AUDIO WARNINGS

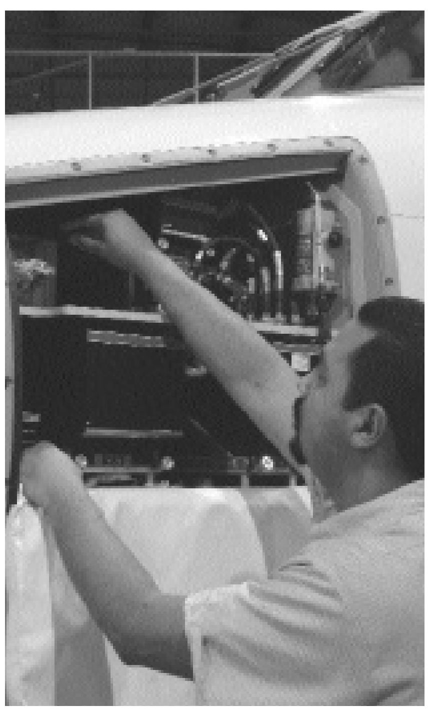
Does that beep mean the coffee's done?

BY PAUL NOVACEK

The audio alert system is often one of the most neglected displays in the cockpit. Yes, I said display. The audio system conveys information to the pilot, therefore it really is a display. But this display is actually a collection of displays all feeding the single and limited channel we call hearing.

Pilots use many of the senses to gather information about the craft—sight, touch, hearing and to some extent smell. I haven't heard of a taste display yet, but give 'em time. Of the five senses (some claim to have six), sight is given the highest priority and uses the most brain matter. But as cockpit designers, we can use more than just sight to communicate the condition of the craft to the pilot—hearing, or auditory displays give us a second tool to get information to the pilot.

Just about every new avionics system added to the cockpit adds another audio alert, contributing to the audio clutter in some aircraft. Add a traffic sensor, get audio; add a terrain warning system, get audio; add a CD player, get audio; add an autopilot, get audio. With all of this new audio clutter, who's minding the store? There have been some systems that address the dilemma, most notably the combined traffic/terrain warning systems, but not unless the cockpit is built around a central Caution and Warning System do you get the benefit of audio alert prioritization. These systems are just beginning widespread use in the corporate jet and airliner world, but still the sheer amount of audio alerts can cause a musician to give up trying to keep track of them all.



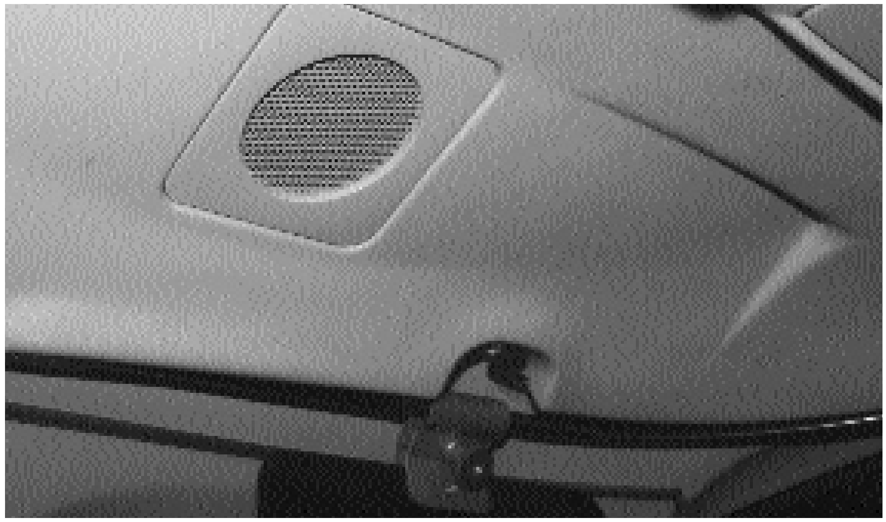
The volume of the audio alerts should be set 15-25dB over the cockpit ambient noise in cruise flight.

