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DEVELOPMENT OF BIOSATELLITE
PRIMATE MISSION COMPONENT QUALIFICATION LEVELS

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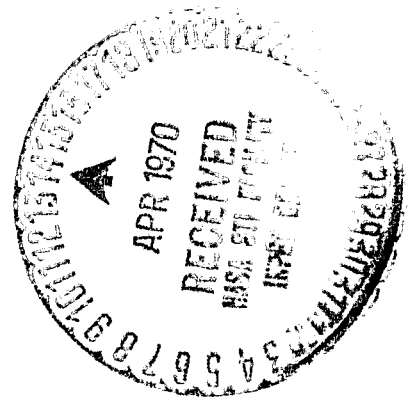
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DEVELOPMENT OF BIOSATELLITE
PRIMATE MISSION COMPONENT QUALIFICATION LEVELS[†]

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Abstract

This presentation outlines the procedure used in the Biosatellite Primate Mission Program for development of component qualification levels which have recently been validated by flight data. Component qualification levels were established early in the Biosatellite program using limited flight component response data. Subsequent system development vibration tests were performed on a prime structure spacecraft with simulated components. Since the spacecraft external flight (acoustic) loading was negligible and the booster - spacecraft interface flight environment was known, the system test simulated the flight conditions. Based on the dynamic characteristics of the components in their system installations, the component qualification test levels were further defined. These levels were envelopes of the component system responses with a margin of safety included. Subsequent flight test data verified this approach since responses were within the developed component qualification envelope.

Introduction

Development of spacecraft component qualification test levels which adequately represent the flight environment and yet are not overly severe to cause unnecessary and costly failures have long posed a problem to vibration engineers. As stated in reference 1, development of vibration test specifications is usually influenced more by personal judgments and precedence than by a scientific evaluation of available information.

The Biosatellite Primate Mission spacecraft contains several hundred components which are sensitive to vibration. In order to meet schedule commitments, it was necessary to establish component qualification tests early in the program. Here it was mandatory that these levels be conservative, since flight data was limited. In addition, stringent requirements were placed on high reliability similar to manned spacecraft in order to guarantee the primate's safety.

Based on a study of components similar to those in the Biosatellite program and some preliminary Biosatellite development vibration tests, it was determined

that for many components to successfully pass qualification tests, major design changes would be required, resulting in flight schedule delays and additional costs. This necessitated finding a method to determine more realistic component qualification vibration test levels.

This report presents a review of system test procedures used on the Biosatellite Primate Mission for development of component qualification levels.

Spacecraft Configuration

The Biosatellite Primate Mission spacecraft consisted of a mated adapter and a satellite re-entry vehicle (SRV) as shown in Figure 1. The SRV assembly included a recovery capsule and thrust cone. The recovery capsule housed primate experiment payload, necessary life support equipment and recovery devices. The thrust cone supports a retro-rocket and other components necessary to provide controlled impulse to deorbit the spacecraft. All other equipment necessary for orbital operation, but not needed for re-entry or required to be recovered, was contained in the adapter located between booster and SRV.

The launch vehicle for the Biosatellite mission was a long tank Thor-Delta booster. The Biosatellite spacecraft was enclosed in a protective shroud about 19 feet long which effectively attenuated external acoustics.

Flight Vibration Environment

During lift-off and atmospheric flight, the Biosatellite spacecraft is exposed to low and high frequency vibration. Mechanically induced vibrations are transmitted from the main booster structure through the spacecraft interface. Interface vibration data was recorded on two Thor Delta flights which launched the Biosatellite I and Biosatellite II spacecraft without primates.

Interface vibration levels presented in Figure 2 are low frequency sinusoidal measurements from these flights. Primary cause of this environment is low frequency booster bending effects and POGO oscillations due to fuel slosh prior to first stage separation. Low frequency system qualification sinusoidal test levels are also plotted on Figure 2.

