SVB '86

COMPARISON OF RESPONSE FROM DIFFERENT RESONANT PLATE SIMULATION TECHNIQUES

Robert E. Morse
TRW
Redondo Beach, California

I will talk about two applications of one technique, the "Resonant Plate" technique, which you have heard other speakers talk about earlier. It is not a method that I developed. The two systems that I will describe have been developed by two different test labs. One was developed by the TRW test lab, and I think Don Pugh gets the biggest portion of the credit for developing our "Resonant Plate" technique. The other one was developed at Lockheed. They did a very good job on their "Resonant Plate" system; we are presently using it on a program I am involved with now.

I want to give credit to several people for Figure 1 which essentially depicts the Resonant Plate system in terms that we all should understand. This is essentially what we are trying to accomplish with the Resonant Plate system.

The first plate is one we developed at TRW with a longitudinal impact. The shock response spectrum requirement that we had to meet was the same in all three axes so the spectrum for our component was the same in all three axes. The spectrum had fairly tight tolerances on it, but we got some relaxation later. We had a major problem in the low frequencies where we were out of the dynamic range of the measurement system, and it took a great deal of work to convince the customer, and even some of our colleagues, that the data were poor and the reason was that the measured data were out of the instrumentation dynamic range. We were getting about a 4,000-g peak response spectrum. We mounted the specimen in three separate orientations on this plate.

Figure 2 shows the response spectrum that we were required to meet. It peaks up to 4,000 g's at about 3,500 Hz.

Figure 3 shows the plate we developed for this response spectrum at TRW. The specimen was mounted at the center for two of the axes. We can just rotate the box itself to get the two axes - with the plate impacted at the top. We mounted the box for the third axis on the bottom of the plate. The advantage of the plate over the shaker is that when you impact the plate at the end, you get a traveling wave shock; the transmission path approximates the real path much better; you do not over-correlate the input at the mounting points. The shock arrives at each mounting point at a different time, and the shock is closer to what it would be in real life. That is not quite the same for the third axis. You get these at about the same time, but the transmission path is attenuated by going through a couple of interfaces.

Figure 4 is the fixture, and it reflects the total set-up and the parameters that we had to work with. We had a compression system where we could put different compression loads into the plate to tune it to different resonant frequencies. The width of the plate and the length of the plate affected it. The weight of the hammer, the distance of the drop, all had an influence on the amount of shock we would get into the unit. We had some rubber compression members, and we have also tried several different materials to influence the shock response of the plate.

Figure 5 is a labeled picture of that system. Again, the unit was mounted at the center for two axes, and it was mounted at the bottom of the plate for the third axis. The slide hammer slides on the rod, it hits the anvil, and it transmits the shock down the plate and into the unit. Three curves (Figures 6 - 8) show the response spectrum and the tolerances that we got with the box mounted in each of the three axes. The data at the low frequency end are not really valid. However, we did a fair job of staying within the tolerances that were finally negotiated. Again, there is not too much difference in the data we got on each of the other two axes. You would expect the same from those two axes because the box is essentially merely reoriented. This particular fixture was developed by the Environmental Test department at TRW, and I thought, it did a good job by providing for our 4,000-g shock requirement.

We had other projects that had the same order of magnitude shock response requirement. Figure 9 shows a similar "Resonant Plate" system that did the same thing. This plate is a little bit different in length, and a bit different in width. The general arrangement and the technique are the same. Some of the things that we varied were the width and the thickness. We also tried aluminum plates and steel plates. You can vary a few parameters to accommodate some differences in your requirements, and we have had some success in this; this is the state of develoment of the resonant plate shock technique at TRW.

Figure 10 shows our approximate status at the present time. We have added a system to measure the force that we actually apply to the hammer, so we know what that force is. We use some Bungee cord, which is not very elegant, but by adjusting the cord tension, you can get some added force to get a higher impact and vary the load and the acceleration that are input to the specimen. Again, it is the same general arrangement and technique of the resonant plate, impacting at the end, getting the transmission down through the plate into the specimen.

The next system is a "Resonant Plate" system that was developed by Lockheed. We are using it on a program that we are performing for them. The vertical impact in this case is perpendicular to the plate. The spectrum requirement we have is for one axis only. We get the response spectrum now in a single axis, and we don't have to meet a particular requirement in the other two axes, which simplifies the test requirement considerably. Tolerances are also more reasonable for this response spectrum. It is a 4,200-g peak response spectrum, and we mount the specimen in two different orientations so that we do get some variability in the amount going into the component.