It's getting to the point where auditory clutter is approaching the sad case of visual clutter running rampant in modern cockpits. Originally intended to utilize an auxiliary sensory channel to get information to the pilot, the sound waves are getting very cluttered indeed.

Audio alerts are employed for two basic reasons, to gain the attention of the pilot to look at a visual display, or to give the pilot critical information when attention may be directed elsewhere. But this sensory channel is very limited, in both the delivery method and sensory throughput.

With the constant barrage of ATC communications, the questions from passengers over the intercom and all those whistles and bells, you'd think a pilot would just throw the headset down and yell, "stop the madness." Luckily, not all of the whistles and bells are supposed to go off at the same time. Most of the alarms are generated when things go really wrong and the systems are protecting the pilot from a bout of inattention. A well designed avionics suite is silent if all is going right—part of the Quiet/Dark Cockpit design philosophy.

As a retrofit installation, often the audio alert function is just a marketing feature and not required by certification. This leaves much room for the decision whether to connect the audio alert feature or not. Just because the system does have an audio alert capability, doesn't really mean that it should be connected. Perform an analysis on the currently installed equipment to determine if this new equipment will actually contribute to the overall cockpit philosophy or just lead to audio overload.



The audio alerts should be connected to both the headsets and speakers.

Selective Attention

Our auditory sensor is a wondrous collection of bones, cartilage, fluid and tissue. But the ear and its inner workings are a small part of the way we sense sound. The processing power, our brain, is capable of filtering-out and zeroing-in on sounds that our conscious or sub-conscious mind deems important. The sounds you hear do not travel directly to your consciousness, but pass through a filter in your brain that separates and prioritizes sounds. Your brain can only process a few sounds at a time although you are hearing it all. The steady sound of this computer that I'm using to write this article fades into the background and I'm not aware of it unless I consciously try to be aware of it.

Likewise, the absence of a sound does not register right away, but you sense that something is eerily wrong. It takes conscious attention to perceive and realize what you're not hearing. Your memory is involved here and everybody has his or her own pace when it comes to recalling memory. It's somewhat dependent on age, among other factors, but that's another article entirely!

As for warning, caution and alert tones, the auditory channel is generally a serial processor. We can sense multiple sounds, but we're actually only hearing one at a time and we can only concentrate on one at a time. Fortunately, our ability to switch back and forth between senses and comprehend the situation is extremely quick.

This selective attention mechanism requires the designer to carefully decide on the best method for an audio alert. It must be different enough to be noticed and at the same time recognizable enough to be associated with the intended meaning. Training and memory become big factors when audio tones are used to alert of a dangerous condition. If the training is insufficient and the various audio alerts are not experienced and committed to memory, the result is that the pilot may not know the meaning of the alert when it's experienced for the first time—a bad situation to be in.

Sound Perception

The human ear is sensitive to frequencies in the range of 20 to 20,000 Hz, but not equally sensitive to all frequencies. This is another factor that varies between individuals. Generally, the most sensitive range of frequencies include human speech, at 500 to 5,000 Hz, called the critical band. Although, we are more sensitive to the higher frequencies within that range. For example, if two tones were played for our ears, 200 Hz and 4,000 Hz, at the same sound-pressure level, we would perceive the higher frequency as louder.

A strange phenomenon occurs to the perceived pitch (frequency) as intensity (volume) is increased. As the intensity is increased at low frequencies (below about 1,000 Hz), the pitch becomes lower and at higher frequencies (above about 3,000 Hz), the pitch becomes higher. Frequencies in the 1,000 to 3,000 Hz range are relatively insensitive to pitch changes when the intensity is increased. See where this is going? Most of the audio alerts we experience in aviation fall within this frequency range. And why not, that's where we are the most sensitive. Unfortunately, this is also the frequency range where most of the aircraft noise is located—both engine and to some extent slipstream noise.

Masking is a condition in which one component of the sound reduces the sensitivity to another sound. This is a fancy way of saying you need to shout to be heard over the noise of a loud engine. Who hasn't done that around airplanes? The effect is most noticeable around frequencies that are close to the critical band and its harmonic overtones.

