The Space Congress® Proceedings

1994 (31st) Space Exploration and Utilization for the Good of the World

Apr 26th, 2:00 PM - 5:00 PM

Paper Session I-C - Shuttle Component Structural Integrity Monitoring in Harsh Noise Environment

James C. Yeh

United Technologies Corporation/USB I Co. Kennedy Space Center, Florida 32815

R. R. Stephan

United Technologies Corporation/Pratt & Whitney West Palm Beach, Florida 33410

Shuttle Component Structural Integrity Monitoring
in Harsh Noise Environment

James C. Yeh
United Technologies Corporation/USBI Co.
Kennedy Space Center, Florida 32815

R. Robert Stephan II
United Technologies Corporation/Pratt & Whitney
West Palm Beach, Florida 33410

Introduction

Inspection for structural integrity of the Space Shuttle Solid Rocket Boosters (SRBs) is of paramount importance to mission safety. After every shuttle launch, the booster rockets are retrieved and an extensive inspection performed to components and welds to detect any degradation that occured as a result of the mission flight. The cost of refurbishment related to preparation, actual inspection, and reassembly after inspection, is substantial. It is a major factor concerning availability of these crucial components.

Recent studies reported that AE energy counts are physically related to fracture mechanics parameters, and that AE energy count versus strain energy release rate or J-integral has a linear relationship for Inconel 718 and aluminum alloys.[1,2] An AE structural monitoring system will assure that, if damage occurs to the structure during shuttle mission, AE from the damage area could be monitored and used as a cost-effective means for initial screening to identify potential locations for selective postflight inspection, otherwise reinspection may reasonably be eliminated. AE can therefore be a cost-effective approach to control refurbishment cost of major shuttle components. Two crucial issues must be addressed: filtration of severe noise background from a rocket launch environment as well as AE signal correlation to fracture parameters.

Test Plan

Most AE equipment has a nominal frequency ranging from 20 Kilohertz (kHz) to 2 Megahertz (mHz). AE sensors in conjunction with bandpass filters should eliminate unwanted signal or noise generated from mechanical vibration or electric interference. However, based on result of our literature review, very little had been done on actual AE structure monitoring during live rocket firing.[3,4] Our task was therefore dedicated to feasibility of running acoustic emission testing during simulated shuttle SRB launch noise background to monitor crack growth in a structure. In this research study, AE signals from cracking of material and weldment were transmitted to an aluminum test bed under high noise background to verify that AE signals are reasonably detectable under harsh acoustic environment.

Generation of Simulated AE Signals

Real AE signals were first generated using controlled crack growth compact tension specimen of 2219 aluminum alloy and a standard cyclic fatigue testing machine. Discrete AE signals as received by a special broad band sensor were "captured" using a high speed Digital Storage Oscilloscope (DSO). The AE signals were then analyzed for characteristics such as peak amplitude, energy, and frequency spectra with both conventional AE test equipment and a signal analysis computer software package. These charactreistics were used to identify and produce an appropriate AE signal simulation technique.

In order to standardize our test result, an additional signal simulation was produced by breaking a pencil lead near the fracture surface of the specimen. The pencil lead breaking was also found to closely resemble that of aluminum specimen rupture crack signal. These simulated signals were used extensively throught the testing.

SRB Background Noise Data Basis

Several articles contain information on subjects of solid propellant burning, rocket noise, and subscale aeroacoustic monitoring of the shuttle vehicle. Marshall Space Flight Center (MSFC) provided formation pertaining to test firing of a SRB. The data states that the overall Sound Pressure Level (SPL) at the aft skirt external is 162 Decibel (dB) in the 5 Hertz (Hz) to 10 kHz frequency range. Further up the SRB at the external ring thermal curtain to nozzle, SPL frequencies ranging from 125 Hz to 400 Hz was recorded.[5] On March 24, 1992, during launch of Atlantis, mission designation STS-45, environmental health personnel at Kennedy Space Center (KSC) collected octave band data from a parking lot north of Complex J, which is 3 miles from launch site. Acoustic data shown in Table 1 were extrapolated back to the launch site with simple adjustment made to accomodate for sound attenuation in air which resulted in a 64 dB correction. Based on this crude analysis, the largest SPL is 176 dB at a frequency of 63 Hz tapering off to approximately 140 dB at frequencies above 1 kHz.

