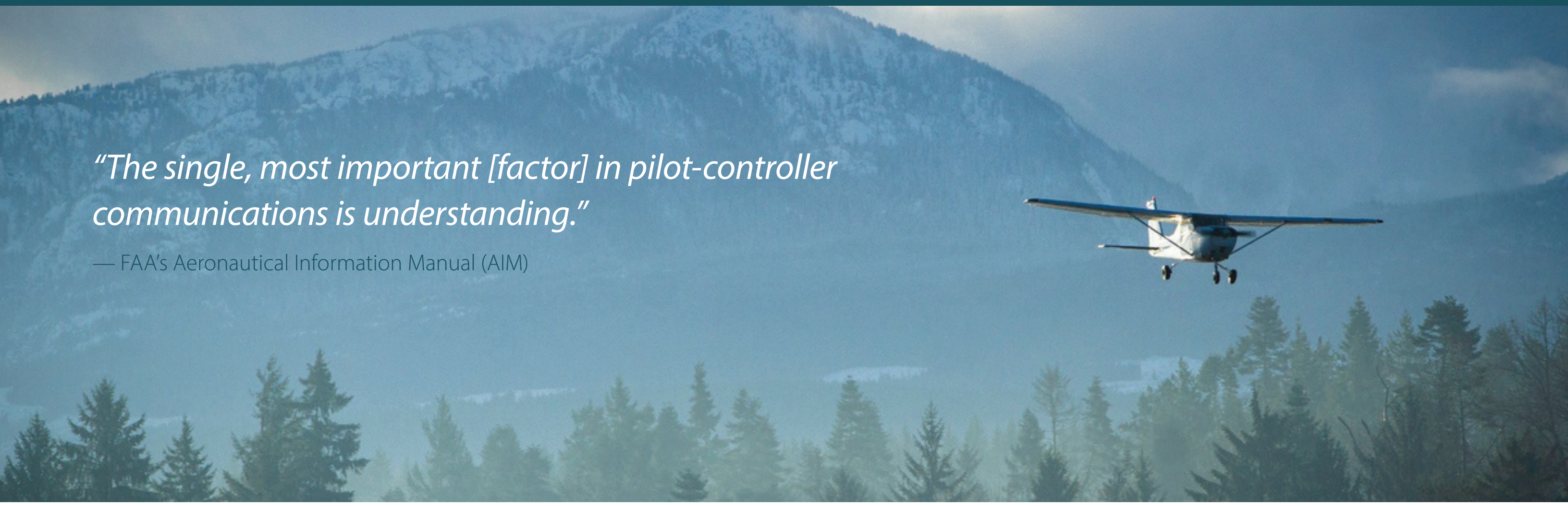
LIGHTSPEED®

ANR Lessons for Pilots

The Science and Application of Active Noise Reduction

eBook



"The single, most important [factor] in pilot-controller communications is understanding."

— FAA's Aeronautical Information Manual (AIM)

Introduction

Active Noise Reduction (ANR) is one of aviation's most trusted safety technologies, shielding pilots from droning noise while sharpening the sounds that matter most. Yet because it's so common, many assume all ANR headsets work the same. In reality, subtle differences in design and engineering can make a major difference in performance, pilot comfort, and even flight safety.

IN THIS EBOOK YOU'LL LEARN

- The fundamentals of ANR technology and its advantages in aviation
- Which headset design features truly matter—and which do not
- How aircraft acoustics and operating conditions impact ANR performance
- Why personal perception influences which headset feels "quietest"
- The role of ANR headsets as important pieces of safety equipment
- How ANR enhances communication clarity
- What key performance and design features to look for when choosing a headset to give you the ultimate flying experience

Contents

About Lightspeed Aviation

Lightspeed Aviation is a leading manufacturer of premium ANR aviation headsets and helmet products. We operate with a simple strategy: know your customer well and remain committed to relentless product evolution. By combining advanced technology with pilot-focused design, we create products that make flying quieter, safer, and more enjoyable. Trusted by aviators worldwide, Lightspeed is dedicated to advancing the general aviation industry through products that push performance to the edge of technological possibilities.

LIGHTSPEED®

CHAPTER 1

The Basics of ANR

"Don't all active ANR pilot headsets work the same way…or do the same thing?"

It's one of the most-asked questions that we receive from pilots. The short answer is yes—they all rely on the decades-old principle of canceling noise with out-of-phase sound. The longer answer is no—because design differences lead to very different results.

THE THREE ELEMENTS OF AN ACTIVE CANCELLATION SYSTEM

- Microphone – "hears" the sound levels that have gotten into the dome cavity
- Electronics – "process" that signal and relay it to the anti-noise speaker
- Speaker a.k.a. ANR driver – "adds" sound into the dome cavity

This "added" sound combines with the existing ambient noise to reduce the overall noise level. It's the "summing" of those signals that represents the active cancellation. How much cancellation can be achieved is a function of many variables — which we'll cover later in this chapter.

What does "cancellation" mean?

Masking Sound vs. Canceling Sound

We often get questions about whether ANR is just a "masking" sound that "hides" noise, much as a dentist might use music or white noise to "mask" the pain of drilling. Such a "masking signal" approach would inject additional noise into an acoustic environment and cause the ears and/or brain to perceive a different, more acceptable overall frequency response than what was originally present. But obviously, this would not be "cancellation" and is not what an active-canceling headset does.

Active cancellations adds "anti-noise" signals to cancel sound

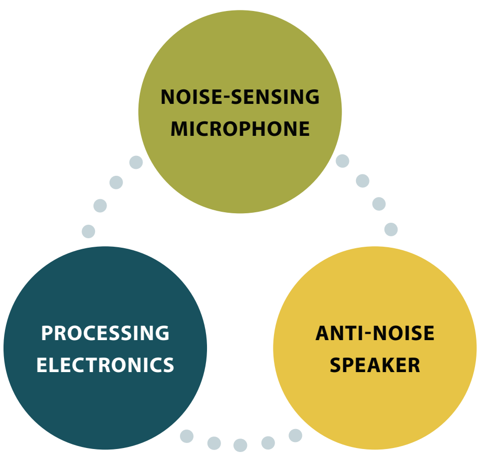
Active cancellation involves the "addition" of sound waves — mixing one wave with another to dampen its energy. Most headsets use analog cancellation techniques, but we'll also touch on digital cancellation later on. While it might seem odd to add large amounts of "new" sound energy into the dome cavity and ear canal, that's exactly how these active systems work. A microphone inside the dome detects the incoming noise, measuring its frequency and amplitude at that instant. The electronics then process and amplify that signal, flip it into an inverted "anti-noise" wave, and send it through the headset's speaker. When the two waves meet, they cancel each other out, reducing the noise that reaches your ear. The higher the level of cancellation, the more exact each part of the design must be for the system to function properly.

Limits on how much cancellation is achievable

Effective cancellation requires the canceling signal to fall within the contour of the existing noise spectrum. At low levels of cancellation, this is relatively easy. But the more you try to cancel, the harder it is to keep it functioning properly. If the canceling signal is either over-amplified or distorted in some way, the new signal will partially fall outside of the existing noise profile, and will thus be audible as new noise. In addition, improper phase or gain can also cause feedback ("squealing").

This limitation, known as system gain, must be carefully set to make sure the system has good stability — that is, that it works repeatedly and doesn't oscillate.

Add in the variables of ear shape, different sized heads, existing cavity shape and designs, etc. and stable performance is no small task! And that's why the answer to our original question, ***"Don't all active ANR pilot headsets work the same way… or do the same thing?"*** is an educated, qualified, ***"No"***.



What affects how well ANC works?

We've already seen that any active noise cancellation system involves three basic components:

- A noise-sensing microphone
- Some processing electronics
- An anti-noise speaker

Getting exceptional performance from an ANC design requires attention to each element of the system we've described. Let's look at each of these three elements in detail.

1) The "accuracy" of the noise-sensing microphone

To begin with, we need to pick up the most accurate sound replication within the dome if we hope to provide effective cancellation. When we talk about accuracy, we're really addressing two separate issues:

- **Sensitivity and fidelity:** how well the microphone reproduces the sound it hears.
- **Correlation:** how closely the sound that the microphone picks up corresponds to the sound your ear hears.