The male voice is very close to the frequency of a piston engine, and prone to the masking effect. A female voice is higher and closer to the upper

Continued on following page

AUDIO WARNINGS
Continued from page 61

limit of the "critical band." This gives you ladies out there a distinct advantage when talking over the radio.

Information Overload

The amount of information available in a modern cockpit could easily overload our capability if we were not trained to selectively prioritize all the various signals. Our brains have an amazing ability to subconsciously reduce the amount of incoming signals to a reasonable level. This ability causes us to fixate on a single source of information or selectively ignore other information signals. A good example of this is when we turn down the car radio when approaching an accident. Our brain is actively reducing the amount of input signals to a comfortable level—thus allowing more processing power to be allocated to the visual channel and the car accident ahead of us.

Because of this "tuning-out" of seemingly unrelated information during high-workload situations, new sensory input may get ignored. This phenomenon also occurs in the cockpit. Therefore, a well-designed audio alert first gets our attention and then directs our attention to a visual display. These audio alerts either directly focus our attention at a visual display, like a master caution, or provide all the information in the audio alert. A method used with good success is a two-part audio alert; an attention getting tone called an attensen, then a voice announcement. For example, the audio alert "Whoop, whoop (attensen), Pull-up, pull-up (message)," is an excellent example of an attention getting tone followed by information about the condition—either stating the problem or what to do about it.

The various mix of audio alerts cause another problem though—non-standardization. A quick survey of corporate jets revealed that there is not one standard set of tones associated with their meaning. Since most of these audio alerts are warnings or cautions, they're not used every day and the meaning is not easily recalled months after simulator training. A pilot that flies different aircraft as a matter of course may get very confused. In times of crisis, the wrong association will have dire consequences.

The vast array of audio can get overwhelming.

Research found that a normal pilot could remember and differentiate 10 different caution/warning signals. This led the FAAto limit the amount of different warning signals to eight (Part 25 certification), with speech counted as one of those eight. This speech capability allowed aircraft manufacturers to increase the amount of auditory signals without a limit. As long as the speech announcement is clear, easily understood and in the language of the pilots.

Even though the international aviation language is English, voice announcements still have their limitations. There was an accident where the last thing heard on the cockpit voice recorder tape was "What does pull-up mean?" This of course spoken in the native tongue of the pilots', who just barely spoke English.

Designing for our Hearing

Hearing has been used as an information gathering channel from the first Wright brother's flight. Orville used hearing to determine the speed of his craft, as hang glider pilots do today. Over the years, the development of audible alerts have reached maturity and are a valuable tool to convey information to the pilot.

An excellent human factors design is the audio scheme used with the 1940's era marker beacon receivers, still very effective today. The nature of the auditory signal conveys the urgency of the information. As the aircraft gets closer to the ground, the tones become higher pitched at the same time they become more insistent—thereby increasing the urgency as the danger increases.

Various techniques are used to design audio alerts, but still there are very few options. The frequency can be varied or multiple frequencies combined (chorded). Even voice announcements are used with varying levels of success. Our brains though can only perceive and process a limited amount of information.

Audio Alert Volume

As humans, we only have two fears that we're born with, falling and loud noises. All other fears are learned as we develop. The response to a loud noise, called the startle response, is very primitive and illicits a fight or flight action that takes some time to recover. Therefore, it's no surprise that many studies found that the startle response actually degraded performance.

The optimum volume for an audio alert is 15 to 25dB above the ambient noise. This has been found to reduce a startle response, yet still loud enough to alert the crew in a noisy cockpit.

Many of the newer stand-alone warning systems provide an adjustment over the alert volume, set by the pilot. A case of the "Let's give the pilot control over the volume because we can, not because we should." Unless properly designed to limit the amount of adjustment, these systems have the capability to let the pilot turn the volume down far below the ambient noise, thus the audio alert is totally masked and will never be heard.

Consider a scenario; the pilot is just learning the new piece of avionics and exploring all of the features. "Wow, I can control the volume. While I'm here, I'll just set it to a comfortable level." But, guess where the airplane is? In a quiet hangar, with the ambient noise dozens of dB below what it would be in flight. The pilot just rendered the audio warning ineffective.

