TEST
Engineering & Management

Reprinted from
AUGUST / SEPTEMBER 1997

IN THIS ISSUE:

Automotive Testing Test Techniques, Ideas, and Information!

- Capacitive probes for automotive brake component testing
- Six-axis simulator tests automotive parts shipping racks
- Microphones for automotive BSR investigation
- Digital recorders improve flight vibration tests
- Small changes, big impact— one is the lowliest number
- Analysis techniques for package distribution environment data

Cover story:

Squeak and rattle and durability testing of automotive components

(details, see page 5)

Onboard digital recorders
improve flight vibration tests

By SCOTT FLING
Mechanical Engineer
Sverdrup Technology
Eglin Air Force Base, Florida
and GREG HOSHAL
President
Instrumented Sensor Technology
Okemos, Michigan

This article discusses a new approach to acquiring random vibration environment data during aircraft flight tests, and for using these data to improve random vibration test specifications. Traditionally, flight vibration data have been acquired using telemetry systems or tape recorders, which have many disadvantages. Recently, engineers at Eglin AFB have used state-of-the-art digital recorders developed by Instrumented Sensor Technology (IST) to measure vibration data on "Smart" bomb racks during F-16 flight tests (Figure 1).

The aircraft was flown through a series of harsh maneuvers at speeds approaching Mach One. Tri-axial vibration time history data were recorded continuously during the 80-minute flight tests using the onboard recorders. The data were then post-processed to generate Power Spectral Density profiles for the various flight maneuvers. The analysis results were compared against MIL-STD-7743, which provides a conventional vibration test profile for bomb racks.

The results show that MIL-STD-7743 fails to accurately represent the flight environment from 10 to 2000 Hz, and using it can result in over-testing in some frequency ranges, while under-testing in others.

FIG. 1—F-16 carrying two BRU-55 smart bomb racks and four JSOW weapons.

Previous data acquisition approach

Historically, all environmental flight data have been collected using either a telemetry (TM) system or an onboard tape recorder. Both of these approaches have serious limitations. Telemetry has been the primary flight data collection approach for years. However there were drawbacks to using a TM system. A TM system consists of several components that must be installed inside of the weapon, usually under severe space constraints. In addition, the power for the TM system must be provided by the carriage aircraft, which usually requires an often expensive and time-consuming aircraft modification. Further, a ground station is required to receive the TM signal from the weapon and record it on magnetic tape.

> **"Using MIL-STD-7743 to test the BRU-55 would have resulted in an overtest in some frequencies and an undertest in others."**

Several days or even weeks were often needed after the flight test in order to process the TM signal before the data could be analyzed. One of the biggest limitations of the TM system was the requirement for a direct transmission path between the weapon and the ground receiving site in order for the TM signal to be successfully transmitted. If the aircraft is too far away and/or flying at low altitude, the signal could be masked by the curvature of the earth, resulting in recording dropouts. In addition, during aircraft maneuvers the wing or fuselage could mask the signal resulting in additional dropouts.

Onboard tape recorders have recently become another popular recording method option. However, a significant limitation of electromechanical tape recording devices is that during severe high-G maneuvering the recording heads can separate from the tape, resulting in possible data loss.

The BRU-55 Smart Rack

In late 1996 as part of the BRU-55 Smart Rack program, state-of-the-art digital data recorders were successfully flown at Eglin AFB to collect flight vibration data. The BRU-55 is a smart rack, developed by M. Technologies Inc., which accommodates the new generation of smart thousand-pound-class munitions. The smart rack supports data communications between the aircraft stores management system and the weapon through the rack. The new rack also enables a doubling of stores while still being able to control each weapon, resulting in a true force multiplier for the Air Force and the Navy. In order to ensure operational reliability of the new smart rack and the embedded electronic systems, it was important to obtain actual flight vibration data so that realistic laboratory qualification tests could be conducted.

The flight test

The 39th Flight Test Squadron successfully completed two F-16/BRU-55 vibration fly-around missions in late 1996. The flight conditions ranged from sea level to 20,000 feet with aircraft loads up to 5.5 gs. The flight profile included accelerations, decelerations, roller

***Scott Fling** is a mechanical engineer with Sverdrup Technology Inc., Technical Engineering and Acquisition Support (TEAS) Group, Eglin AFB, Florida. He is currently responsible for structural and vibration analysis, qualification testing, and specification development of conventional weapons developed and tested by the Air Force at Eglin. He has worked in the environmental test field for eight years and has authored numerous papers on these subjects. Fling holds 1986 BS and 1988 MS degrees in aerospace engineering from the University of Florida.*

