TAMING THE NOISE

Understanding aircraft acoustics will help you hear the sounds of silence

DAN NEWLAND

As a newly minted private pilot, I was excited to take my wife and a friend, both of whom were starting ground school, along with me on my first flight as pilot in command. Yep, there I was, the top dawg, the big cheese, the alpha male, the PIC.

I was taking a short trip in a rented Cessna 172 to drop off my emergency parachute for a repack and took Linda and Jack along for company. Our return trip was also going well until about halfway back when the radio went dead.

Back to basic ground school. Switch the transponder to 7600 and try to remember the light signals. Livermore (LVK) is a Class D airport with relatively little traffic at sunset on weeknights, so I figured I could land there safely with the light gun. Not having done this before, my plan was to circle above its airspace until I got a green light.

I called on the radio in case they were receiving and then in a flash of brilliance realized I could phone them. I had my wife call the tower and let them know my plans via cell phone. There was just one hitch: The plane was so loud that my wife couldn't hear the tower responding. Nevertheless, the green light came on, and I made an uneventful landing.

Because my wife and Jack were student pilots, it was a great lesson for them. Jack, in particular, enjoyed regaling the ground school class with our "brush with death" and had them in stitches.

All fun aside, however, our adventure pointed to one thing that we tolerate in small planes that we would never allow in our cars, homes, or offices: noise.

Having designed insulation systems for large airliners and corporate jets for my employer, the Orcon Corp., I decided to investigate ways of making small aircraft quieter without eating excessively into useful load.

Company management decided this was a good area to research and concluded Orcon might be able to manufacture a more efficient acoustic insulation package based on this research.

WHY INSULATE AT ALL?

Many pilots spend an extra few hundred dollars to get the best active noise reduction (ANR) headset they can find and resign themselves to the rest. This is a viable approach for many, and indeed it is the only option on some airplanes. ANR headsets have been the single greatest improvement in flying comfort since cabin heat, and I personally would not trade my Lightspeeds for anything. But there is only so much a headset can do.

The laws of physics place limits on how much noise can be eliminated with a given amount of mass, ear cup thickness, and computer processing power. In addition, the "anti noise" signal ANR headsets broadcast to cancel out cockpit noise isn't capable of responding to every tone or short duration noise.

Therefore, a two pronged approach of a good ANR headset plus a well-insulated aircraft will make most people a lot happier on long cross-country flights. Insulation can also get you a few steps closer to that Holy Grail: an airplane quiet enough to talk to the folks in the back seat without an intercom.

Noise is a form of energy, and it travels in a wave that alternately compresses and decompresses air (compression and rarefaction). The waves of air pressure make your eardrum vibrate, which translates to waves in the fluid parts of your ear that make hairs inside sway back and forth, firing off to the neurons. That description won't win a science fair, but it's okay for this discussion.

Inside your airplane, you can't hear the engine, propeller, or wind noise. Yes, it's a trick. You are not directly hearing most of those noises in an enclosed, well-gasketed plane. Sound cannot travel through a completely airtight enclosure, so the noise you hear in a well-sealed aircraft comes to you indirectly.

Anything that shakes—the engine, hydraulics, or other parts mounted to the airframe—will add vibration to the frame. The frame then will "broadcast" the noise to the inside. Another source is from the sound of external air turbulence hitting the aircraft, causing it to vibrate, and then broadcasting it into the cabin. Most of the noise you hear starts somewhere else and travels along the structure to be heard inside.

The implications are logical when it comes to making a plane quieter. For maximum noise control, the airplane should be addressed in the following order:

First, reduce the noise or vibration at the source. That means balancing the prop and engine to reduce vibration. The drawback is that this is expensive.

Next, interfere with the vibration traveling into the structure. That means using isolation mounts on all vibration and noise sources. This is moderately expensive and technically difficult.

Third, reduce the structural vibration by using dampers. This is heavy.

