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Saturn V

VIBRATION AND ACOUSTIC ENVIRONMENT CHARACTERISTICS OF THE SATURN V LAUNCH VEHICLE

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This paper presents representative examples of vibration and acoustic data from flights of the Saturn V launch vehicle and static firings of Saturn V launch vehicle stages. The purpose of the paper is to provide vibration and acoustic environment characteristics which are pertinent to the design of launch vehicles.

Comparisons of vibration spectra are presented which illustrate differences between flight and static firing environments, effects of mass loading on the vibration environment, vibration transmission through structure, and the effects of fluid flow rate on vibration level.

Comparisons of acoustic data are presented which indicate differences between static firing and flight acoustic environments, differences in the acoustic environment internal and external to the vehicle, and variations in sound pressure level due to engine exhaust direction.

Flight vibration and acoustic time histories are presented. The time histories are compared with time histories of dynamic pressure and Mach number to illustrate the correlation between these parameters and the vibration and acoustic environment.

INTRODUCTION

The Saturn V launch vehicle consists of three stages, the S-IC, S-II, and S-IVB (Figure 1). To date there have been approximately 30 static firings of the flight stages. Over 3000 vibration measurements have been made during these static firings. In addition about 400 vibration measurements were taken during the first two flights of the Saturn V vehicle. This paper presents representative examples of vibration and acoustic data from flights of the Saturn V launch vehicle and static firings of Saturn V launch vehicle stages. The purpose of the paper is to provide vibration and acoustic environment characteristics which are pertinent to the design of launch vehicles.

STATIC FIRING AND FLIGHT VIBRATION ENVIRONMENTS

The vibration environment of a stage during static firing and flight can differ radically as illustrated in Figure 2. This figure shows the spectrum of a typical measurement taken during S-IVB static firing as compared with a spectrum of the same measurement during the liftoff period of the Saturn V. Note the large level difference between 10 and 500 hertz. This difference is attributed to the structure response to dissimilar acoustic noise fields produced by the engines of the stage and the launch vehicle. The S-IVB has one engine producing over 200,000 pounds thrust while the S-IC has five engines producing over 7.5 million pounds of thrust.