TABLE I

Remotely Measured Acoustic Sound Pressure Level Data From the March, 24, 1992 Launch of the Space Shuttle, Extrapolated back the Pad For Use in Estimating Acoustic Background Noise Levels For This Test.

Octave Band (Hz)	SPL (dB) (3 miles)	Corrected SPL (At Launch Site)
31.5	95	159
63	112	176
125	110	174
250	100	164
500	85	149
1000	70	134
2000	74	138
4000	70	134
8000	79	143
16000	78	142

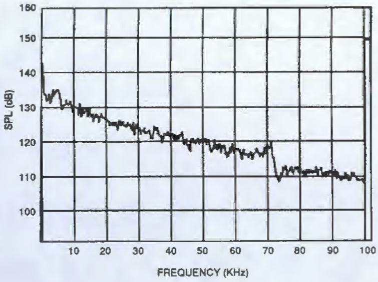
Weather data provided by Lt. Marvin Troy, CCAFS Weather Station.
Weather data at the Shuttle Landing Strip at 0814 on March 24, 1992

Wind Speed	9 knots (gust to 17 knots)
Wind Direction	10 degrees
Temperature	65°F

Background Noise Simulation

A small 12 inches by 12 inches by 4 inches dual sound-source Progressive Wave Tube (PWT) acoustic chamber located in Pratt & Whitney's facility in West Palm Beach, Florida, was used to generate harsh acoustic environment for this effort. Our noise was generated both by an enormous air supply system and a Team MK-VI reciprocating air stream modulator sound driver to achieve the desirable low frequency acoustic environment. The desirable frequency spectrum shape was adjusted by filtrering the random noise drive signal using a suitable band filter and a brick wall bandpass filter. The acoustic noise spectra are measured for display, analysis, and hard copy by a pair of miniature pressure transducers installed on the PWT side wall. Figure 1 is a typical frequency response distribution display at 160 dB SPL. A heavy block building was available as a control center which housed the vast amount of electronic data acquisition equipment.

FIGURE 1 FREQUENCY RESPONSE DISTRIBUTION DISPLAY AT 160 dB SPL



Test Set-up

After deciding on appropriate simulation techniques, an aluminum test bed was outfitted with four test sensors and one broadband sensor to serve as pulser in transmitting in simulated AE crack signals. (Figure 2) The four passive AE sensors were all commercially available and represented the anticipated frequency spectra of return AE crack signals. Frequency spectra of these resonance sensors ranged from 150 kHz, 500 kHz to a broad band general application sensor. Filtered preamplifier was initially set at 40 dB and having a frequency bandpass width of 100 kHz to 1200 kHz on each of the four channels. Once the test bed was fully assembled, minor system gain and threshold adjustments were made to optimize signal responses from all channels. Later during the test runs because of spurious signal spikes, the frequency bandpass width was adjusted to 600 kHz to 1200 kHz for all four channels. The test bed was then mounted on the test chamber window with sensors mounted on outside face of the test bed. Figure 3 provides schematic for the AE test equipment layout.