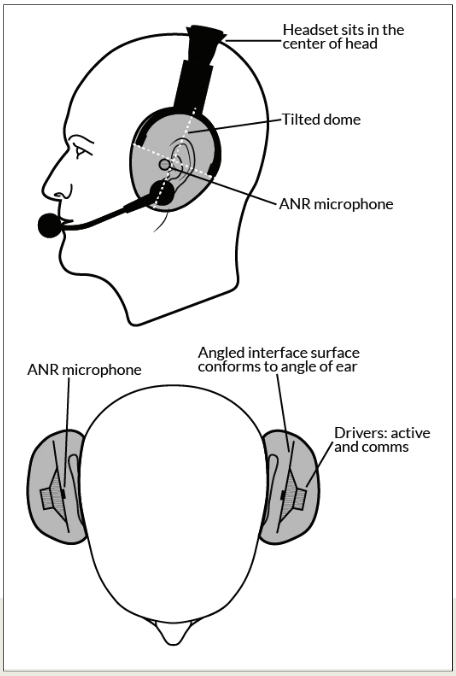
The first issue (sensitivity and fidelity) is important, but it's an easy problem to solve because there are many very good mics available for a manufacturer to use. It's the second issue (correlation) that's the difficult part of getting good information into the cancellation system. Simply put, an ideal system would cancel noise right in your ear canal, not just at a mic positioned somewhere in the dome. While it's not practical to stick a mic in your ear canal, a good headset design can go a long way to ensure that what the mic picks up is very close to what your ear hears. To get this right, it's important to know some things about the ear opening and the acoustic cavity we're working in.

IS THIS A "LEFT" OR A "RIGHT" EAR CUP?

Ears vary in shape and size, but statistically the ear opening is not centered—it sits slightly forward and below the middle of the dome. Mic placement must account for this physiology to deliver optimal performance. That's why the best results come from ear cups designed specifically for left and right ears. (In fact, manufacturers are increasingly noting in their documentation that although some headsets can be reversed they should not be worn that way!)

WHAT IS THE POSITION OF THE MICROPHONE RELATIVE TO THE ANR DRIVER AND THE EAR OPENING?

Mic placement relative to the ANR driver and ear opening is critical. If the mic sits directly above or next to the driver, you get stable, predictable cancellation at the mic—but noticeably less at the ear opening. Many advertised cancellation numbers are measured at the mic, not at the ear, which can be misleading. What matters most is cancellation where you hear it — at the ear. Careful mic positioning directly affects how much noise reduction reaches your ear. Ultimately, the best way to judge is by listening and comparing headsets in your own aircraft.

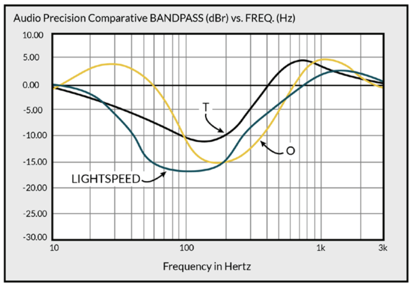


Domes are tilted and shaped for a better fit, and the mounting plates for the mic and speaker are angled to follow the ear's profile. These ergonomic and acoustic details significantly improve both comfort and performance.

2) The sophistication of the processing electronics

The signal from the microphone is sent through the electronics and is amplified or "processed." There will be substantial differences in delivered cancellation depending on the design of the acoustic cavity, the mic placement issues already covered, and the gain levels the design will support. The actual performance can be measured and plotted for comparison, as shown in the graph below.

The sophistication of the electronics, amplifiers, and audio filters has a great deal to do with overall headset performance. The differences can be seen in more than just the effectiveness of cancellation. The way the audio is processed will affect what you actually hear.



This graph shows significant variations in active canceling effectiveness for pilot headsets on the market today. We'll cover this more in Chapter 2, so you can begin to make educated judgements about comparative performance.

THE COMMUNICATIONS AUDIO: WHAT YOU HEAR FROM YOUR COMM RADIO

The less sophisticated ANR systems process the audio together with the ambient noise. The result is that the low frequency components of the radio and audio communications are cancelled along with the noise. This causes frequency response to be degraded, sounding tinny and unnatural. More sophisticated ANR systems process the signal and noise separately, allowing for full reproduction of the original audio signal.

THE SIGNAL-TO-NOISE RATIO: WHAT YOU'RE LOOKING TO ANR TO IMPROVE

All active products provide at least a modest S/N improvement when the masking effects of loud, low frequency noise are reduced. More sophisticated designs boost the signal levels to further enhance intelligibility, producing clearer communications… particularly for those who have suffered some hearing losses already.

Both of these are tangible examples of real differences among different ANR headset designs. Again…hearing is understanding!

What to look for

With the highest decibel levels in most planes between 80-120 Hz., you want a headset that provides maximum performance in that part of the noise spectrum.

3) The effectiveness of the speaker

After sampling the ambient dome sound profile (hopefully well-correlated to the ear opening) and processing that signal for proper fidelity, the system needs to produce the canceling "waves" of sound effectively and efficiently.

Speaker "effectiveness" would be measured by how closely the wave profile produced matches the input mic signal. The long, low-frequency "waves" are most critical to canceling of the 50-300 Hz. noise so prevalent in piston engine airplanes. More effectiveness will translate into better low-frequency cancellation. With the highest decibel levels in most planes between 80-120 Hz., you want a headset that provides maximum performance in that part of the noise spectrum.

In the next chapter, we'll learn more about specific headset cancellation performance and the actual airplane noise spectrum.

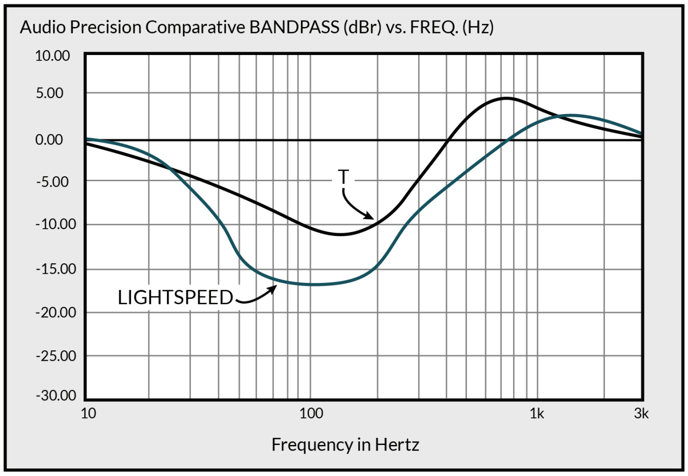
Over 10,000 pilots have tried a comparative demonstration of Lightspeed headsets, and we continue to offer the service year after year at industry tradeshows.

CHAPTER 2

Acoustic Issues

Understanding and comparing cancellation specifications

Many claims are made about the amount of cancellation a given headset will provide. But the very best way to choose an ANR headset is to actually try out various headset models in the aircraft you usually fly. No chart, graph, or product review is as effective in determining your best choice of headsets as actually flying with them. Since that is often not feasible, our goal in this chapter is to give you the knowledge you need to ask better questions and make a more critical analysis of the active and passive cancellation you can expect from a particular ANR headset model.



The cancellation profile

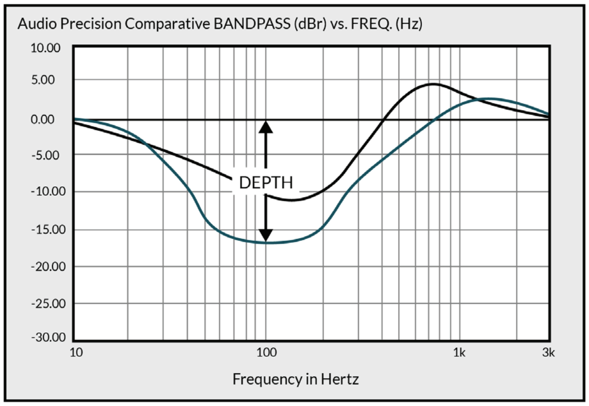
All active headsets have a cancellation profile, which shows the amount of noise reduction across the frequency spectrum. Profiles are measured by sophisticated laboratory equipment in a controlled acoustic chamber using a headset mounted on a fixture with a microphone inside an artificial "ear". A frequency sweep from 10 Hz to 10,000 Hz is done twice—once with ANR off and once on. The difference shows the cancellation, usually plotted with frequency (Hz) on the horizontal axis and cancellation (dB) on the vertical axis.

ATTRIBUTES OF THE CANCELLATION CURVE

- Depth: how deep is the cancellation at its deepest point?
- Breadth: how wide is the cancellation frequency spectrum?
- Position: at what frequency the cancellation profile is centered?
- Boosting: places in the cancellation spectrum where ANR actually does more harm than good (i.e., noise is amplified rather than cancelled).