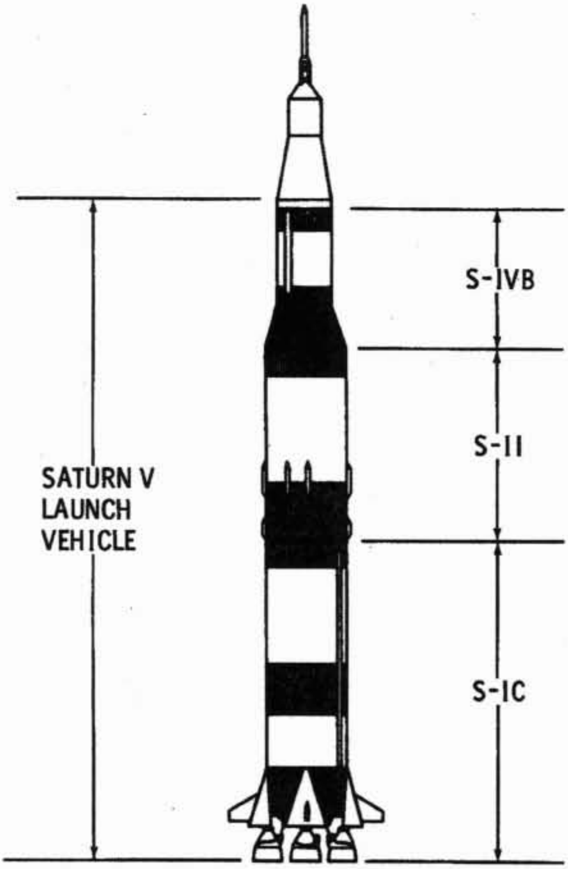

Figure 1: SATURN V SPACE VEHICLE

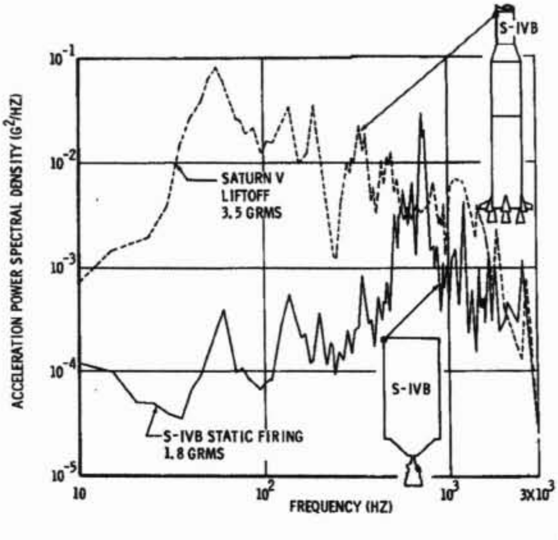

Figure 2: COMPARISON OF S-IVB VIBRATION ENVIRONMENT DURING S-IVB STATIC FIRING AND SATURN V LIFTOFF

Figure 3 illustrates the comparison of spectra from the same measurement for S-IVB static firings, Saturn V launch, and flight at Max q (Maximum Dynamic Pressure). This figure shows that the vibration environment during Max q flight differs from both the static firing and liftoff environments.

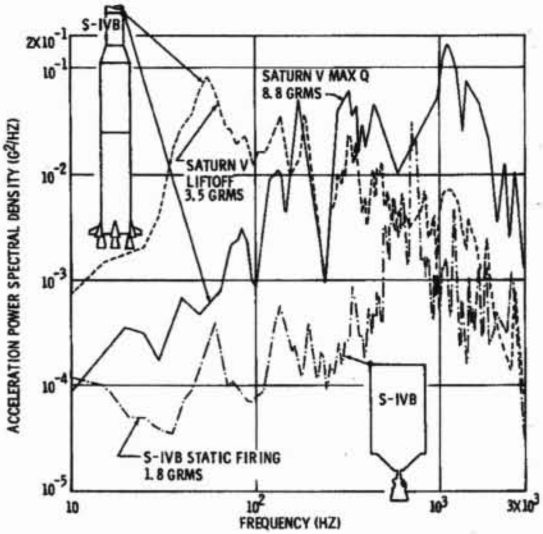

Figure 3: COMPARISON OF S-IVB VIBRATION ENVIRONMENT DURING S-IVB STATIC FIRING, SATURN V LIFTOFF AND SATURN V MAX Q

MASS LOADING EFFECTS

Mass loading has a significant effect on the vibration environment as illustrated in Figure 4. The figure shows the difference between two measurements located on the S-IC LOX bulkhead. The dotted spectrum is a measurement located on a portion of the bulkhead which is one-fourth inch thick and of uniform mass distribution. The solid spectrum is from a measurement located next to a massive fitting (approximately 54 pounds) on the bulkhead. The overall vibration level for the mass loaded bulkhead is approximately one-third of that for the unloaded bulkhead.

Figure 5 also illustrates mass loading effects resulting from liquid level variations in a tank. When considering vibration levels on a tank, it is very important that the vibration levels be considered as a function of liquid level. The solid line on Figure 5 shows the spectrum level when liquid is above the measurement while the dotted spectrum is the vibration level with liquid below the measurement. The liquid mass attenuates the overall vibration level by a factor of approximately four.

