

Hooked on Vibration

Robert E. Coleman, Signalysis, Inc., Cincinnati, Ohio

Looking back, I'm sure that many of us can pinpoint when it was that our career choices began to come into focus. For me, the path to vibration technology began in August of 1960. The Navy had just launched the first missile from a Polaris submarine one month before I arrived as the new physicist test engineer for the Polaris second-stage solid rocket motor (I know, quite a title!) at the Navy Propellant Plant in Indian Head, MD.

Polaris Missile Program

As you may know, submarines during that time were armed with Polaris rockets. These mobile and stealthy launch points were vital to help maintain peace during the cold-war years. The revised second-stage rocket was being tested for the Polaris A-2 at that time with adjustments to the solid-propellant formulation, also incorporating the much lighter Fiberglas case. This effort also included the testing of a new thrust-vectoring innovation. But as new rockets were being developed, a serious problem emerged – rocket motors were blowing up on my test stand!

Ultimately the source was traced to an interesting mechanism involving a basic characteristic of the rocket motor. Testing revealed that the oscillatory pressure build-up causing the rocket case to rupture involved acoustic resonance of the rocket chamber itself.

To help solve the problem we connected a speaker to an audio oscillator. The speaker and microphone were inserted into the rocket motor chamber and sinusoidal sound waves were broadcast over the audible frequency range. It was discovered that certain frequencies resulted in highly amplified sounds. The match between the dominant chamber resonance frequency and the rocket test pressure oscillation frequency was noticed immediately, and the failure mechanism was obvious.

It was well known that solid propellant burning rate is exponentially sensitive to an increase in pressure. The first instance of a pressure increase due to resonant response caused an increase in burning rate with a corresponding increase in pressure, which in turn became further amplified due to the acoustic resonance – then further increase in burning rate and pressure followed. This initiated a continuous feedback amplification mechanism with endless increasing pressure oscillations. Rocket case rupture could be the only possible outcome. Armed with this data, the propellant chemists and mechanical design engineers we were able to solve the problem.

The project included use of one of the first discretized digital computers, the RCA 501. The flip-flops for mathematical ones and zeros were implemented with discrete



Silver Snoopy Award being presented to Bob Coleman on October 7, 1993 by Astronaut Kent V. Rominger for contribution to Space Shuttle Orbiter damage detection using advanced vibration technology.



Meeting Dr. Edward Teller (considered the father of the hydrogen bomb) for lunch in Dallas while working at LTV Missiles and Space Division. I tried talking to him about Einstein's relativity theory, but he just wanted to talk about what was later referred to as "Star Wars" and the dangers presented by Russian leaders at the time.

transistors. I remember the computer running hot and had to be water cooled. A large magnetic drum was used for mass-memory data storage – quite a bit different from the computers of today.

It was exciting for me to apply my education and years of classwork in a real-world problem-solving situation. As I mentioned earlier, this was the time of heightened alert for our military in general and Navy in particular. Tension between the United States and Soviet Union was very real and our defense was critical.

Polaris A2

As it would turn out, I would have yet another encounter with vibration for the Navy. For the engine test, a force transducer was mounted to a reinforced concrete abutment to react the rocket motor thrust and provide a force vs. time measurement. I developed a dynamic math model of the rocket and test stand.

Results of the analysis revealed a test stand-rocket motor-force transducer vibration resonance frequency of 94 Hz. Testing

and analysis further showed that the model resonance frequency of 94 Hz matched the measurement from the rocket motor test. This vibration showed up on the force-time measurement, obscuring the true measurement. But now the artifact component of the measured force-time could be mathematically removed, leaving just the true rocket dynamic thrust data. Little did I know then how frequently similar vibration problems would confront me and how these experiences with the Polaris rocket motor would influence my career path.

Sure enough, I later found myself faced with some of the same old vibration problems working on Mauler and Corporal static testing at White Sands Missile Range. This time, I had two computers to work on, one was analog (using operational amplifiers) and the other was a computer that used electromechanical relays to store ones and zeros. But those were fun times, going up range after missile launches and witnessing the final test of the Corporal. And then, more fun at the nuclear test site in Nevada with nuclear rocket testing. (Don't ask me about area 51 – "I know nothing.") But NASA Houston was where all the fun *really* was.

Payload Vibration Analysis

When we think about vibration, what comes to mind is usually an engine, motor, sound wave, or how some subsystem or component reacts to vibrational forces. Over the years I've spent a considerable amount of time analyzing these and other vibration characteristics. But one of the more interesting applications of vibration analysis are the effects associated with payload. Believe it or not, vibrations as related to payloads can have a significant, even catastrophic, effect.