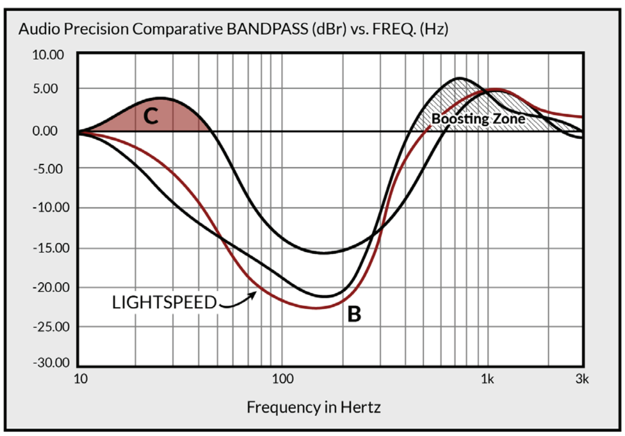
Of course, different headsets provide different results based on how well they have managed the variables we learned about in **Chapter 1**. Before we begin to do any comparisons, let's first talk about the attributes of this cancellation curve that will be present in every active headset.

Each attribute tells us something about the effectiveness you can expect to hear from the cancellation.



Depth

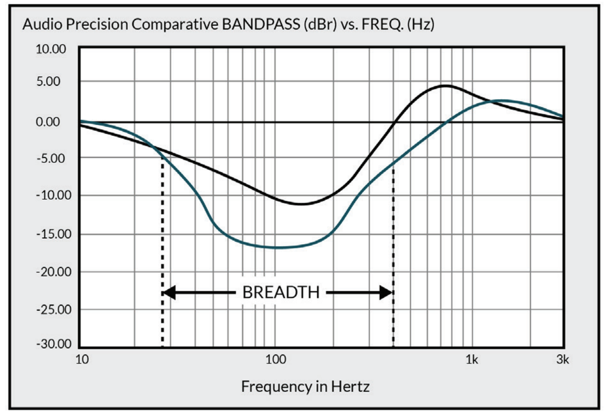
- **What it measures**: Expected max amount of cancellation
- **Typical range**: 2–4 dB variation due to mic sensitivity, calibration, and pilot-specific ergonomics. **NOTE: Some manufacturers measure noise reduction at the mic, leading to skewed results. For example, in the Diagram Headset "T" claims 14–16 dB, but measured at the ear it's 11 dB.*
- **Why it matters**: Each 3dB roughly doubles sound pressure.



All of the tested headsets show declining cancellation at frequencies above 300 Hz. The deeper the 100 Hz cancellation, typically the steeper the profile drops off between 300 and 600 Hz. The steeper the drop-off, the harder it is to avoid some "overshoot" of uncancelled noise.

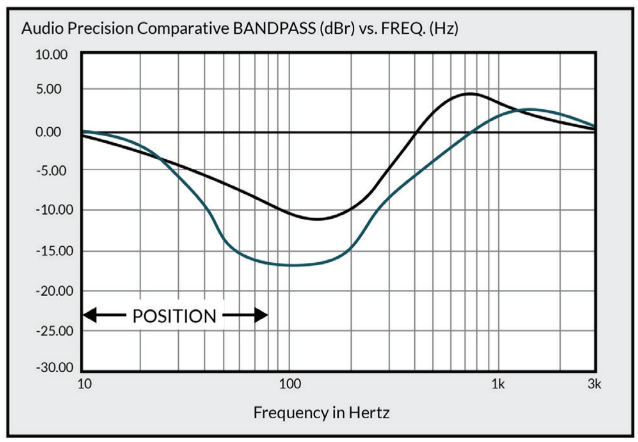
Boosting

- **What it measures**: Where ANR may amplify noise instead of canceling it — "overshoot" range of the anti-noise signal.
- **Cause**: Significant cancellation is much more difficult as frequencies increase, due to the shorter wavelengths of sound at higher frequencies relative to mic-to-speaker distance.
- **Why it matters**: Boosting is present to some extent in virtually all active headsets. When comparing headsets it's important to understand the limitations of achieving deep cancellation at higher frequencies, and know that some added noise is inevitable.



Breadth

- **What it measures**: The range of frequencies effectively cancelled by the electronics.
- **Why it matters**: Cancellation above ~5 dB is generally meaningful to the pilots
- **Combined effect**: Breadth + depth = total electronic cancellation capability



Notice in the graph how one headset cancels more low frequency than the other.

Position

- **What it measures**: The frequency at which cancellation is centered.
- **Typical range in piston aircraft**: A cancellation profile "position" centered between 85 and 130 Hz will often be the most effective in the typical piston-powered airplane.
- **Why it matters**: Every plane has its own unique noise signature. The resonant frequency of the propeller generates the loudest part of the noise spectrum. For direct-drive engines red-lined at 2400-2700 RPM, that will occur at 80-90 Hz for two-bladed props and 120-130 Hz for three-bladed ones. The overall noise envelope in the cabin of these airplanes is loudest from about 40 Hz to 250 Hz, and thus the range where cancellation is most important. Noise levels at even 500 Hz are typically down at least 10dB from those at 100 Hz.

IS BOOSTING A BAD THING?

While not disastrous, we'd always like to have less. Like so many things, tradeoffs have to be made between the amount of boosting and the overall system cancellation. Unfortunately, greater overall cancellation generally means higher levels of boosting. This explains why the best canceling headsets often have the largest boosting effects. All things considered, the additional cancellation is generally worth it for at least two reasons:

- Typically the boosted dB levels are relatively low (3-6 dB) while the additional cancellation at low frequencies are much larger. The actual amount of boosted noise (shaded area under the curve) is quite small compared to the total noise cancelled.
- The boosting generally occurs at higher frequencies around 1 kHz where headsets typically have significant passive attenuation, and where most airplanes have relatively low noise to begin with. The net effect is still significant noise reduction at those higher frequencies…just a little less.

The one exception is low-frequency boosting like that shown for Headset "C" in the graph. While only 3-5 dB, the headset might provide less than 5 dB of protection passive at 40 Hz, so the additional noise introduced by the ANR circuitry could be more noticeable at those frequencies.

Congratulations—you now know more about interpreting ANR headset cancellation profiles than most pilots and even many avionics experts. Of course, comparisons are only valid if the data was collected using similar test methods, since variables like mic placement, sensitivity, and fixture design can substantially skew results. Ultimately, the best test data comes from your own ears—trying different headsets in different planes and with different people.

Testing variables can substantially skew results. Remember, the best test data comes from your own ears.

So how can you judge which ANR headset is most effective?

If you've read this far, you already know the answer.

- **COMPARE** active cancellation profiles (depth, breadth, position, and boosting) — provided they were derived using comparable measurement techniques
- **CREATE** a "short list" of headsets to try
- **TEST** headsets personally in real conditions, when possible
- **PICK** the headset that passes the ultimate test: your own head in your own cockpit

What about "Total" Cancellation?

Some headset makers claim "total cancellation" by adding passive and active noise reduction together. Sounds impressive—but the math doesn't hold up. Curious why?

Read more on our blog »

CHAPTER 3

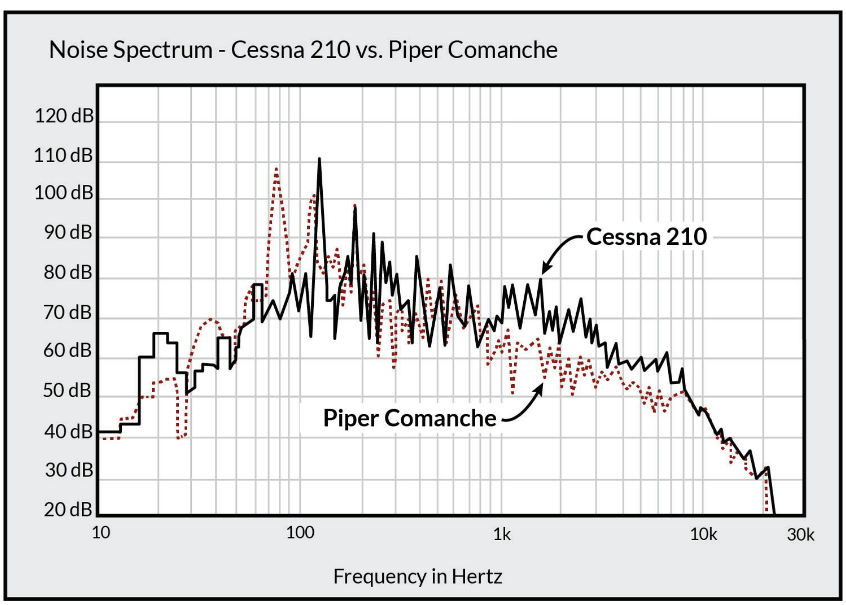
Airplane Issues

How aviation headsets cope with true cockpit noise profiles

If you've read this far, you've learned how engineers measure effectiveness of active noise canceling systems in the laboratory. But since we don't fly in the lab, our emphasis will now shift to studying the actual noise spectrums in various aircraft to focus on what ambient noise we're trying to cancel, and how serious a threat this noise poses to our hearing. Clearly, we want our aviation headset to cancel noise most effectively in the areas of the spectrum where there is the most noise. We'll look at some actual noise profiles in piston-powered single-engine cockpits, and see how well passive and active headsets deal with it.