Figure 11 shows a sketch of the general test arrangement. The specimen would be mounted on the plate, and a pneumatic actuator impacts the plate. It is an aluminum plate about 1/2 inch thick and its size is 4 feet by 6 feet. The plate has a 3-inch foam pad underneath; the rest of the structure and control panel are built up to support the plate and handle it.

We have a single axis response spectrum that we are trying to meet with this particular arrangement: a 4,200-g proto-qual requirement. Figure 11A shows the response spectrum that we will be obtaining with that system. Figure 12 shows that test set-up. Again, the unit is mounted on the plate, and you can vary the distance from the impact point to the test unit. Some damping material can be put under the hammer, and in this particular case, it is some paper and a felt pad. The pneumatic actuator is controlled by a panel. Figure 12 shows the foam and the plate. Figures 13 and 14 show the test setup from the opposite end. You can see the foam pad and the plate a little better in Figure 13. Figure 14 is essentially the same as Figure 13; you can see the hammer and the damping material.

Figure 15 gives a pretty good idea of how well Lockheed did in meeting the requirements with this particular piece of equipment. The 4,200-g spectrum with the tolerances is shown, and they met it pretty well except at the low frequency. Then we tried to vary some of the parameters. The distance was 2 1/2 inches from the unit to the measurement point, and the distance from the measurement point to the impact point was 6 1/2 inches. The actuator pressure was 150 psi and 15 sheets of paper were used for damping; that is not real elegant, but it does the job.

We decided we wanted to know what would happen if we changed the actuator pressure, and Figure 16 shows that. We have gone to 250 psi, using the same damping and the same distances. The higher pressure has raised the whole spectrum. Then we thought we would try changing the damping. We got 26 pieces of paper; we use the same pressure, 250 psi, and the same distance; the damping knocks off the tail of the high frequency-response (Figure 17). It did a very nice job; it shows what you can do by adding a little damping if you want to bring the high frequency end down. Then we tried varying the distance to the impact point. We went from 6 1/2-inches to 8 1/2-inches. It knocks down the whole high frequency end of the spectrum, not just the tail of it, not just one end. So increasing the distance between impact point and unit brought the entire high frequency range down nicely (Figure 18).

Figure 19 shows the effect of adding a felt pad which as you can imagine, changed the damping considerably. That is evidenced by the amount of tail-off we got at the high frequency with much more damping. So, the few things that you can vary on that system don't look like they are very significant but you can do quite a bit with the spectrum by just varying a few of the parameters.

Initially when this requirement was imposed, we didn't have a very good idea of what kind of shock this would put into our components. We took exception to the requirement until we could get some feel for the response on a specified plate, since Lockheed did not have the data at the time. We collaborated with Lockheed on a test. We supplied an instrumented unit, just a dummy mock-up of a couple of slices of electronics that are typical of the type of equipment that we will be using on this project (Figure 20). We had many response accelerometers mounted inside the test unit for this test. Figure 21 is a prototype of the system that we are using on this project. It is a little bit different but essentially the same set-up. We took data at the input to the box, and we measured some responses inside to see how much attenuation we were getting.

I mentioned we are doing this in two axes of orientation. Figure 22 shows the other axis where we are mounted face-on to the shock wave as opposed to the shock wave coming in from the unit edge. Figure 23 is the same picture but with the labels on it showing the impact hammer and the pneumatic cylinder forcing the hammer down against some damping pads on the large resonant plate. When you hit the plate, the plate goes into some sort of resonance. To get what we wanted on this particular test, the plate was free at the middle, and we had foam at each end of the plate. So there are several ways that mounting the plate can be handled.

Figure 24 shows the instrumented test unit. We mounted accelerometers at the top to find out how much of attenuation we got all the way up. We mounted some accelerometers right near the mounting feet to find out what we were getting across the mounting interface and we mounted many accelerometers inside the unit to show how much acceleration we got, inside in the middle of the boards and where parts would be located, because we have sensitive parts that we are concerned about. Our major concern was whether the parts inside the components could survive the 4,000-g shock requirements imposed on this resonant plate when we were not exactly sure what type of attenuation or amplification would occur.

Figure 25 shows the instrumentation we had inside. An accelerometer is inside at the middle of some mocked-up boards to get responses inside. Figure 26 shows close-ups of the accelerometers at their mounting points.