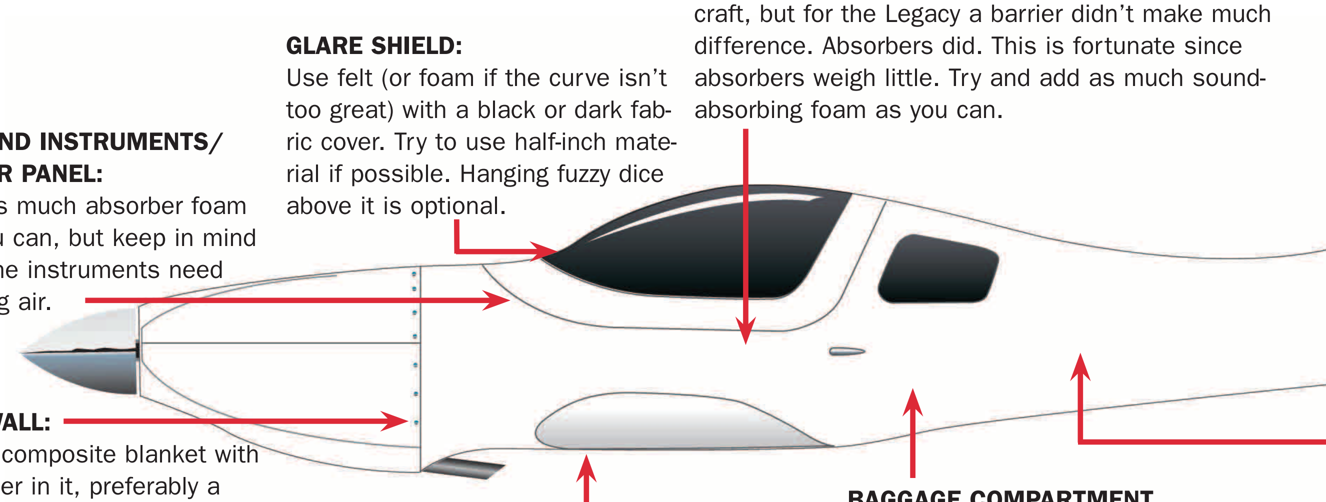
Fourth, put barriers between the noise and the occupants. Add barriers to the insulating blankets. This works well, but the most effective barriers will be heavy.

Finally, absorb the noise that does enter the cabin, such as by using absorber blankets, which are lightweight and easy to fabricate.

To insulate an aircraft, the materials should be safe. Use common sense when selecting materials to put into your airplane. Many experimental airplanes contain insulating materials that were picked up at a hardware store. These may be fine and probably will reduce the noise.

However, this is one area where it makes sense to follow FAA recommendations on the materials' burn resistance, regardless of whether you're installing it in an experi-

MAKING AN AIRPLANE QUIETER



Some general rules for reducing sound:

Start at the front. Balance the prop and engine and make sure that you have the correct engine mounts. Paul Snyder, an engineer at the Lord Corp., said an engine mount is designed to last roughly as long as the engine. Each mount is designed taking into account the intended number of propeller blades, engine speed, and combined weight.

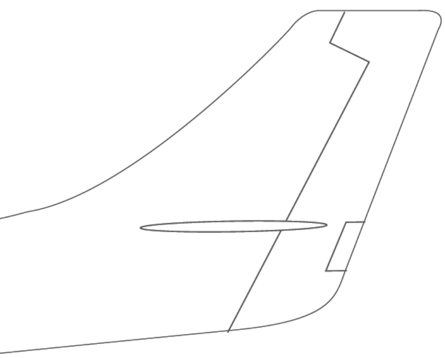
Figure a weight budget for the airplane so you have a target weight, and figure how much space you have available. Both of these are crucial, and in both cases more is better. The more weight you add, the more effective the barrier and the greater the thickness of your absorber, the wider the frequencies absorbed. If weight must be kept to a minimum, then the floor and firewall blankets should be made from a lightweight barrier.

If possible, add thickness to the forward side firewall blanket. This should be with an open-cell foam, or perhaps a semi-rigid high-temperature glass. Isolation mount fittings should be bolted to the firewall with silicone grommets or mounts.

Go with a thicker windscreen. This obeys the mass law where more mass requires more energy for acceleration, so doubling the thickness would reduce the noise entering by about 6 dB in the area near the windscreen.

mental. In our tests, we limited the insulation to those that complied with FAR 25.853, the 12-second vertical burn test.