Noise profiles

Having analyzed dozens of aircraft noise spectrums, we know that these profiles are typical of most makes and models of single-engine planes. The noises generated by the propeller and its resonant (harmonic) frequencies make up the most predictable part of the noise spectrum.



Actual noise data measured during flight in two different single-engine airplanes: a Cessna 210 and a Piper Comanche.

The Comanche had a two-bladed propeller that creates its peak noise levels at about 80 Hz, while the Cessna 210 has a three-bladed propeller with a peak noise level at around 120-130 Hz. Engine, exhaust, and wind noise add most of the rest of the sound in the noise profile. Obviously engine size, aerodynamics, and many other aircraft-specific design features contribute to the actual profile of any specific plane.

While these two planes look different in many ways, there are two general characteristics that are evident:

- There is a lot of noise in the low frequencies…between 70 and 300 Hz.
- Noise levels decline in the higher frequencies…particularly beyond 500 Hz.

Both these characteristics create a perfect fit for using active cancellation for optimal sound reduction. Remember that active cancellation works well only in the lower frequencies…it doesn't provide a noticeable dB reduction at frequencies over 500 Hz. Recall also that active systems require some tradeoffs in passive attenuation to support the needed modifications inside the domes. As such, they are not quite as effective in blocking out the higher frequency noise.

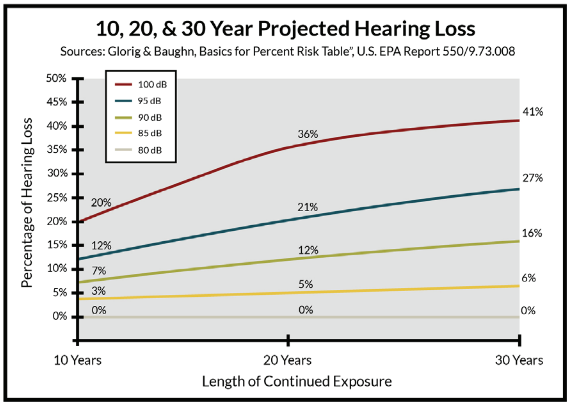
But isn't high-frequency hearing protection more important?

That all depends on both the level of noise and the duration you are exposed. High levels of low frequency sound could actually be more damaging than the higher frequency noise. As you can see from the airplane noise spectrum graph, there is usually 20-30dB more noise at 100 Hz than at 1,000 Hz in a piston-engine airplane.

Typically people are focused on hearing damage and "saving what they have left." That's a key reason they're interested in getting a new headset. Prolonged exposure to noise has a variety of effects on the body and brain that have daily and direct effects on your ability to fly a plane safely. (**Chapter 5** of this series will cover those issues in more detail.) Meantime, it's sufficient to state that active noise reduction headsets create both a quieter and safer environment for your ears.

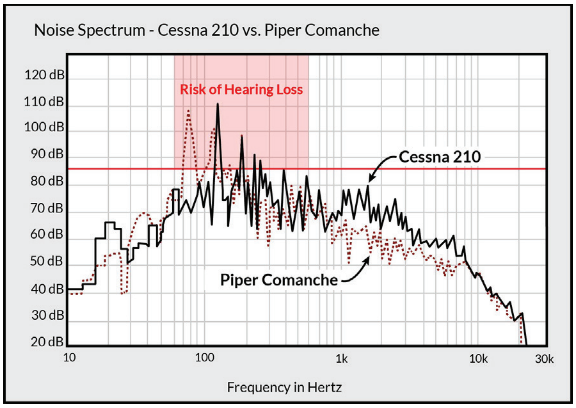
What we know about hearing loss

The data relating to hearing loss is actually the simplest to understand and has been well studied. These charts show data gathered from studies done by the EPA correlating levels of noise to the length of time the subject is exposed.



Projected hearing loss from continued noise exposure

These figures were calculated assuming exposure to the given level of noise for eight hours a day, five days a week. Not surprisingly, more noise for longer times means greater risk of hearing loss. But the most interesting piece of data here is that there is no projected loss from exposure to 80 dB for eight hours a day, and even 85 dB results in just nominal hearing loss. The real damage begins to develop with prolonged exposure to levels above 90 dB.



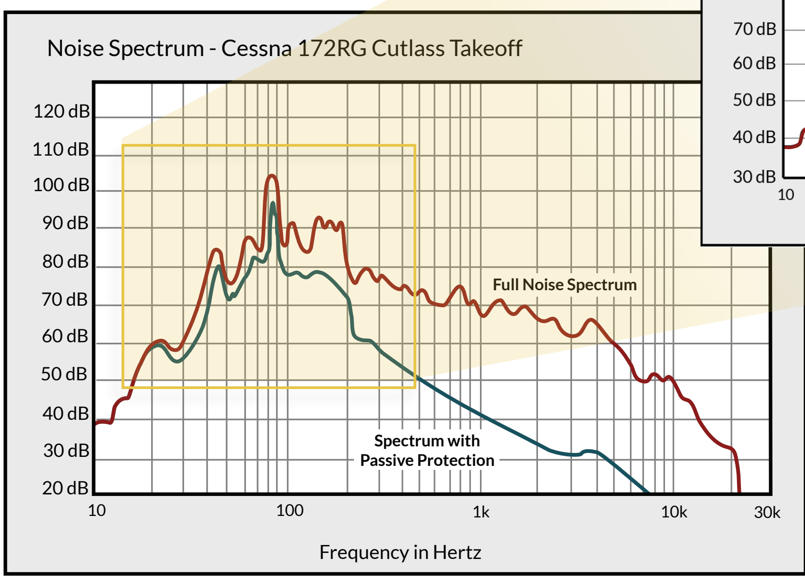
In propeller aircraft, noise of this intensity occurs only at low frequencies. Now you can see why it is so important to reduce the very low frequencies.

Why ANR works so well in aircraft

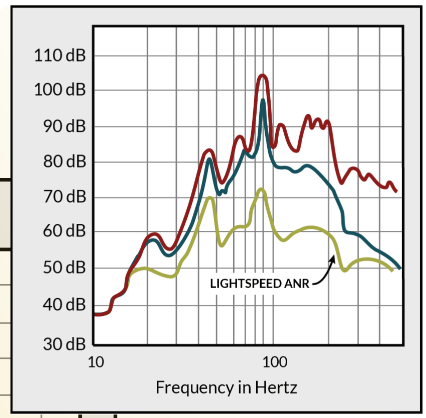
One of the reasons active cancellation is so effective in airplanes is just this: there is lots of low frequency noise. As we've seen, passive hearing protection is very effective where there is less noise, or where the noise is predominantly at higher frequencies.

It's just not the ideal solution for an aircraft noise environment. Compare that to the protection provided by excellent active cancellation in the low frequencies.

The graph below is a smoothed output of the takeoff noise spectrum of a Cessna 172RG Cutlass. It has a similar profile to the planes we looked at earlier in this chapter. The lower line is there to represent the attenuation you can expect from a typical passive headset. Note how poor the attenuation is at 100 Hz and how much better it gets at the higher frequencies. While there is substantial quieting at 1,000 Hz, you're still exposed to levels well over 80 dB at the lower frequencies.



Effects of typical passive cancellation on noise spectrum. (Cessna Cutlass with adjustments for passive cancellation over the full spectrum.)



