DAMPING - A KEY TO MORE, FASTER, FARTHER, HIGHER

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Vibration is everywhere. And where there is vibration, there is damping. Most often, vibration is bad and damping is good. There are exceptions, but since this conference is about damping, we will leave the undamping crowd to their own devices.

After getting my primer on this subject, I was reminded that damping is a complicated subject. In simple terms, vibratory response can lead to cracked structure, defocused optics, or other types of degraded performance. Historically, the damping in a vibratory system has been "take what you get", called intrinsic damping. Only in the last few years has damping been a design parameter. So let's begin with a scramble: start the engines...on take off, light the burner. In my flying experience with the B-52, it was be sure all eight were running and start the Hound-Dogs on the roll...there's a lot of noise coming out of these engines. During take-off roll, there are two paths from the engine exhaust noise to the aft structure: one is direct, the other is reflected from the runway. Take-off is typically the highest acoustic environment the structure is exposed to. The skin panel responds to sound pressure level as does a microphone and it vibrates. It can vibrate enough to literally crack and break. The skin panel also re-radiates the sound into the interior. That's called "thru transmission." That's also the technical term for being able to hear people thru the motel wall, at least the motels government per diem can afford in places like Boston and Washington.

That aircraft skin panel also transmits vibratory energy into the substructure--the stringers, frames, and bulkheads. So internal equipment also gets hit with structural-borne vibratory energy at points like mounting brackets and with acoustic energy on their covers. Internal equipment can fail, malfunction or degrade to lower performance levels. As our pilot retracts the gear and accelerates, the dynamic pressure increases and the turbulent boundary layer, especially behind protuberances, can create very high sound pressure levels. At about mach 0.9, the oscillating shocks have the same effect. When we maneuver, especially transonically, the aeroacoustic levels on the leading and trailing edges (and external stores) reach high levels. When we open weapons bay doors, the open cavity acts like a giant whistle and the internal structure and stores can be subjected to tones of extremely large amplitude. Since we fly to fight, we carry weapons; we fly at ever-higher dynamic pressures and maneuver at transonic speeds to survive: This makes the vibroacoustics problem more severe. Today, to do our engineering right, structures-and-vibration-and-damping-engineers must participate in the original design of these modern flying machines.

Vibration is also no longer an earthly problem. It is becoming a design factor in satellites as well. Launch vibroacoustics typically cause the highest vibration levels and can break equipment. There are also more vibratory disturbances in orbit than you might think. There are always imbalances in reaction wheels, momentum wheels, and control moment gyros used for attitude control. Coolant flow, shifting solar arrays, liquid slosh, gravity gradient, particle impact, to name just a few, are all vibratory disturbances which, just for example, can degrade performance of sensitive optics.

I shouldn't have to convince this audience--we know that vibration is everywhere. Although the obvious is obvious to us, let's also acknowledge that damping is a highly specialized subject. A damping engineer is a specialist because he must first be a vibration engineer, who was probably a structures engineer to start with. So, right off, we have a specialty within a specialty within a specialty. The successful damping engineer must know more than damping. He'd better know systems integration and be very conversant about the operational environment. A prime example of this is the highly successful "Damping Wrap" for the inlet guide vanes on the engines used in the F-111F fighter. So many cracks were forming so quickly that the inlet guide vane case had to be refurbished after TOO few hours of service. Air coming into the engine is turned slightly by the inlet guide vanes to get best performance from the rotating first stage compressor. The IGV case consists of titanium inlet guide vanes welded to inner and outer rings. Vibration was suspected as the cause of the cracks which were forming in the heat affected zones of the welds. The intrinsic damping was extremely low, and in this case, the dynamic magnification factors at resonances were high. Obviously, the stage was set for a damping engineer to really impress his boss. Adding damping to the inlet guide vane was easy; developing a satisfactory damper wrap for a complex systems operational environment was not. Sophisticated bonding technology was used so that the damper wrap would adhere while exposed to the air flow. The wrap had to be thin to minimize inlet blockage area, since reduced air flow would affect engine performance. Engine stall characteristics, anti-icing effectiveness, erosion, corrosion, and durability were all investigated and proven satisfactory. The point being...this was a complex interdisciplinary problem--solved very successfully. This project has estimated cost avoidance savings to the Air Force of $50M. Spin-off damping applications in similar situations may well account for another $200 million. Other very recent demonstrations of vibration-caused structural failures fixed by damping are the A-7 center section leading edge flap, A-10 gun bay floor and side wall, and F-111 spoilers. Once again the logistics improvements in terms of dollars were significant. I should also add these improvements lower the heart rate for our maintainers.

For the most part, successful damping treatments have been of the add-on variety. The hardware has been designed and a vibration problem rears its ugly head. A damping treatment is designed and "added to" existing structure. Once the hardware exists, add-on damping may be an extremely cost effective solution. But it's better to avoid the problem altogether and that can be done with integral damping. Commercial examples are laminated valve covers, oil pans, and timing gear covers used in automobile and diesel engines.

Integral damping is also the key to longer life, more durable aircraft structure. The objective is increased sortie generation rate and reduced maintenance cost. Since we often learn more from our failures, there's no shame to admit there have been many unsuccessful attempts to design damping solutions. I'm told you don't have to be in this business very long to have been bit. In fact, you don't earn your damping wings until you've been humbled more than once. I don't want to focus on this aspect, but during breaks and at social opportunities it also pays to discuss the failures as well as the successes.