You are not required to have burn certificates for insulation you put in your own experimental airplane, but it makes sense to use materials that comply with that requirement. A burn certificate adds about $25 to $100 and states tests were performed on these materials and they passed. This may help those selling

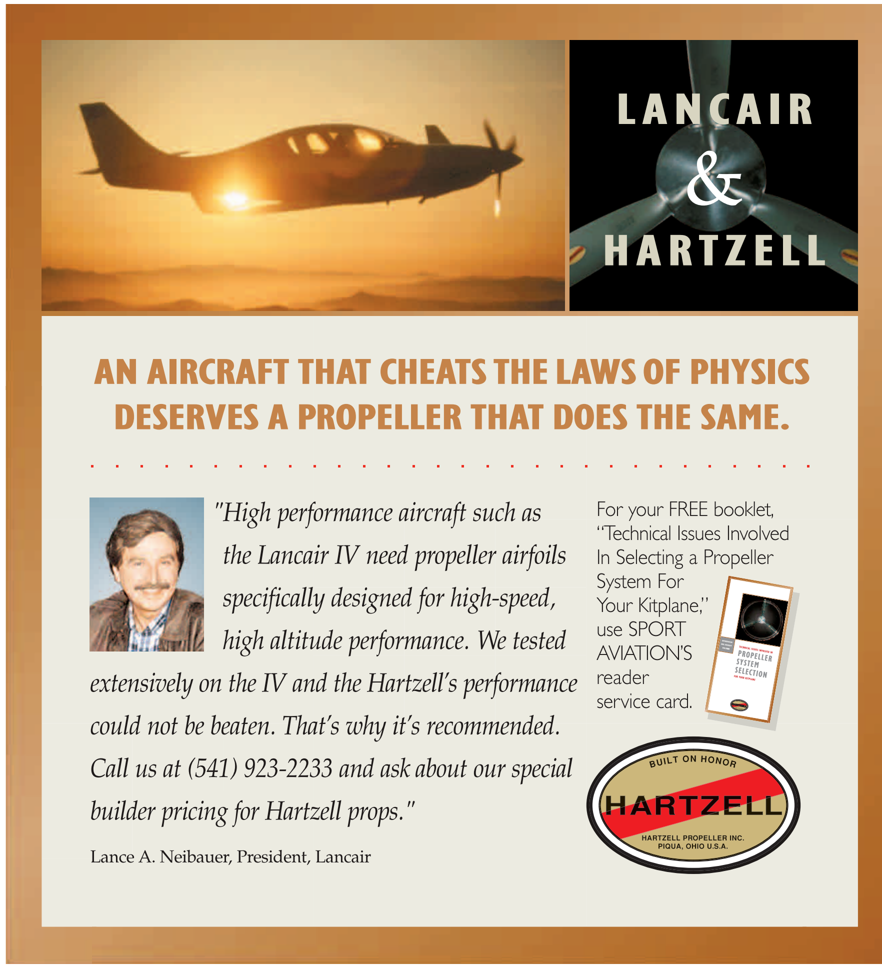


REAR BULKHEAD:
Half- or 1-inch foam with upholstery over.

Gasket. Make sure there are no air leaks on any door, window, or firewall penetration.

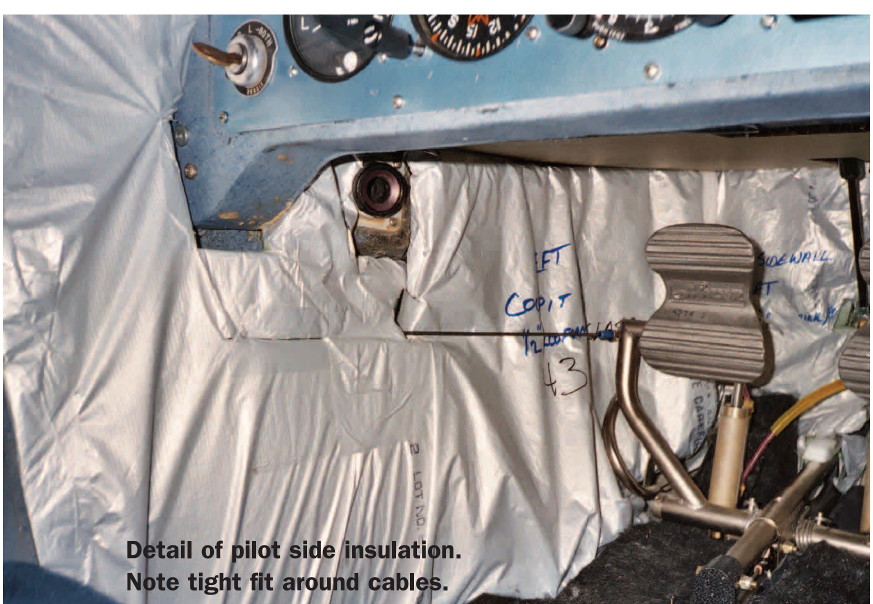
As a general rule, eliminate as many hard surfaces on the interior as possible. Noise reflects off hard surfaces like light from a mirror, and any padding will help.