In this close-up of only low frequency noise, the red line shows a noticable reduction in the additional attenuation provided with active cancellation over a typical passive headset. Understand that there will be a slight reduction in higher frequency attenuation with ANR headsets. This is generally a good tradeoff because the residual cockpit noise levels are already very low at higher frequencies…well below any levels which can cause damage.

So where are we?

You should now have a good understanding of the noise levels and spectrum we live in as pilots. The high-decibel, low-frequency components are not effectively removed by a traditional passive headset. In contrast, active cancellation is specifically designed to reduce this portion of the noise spectrum and get it well below the hearing damage thresholds. All of that creates a quieter, safer, more relaxing environment to enjoy during your time aloft.

In the next chapter, we'll change gears from noise to comfort and ease of use.

CHAPTER 4

Ergonomic and Interface Issues

There are also several comfort and human-factor issues associated with ANR headsets. The ergonomics of the human head demand a wide range of adjustments to deliver comfort over hours of use.

Optimizing the physical headset for pilot use

Pilots have long sought more comfortable headsets, but designing them isn't easy. Active cancellation helps reduce fatigue, yet physics—pressure, weight, and temperature—still impact comfort. These issues affect all headsets, but ANR models add complexity: ear seal design, electronics, and portable power packs all introduce new constraints and impact convenience in the cockpit.

Why is it so hard to design a headset that fits well and wears well?

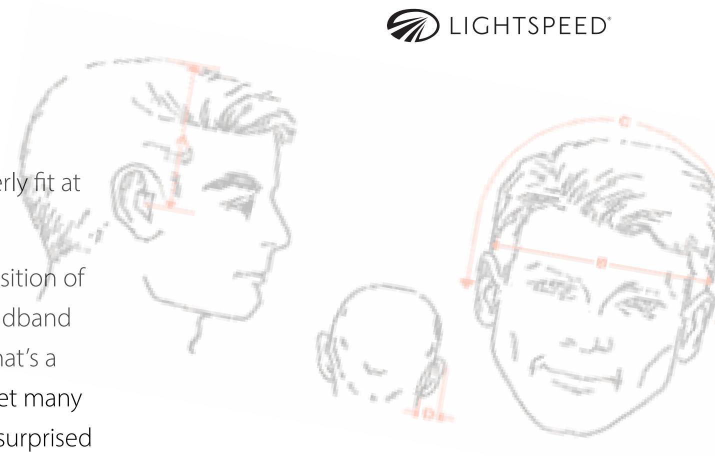
It turns out there's substantial variation in the size and shapes of human heads. The chart below is data gathered from military ergonomic standards for head sizes. It compares the dimensional differences for men and women covering the 5th to 95th percentile of people…basically almost the whole population!

MEASUREMENT	5TH PERCENTILE	95TH PERCENTILE	RANGE
Ear Height	11.6 cm	14.4 cm	>1″ (each side)
Head Breadth	13.5 cm	16.5 cm	>1.2″
Overhead Circumference	31.3 cm	37.8 cm	>2.5″
Ear Protrusion	1.3 cm	2.8 cm	>1/2″

Source: Human Engineering Design Criteria for Military Systems, Mil-Std 1472C

As you can see, the challenge to get both adjustability and a comfortable fit is a difficult one. The classic design relied on side pressure to compensate for the width variations. The metal overhead band has some adjustment for circumference but no accommodation was provided for ear protrusion. In analyzing how to make a more versatile headset design, the issues boil down to size and side pressure.

The challenge for fit: How to design a headset that fits the 5-95% dimensions for head width, height, and ear position?



Adjustability

Obviously the headset needs to adjust big enough (or small enough) to properly fit at the start of your flight.

Look at some of the variability in things like head width (over 1 inch) or the position of ears on the side of an “average” head. Overhead circumference means the headband needs to have ample “length” adjustment to extend the needed 2.5 inches. That’s a lot. Some people and children need it to compress to fit their smaller heads. Yet many pilots are men with size 7 3/4 hats. While all this is certainly possible, you’d be surprised how many existing designs cannot cover that range of heads.

Comfort over time

For most pilots, the “comfort problem” isn’t initial fit but pain after wearing the headset for a short time. Comfort needs also change over the 1–4 hours you might be flying.

Why? Well, without getting too medical, there is very little “subcutaneous fat” (e.g. padding) under the skin covering your skull, and the head is highly vascular, especially around the ears. Constant pressure can restrict blood flow, creating “hot spots”. The combination of minimal fat and high blood flow makes this region especially sensitive.

Making a headset lighter in total weight is good, but actually the distribution of that weight is the more important variable to comfort. Heavier headsets with pads that distribute weight evenly over a broad area will feel much more comfortable than one that is lighter but has limited contour distribution over the top of your head. Proper radial design of the headband system and effective padding determine how well the headset fits and conforms to your head and ears—ultimately defining comfort.

Those all-important ear seals

Perhaps the most important aspect of overall flying comfort is the ear seals. Size, shape, and materials affect comfort, as well as both active and passive noise reduction. Ideally, the ear should float freely in the cavity without touching the seal or speaker—which directly impacts the seal’s size, shape, and construction.

Cavity opening orientation – Proper orientation and shape will help isolate the ear from the seal. Many pilots tilt their ‘oval’ shaped domes backward to better align them with their ear.

Cavity depth – Notice the >1/2” variation in “ear protrusion” on the head measurement chart. This must be accommodated either in the depth of the ear seal or in the dome cavity opening.

Cavity volume and ventilation – Greater depth helps keep the ear cooler. The material used to surround the seal would also ideally be breathable; minimizing humidity around the ear. Within reason, larger is better.

Ideally the ear seal creates a cavity space that is both comfortable and quiet. It turns out there are tradeoffs between optimal comfort and getting the maximum passive attenuation. Let’s take a look at different materials used in ear seals to learn more about the strengths and weaknesses of each.

EAR SEAL MATERIAL	ATTENUATION Cross-sectionally blocks out noise	CONFORMABILITY Material flows to cover an uneven surface	SIDE PRESSURE Pressure needed to seal against face	WEIGHT Weight of a "normal" aviation ear seal	VOLUME Size of cavity compared to silicone seal
SILICONE GEL	Best	Worst	High	1.2 oz	100%
LIQUID	Very Good	Best	Medium	.6 oz	25%
FOAM/LIQUID (GELFLO)	Good	Good	Medium	.6 oz	70%
TEMP-SENSITIVE FOAM	Good	Very Good	Low	.5 oz	150-200%

EAR SEAL MATERIALS: COMFORT VS. PERFORMANCE

- Liquid: Excellent sound blocking, but needs enough side pressure to stay around the ear; small cavity volume.
- Silicone: Stays in place well, but heavy and only conforms under high pressure.
- Foam / Thermal-Conforming Foam: Best balance—comfortable, low side pressure, ample ear volume, and easy on glasses, while still providing good passive attenuation.

EAR SEAL MATERIAL CHARACTERISTICS

At first glance, you may notice the best materials for blocking out sound are liquid and silicone. But they perform poorly for comfort. Liquid will stay at the "bottom" of the seal unless the side pressure is adequate to "squeeze" it up around your ears. Likewise, silicon gel requires relatively high pressure to conform to the side of your face — it's also nearly twice as heavy as other options!

When you weigh the considerations and design tradeoffs, temperature-sensitive foam is the clear winner for conformability, minimum side pressure, and ear cavity volume. It's particularly effective when wearing glasses. The conformability helps minimize the localized pressure of the stems pushing on your temples. All of those characteristics will translate into a more comfortable headset.

WHAT DOES THIS HAVE TO DO WITH ANR PERFORMANCE?

Comfort and fit, by themselves, have little to do with active cancellation but ear seal conformability does. Even more than in a passive headset, an ANR headset needs to provide an "acoustically tight" fit. Tight doesn't have to be vise-like, but a good seal to the head is required to get proper cancellation. If you doubt this, lift off the ear seal of an active headset while flying. You'll hear the system become unstable and start to oscillate.

Particularly when the amounts of active cancellation are high, a stable acoustic cavity with no "leaks" is important. That seal comes from either a dense material under high pressure or something of lower density with lower pressure.

Do lightweight ANR headsets work?

If you have a really quiet, cabin-class plane, it may be worth trying a supra-aural headset, which sits on the outer ear — as opposed to a circumaural (muff-type) headset. They are light in weight and provide good ventilation for the ear. The tradeoff being limited noise isolation, limited passive protection, and a lack of basic headset features like volume controls. Though due to sensitivity of the ear surfaces, some pilots find they are less comfortable than a typical over-the-ear headset.