[†] This work was performed under
NASA Contract NAS2-1900

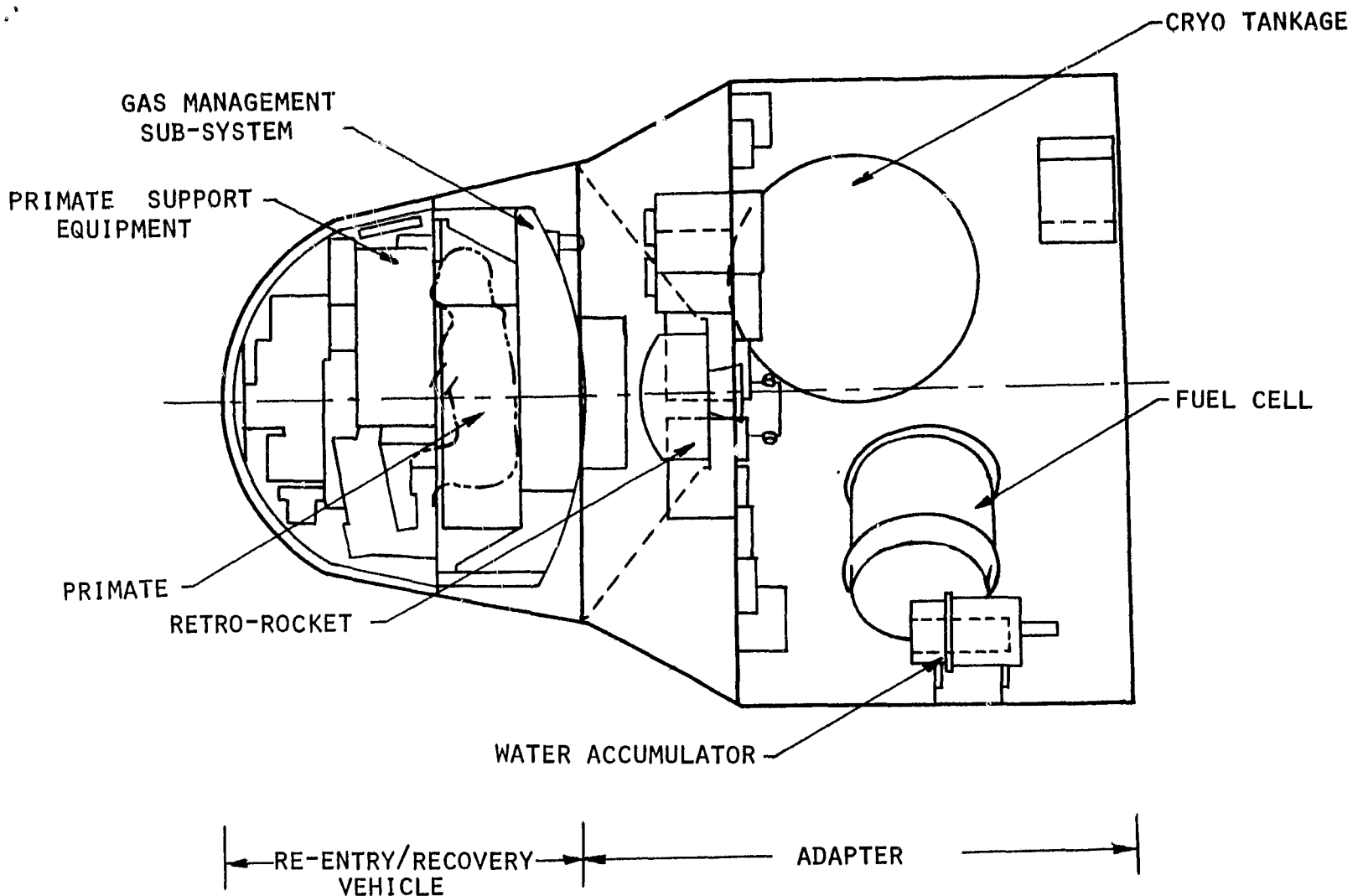


FIGURE 1. BIOSATELLITE INBOARD PROFILE

High frequency spacecraft vibration caused by structurally borne acoustic excitations is transmitted to the spacecraft interface. Figure 3 shows a composite of these high frequency random vibration interface measurements together with the system random qualification test specification.