***Greg Hoshal** is president and CEO of Instrumented Sensor Technology, Inc., Okemos, Michigan. Hoshal founded the 10-year-old company while he was performing doctoral research project work in electrical engineering at Michigan State University. He holds BS and MSEE degrees and has published several papers. He is a member of IEEE, IoPP, ASTM, and ISTA.*

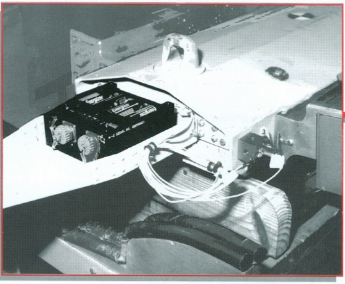

FIG. 3—IST data recorder installed in forward tray of BRU-55.

coasters, wind-up turns, slip-slides, and straight and level maneuvers. Listed in Figure 2 are the 18 different flight maneuvers performed by the aircraft during each 80-minute flight test.

Two missions were required in order to collect the appropriate vibration data to completely define the flight environment. The first mission was flown with a clean aircraft configuration (no additional stores on the BRU-55). This configuration allows the aircraft to obtain maximum performance during the flight.

The second mission was flown while carrying two JSOW weapons on each BRU-55 (loaded configuration). Although the aircraft performance is degraded, in this configuration the presence of the weapons influences the airstream around the BRU-55, changing the vibration environment.

For the purpose of this article, only the data from the second mission will be discussed.

New digital recorders

The onboard digital data recorders used during the BRU-55 flight tests were the Panther Model EDR-4M1 units developed by IST. The digital, all-solid-state recording unit has a rugged aluminum housing, is approximately 5.7 x 5.5 x 2.9 inches in →

Run	Mach	Alt	Maneuver
1	0.65-0.95	20K	Slow Accel
2	0.95-0.80	20K	Rapid Decel, Throttle Chop, Speek Brake
3	0.85	20K	Rollercoaster 1,0,2,1 for 30 sec
4	0.85	20K	5.0g WUT
5	0.95	20K	5.0g WUT
6	0.95	15K	5.0g WUT
7	0.60-550KCAS	5K	Slow Accel
8	550KCAS-0.60	5K	Rapid Decel, Throttle Chop, Speed Brake
9	0.80	5K	SHSS
10	0.75	5K	Rollercoaster 1,0,2,1 for 30 sec
11	0.75	5K	5.0g WUT
12	0.60-550KCAS	5k	Fast Accel
13	550KCAS	5K	5.0g WUT
14	0.60-550KCAS	1K	Slow Accel
15	550KCAS	1K	SHSS
16	550KCAS-0.60	1K	Rapid Decel, Throttle Chop, Speed Brake
17	0.70-0.95	10K	Slow Accel
18	0.95-0.70	10K	Rapid Decel, Throttle Chop, Speed Brake

Sta 1,9	16S210 or LAU-129 Launcher
Sta 2,8	16S210 or LAU-129 Launcher CATM-9L/M
Sta 3	BRU-55/2 JSOWs
Sta 4,6	370 Gal Tank
Sta 5	300 Gal Tank
Sta 7	BRU-55/2 JSOWs (EDTV Inboard)

FIG. 2—F-16/BRU-55 mission 2 flight profile.

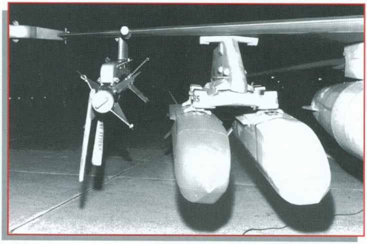

FIG. 4—BRU-55 (with two JSOWs) installed on the F-16 aircraft.

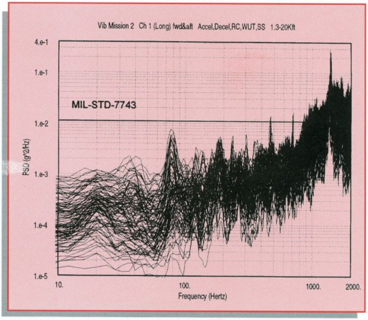

FIG. 5—Longitudinal BRU-55 flight data vs. MIL-STD-7743.

Flight tests (cont'd.)

dimension, and weighs five pounds. The self-powered recorder has input channels for direct connection of external piezoelectric voltage mode accelerometers. The accelerometers used in this test were PCB Model 353M193s mounted tri-axially on an aluminum mounting block. The accelerometers connect directly into the recorder, which supplies constant-current excitation for powering the transducers. No additional power supply or signal conditioning instrumentation is needed. The transducer/recorder setup installed on the bomb rack is shown in Figures 3 and 4, before and after installation on the aircraft.