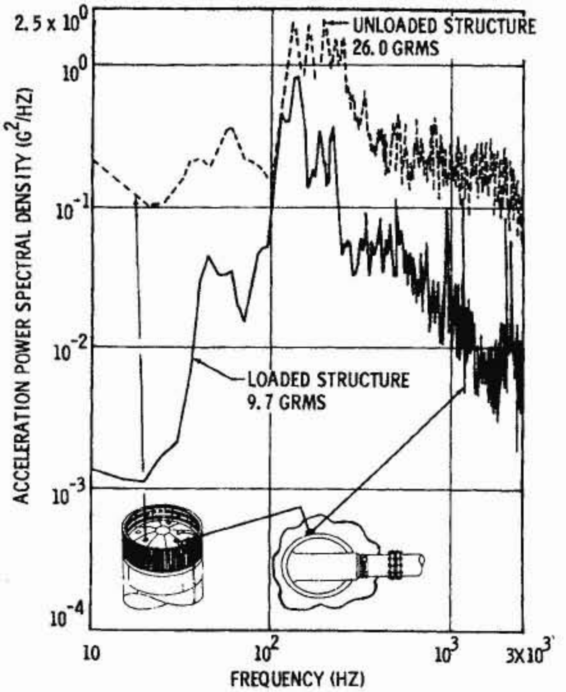

Figure 4: COMPARISON OF LOADED AND UNLOADED STRUCTURE VIBRATION ENVIRONMENTS

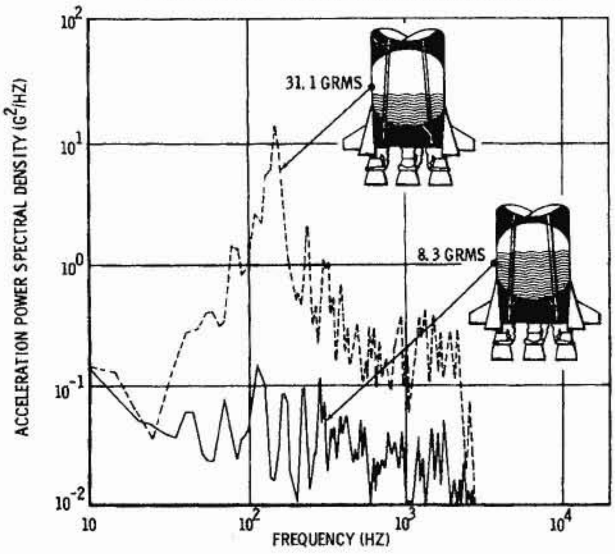

Figure 5: EFFECTS OF LIQUID LEVEL IN A TANK ON THE VIBRATION ENVIRONMENT DURING STATIC FIRING

VIBRATION TRANSMISSION THROUGH THE STRUCTURE

Vibration transmission through a structure is illustrated in Figure 6. The figure shows the vibration spectrum for various locations, along the S-II thrust cone. A measurement (A) located about 28 inches up the thrust cone from where the engines are mounted indicates a level of 5.5 Grms. Another measurement (C) about 60 inches further up the thrust cone shows a level of 1.6 Grms. A third measurement (B) located between measurements A and C shows a level of 2.4 Grms. The B spectrum is not plotted, but it falls between the two. The vibration source for this example is considered to be the J-2 engines since the measurements were taken during S-II powered flight. During S-II powered flight, acoustic noise levels are low and hence vibration due to acoustic noise is insignificant.

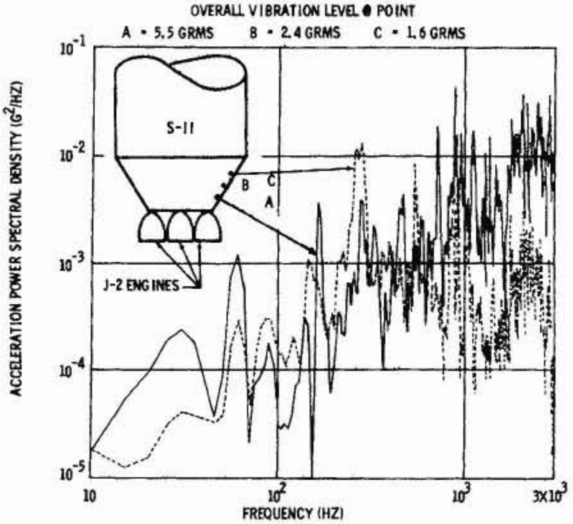

Figure 6: VIBRATION TRANSMISSION THROUGH STRUCTURE

FLUID FLOW EFFECTS

Figure 7 shows the effect of fluid flow rates on the vibration environment. The data shown in this figure were obtained by recording the vibration level resulting from LOX flowing through a 6-inch diameter line. Note that the vibration level increases exponentially with an increase in flow rate. A metalic bellows in this line failed while LOX was being pumped through the line. The failure was close to the vibration measurement point shown in Figure 7.

STATIC FIRING AND FLIGHT ACOUSTIC ENVIRONMENTS

The characteristics of the acoustic environment associated with a large launch vehicle can vary widely. The acoustic environment differences between a stage static firing and launch vehicle liftoff are shown in Figure 8. The environment differences, as discussed previously, are the result of dissimilarities in the size and number of engines on the S-IVB stage and the Saturn V launch vehicle. The difference in the overall sound pressure level is approximately 6 db with the significant level differences occurring below 500 hertz.