If you have the payload to spare after adding massive barriers to the firewall and floor, add constrained layer damping to the sidewalls and firewall.



Aft baggage compartment.


Three blankets on pilot side.


Detail of pilot side insulation. Note tight fit around cables.

the planes later or help score points with judging on documentation.

For those flying certificated aircraft, you will need to apply for an STC and you will need this documentation.

BEFORE YOU INSULATE

Insulation is actually the last thing to go in your aircraft. Acoustic treatment of the aircraft should be a systematic approach taken one step at a time to maximize the effectiveness. There are two broad types of interiors for aircraft, those that have an interior liner and those without.

The liner, regardless of how light in weight, can reduce interior noise. It can be one of the most effective ways to quiet your aircraft, but done incorrectly it won't do much. Another area that should be treated separately is the fuselage construction. A fabric-covered tube frame aircraft has a completely different need for insulation than a carbon fiber/epoxy/honeycomb fuselage or an aluminum skin on aluminum frames. All can be made quieter, but the weight penalty varies.

Before you start insulating your aircraft, check it for leaks. Air leaks equal noise, so if there is a gap for air to go through, noise will get through, too. Even if there are only a few square inches of gaps, don't bother insulating for noise because it won't make any difference. Thus, before you begin, gasket every door, window, canopy, and fuselage/firewall penetration. For the firewall, high-temperature silicone or fire-sealant putty should surround every wire bundle and hose that goes through. For aircraft with liners, gasket the joint at the fuselage to trap sound between the liner and the fuselage.

Related to gasketing is the elimination of rattles. The gaskets used to close air gaps can also be used to prevent hard surfaces from contacting each other, thus doing double duty. Any contact of hard surfaces should be avoided, so it's possible to use the same soft gasket material as a bumper between the two.

Upholstery is an excellent material for this purpose. Used with foam padding and a fabric or leather cover, upholstery rolled over a trim liner can prevent hard surface contact and give a plush look to the interior, and it may act as a gasket. Silicone adhesive is another good material to stop rattles from happening, but it is semi-permanent. One benefit of silicone adhesive is its natural tendency to handle high temperatures. Temperature resistance can be further enhanced with special “hi-temp” formulas for more demanding applications such as forward of the firewall.