The digital recorder was supplied to Eglin AFB with 108 MB of installed solid-state data memory. Using a pre-selected digitization rate of 4096 samples/second/channel the unit was able to record 12-bit data continuously for more than 80 minutes during the flight. User-adjustable anti-alias filters in the unit were preset to a 2 kHz cut-off frequency. The data was recorded into memory in contiguous 4096 sample block sizes to facilitate analysis following the flight test.

The recording system was completely installed within the store being tested with its own internal batteries. Therefore no aircraft modifications (e.g., special power umbilical) were required. The pilot's work load during the flight test was also reduced, since the recorders are pre-programmed before the flight to start and stop at certain times automatically. Since the data was stored digitally in the solid-state memory with the recorder, it overcame the limitations of the tape recorder and TM approaches. In addition, a ground site was not required to receive the signal. Data that was recorded digitally during the flight could be downloaded directly to a host PC or laptop immediately following the flight. This allowed for data analysis to begin within hours after the flight, rather than taking the days or weeks required by other approaches.

Analysis results

Data obtained by the recorder units during the second flight were first downloaded to a host PC running an applications software package supplied by IST. The data were then exported in order to process the acceleration time histories into power spectral density (PSD) profiles using the same algorithm that Eglin engineers have used on previous flight test data collected by either TM or tape recording means.

The PDSs were separated and combined according to axes and maneuver type. This allowed an evaluation of what maneuvers were driving the BRU-55 vibration environment. The PSDs were then combined to form overall composites in each axis as shown in Figures 5–7. The Grms levels for the envelopes of the longitudinal, lateral, and vertical composites are 8.2, 4.8, and 11.6, respectively.

Figures 5–7 provide a comparison between the captive flight data and the MIL-STD-7743 specification for a loaded bomb rack. In all three figures, the straight horizontal line represents the test level as specified in MIL-STD-7743. This specification has a total Grms value of 4.7. For the longitudinal axis the flight data are significantly higher than the specification level above 850 Hz, with a strong peak at 1380 Hz. Below 850 Hz the flight data fall under the specification level. For the lateral axis the flight data compare reasonably well with the specification level. However, the flight data fall under the specification level at frequencies below 80 Hz and between 300 to 1200 Hz. In addition, there are several narrow frequency bands at which the flight data above 70 Hz are significantly higher than the specification level.

As can be clearly seen in Figures 5–7, MIL-STD-7743 failed to accurately predict the flight vibration levels for the loaded BRU-55 smart bomb rack. Using MIL-STD-7743 to test the BRU-55 would have resulted in an overtest in some frequencies and an undertest in others. Analysis performed on data obtained from the first mission provided similar results.

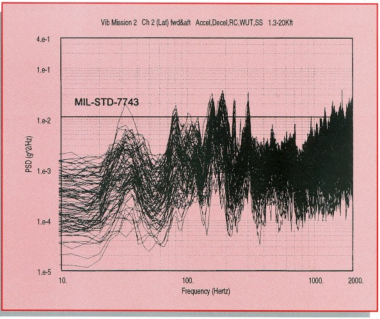

FIG. 6—Lateral BRU-55 flight data PSD vs. MIL-STD-7743.

Conclusions

F-16/BRU-55 vibration flight tests have shown the viability of using the IST digital data recorders to collect flight vibration data. The digital recorders proved to have many advantages over traditional data collection systems. The collected flight data were compared to the MIL-STD-7743 test levels for bomb racks. This comparison indicated that the MIL-STD-7743 cookbook levels fail to accurately represent the true flight environment. The BRU-55 flight data were used to create realistic test levels to replace the existing MIL-STD-7743 test levels. Future flight vibration testing that takes advantage of new solid-state onboard recording devices will undoubtedly result in more accurate and more realistic vibration test specification development for specific locations on board aircraft and weapons systems.

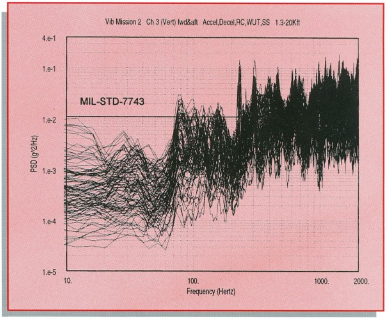

FIG. 7—Vertical BRU-55 flight data PSD vs. MIL-STD-7743.

For more information, contact Greg Hoshal, IST, 4704 Moore Street, Okemos, MI 48864 Phone (517) 349-8487 • FAX (517) 349-8469