DAMPING '89 is put together to detail the state of the art, but the keynote role allows me latitude to summarize. A baseline of damping materials and manufacturing processes is established. We can measure properties of materials fairly well. Data banks on damping materials are also established. You can analyze simply supported beams in closed form and can perform finite element analysis of damped structure to predict modal frequencies and damping limits. You can experimentally measure the modal frequencies and damping of structure. There are a growing number of successful add-on and integral damping applications and you have quantified these successes in terms, pay-off terms, that management understands. Damping, in fact, is a hot, new tool in the engineer's kit bag. But it's good not to believe as the song goes "Oh Lord it's hard to be humble when you're perfect in every way." What we already know is just a glimpse of the future. There is still great opportunity. Therefore, it's important to make good investment decisions as we plan the future.

As in most technical disciplines, the explosion in computational power, coupled with advancements in damping technology, can greatly accelerate our knowledge. Better dynamic test techniques are needed; a greater range of materials properties should be measured and catalogued: and extensions to analytical methods would really expand the range of applications. With these wishes met, let's peer in the not too distant future and I'll make some predictions:

- Measurement of the dynamic mechanical properties of viscoelastic damping materials will be more accurate, more efficient, and have less scatter.

- Existing materials will be screened for toxicity, flammability, outgassing, corrosion, long-term environmental stability and others. These are properties which are mandatory for system application.

- A fully computerized data clearing center will exist soon.
- Wide-temperature range and low-temperature damping materials will be developed.
- Approximate closed form analysis methods will come into use for structures like thin plates and shells, brackets, pipes and tubing.
- Approximate finite element analysis models will be developed as preliminary design tools for damped structures such as satellite equipment support structures.
- Computer aided design will yield optimum solutions by interacting finite element analysis of damped structure with a data base of damping materials.
- Most aircraft sheet metal will be laminated, ditto for automobiles and household appliances.
- Interest in damped composite structural materials will rise.
- Housings and circuit boards of avionics equipment will be damped.
- Logistics imperatives--maintainability and reliability--will dictate much more use of damping.
- And, some of you who think you'll be millionaires exploiting these opportunities will probably go bankrupt because of Murphy. So, maximize the opportunity this conference offers.
- Learn!!
- Go home and apply the technology: Be passionate...become zealots for your work and the opportunity it presents.
- Share your successes and failures with as wide a technical community as possible.
- Think of yourselves as a team: Academia and practitioners in commercial and military applications. All must play their roles to see the most intelligent and widespread use of this technology.

I want to conclude with some non-damping thoughts. My boss, the AFSC Commander, General Randolph, just gave a talk at the AF Association's Tactical Air Warfare Symposium. He ok'd my use of some of his remarks because the message is so important for all of us. That message is about total quality management.

In the book, "A Passion for Excellence," Peters and Austin recall the management style of General Electric's aircraft engine pioneer, Gerhard Neumann when he worked with Claire Chennault's World War II Flying Tigers. Neumann wanted make sure his maintenance people fixed aircraft engines right...the first time. So each day he used to ask a few of his squadron mechanics to "volunteer" to test fly in the Single-Seat fighter they'd just repaired. The pilot would sit on the crew chief's lap, and neither could sit on a parachute because the cockpit wasn't big enough.

Well, improvements in workmanship were dramatic! In his book, "Herman the German," Neumann writes that each night, "Way past dinnertime, the airfield looked as if it were invaded by glowworms; the twinkling came from flashlights mechanics used to check--once more--the tightness of pipes or connections they had made in case Neumann might suggest that they 'Volunteer' to ride in their planes the next day."--Now there's a guy who knew how to motivate quality. TQM's an overdue sign of a national quality revolution. It's a buzzword you see in commercials, hear at symposiums, and notice in bookstores. But don't just dismiss TQM as yet another acronym that will die off. As a term, TQM might well change over time. However, as a philosophy TQM will last, as more companies and managers come to understand what continuous quality improvement means and what it can do. Affordable price tags, fair profits and high product quality will prove TQM's merits long after the trendiness of the buzzword disappears. It offers opportunities for every person involved in research, development, test, production and operations.

TQM--is BETTER QUALITY AT LOWER COST. It's the prerequisite to good performance. AFSC's senior people have been through training seminars with W. Edwards Deming, one of the best-known quality leaders in the world. Deming's philosophy is that 85 percent of quality problems are caused by the system; just 15 percent are caused by people. Just to be sure we're communicating--you're likely to be part of the 85 percent! If the products of U.S. industry are not well liked, loved, by the customer, you are involved because you're that 85 percent of the system that designs-in-problems the manufacturing work force can't correct.

General Randolph was challenged about his intensity on this subject of total quality management. The person said it sounds as if quality issues are a matter of life and death. He said no, they're much more important than that. Think about these statistics:

If the U.S. had service suppliers who did their jobs right 99.9 percent of the time, there would still be:

- 20,000 wrong prescriptions filled each year;

- Unsafe drinking water almost one hour each month;

- 2 long or short airplane landings a day (That's an accident) at Los Angeles and New York;

- And 2000 lost articles of mail per hour every day.

- In the defense arena, given 1 million grenades, you would have 999 duds--and 1 will go off in "0" seconds.

Where is your quality meter set?

General Randolph closed his talk with this story President Kennedy would tell and I'll do the same. It's about a retired French General whose hobby was gardening. He was a very cultured man with a deep sense of history. On his 80th birthday he bought a small shrub and instructed his gardener to plant it in the garden.

"But, Sir," the gardener protested, "that plant won't flower for a hundred years!" "Then by all means," the General said, "plant it now."

The total quality we plant in our work today is FREEDOM FOR TOMORROW. We need to plant more flowers.