Powered headsets…what a hassle!

One key difference with active headsets is their need for external power. With passive headsets the sidetone audio (what you hear) and the voltage to drive your microphone preamp (for what you say) are supplied by amplifiers in your avionics. ANR headsets require additional power to support the active electronics in the headset.

For most pilots, a portable ANR system conjures up images of large, bulky battery packs with a rat's nest of extra cables. Luckily, improved efficiency has reduced this to just 2 AA's placed inline with your normal headset cord or a rechargeable Lithium-Ion battery— while still providing 40+ hours of use. That's months of flying for many of us! Some pilots prefer headsets that take AA batteries over 9-volt batteries, since they already carry a stash of AA's for other devices.

Battery life is most commonly affected by leaving the headset on after a flight. Many headsets now include "Auto-Off" features—either sensing when the headset is removed or shutting down after power is off from the radio/intercom—which greatly improves convenience. Some form of Auto Shut off should become a standard feature of all ANR headsets.

Did you know?

Most battery failures are due to forgetting to turn headset off, not hours flown.

Find out what comes standard

Most of the latest generation of active headsets come with a full set of standard features for easy use. These would include dual volume controls, stereo/mono capability, some form of battery gauge, and a padded bag for carrying and protecting your investment. Different suppliers provide these features and functions in slightly different ways, so make sure you pay attention to them when you test-fly different headset models.

Choosing the right headset power source

Active noise reduction headsets require power to operate, but the source of that power can affect convenience, portability, and overall performance. Each option has tradeoffs in battery life, ease of use, installation, and cost. The chart below summarizes the key differences to help you decide which power solution best fits your flying style and aircraft setup.

	RECHARGABLE AA'S	RECHARGABLE LITHIUM-ION	AIRCRAFT POWERED
PROS	• Widely available • Easy to replace	• Does not need constat replacement • Can hold 30+ hours of life	• Eliminates batteries and battery boxes
CONS	• Life expectancy about half of alkalines • Must recharge before flight	• Must remember to charge after each flight for optimal performance • Battery life can be shorter than alkaline	• May require multiple connections unless panel-integrated • Installation cost ~$150–200 per position • Limited portability*
TIPS	• Keep spare batteries • Always check charge before flying	• Always remove and fully charge headset after use • Forgetting to turn off previous flight can leave you without ANR	• Ideal for aircraft with compatible avionics • Consider if you frequently switch planes or need portable ANR

**The Lightspeed Delta Zulu and Zulu 4 headsets both offer flex power so your panel power headset can still be used with a dual GA plug adapter*

Make a battery check part of your pre-flight checklist.

CHAPTER 5

Optimizing Your Flying Experience

Safety meets comfort

As with any aspect of flying, safety and occupant protection should come first, and comfort should follow. Although the history of powered flight dates back more than 100 years, concerns about the effects of aircraft noise on hearing are relatively new. We've all heard the axiom, ***"There are old pilots; there are bold pilots; but there are no old, bold pilots."*** We could add, ***"and precious few with normal hearing."***

In fact, in the days of open cockpits and wire struts, pilots flew with ears unprotected and gradually damaged the hearing they desperately needed to be safe while flying. It is said that the whisper test, still used in the flight physical, has its roots in the perceived necessity for pilots to hear the "singing" of the support wires while in flight.

The effects of noise

While it is true that most cockpits today are closed and there have been advances in sound treatment (i.e. mufflers, soundproofing insulation, etc), increases in engine power and extended aircraft range have largely negated any advances in average "quietness."

ADVERSE EFFECTS OF NOISE ON PILOTS AND PASSENGERS:

- Permanent hearing loss
- Stress and fatigue
- Masking of "wanted" sounds
- Negative effects on speech perception and recall

Permanent hearing loss

The human auditory system is a bio-electrical marvel. It's capable of hearing sounds from 20 cycles per second to roughly 20,000. Under ideal conditions, the human ear is said to be capable of hearing a sound roughly equivalent to pressure exerted by a gnat's wing, yet able to tolerate sounds literally millions of times greater. So responsive is the ear that early researchers adopted a logarithmic scale for hearing measurement. In this scaling system, a sound of 100 decibels (dB) is 100,000 times greater than a sound of zero dB, and a 120 dB sound is a million times greater than that same zero dB sound.

Special Thanks to Dr. Jim Yates who provided substantial contributions to this chapter. Dr. Yates is Professor and chair, S.P.A. of John A. Burns School of Medicine, University of Hawaii, and principal of Audiology Associates Hawaii.

Flying without ear protection for long periods and with repeated exposures places us at a risk of hearing loss.

Noise-induced permanent threshold shift can occur from repeated exposure to damaging noise levels. 1-3Khz noise levels have more damage potential for human hearing than do those of lower frequencies, though sufficient levels of low-frequency sounds can produce permanent hearing loss.

One thing is certain: Beyond certain levels (about 85dB, A-weighed), increased intensity and exposure time will produce increased hearing loss. The hazard is most pronounced in the region nearer 4 kHz but spreads over a frequency range as exposure time and dB level increases. In the typical small aircraft, cabin noises tend to be concentrated in the lower frequencies. Noise levels in most aircraft are sufficient to cause threshold shift losses if the exposure is sufficient in duration. Flying without ear protection for long periods and with repeated exposures places us at a risk of hearing loss.

HOW ACTIVE NOISE CANCELING HEADSETS PROVIDE RELIEF

- **Reduce the levels of low frequency noise exposure**
  Most GA aircraft have high levels of low frequency noise and even the best passive protectors are relatively poor at attenuating this part of the noise spectrum sufficiently. The best active headsets are exceptional at this specific range.
- **Enable communications audio signals to be intelligible at a lower volume**
  Because of the masking effects low frequency noise has on speech, pilots often must turn up the volume to be able to decipher normal voice frequencies. That often results in 110db of communications audio directly into our ears (through the headset speakers) in an effort to better hear and understand what's being said. The clarity of ANC systems improves comprehensibility at lower volumes.

Stress and fatigue

Noise causes stress and fatigue, though measuring its effects on pilots is difficult. Stress depends on past experiences and the type of noise—high-pitched sounds feel more disturbing, while loudness increases stress. Vibration and lower frequency sounds contributes to fatigue and reduced focus, and military studies have identified it as a source of mission errors.

While less documented in recreational flying, the risks are real: long-term noise exposure can cause fatigue and mental errors. Active noise reduction (ANR) lowers overall noise, making flying less stressful. Anecdotaly, pilots regularly report feeling noticeably better during and after flights when using ANR headsets.

Masking of "wanted" sounds

Human speech spans roughly 100 Hz to 10,000 Hz, but most energy lies below 500 Hz in vowel sounds. Consonants, which carry meaning, fall between 1–6 kHz and are much weaker, making them easily masked by noise. Even slight masking can quickly reduce intelligibility, as this chart showing data from a study of adults with normal hearing shows.

LOSS OF CONSONANTS	INTELLIGIBILITY for adults
4% or less	Very Good
5%-8%	Good
9%-11%	Fair
12%-14%	Minimal
15% or more	Unintelligible

Even a 10% loss in consonant sounds will substantially limit comprehension

The implications for pilots are straightforward: even a 10% loss in consonant sounds will substantially limit comprehension. Obviously the danger of missing or mis-hearing verbal instructions is a very real concern.

ANR makes you a safer pilot

The intent of this chapter is not to frighten, but to serve as a reminder of all the sound-related issues we deal with every time we fly. Being a pilot is a complex "job" with many responsibilities. You probably have been using a basic passive headset and those help you stay on top of your many tasks. ANR will make doing those tasks both easier and less stressful. An ANR headset provides additional noise suppression in an area of the noise spectrum that will make communication clearer and increase attentiveness.

ANR will make you a safer pilot. It'll protect you from long-term hearing damage. You'll finish the flight more relaxed and enjoy flying more. A modest investment can enhance the health, comfort and safety of your flying experience to levels unheard of just a few years ago. So keep your altimeter up and your dB down!

Given what we've already learned about the low-frequency dB levels encountered when flying, excessive levels can easily overwhelm the important consonant sounds. The danger of "masking noise" in an aircraft is that we may miss important signals either from controllers or other warning signals that we really need to hear accurately. Masking noises contribute to stress levels as we "strain" to hear, process, and understand the multitude of signals and data we manage as we're flying. In a real sense, masking of "wanted" sounds may be the biggest danger in an aircraft.