FIGURE 2 PHOTOGRAPH OF ASSEMBLED AND MOUNTED ALUMINUM TEST BED

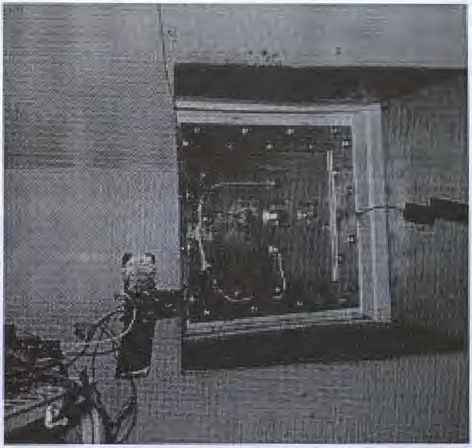
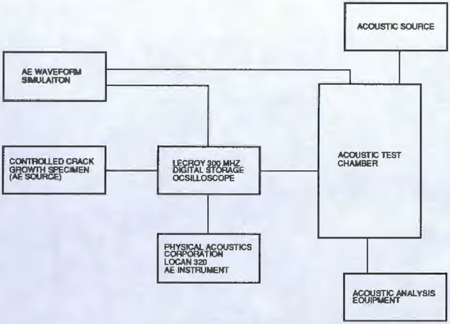


FIGURE 3 AE TEST EQUIPMENT LAYOUT



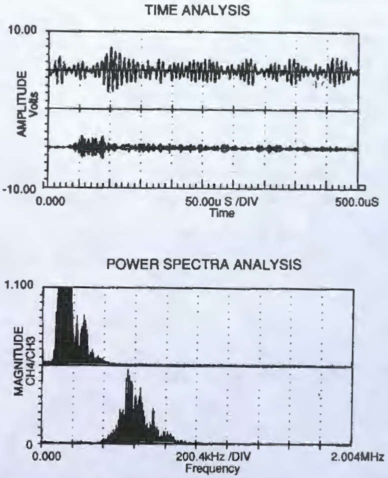
Test Runs and Discussion

During each of the test runs, the first action was to verify that no activity from the background noise would affect our system gain of threshold setting to any of the four sensor channels. The next action was to activate the LeCroy DSO to capture a Radio Frequency (RF) waveform for spectrum analysis. Finally, the Locan 320 acoustic emission system was activated to acquire signals from each of the four sensor channels based on different simulated AE signal inputs discussed before. Where appropriate, additional waveforms were also collected for later analysis on spurious AE signal spikes which were not specifically related to the intended simulation signal input.

A total of six test runs were performed at the Pratt & Whitney facility. An official base run was performed to verify that all four sensor channels were functioning properly and to record steady-state background level which is below the preset detection threshold limit. Five test runs were then performed from backgound noise level of 140 dB to 180 dB, in 10 dB increments.

Simulated signals feeding through the test bed were fully detectable under background noise levels up to 160 dB, except in the 150 kHz sensor channel. Use of 600 kHz bandpass preamplifier device practically eliminated any detectable signals to this channel. Starting at 170 dB noise level, a higher threshold level was used to prevent undersirable spurious background noise signals from infiltrating the AE test instrumentation. The unfortunate consequence was that the relatively lower amplitude simulated AE signals were no longer detectable from the remaining three sensor channels. Following this test run, the sensor channels were verified to be operable with sound driving device taking offline. Test run at this noise level was again performed using additional simulated AE signals produced from a heavier pencil lead. This new simulated AE signal has a peak amplitude around 90 Decibel Acoustic Emission (dBae) and a center frequency slightly higher than 600 kHz and thus is acoustically compatible in both signal amplitude and spectral response to that of a cracking 2219 aluminum weld specimen.[Figure 4] The signal was successfully detected and captured. The final test runs were performed at background noise level of 180 dB. This new heavier pencil lead breaking simulated AE signals was again detectable.

FIGURE 4 TEST RUN AT 180 db SOUND DRIVER MAXIMUM OUTPUT, PENCIL LEAD BREAK (0.5mm)



It should be noted here that during both 170 dB and 180 dB test runs, there were many spurious signal spikes similar to that of the simulated AE signals also detected. These spurious signals were thought to be associated with the sound driver mechanics. Post test spectrum analysis indicated that these spurious signals were of the higher frequency than that of the background noise level. These higher amplitude spurious signals apparantly have infiltrated our 600 kHz bandpass preamplifiers in all sensor channels. Pattern recognition and classification techniques were later used to discriminate these spurious signals from our simulated pencil lead breaking response. We have thus far achieved no concrete result on this signal discrimination task.