System Development Vibration Test

Principal component vibration excitation is induced through the spacecraft - booster interface, therefore, system vibration testing was decided as the best method for developing realistic component qualification levels. By system testing the spacecraft, dynamic environments of components in their actual installations were defined. Because of shroud protection, the internal acoustic environment was negligible. Internal acoustic overall sound pressure levels for the same booster and shroud configuration flying the same trajectory as the Biosatellite Primate Mission were previously measured and found to be less than 110 db. Therefore, component response due to acoustic noise was negligible.

Test Vehicle

The Biosatellite Primate Mission spacecraft used for the system development vibration tests consisted of a prime structure vehicle with mass and C.G. simulations of all flight components. In addition, many of the components were prime designs which had been used in component development phases and, therefore, represented a precise dynamic simulator. Rather than hard mount the spacecraft directly to a vibration test fixture, the flight adapter which mated the spacecraft and booster was utilized to obtain a more realistic test condition.

Test Levels & Input Control

Vibration development testing consisted of imposing sinusoidal and random vibrations along each of three major vehicle axes at the level and durations shown in Table 1. These test levels simulated booster - spacecraft interface induced vibrations during various powered flight mission phases.

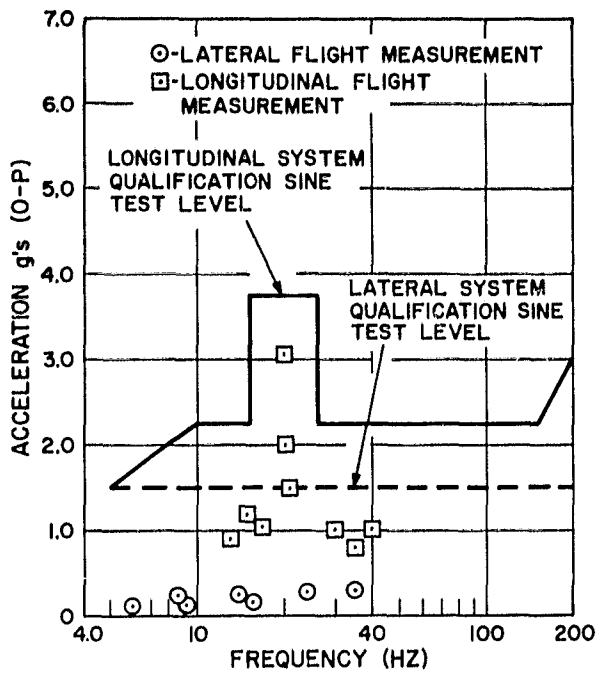


FIGURE 2. LOW FREQUENCY SINUSOIDAL FLIGHT MEASUREMENT

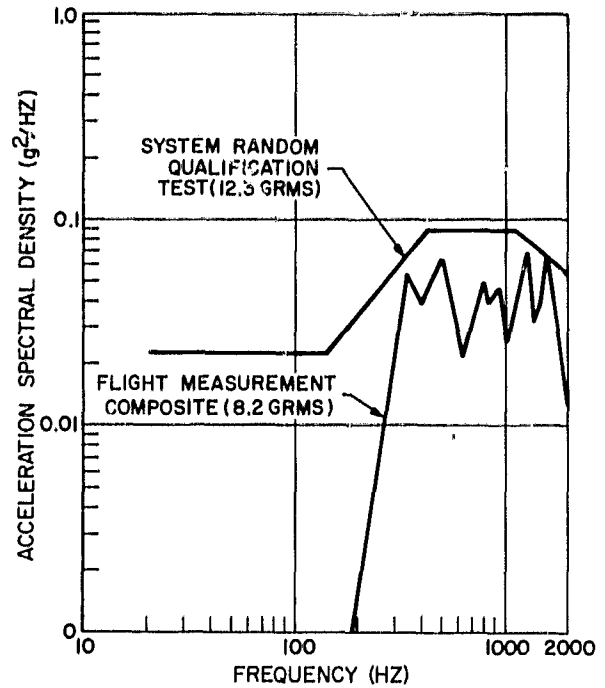


FIGURE 3. HIGH FREQUENCY RANDOM FLIGHT MEASUREMENTS

Tests were performed by mounting the spacecraft and forward section of booster adapter on a vibration fixture and controlling input vibration at booster adapter interface.