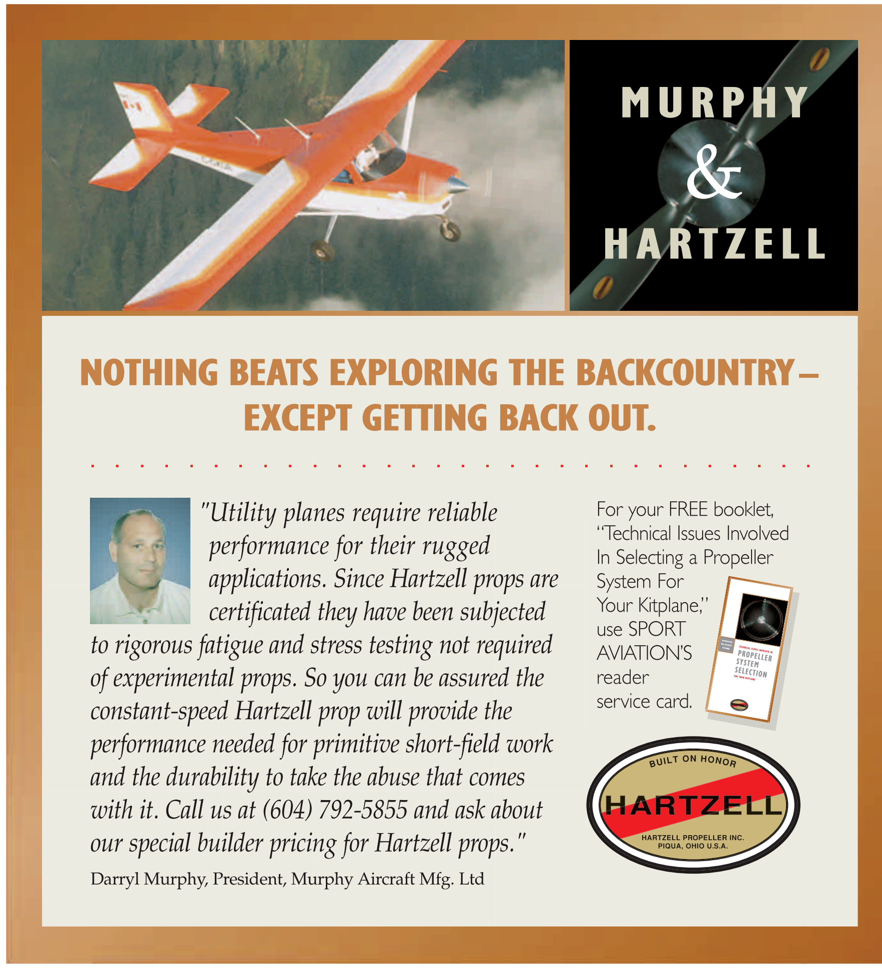
OUR TEST PROGRAM

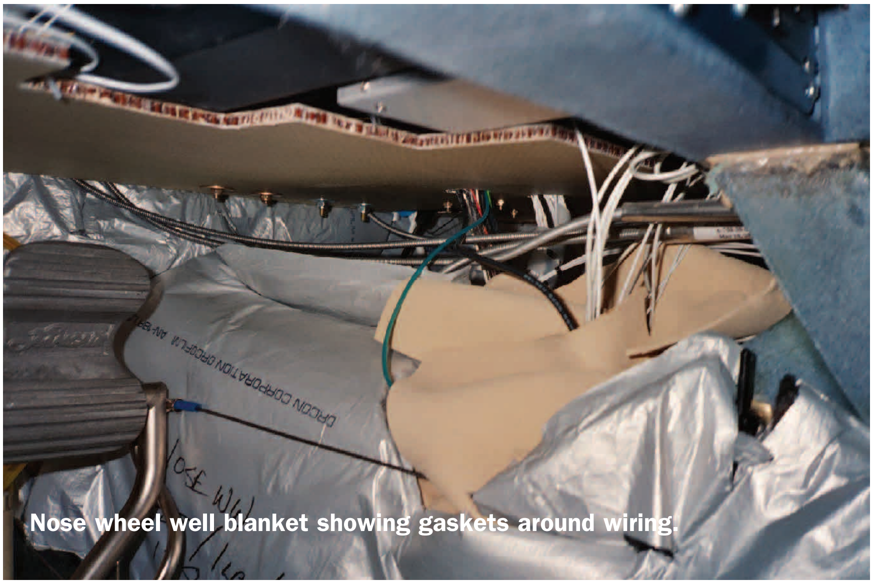
We conducted our testing on an experimental aircraft so changes could be done quickly and without regulatory entanglements when we changed out blankets. We used a digital recorder to capture and measure exactly the noise made in each flight. Later, the recording was analyzed at the Hood Technology acoustics lab.

This method allowed us to permanently save the data and conduct complex tonal analysis. That let us see the “quality” of the noise as well as the intensity of it.

Furthermore, the type of sound is different for each phase of flight, so I wanted to confirm whether some blankets perform better in certain flight regimes than others based on frequency (and this was confirmed).

We used a Lancair Legacy, which is a high-tech carbon-fiber aircraft with a honeycomb core. As such, it is remarkably stiff when compared to an aluminum aircraft. So while the results testing an aluminum plane might be similar, acoustic treatment of aluminum would normally require some additional attention. Finally, data is only as good as its repeatability. I had the good luck to find Dave Morss who was interested in having his




Nose wheel well blanket showing gaskets around wiring.


Twenty-one blankets are required for the whole aircraft. (Firewall in foreground to rear bulkhead in background.)

One of two nose wheel well blankets, with gaskets.

Lancair Legacy insulated. Dave is a test pilot/designated airworthiness representative/Reno air racer with thousands of hours of flying time. Few pilots can fly as accurately or be as repeatable as Dave.

The only treatment we tried was insulation blankets. For the testing, the aircraft was first tested in an empty condition with no insulation at all except for the floor mats. Then it was insulated completely except for the target area. For example, in one test we flew with the firewall uninsulated, and then repeated the flight with the firewall blankets installed.

Each configuration was measured acoustically in takeoff, climb, and cruise, and the Hood Technology acoustic testing lab computed the averages. All blankets were weighed so that noise reduction could be compared to weight in all configurations. Additionally, three tests were done to test flight-to-flight variation and also installation-to-installation variation using the same configuration.