The more complex systems, such as traffic and terrain warning, allow only the technician control over the individual alert volumes, reducing the chance that the volume may be set too low. A compromise between letting the pilot gain control over the volume and eliminating concerns about the volume set too low, involve minimum and maximum limits of control. The technician sets the minimum volume dependent on the background noise for that particular aircraft, or in some new aircraft the centralized audio alert system already schedules the volume to the current flight envelope. Then the pilot would have control over a range between 10 to 30dB above that minimum setting. This volume control technique accommodates the needs of individual pilots and the changing noise level during the course of a flight.

The only way to effectively set the volume of an audio alert system is to actually measure the amount and type of background noise and then set the alert volume accordingly. A sound level meter is used to measure the background (ambient) noise at the pilot's ears during flight at a high cruise speed. Then the individual alert volumes can be set on the ground using that magical 15 to 25dB over ambient noise.

A sound meter is needed to accurately measure the ambient noise in cruise and to set the audio alerts.

The high cruise speed should be used because this is typically the loudest portion of the flight. Engine noise may contribute to most of the noise at low airspeeds, but as the speed increases wind noise becomes the predominant noise source. Jets with steep-raked windscreens often create a shockwave over the cockpit, causing almost a roar inside the cockpit. Helicopters of course have various flight regimes that produce varying noise levels during a typical flight.

Design Criteria

It's very important to know and realize when to use an audio alert to convey a message. Information overload is a big issue and adding an audio alert just because you can is not a reason to do so. The guidelines for the use of an audio display are simple. Only use an audio alert when:

- A visual display needs attention.
- The condition needs an immediate response.
- Ambient light conditions may conceal a visual display of importance.

In some cases, there may be high-noise or selective attention problems when the audio alert is not heard. This requires that critical alerts, such as warnings or cautions, must be accompanied by visual signals that define the condition. Therefore, an alert beep for describing the condition is not enough; there must be a visual indication also. This may take the form of a labeled annunciator lamp or display system such as a PFD or MFD.

The duration of an alert tone or attensen should be between 0.5 and 1 second. Because we do not instantly respond to sound, an audio alert rise time needs to build for at least 200 to 300ms and employ a decay of about 140ms. Tones less than about 200 to 500ms do not sound as loud as tones of a longer duration. This gentile rise time also reduces any startle response.

Multiple-frequency, or chorded, signals aid in recognizing the alert over ambient noise and also aid in the recollection of the associated meaning. A complex audio alert is both easy to remember and descriptive, somewhat like mimicking a musical melody. Use multiple-frequency alert signals with frequencies between 1,000 and 4,000 Hz.

Be aware of the environmental noise when deciding on an alert tone

Continued on following page

AUDIO WARNINGS

Continued from page 63

and try to pick frequencies that are outside of the resident noise from the engine or slipstream. Piston engine aircraft have a predominantly lower set of noise frequencies caused by the engine and propeller, whereas a jet has much higher frequencies caused by the engine and slipstream. Also be aware of the Mach rumble that sometimes occurs with fast jets.

Any alert signal should have an automatic reset capability if there is any control over canceling the audio alert. Therefore, when the condition reappears, the audio alert signal will once again play. Please don't use a toggle switch to mute an audio alert. There is too much temptation to leave it muted.

A poor design would use a single tone to mean different things. This often happens when a sonalert is used for audio warnings. There are only a few different sonalert frequencies available and often three of the same frequency end up in an airplane. There is no distinction between the tones and one could be mistaken for another. Automobiles are notorious for this; the same tone is used for key-in-ignition, lights-on and seatbelts. It's so familiar that people still leave their keys in the car and leave their lights on because the same tone is heard every time the car is started. The single tone is so familiar that it's usually ignored.

Multiple levels of warnings should match the tone levels. For example, the master warning would have a more urgent, but similar, tone than the master caution.

There are many decisions to be made when adding equipment to an aircraft or designing a suite from scratch. Just be aware of the amount and types of audio alerts, your ears will thank you. q