Vibration control was maintained by using the average of four accelerometers. Average input was used providing none of the accelerometers exceeded the specified level by 20%. Whenever the 20% level was exceeded, control automatically switched to control the highest reading thereby alleviating the problem of spurious vehicle inputs due to fixture resonances.

This method of average control produced an input that was more uniform and therefore reduced potential overtesting.

For longitudinal direction tests, fixture and vehicle with booster adapter were mounted directly on an MB-C-210 electro-dynamic exciter. In the lateral directions, spacecraft, adapter and fixture were mounted on a team bearing system which constrained motion to only the lateral plane and eliminated overturning moment effects.

TYPE OF VIBRATION	AXIS OF EXCITATION	QUALIFICATION		
		Frequency (Hz)	Amplitude or Level	Sweep Rate or Time
SINE	LONG,	10-15 15-26 26-160 150-500 500-2000	2.25g o-peak 3.75g o-peak 2.25g o-peak 0.922 in/sec. 7.5g o-peak	2 oct./min.
	2 Lateral Axes	5-250 250-400 400-2000	1.5g o-peak 3.0g o-peak 7.5g o-peak	2 oct./min.
RANDOM	3 Axes (1 Longitudinal & 2 Lateral)	20-150 150-425 425-1200 1200-2000	0.0225 g ² /Hz. 4db/oct. increase 0.09 g ² /Hz. 2db/oct. roll off	4 min. per axis.
		(Overall G-RMS level over excitation frequency range of 20-2000 Hz is 12.3g RMS)		

TABLE 1. SYSTEM VIBRATION INPUT LEVELS

Instrumentation

Ten piezoelectric crystal accelerometers were used to monitor input levels and 96 such sensors were used to measure responses throughout the vehicle. Endevco Models 2213/2217 or CRL Model 302-2 accelerometers were used at all locations where weight (1 to 1.1 oz.) would have a negligible affect on frequency response of the installation. Endevco Model 2229 or CRL Model 302-6, which are microminiature accelerometers (5 to 10 grams), were used at locations where space and weight were a problem. Emphasis was placed on individual component requirements rather than defining a zonal representation. Measurements were made at interfaces between support structure and components thereby acquiring response signatures at component mounting locations.

Output of the accelerometers was conditioned by means of CRL Model 9006 Charge Amplifiers and recorded in conjunction with a 100 Channel Multiplex System on a Sangamo Model 471RB Tape Recorder operated at 60 inches per second to give a flat frequency of the recording system within 0 to 1.5db to 4000Hz. Recorded data was played back through a Spectral Dynamics Analyzer into Moseley Model 136A X-Y Plotters (Sine) and a CEC 124 Oscillographs (Random).

Data Evaluation & Observations

Recorded data (2) were reduced to power spectral density plots for random tests and g vs. frequency plots for sinusoidal tests. Typical data plots are shown in Figures 4 through 8 and provide a general indication of Biosatellite vibration characteristics. One common characteristic notable in all vibration data is major response peaks at 40Hz, which is the major resonant frequency of the Biosatellite spacecraft. At vehicle resonance, 18 g's were measured at the oxygen cryogenic tank inner shell. Based on structural calculations and component test results, levels greater than 20 g's would degrade tank performance. As a result of this finding during system qualification testing, response of the oxygen tank was carefully monitored. System vibration inputs were imposed in increasing steps approaching the qualification level. Tank critical levels were not reached.

Above 100Hz, the Biosatellite spacecraft is effectively decoupled from the booster and does not experience significant high frequency vibration.