One final note on the test blankets. These were not upholstered or made to do anything other than be installed quickly and removed even faster. As such, they were only covered with an Orcon waterproof film and not fitted as tightly as a fully upholstered interior might be. A more tightly fitted and upholstered interior would improve the acoustics even more.

TEST RESULTS

We were able to reduce the noise in the test airplane by almost 8 dB while keeping the weight below 23 pounds. While 7.7 dB may not sound like much, it is a large amount of noise because the decibel scale is logarithmic. A reduc-


Types of isolation mount grommets, color-coded for hardness.

Dave Morss and his winged rocket.

tion of 6 dB is half the sound pressure.

To put it into perspective, Dave had never heard the wind noise from his plane before because the engine and prop noise drowned it out. When we were done, wind noise was a "new" sound. Reductions of up to 5 dB were had for weights as little as 5 pounds. I want to point out that additional reductions are possible by using damping materials against the skin and adding more insulation; however, we did not try these because of weight restrictions.

From the Legacy we learned six primary lessons about insulating airplanes.

1) Most of the noise comes from the firewall and floor, and is best handled with barriers. The more massive those barriers, the better.

2) The sidewalls and turtledeck add a lot of noise, but absorbers worked well at a fraction of the weight of massive barriers.

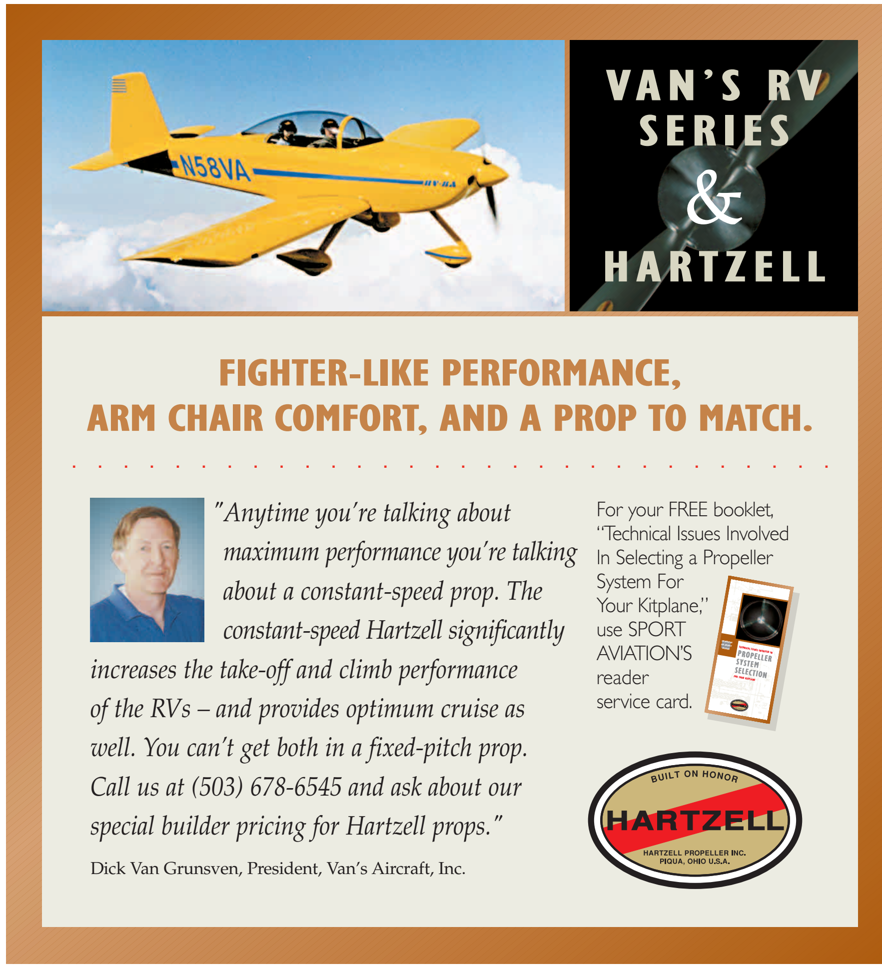
3) The baggage area and rear bulkhead don't add a lot of noise and can be treated with a carpet on the floor (for durability) and an absorber on the bulkhead.

4) Absorbers on top of the glare shield and in empty spaces around the instruments reduce noise that radiated from the canopy and the firewall.