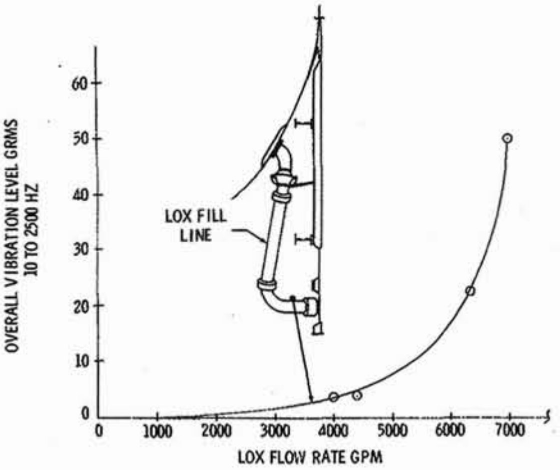

Figure 7: VARIATION IN VIBRATION LEVEL DUE TO FLUID FLOW RATE

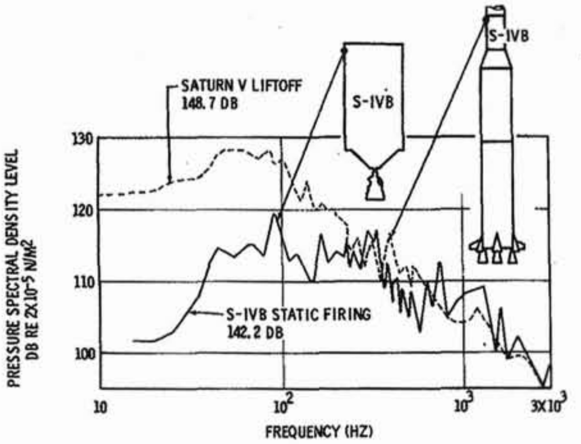

Figure 8: COMPARISON OF ACOUSTIC ENVIRONMENT DURING S-IVB STATIC FIRING AND SATURN V LIFTOFF

Other interesting characteristics of the acoustic environment are shown in Figures 9 and 10. Figure 9 shows the typical variation in the acoustic sound pressure level due to the shadowing effect of the stage. The overall sound pressure level drop due to the shadowing effect of the stage is generally 8 to 10 db. Two acoustic measurements taken during a static firing of the S-IC stage are shown in Figure 9. The measurements were located externally, one on the same side to which the engine exhaust was deflected and the other 180 degrees away. The solid spectrum is the one of the exhaust side and the dotted spectrum is the one taken on the opposite side.

Figure 10 shows the variation in the acoustic spectrum from measurements internal and external to the launch vehicle. A typical variation in overall sound pressure level is 8 to 10 db.

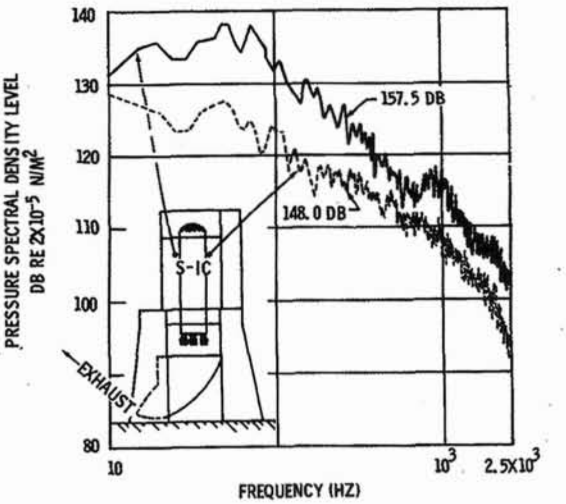

Figure 9: EFFECT OF STAGE SHADOWING ON THE ACOUSTIC ENVIRONMENT

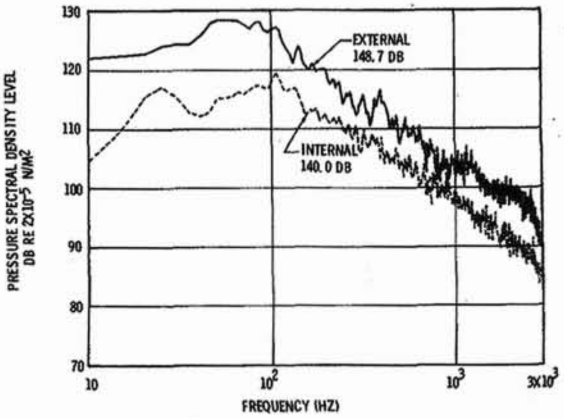

Figure 10: COMPARISON OF INTERNAL AND EXTERNAL ACOUSTIC ENVIRONMENTS

FLIGHT VIBRATION AND ACOUSTIC TIME HISTORIES

The acoustic environment of a launch vehicle is time variant as illustrated in Figure 11. The data shown in this figure came from a microphone mounted externally near the top of the S-II stage. The sound pressure level time history for this particular location has three distinctive features. First, the sound pressure level near time zero increases rapidly and then decreases as the vehicle speed increases. This is characteristic of the liftoff environment. Second, the sound pressure level increases and decreases at a rate coincident with the variation in dynamic pressure. Third, the sound pressure level increases rather abruptly at the critical Mach Number ($M_{CR} \simeq 0.8$). This increase is attributed to the presence of a normal shock wave near the microphone location. Figure 12 shows data from a vibration transducer at a location similar to the microphone location. The vibration environment has the same distinctive features as the acoustic environment with one exception. The structure responds more readily to the liftoff acoustic environment than to the flight acoustic environment.