Active systems reduce the masking effects of the low frequency spectrum your ear hears. The most effective systems will substantially enhance your ability to hear and understand audio communications. Virtually every pilot who tries an ANR headset for the first time notices this benefit.

Negative effects on speech perception and recall

Elevated levels of noise substantially impair our ability to recognize words. When noise levels exceed 85 dB, they begin to have adverse effects on the speech comprehension. The key to greater word recognition is in getting the communication audio "signal" significantly above the ambient "noise." That's a hard task for pilots since we're exposed to cabin noises with a significant low frequency component. When audiological professionals want to create speech masking sounds, that's precisely the type of noise they use. The typical cockpit is an excellent speech masker.

Studies have shown we need at least a 9 dB difference in the audio signal above the "ambient" noise levels in our headset to achieve 80% word recognition or better. That difference in dB level is typically expressed as Signal-to-Noise Ratio (abbreviated S/N or SNR). A S/N ratio of 12-15 dB allows a 90% recognition rate. We know how loud the noise spectrum is in most planes…particularly at the lower frequencies. The combination of masking effects and overall ambient sound levels makes hearing and understanding communication very difficult. Most of us know what that "sounds" like…from ATC calls we miss altogether to ones that prompt us to make repeated "say again" requests. The higher background levels of noise when flying also changes our hearing "threshold," making previously understandable words unintelligible. Beyond just the S/N ratio issues involved in protecting word recognition, our ability to "process" speech and sounds is adversely affected by higher background noises.

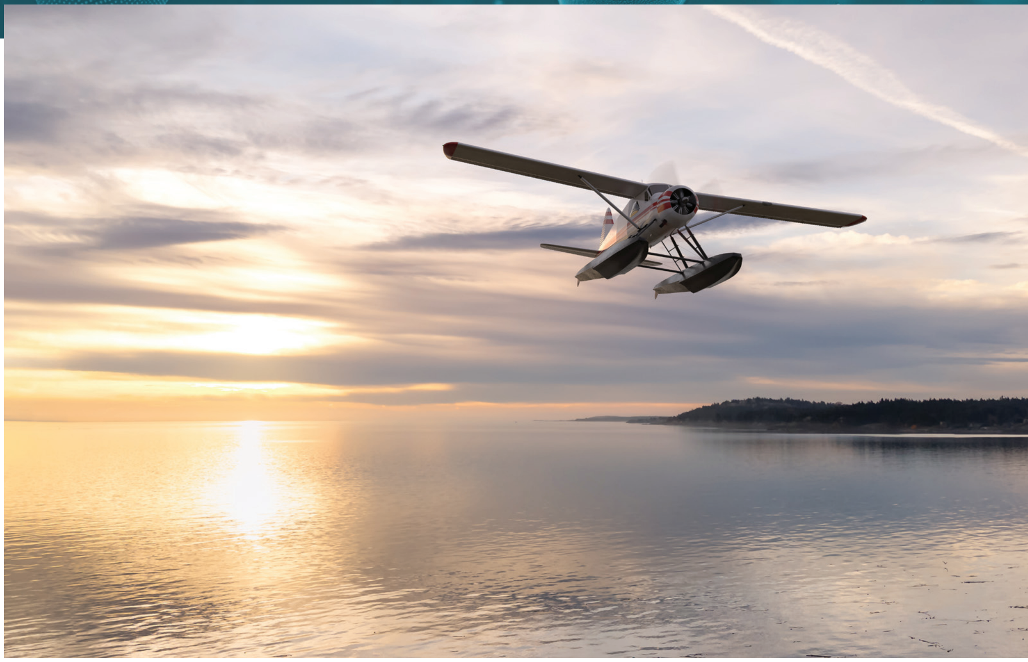
EFFECTS OF HIGH BACKGROUND NOISE

- Decline in accuracy of comprehension and response speed
- Increased difficulty in sharing of attention among several potential signals
- Impaired recall (memory) and ability to handle delayed information effectively

Noise affects our understanding, attention sharing, response time, and short-term recall of what was said. None of these are good things for a pilot — so anything that can be done to quiet things down is good!

CHAPTER 6

Factors that impact "quietness"



Now that you understand ANR, let's explore the factors that affect your choice in headset.

With dozens of aviation headsets on the market, there are a multitude of claims about battery life, ease of use, weight/comfort, design innovations, and performance specifications for passive and active attenuation. Many features have inherent tradeoffs associated with them…providing a benefit and potentially an adverse effect depending on the users particular habits and application needs.

The most frequently asked unanswerable question remains: "Which headset is quietest?"

This is a very subjective question that only partially depends on the characteristics of the headset itself. Much of what the user calls 'quietness' is related to individual characteristics of hearing and ergonomics…factors that cannot be predicted for you but must be experienced.

Certainly the most dominant factor affecting quietness is the acoustic properties of the headset …how well it attenuates noise passively and actively.

Much of what the user calls 'quietness' is related to individual characteristics of hearing and ergonomics

FACTORS THAT CAN AFFECT NOISE ATTENUATION:

- How an individual headset fits your head
- Your hearing 'acuity': the efficiency and capability of your ears
- The noise environment you are in. Is it a 'typical' GA noise spectrum — or different, due to engine size, aircraft design, or other issues?

Comfort depends on more than noise reduction—factors like weight, side pressure, battery use, and auto shutoff all shape satisfaction. Even the "quietest" headset may not feel right to you. In headset design, passive and active attenuation are 'traded off' to provide a balance of low and high frequency attenuation. But since attenuation claims can be misleading, it's important to understand the data behind what truly makes a headset quiet. Let's look at the building blocks...

CHAPTER 7

Passive vs. Active

Understanding and comparing cancellation specifications

Before going any further, let's explore what passive and active attenuation are and how they affect the total cancellation.

- **Passive noise reduction** - How much noise is eliminated by the 'physical' characteristics of the headset.
- **Active noise reduction** - How much noise is reduced via the 'electronic' cancellation generated within each dome.

This cancellation can be measured and graphed…typically using noise levels (in dB) on one axis and frequency on the other. These characteristics are unique to each headsets style/shape/design. These two attenuations, when graphed and overlaid, form the basis for any claims of 'total' cancellation.

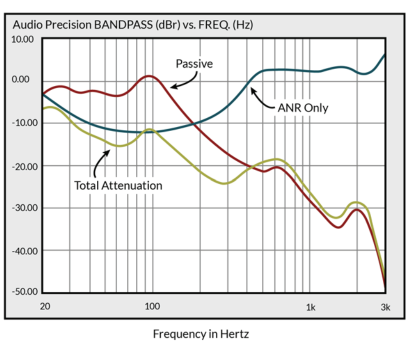
Before we address the issue of advertised claims on various models, let's compare data on cancellation for different products. Below is a set of attenuation graphs for three different headset models. For each platform, the graph lines show Active performance, Passive only, and a third line showing the combined or Total Attenuation.

Why not just add the active and passive claims together?

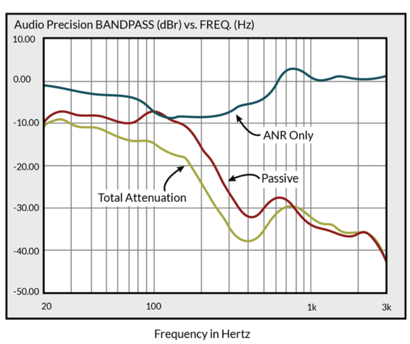
If only it were that simple! Take a deep dive into the math and see why simply adding doesn't add up.

Read more on our blog »

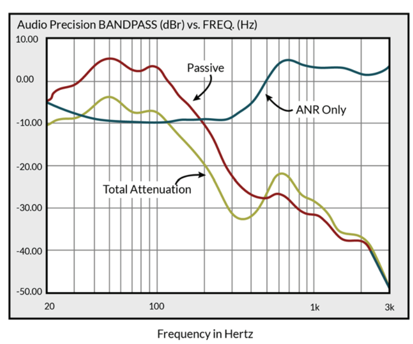
HEADSET #1



HEADSET #2



HEADSET #3



There are several interesting things worth noting about these results. Headset #1 with the greatest active performance is actually the *worst* for Total Attenuation. Headset #2 provides the lowest Active performance yet yields the BEST overall quieting. We'll cover the reasons for this later on in this ebook. Headset #3 is quieter than #1 at frequencies above 300Hz, but the passive performance was severely compromised by the conversion to an active product.

