation to the ‘landing gear unsafe’ auditory alert.

Lastly, the present study had a shortcoming in data collection. The questionnaire did not include a question that asked the subject whether a constant ‘landing gear unsafe’ auditory alert would be beneficial for reminding the pilot to extend the landing gear. The questionnaire only included a similar question for each of the dynamic ‘landing gear unsafe’ auditory alerts. Excluding this question for the control meant that the responses to the dynamic alerts could not be compared to the control alert.
References


General Definitions, 14 C.F.R. § 1.1 (2012)


University of Winnipeg. (1999a). *Music and sound*. Retrieved from Theoretical Physics at the University of Winnipeg website:

http://theory.uwinnipeg.ca/mod_tech/node121.html

University of Winnipeg. (1999b). *Properties of waves*. Retrieved from Theoretical Physics at the University of Winnipeg website:

http://theory.uwinnipeg.ca/mod_tech/node120.html


Appendix A

IRB Approval
Application for IRB Approval

Determination Form

11-152

Principal Investigator: Dr. Guy Smith

Other Investigators: Vincenzo Fasano, Dr. Nickolas Macciarella

Project Title: “Effectiveness of ‘landing gear unsafe’ Auditory Alarms”

Submission Date: September 23, 2011

Determination Date: October 14, 2011

Review Board Use Only

Initial Reviewer: Teri Vigneau/Bert Boquet

Exempt: X Yes ___ No

Approved: X Yes ___ No SEE BELOW COMMENT

Comments: The purpose of this study is to determine if a prolonged use of safe landing gear retractors will allow the gear alarms to sound for prolonged periods of time, and cause them to become ineffective during prolonged exposure. Trained pilots will be using a Personal Computer Aviation Training Device (PCATD). Risks to participants are those normally associated with non-motion flight training device with visual display, therefore an expedited review may be required. According to the consent document, an end-of-experiment survey will be emailed to each participant that could negate the anonymity of the participant. [Teri Vigneau 10-6-11] This qualifies for exemption. One caveat, have them post they MUST post the survey online and then provide participants the email link. This will take care of the anonymity issue. [Bert Boquet 10-14-11]
Appendix B

Data Collection Device
## Effectiveness of Landing Gear Unsafe Auditory Alarms

**Subject #__________**

<table>
<thead>
<tr>
<th>Approach #</th>
<th>Type of approach</th>
<th>Type of landing</th>
<th>Gear Up</th>
<th>Descent Checklist Completed?</th>
<th>Gear stabilized by 200'?</th>
<th>Missed approach executed?</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
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<td></td>
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<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
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<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
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<td></td>
</tr>
</tbody>
</table>
Appendix C

Details for Incorrectly Executed Procedures for Each Alert Type
<table>
<thead>
<tr>
<th>Approach #</th>
<th>Type of approach</th>
<th>Type of landing</th>
<th>Descent Checklist Completed?</th>
<th>Descent Final Items Checklist?</th>
<th>Gear Up callout at FAF?</th>
<th>GUMP Check at 500 ft above MDA?</th>
<th>Busted MDA?</th>
<th>Gear stabilized by 200'?</th>
<th>Missed approach</th>
<th>Gear up Landing?</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Straight In</td>
<td>Control</td>
<td>2</td>
<td>5</td>
<td>1</td>
<td>6</td>
<td></td>
<td></td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Circling</td>
<td>Control</td>
<td>3</td>
<td></td>
<td>4</td>
<td>2</td>
<td></td>
<td></td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Straight In</td>
<td>Changing Pitch</td>
<td>1</td>
<td></td>
<td></td>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Circling</td>
<td>Changing Pitch</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Straight In</td>
<td>Changing Loudness</td>
<td>3</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td></td>
<td></td>
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<tr>
<td>6</td>
<td>Circling</td>
<td>Changing Loudness</td>
<td>1</td>
<td></td>
<td></td>
<td>7</td>
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<tr>
<td>7</td>
<td>Straight In</td>
<td>Changing Duration</td>
<td>2</td>
<td>4</td>
<td>6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Circling</td>
<td>Changing Duration</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>
Appendix D

End-of-Experiment Questionnaire
Effectiveness of ‘landing gear unsafe’ Auditory Alarms.
End-of-Experiment Questionnaire

Participant Number: ______________

1. A distraction, such as an engine failure, during the approach and landing phase of flight, could contribute to my forgetting to extend the landing gear.