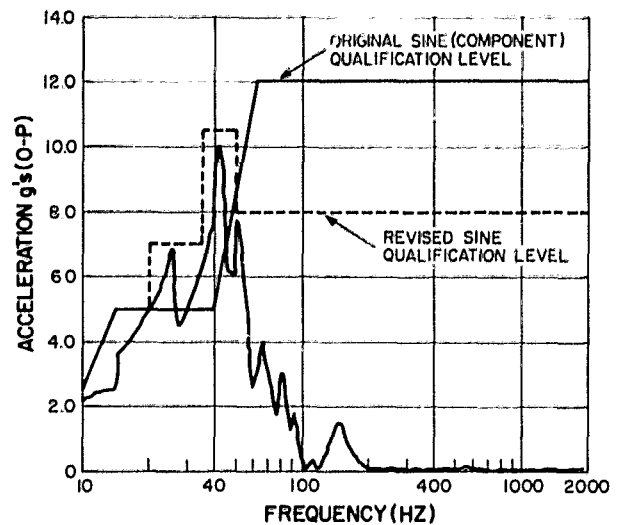


FIGURE 4. PELLETT FEEDER-SYSTEM TEST SINUSOIDAL RESPONSE

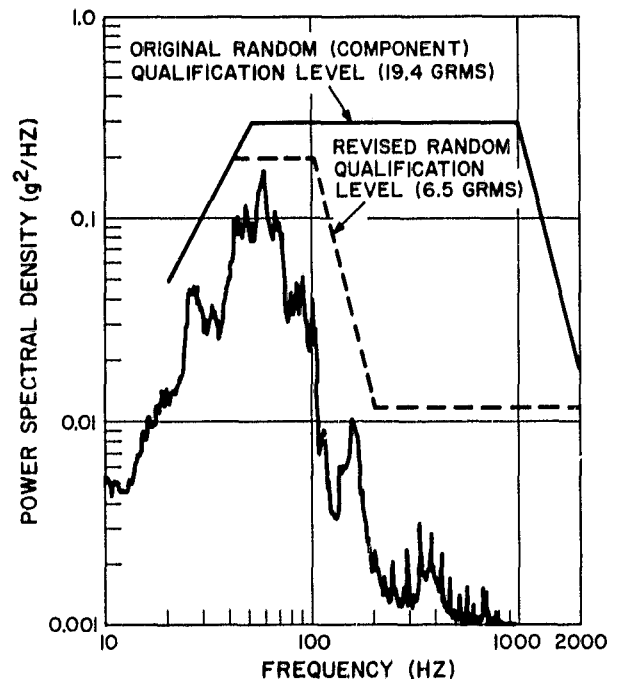


FIGURE 5. PELLETT FEEDER-SYSTEM TEST RANDOM RESPONSE

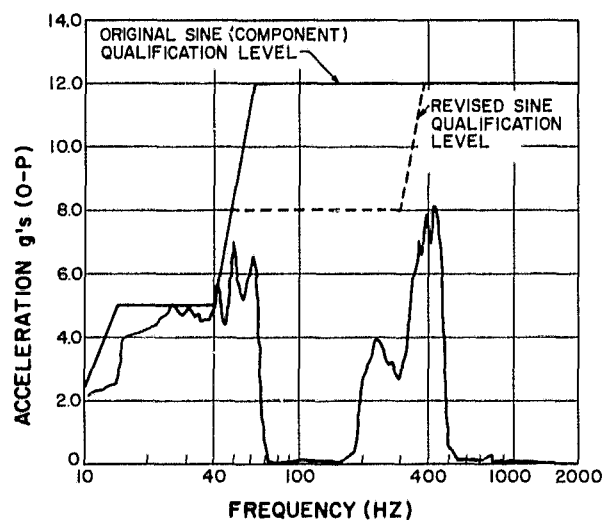


FIGURE 6. WATER FILTER-SYSTEM TEST SINUSOIDAL RESPONSE

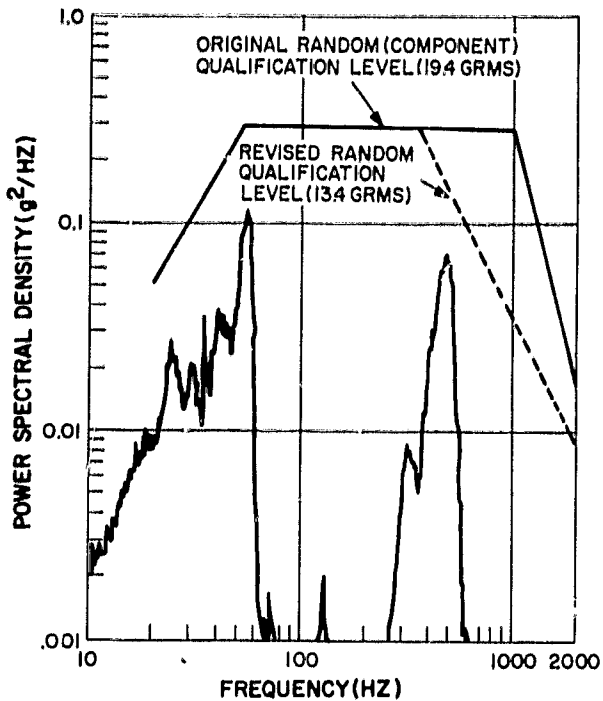


FIGURE 7. WATER FILTER-SYSTEM TEST RANDOM RESPONSE

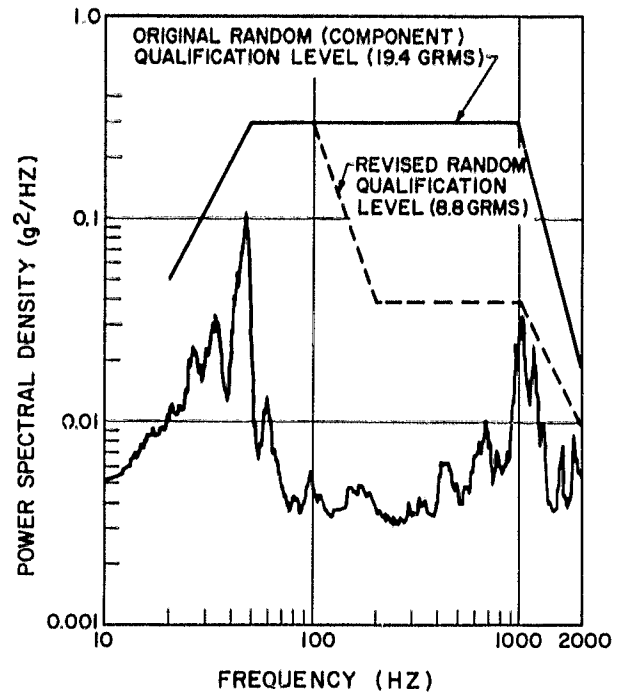


FIGURE 8. ADAPTER POWER CONTROLLER-SYSTEM TEST RANDOM RESPONSE

Component Qualification Level Determination

Comparison of system test results with initial component qualification levels (see Figures 4 through 8) shows the uncertainty in the original level definition. For frequencies greater than about 100Hz, the original component level is much more severe than that observed in the system test, especially in the frequency range between 100 and 400Hz where electronic and electro-mechanical components exhibit critical resonances.

Biosatellite qualification levels were revised based on individual system test responses. These responses were enveloped and included a margin for anomalous effects as typified in Figures 4 through 8. It is also interesting to note that in some cases the redefined level is greater than originally specified. Note that in Figure 4, low frequency sinusoidal responses of the pellet feeder (Primate food dispenser) exceeded the original qual level. Revised requirements were developed by enveloping the total response.

Flight Results

The Biosatellite Primate Mission spacecraft was successfully launched from the Eastern Test Range (Cape Kennedy) by a Thor-Delta booster 28 June 1969. For diagnostic purposes, the vibration environment experienced by the Biosatellite spacecraft was recorded by vibration sensors installed in the adapter which mated the spacecraft and booster. These flight sensors were mounted at corresponding locations to those in system development tests, in order to obtain one to one correlation.