CHAPTER 8

Acoustic Design Tradeoffs

As you've learned, reductions to passive attenuation are inherent in an active implementation. It turns out that there are several key acoustic design parameters for maximizing *passive* performance that work against having "Industry Bests" in ANR performance and comfort. Let's review two aspects of design that prove this point.

1) Ear cavity volume

Cavity volume refers to the open space around the ear, shaped by the dome's interior and ear seal. It's often partially filled with acoustic foam to boost attenuation at certain frequencies. Larger cavity volume generally improves passive attenuation—though in practice, added components like speakers and cabling reduce it. This is why passive headsets rarely match the attenuation of pure hearing protectors.

To make a headset active, more electronics (and sometimes extra speakers) must fit inside the cup. Critically, the ANR speaker must be acoustically isolated front-to-back to prevent reflected sound waves from interfering with noise cancellation.

Why it matters

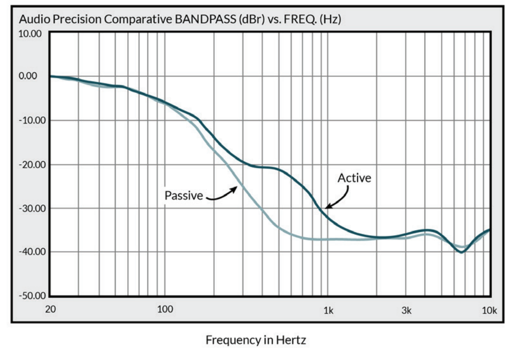
Remember that the 'anti-noise' signal comes from a speaker generating a sound wave that cancels the incoming noise picked up by the internal mic. But when the diaphragm rebounds, it produces an equal wave into the back of the cup. If this 20+dB wave leaks into the front cavity, it interferes with the noise signal and makes ANR unusable. To prevent this, the back cavity must be sealed from the front.

In most headsets, the back cavity takes up about 60% of the total dome volume, leaving less space near the ear. This smaller ear-side cavity reduces passive attenuation but actually benefits ANR design: it stabilizes cancellation, creates a more predictable acoustic environment, and lowers power demands. Larger back cavities also improve battery life by reducing back pressure on the diaphragm.

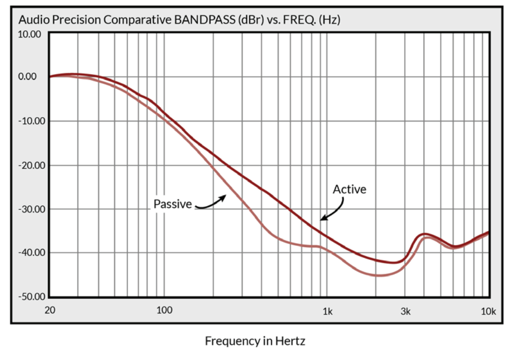
The tradeoff is clear—while ANR performance improves, the loss of ear-side cavity volume and added electronics reduce passive NRR performance. The graphs to the right show the impact across the frequency spectrum, comparing passive reduction in identical headset platforms with two different dome designs.

Platform #2 out performs #1 all frequencies…sometimes by as much as 6-8 dB. This is further proof that there are substantial differences in the way different platforms

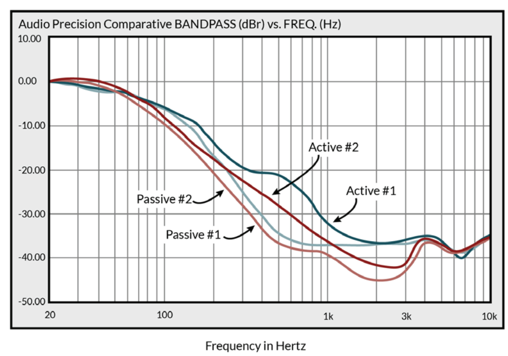
PLATFORM #1



PLATFORM #2



PLATFORM #1 VS #2



Notice the similarity in passive performance differences in the middle frequencies, from about 400 to 1000Hz. The passive implementations of each platform are quieter by 3-14 dB in that range over the performance of the active versions. Some of that difference is attributed to how the ANR module is designed and implemented. Careful attention to acoustic detail will protect more of the passive attenuating characteristics of the dome design.

perform beyond just the active and passive design differences. Again, you have got to try them on and compare them to each other in a noisy environment to really know.

2) Ear seal design

As a second example of design tradeoffs, consider the choices for ear seals and their effect on overall headset performance. Even something as seemingly simple as ear seals involves numerous design tradeoffs that can significantly impact headset performance. Cup size, shape, and how the headset interfaces with your ears and head are central to both comfort and acoustic effectiveness. Optimizing for comfort and acoustics often requires compromising some passive attenuation in the ear seal design.

Consider the design features and tradeoffs outlined in the table below. All these tradeoffs need to be understood and planned into the product so the customer is clear about exactly what his headset is good at. It can't be all things to all pilots.

FEATURE	ANR Performance	Passive Attenuation	Comfort / Fit	Key Tradeoff
Ear Seal Material	Conforming, compressible material helps create stable acoustic cavity for ANR	Best attenuation materials are less conformable and may cause side pressure	Softer, conforming materials improve comfort	Designer must balance material choice: high attenuation vs. comfort
Seal Depth / Ear-Side Volume	Larger cavity requires more ANR effort to maintain performance and stability	Dense, inflexible seals improve passive performance; foam-based large seals offer little gain	Deeper seals improve fit, comfort, and glasses compatibility	Comfort may reduce passive effectiveness
Cup Size / Shape / Interface	Larger internal volume affects ANR stability; ANR designer must compensate	Allocation of cavity volume affects passive attenuation	Optimized shape improves fit and comfort	Must balance cavity volume for battery efficiency, ANR performance, and passive attenuation
Back Cavity Volume	Larger back volume can improve battery efficiency for ANR electronics	Indirect effect via ear-side volume allocation	Minor direct impact	Tradeoff between internal electronics efficiency and ear-side performance

The two 'classes' of ANR

Design decisions to maximize Passive attenuation will limit the levels of comfort and Active quieting the product will deliver. This is why two basic 'classes' of ANR products have emerged: Passive-optimized and ANR-optimized.

Each has its advantages in quieting noise—but the resulting profile of residual noise is noticeably different. The low rumble noises are substantially eliminated with the ANR optimized models but there is a more noticeable mid frequency noise present. That's because of the sub-optimized passive performance of that design. The converse is true of the passive-optimized versions.

TYPES OF NOISE REDUCTION

- **Passively Optimized**: Those with good to very good Passive performance but relatively weak Active cancellation
- **ANR Optimized**: Those designed for optimal Active performance but with below average Passive attenuation

So then I should buy the one that has the quietest total performance…right?

Probably not…though it will depend mainly on the noise spectrum you are experiencing. The fact that a product delivers the most attenuation may—or may not—make it the quietest on your head, in your airplane.

In the 'typical' single-engine GA plane (172/182, Warrior, etc.), the 'ANR Optimized' models will probably perform better. Reference **Chapter 3** for the details regarding noise spectrums and why the tradeoffs of passive vs active headsets are generally worthwhile. Even if it's the quietest, you may choose other headsets that fit you more comfortably and/or have features you desire. Certainly from a comfort standpoint, the 'ANR Optimized' group would also generally rate higher for long-term comfort. While this is less 'empirical' feedback than the acoustic issues of active and passive performance, discussions we've had with literally thousands of pilots confirm this.

There *are* aviation noise spectrums where the 'passive-optimized' versions provide superior performance. These include aircraft with rotary engines, kit-built planes with limited insulation, open cockpits, etc.

In the end, this question of which is 'best' for you has a high degree of personal preference and subjectivity. You can narrow your choices with data but you're still going to have to try out the models that are most popular (and within your budget) to make a final choice.

Conclusion

You now have a clear picture of how active noise reduction enhances pilot safety, comfort, and enjoyment, and how aviation headsets implement ANR to achieve these benefits. We've covered the fundamentals of ANR, the impact of acoustics on performance, and which specifications matter most in different environments.

By exploring headset ergonomics and design, you've seen why choosing the "best" headset is a personal decision. We've also highlighted the continued importance of passive noise reduction and why focusing on a single "quietness" number can be misleading.

Finally, you understand how ANR supports clear communications and safe piloting. With this knowledge, you're equipped to evaluate headsets critically, make choices that suit your flying style and aircraft, and fully experience the comfort, clarity, and safety that ANR can bring to every flight.

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