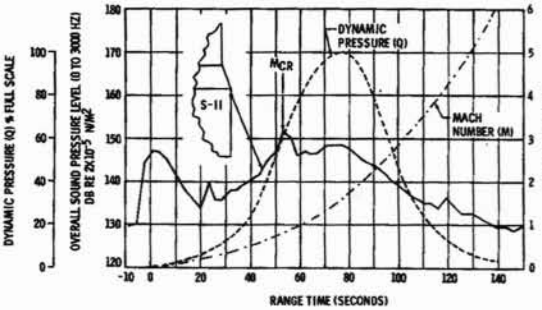

Figure 11: CORRELATION BETWEEN ACOUSTIC ENVIRONMENT AND AERODYNAMIC PARAMETERS

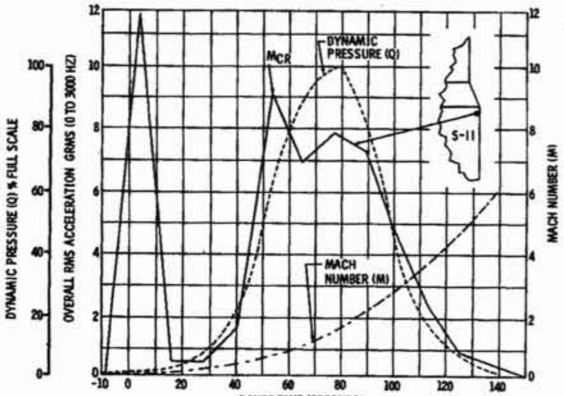

Figure 12: CORRELATION BETWEEN VIBRATION ENVIRONMENT AND AERODYNAMIC CHARACTERISTICS

CONCLUSIONS

The vibration and acoustic data in this paper are presented to provide an idea of the environmental levels associated with a large launch vehicle. The data are also selected to provide an insight into how the environmental characteristics are influenced by operating conditions. The reader should realize that the data presented represents a small sample of the available data. However, the examples discussed are characteristic of the larger body of data. These characteristics should be considered in the design of launch vehicles and equipment. An extensive bibliography has been included with this paper to provide a list of documents which contain a majority of the Saturn V data.

ACKNOWLEDGEMENTS

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DISCUSSION

Mr. Bendat (Measurement Analysis Corp.): I hope you will accept my comments objectively, but there are many many questions that your paper raises which are typical of other questions I have heard. There are so many open ended areas which would lead one to feel that these results are only a start and in many cases misleading. You show that the data is non-stationary in some of the later slides, and yet in the earlier slides you were doing spectral analysis as if the data had been entirely stationary. There is just no way to reconcile those two matters. If the data is non-stationary, all your spectral results are wrong. There is no way to interpret the results properly. You are interested in variations which are dependent on time and you have removed time from consideration by the ordinary spectral analysis. Furthermore, as the chairman has mentioned a couple times earlier, there is nothing noted here about any amplitude properties, and frequently amplitude properties will reveal completely separate and distinct information. You have amplitude fluctuations which are also a function of time and cannot be handled in the usual way. But even when the data is stationary, which you may be able to justify in certain specialized cases, even there, if the data is not Gaussian the amplitude information reveals further properties that are not revealed in this spectral density information. Here you have a case of lift-off and dynamic pressures and rapidly changing dynamic environments which are not stationary, and you cannot use stationary methods to describe the environment. The fact that you compare something that was done in the past incorrectly with something that is being done incorrectly today still does not make a good comparison.

Mr. Caba: The measurements which you spoke of as being done in the past incorrectly were made on a static firing, and were quite stationary, and those that were compared to flight data were chosen during the lift-off perio at a portion on the oscillograms that appeared to be stationary in the data reduction which showed data distribution which appeared to have a Gaussian distribution.

Mr. Woolam (Southwest Research Institute): One problem which you touched on and passed over rather rapidly is the failure of the metal bellows used in piping. This seems to me to be a very serious problem. We have done some work at Southwest Research Institute on vibration frequencies of bellows, which is exactly the same problem - they are predictable. The problem is the cryogenic temperatures. Failures are quite rapid and there is a good case for a good application of some sort of damper or damping material. Cryogenic temperatures are not favorable for most typical damping materials. It is quite a serious problem and, I think, one which should be considered at this time. You might make some comments further on the work on the failures of flexible baffles.

Mr. Caba: The baffles themselves caused the turbulence, and we applied the telescoping sleeve to cut down the turbulence and this seeme to solve our problem.