Acoustic Emission Structural Monitoring

It is mentioned above that earlier study result showed that acoustic emission energy is in proportion to strain energy release rate at crack tip. By monitoring acoustic emission energy release during loading application, it is possible to assess structural integrity of a component for selective postflight inspection. In an other previous study, it was revealed that the acoustic emission energy release from a relatively small aluminum weld defect is approximately ten times higher than that of a non-weld fatigue crack of the same flaw size. The result indicated that incipient fracture propagation, quick development of large plastic zone, and defect surface oxide break-down are major contributors to this large high energy emission.[6,7] This finding is important in our overall approach concept that a large AE signal from a propagating weld imperfection has a much greater chance to be detected among harsh noise background.

With AE signal detection threshold set based on fracture parameters, detection of detrimental weld imperfections is certainly assured if the imperfections are propagating, or enlarging, under stress field. With this understanding, an expert system can then be developed to perform structure monitoring based on specific AE signal threshold values. Instrumentation system would be simple and light-weighted because in this simplified approach, monitoring of only one or two testing parameters would be adequate. A preset AE energy value which corresponds specifically to a quantitative requirement from engineering fracture analysis can be used as pre-screening criteria to determine if post-mission inspection is warranted. This concept on selective inspection would provide a very promising tool in formulating a cost-effective maintenance activity during routine refurbishment schedule.

SUMMARY

The study shows that acoustic emission crack growth signals can be detected in a noisy rocket launch environment. Electronic simulated acoustic emission signals similar to that from a cracking aluminum weld imperfection were recognized from standard off-the-shelf commercial sensors up to a noise background of 180 dB SPL.

Acoustic emission energy release from an aluminum weld defect is approximately ten times higher then that of non-weld fatigue crack and the acoustic emission energy releases from fatigue crack tips are in proportion to fracture parameters. It is therefore possible to assess integrity of a structural component for selective postflight inspection by monitoring acoustic emission energy release during shuttle mission,

ACKNOWLEDGEMENTS

The authors wish to express their appreciation to USBI Co. Florida Field Engineering and Independent Research & Development Committee for support and guidance. Thanks also to Dr. A. Pollock of Physical Acoustic Corporation and Dr. C. Tsai of The Ohio State University for their guidance in testing approach and data acquisition, to USBI Co. Environmental Safety for their assistance in shuttle launch background noise data acquisition, and to USBI Co. Florida Graphics Department for preparation of this manuscript.

REFERENCES

1. Yeh, J.C. and Tsai, C.L., "Study of Acoustic Emission Characteristics for Fracture Assessment," Review of Progress in Quantitative Nondestructive Evaluation, Vol. 12, pp. 2207-2213, 1993.

2. McBride, S. and Hong, Y., "Acoustic Emission from Crack Growth in 7050 Aluminum and 7075 Aluminum as a Function of Temperature and Heat Treatment", Review of Progress in Quantitative Nondestructive Evaluation, Vol. 12, pp. 2199-2206, 1993.

3. Dougherty, N.S. and Guest, S.H., "A Correlation of Scale Model and Flight Aeroacoustic Data for the Space Shuttle Vehicle", AIAA/NASA 9th Aeroacoustics Conference, Williamsburg, Virginia, 1984.

4. McInerny, S., "Rocket Noise – A Review," AIAA 13th Aeroacoustics Conference, Tallahassee, Florida, 1990.

5. Stephan, R. R., "In-Flight Acoustic Emission Monitoring of Welded Aluminum Structures in Space Shuttle Solid Rocket Booster Components", Final Report prepared for USBI Co., United Technologies Corporation Pratt & Whitney, 1993.

6. Yeh, J.C., et al, "Study of Acoustic Emission Characteristics for Fracture Assessment of Structural Weldment," submitted for publication under Review of Progress in Quantitative Nondestructive Evaluation, Vol. 13.

7. Enneking, J.A., et al, "Acoustic Emission Characteristics of Space Shuttle Structural Weldment", technical paper presented in Symposium on Nondestructive Evaluation and Material Properties, 1993 TMS Fall meeting, Pittsburgh, Penna.