<table>
<thead>
<tr>
<th>Strongly disagree</th>
<th>Neutral</th>
<th>Strongly agree</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 2 3 4</td>
<td>5 6 7</td>
<td>8 9</td>
</tr>
</tbody>
</table>

2. A ‘landing gear unsafe’ auditory alarm which changes pitch over time could help me to remember to extend the landing gear, even during high levels of flight deck workload.

<table>
<thead>
<tr>
<th>Strongly disagree</th>
<th>Neutral</th>
<th>Strongly agree</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 2 3 4</td>
<td>5 6 7</td>
<td>8 9</td>
</tr>
</tbody>
</table>

3. A ‘landing gear unsafe’ auditory alarm which changes loudness over time could help me to remember to extend the landing gear, even during high levels of flight deck workload.

<table>
<thead>
<tr>
<th>Strongly disagree</th>
<th>Neutral</th>
<th>Strongly agree</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 2 3 4</td>
<td>5 6 7</td>
<td>8 9</td>
</tr>
</tbody>
</table>
4. A ‘landing gear unsafe’ auditory alarm which changes duration over time could help me to remember to extend the landing gear, even during high levels of flight deck workload.

<table>
<thead>
<tr>
<th>Strongly disagree</th>
<th>Neutral</th>
<th>Strongly agree</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>4</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>7</td>
<td>8</td>
<td>9</td>
</tr>
</tbody>
</table>

5. In this study you executed eight approaches with four different types of ‘landing gear unsafe’ auditory warnings: two were standard, two were with changing pitch, two were with changing loudness, and two with changing duration. Rank the following alarms for their effectiveness in reminding you to extend the gear (1 being the least effective, and 4 being the most effective).

<table>
<thead>
<tr>
<th>Type of ‘landing gear unsafe’ warning</th>
<th>Your Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard</td>
<td></td>
</tr>
<tr>
<td>Changing Pitch</td>
<td></td>
</tr>
<tr>
<td>Changing Loudness</td>
<td></td>
</tr>
<tr>
<td>Changing Duration</td>
<td></td>
</tr>
</tbody>
</table>

6. Are there other types of alarms, not included in this study, which would be effective in reminding you to extend the landing gear? If so, please include a brief description of the type of alarm you feel would be most effective.
Appendix E

Subject Consent Form
Embry-Riddle Aeronautical University

I consent to participating in the research project entitled:

Effectiveness of ‘landing gear unsafe’ Auditory Alarms.

The principle investigator of this study is:

Dr. Guy M. Smith

Participants in this study must be an Embry-Riddle Aeronautical University trained pilot with a minimum of a private pilot with instrument and multi-engine ratings. You will be asked to conduct a single engine non-precision approach in a multi-engine Personal Computer Aviation Training Device (PCATD). You will be required to use ERAU’s SOPs for a single engine non-precision approach. You will be asked to conduct eight approaches. Each participant can expect the entire study to take approximately two hours with a 20 minute break after conducting four approaches. Each participant will be e-mailed a link to a survey to be completed after all participants complete the eight approaches. Participants will be compensated $7.67 per hour. Participants who do not complete all eight approaches and the survey will not be compensated because only complete datasets will be used.

The individual above, or their research assistants, has explained the purpose of the study, the procedures to be followed, and the expected duration of my participation. Possible benefits of the study have been described, as have alternative procedures, if such procedures are applicable and available.

I acknowledge that I have been given the opportunity to obtain additional information regarding the study and that any questions I have raised have been answered to my full
satisfaction. Furthermore, I acknowledge that I am free to withdraw consent at any time and discontinue participation in the study without prejudice to me.

Finally, I acknowledge that I have read fully understand the consent form. I sign it freely and voluntarily. A copy has been given to me.

Date: _______________________

Name (please print): __________________________________

Signed: ____________________________________
    (Participant)

Signed: ____________________________________
    (Researcher/Assistant)