5) Soft closed-cell foam gaskets wrapped around any penetration dramatically reduce noise.

6) Air vent noise was only 1 to 1.5 dB, but sounded louder. This gets into psychoacoustics, or how we perceive sound.

SOURCES:
Insulation: Orcon Corp., 1570 Atlantic St., Union City, CA 94587, 800/227-0505
Engine mounts: Lord Corp., 814/868-5424
Isolation mounts: Newact Inc., 3470 Cardiff Ave., Cincinnati, OH 45209, 513/321-5177



DEFINITIONS AND TERMINOLOGY

Absorber: An absorber is just like a sponge. All materials absorb sound to some extent, but the best generally are porous and have a lot of air in them. Fibrous or open-cell materials are some of the best absorbers and perform by letting the sound in through their porous open structure, which then causes the fibers or cell walls to vibrate, creating heat. Cell and fiber size, density, and material stiffness all play a part in determining the absorption characteristics. Thickness also plays an important part with greater thickness absorbing a wider range of frequencies. Absorbers do not need to be heavy. Typically they are between 0.6 and 0.4 pounds per cubic foot, so a 1-inch thick piece may only weigh 0.03 pounds per square foot. Maximum absorption is achieved at one-fourth the wavelength of the sound. So 1 inch of insulation is most effective at absorbing wavelengths of 4 inches (3400 Hz) and less, 2 inches absorbs wavelengths of 8 inches (1690 Hz) and less.

Acoustic Short Circuit: Mounting a part to an insulated structure so that it vibrates and generates noise, thus negating the effectiveness of the insulation. Use isolation mounts to prevent this.

Barrier: Barriers literally get between the source and the receiver. A good barrier should be limp to prevent vibration from traveling through it and should be nonporous.

Composite Blanket: A blanket made of two or more elements, for example absorber on one side with a barrier on the other.

Dampening: Standing in the rain. Acoustically, there is no such thing as dampening.

Dampers: These are materials that are both heavy and elastic to reduce vibration of the structure to which they are attached. Dampers must be heavier than the panel they are attached to for maximum effect. These are particularly effective on lightweight aluminum skins and on interior liners.

Decibels (dB): The logarithmic scale of noise created by Alexander Graham Bell. Note that dB A and dB C refer to the weighting that is placed on the scale. Humans do not hear all frequencies the same. dB A tends to equalize that by adding a "weight" to some frequencies to adjust for how we hear it.

Decouple: To isolate the movement of one surface from another. A soft layer of fiberglass insulation against a massive barrier decouples much of the vibration of the fuselage from the barrier, which can keep the blanket from vibrating and creating its own noise.

Frequency: Cycles in a given length of time. Sound is normally expressed in Hertz (Hz), which is the same as cycles per second. Rpm is 1/60 of a Hz, thus 2500 rpm = 41.7 Hz.

Harmonic: A multiple of a primary frequency. If the engine produces a noise at 120 Hz, there will be harmonics at 240, 360, 480 Hz, and so on.

Isolation Mounts: Soft materials to isolate the vibration of one object from another. If an interior liner isn't isolation mounted, it will not be effective because the vibration of the frame will be directly transmitted through the liner, thus making an acoustic short circuit.

Massive Barrier: A barrier to noise that works by being massive. It takes energy to move an object; therefore, the more it weighs, the less easily it can be moved. With a massive barrier between the source and the cabin, the noise must first move the barrier before transferring its energy elsewhere. For barriers to work, they must be tightly fit.

Octave: A doubling of the frequency. If your propeller is producing sound at 80 Hz, the octaves would be at 160, 320, 640, 1280 Hz, and so on.

Tones: Narrow band sounds. For example, a two-blade propeller turning at 2400 rpm (40 Hz) would generate two pulses per revolution, thus you can expect to see a noise spike at 80 Hz. If that engine were a six-cylinder four-stroke, there would be three power strokes per revolution. Therefore, at 2400 rpm, there should be a large tonal spike at 120 Hz. Two-blade props on a four-cylinder, four-stroke engine and three-blade props on a six-cylinder engine both have coincidental frequencies that exacerbate the problem.

Trim Liner (or simply Liner): A lightweight interior part to cover the aircraft frame. Often more cosmetic than structural, it can be used effectively for acoustic treatments if isolation mounted, gasketed, damped, and filled with absorber in the cavity.