I've performed payload vibration testing and analysis for the LTV Missiles & Space Division as well as NASA. Some of the payload programs I've worked on include those associated with the Scout Missile System, Skylab, and the Space Shuttle.

Let's look at the space shuttle for example. Each shuttle mission included a payload of one type or another. Each unique payload had to have good dynamic design to avoid structural failure associated with vibration coupling to the payload bay during ascent. Failure to achieve this could be catastrophic, since the unstable payload could easily have a detrimental impact on overall system performance.

Imagine the catastrophic outcome of a space satellite attached to the Shuttle payload bay breaking loose under excessive vibration forces during ascent. This is why every payload was subjected to vibration testing. The payloads were mounted on big electrodynamic shakers – some capable of applying 50,000 pounds of force with frequencies extending to 2000 Hz. Also, ascent vibration levels, along with resulting stress levels, had to be predicted using computer finite-element modeling. Unacceptable vibration limits had to be established before a payload was approved for a Space Shuttle launch.

NASA

My years at NASA were consumed with vibration testing and analysis. In addition to analysis on payload vibration characteristics, we performed similar tests on the crew cabin, wings, vertical tail, payload doors, body flap, and so on. Needless to say, precision and accuracy are vital to any aircraft – especially one designed to absorb the tremendous forces associated with lift-off, flight, and reentry.

During this time, I also worked with damage detection on the shuttle. As events have shown, this was a critical element of each mission. While I've had the pleasure to personally meet a number of shuttle crewmembers over the years, one particular encounter stays with me. It was common for crewmembers to meet with department heads to learn more about certain aspects of the shuttle. NASA thought it important for the crew to be as familiar as possible with the ship and related sciences.

So while making a 1985 presentation to some of the astronauts on the status of Shuttle vibration issues, I had the opportunity to meet with astronaut Judy Resnick. I was impressed by her interest in vibration analysis and eagerness to learn more. We agreed to meet again following her next mission; she was scheduled to be a part of the Challenger mission in January of 1986. Unfortunately that was the last time we would have the chance to meet.

I can't reflect on those years of NASA without recalling the impact a couple of

people had on my professional development: Albert Klosterman and Dave Brown. These two were leaders, essentially founders, of the vibration test and analysis industry. Klosterman was the director of R&D at then Structural Dynamics Research Corporation (SDRC, Cincinnati – now owned by Siemens) and Brown headed up the Structural Dynamics Research Lab at The University of Cincinnati. While heading up the experimental modal analysis effort at NASA Houston, I bought into the SDRC technology – experimental as well as FEM. And it was primarily through encounters with these two that really fully engaged me in the application of normal mode vibration theory.

Applying Lessons Learned

If you've hung in here up to this point, you may be wondering if this stroll down memory lane has a point. My point is that whether you're talking about rocket science or an automobile seat motor, I can assure you that vibration issues are no more important to the engineers at NASA as they are to motor manufacturers. It was inevitable that at some point I would leave Houston and head north to Cincinnati. My two sons headed up a company there and were anxious to get some NASA technology transfer.

There I joined Signalysis, a company with expertise in NVH testing that provides end-of-production quality inspection test systems to manufacturers throughout the automotive, medical, appliance and

related industries. These past few years have allowed me to apply aerospace vibration technology and methodology to help manufacturers identify defects at the end of manufacturing plant assembly lines. When you think about the warranty claims, lost sales, and poor reputation associated with quality issues, these systems have proven to be extremely valuable.

Think about all of the components, assemblies and subassemblies that are monitored on the shuttle. With 500 to 1,000 measurements needed to generate a vibration analysis, this is a complicated and lengthy task. On the other hand, while we at NASA had weeks to analyze and make decisions the pass/fail window for end-of-production inspection systems is just a few seconds. So what's the answer?

For many years, assembly line damage detection has been more like watching a tree grow than a rocket launch. Today we are leveraging space shuttle testing technology to overcome assembly line constraints and cycle-time restrictions. Allowing vibration deformation patterns to be developed in just seconds enables a more thorough analysis, and perhaps in the near future, we'll be able to pinpoint and graphically display exact areas of defect.

Robert E. "Bob" Coleman is senior applications specialist for Signalysis, Inc. He has published a book *Experimental Structural Dynamics: An Introduction to Experimental Methods of Characterizing Vibrating Structures*. Contact the author or to request a copy of the book at: bob.coleman@signalysis.com.