Flight vibration g levels were recorded and monitored in real time at Cape Kennedy. Critical flight vibration environment was at POGO where a maximum level of 2.2 g's (O-P) at 20Hz was observed. Figure 9 compares response between flight and that obtained during the system vibration test. Note that the system test levels adequately envelope flight measurement data, providing ample margins for added reliability.

Figure 10 is a direct comparison between high frequency random flight and system test data. Again, flight measurements were below system test responses. Therefore, the refined component vibration levels sufficiently represented flight environments.

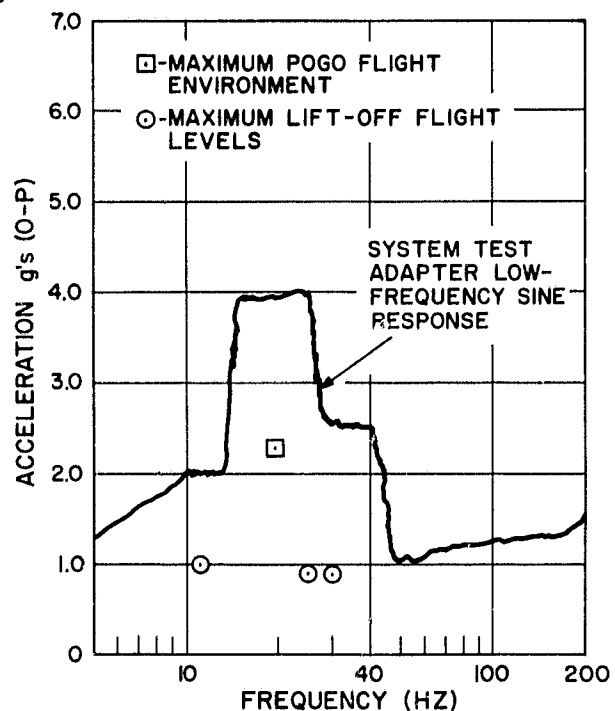


FIGURE 9. COMPARISON OF CORRESPONDING LOCATION-FLIGHT AND SYSTEM TEST SINE RESPONSE

Conclusion

System vibration test data can be used to establish realistic component test specifications. This is particularly true when the primary source of excitation is through the spacecraft-booster interface. Results of the Biosatellite Primate Mission program verified this approach.

Future spacecraft programs should consider the implementation of a "stage" release system whereby component qualification test specifications may be periodically updated as system test data becomes available. This provides a means of establishing component tests more representative of actual flight conditions.

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2. L. Condran, "Biosatellite Vehicle Development Vibration Test - 30 Day Configuration," General Electric Document No. 67SD7111, September 1967.

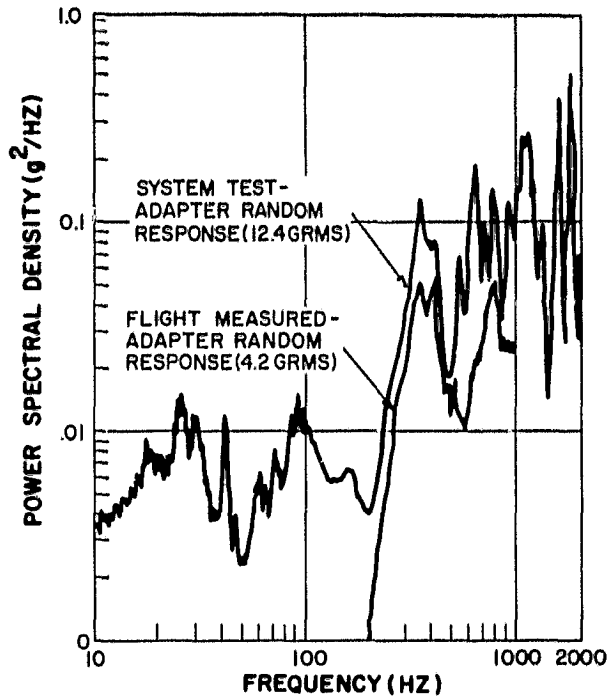


FIGURE 10. COMPARISON OF CORRESPONDING LOCATION-FLIGHT AND SYSTEM TEST RANDOM RESPONSE