Figure 27 shows the instrumentation mounted at the corner. If you want to generalize on the attenuation that we got going from the input of the box to the inside the box, it is about a 3 dB attenuation. It is not as much as Hank Luhrs measured in some of his spacecraft simulator tests, or what we really expect to see on a real spacecraft. On a real spacecraft it is probably 6 dB or more. If you look at the way vibration specifications are developed over limit load, there is about a 2-1 margin on that. So the 2-1 margin on the shock is probably not too bad a margin, as long as you recognize you have a margin when you are testing, and you are overtesting the equipment. The margin is over and above what you would see in real life. The test is not too bad considering you want a margin for qualification. If you design to meet this type of requirement, you should be in good shape in real life. That is the purpose of the qual test.

Discussion

Mr. Mardis (General Dynamics - Pomona Division): I had seen this apparatus before. How much did it cost? How did you establish your material selection and the contact geometry between the hammer and the plate?

Mr. Morse: I don't have an exact answer on the cost. You can see from the material we used to put it together, it is not expensive. However, quite a few dollars were involved in the development work to arrive at the system that was shown. We did quite a bit of work on several programs with it, so the cost to TRW, to develop the three particular plates that we showed, probably does not represent what somebody like you might have to do to go into a program now, because you have a pretty good idea of where to start. With regard to material selection, we initially tried steel plates, and they ring much more than aluminum. Probably, if you use magnesium you can get more damping. So, you would have to look at your particular requirements and try to tailor the materials that you want to use toward the spectrum that you have and the levels that you have from the other parameters. "The details are left to the student." About the contact geometry, each of those hammers that you saw in the figures shown are slightly curved so it is not a pointed impact point, but it is rounded in a fairly small area. In many cases we did use a Delrin washer at the impact point. We tried different thicknesses, and different thicknesses gave us different levels. So you would probably end up doing some development work to develop your particular spectrum with the impact point and using very different materials. We used a steel hammer and an aluminum anvil.

Mr. Rosenbaum (General Dynamics - Convair): I guess we at General Dynamics should talk to each other more because we have been using an impact tester for seven or eight years that we made out of an old HYGE machine which we use for the pneumatic hammer. We have done a similar type of testing for electronic components for a long time.

Mr. Morse: Many years ago I was very irritated at the methods used for high impact shock, and I thought, "Boy, the Navy is really unscientific with their high-impact medium weight shock machine. They just have a hammer hitting a plate." I thought, "How could anybody be so unscientific as to just hit a plate with a hammer and expect to get the right shocks." Yet, the Navy stuck with that system, and the equipment that went into submarines and ships passed those tests, and never had problems. In retrospect, it was not a bad system. They didn't have much data on it. They may not have known exactly why they were doing it, but they were doing it right; maybe for the wrong reasons, but probably for a lot of the right reasons. So you have to temper some of the judgments you make as a young fellow as you get older.

Mr. Rosenbaum: In retrospect, talking about what Henry Luhrs was talking about this morning, we found "off-the-shelf" 250-g relays that would barely pass drop-table or drop-tower shocks but they would easily pass orders of magnitude more than that on a resonant-type table like this.

Mr. Morse: I discussed the advantages of the resonant plate in a paper that I presented three years ago. One of the advantages of the resonant plate is that the transmission path is simulated and the shock arrives at the box in a similar way as it does in the real world. Also, you do not overcorrelate the input as you do on a drop table or on a shaker. These are the major aspects of simulation that the resonant plate performs. The mounting impedance is still not good because you are using a plate instead of a honeycomb panel, a spacecraft structure, or whatever the real structure is. Although the compliance still is not matched, you at least match the transmission path in some respects.

Mr. Rosenbaum: Like you, we have used felt, rubber, Delrin, and all kinds of things by trial and error to vary the widths of the pulse.

Mr. Morse: Again, this just shows a couple of ways to solve the shock simulation problem. You have a problem. You want to perform a shock test. How do you do it? "Resonant plate" techniques are not too bad. You have a few things that you can vary; you can vary some of the parameters and get where you want by using paper for damping or whatever works.

Mr. Dotson (Lockheed): I was involved in the development of this system. One reason we tried this approach was we were trying to develop a system that would cover a particular spacecraft that had many items mounted on honeycomb panels, and which had very similar characteristics to a flat plate. It was also a system that had a lot of low frequency response. We started off trying to use explosive joints to excite this plate. It was hung vertically at the time, and we found we couldn't generate the low frequencies. In checking one of the accelerometers one of the technicians happened to hit the plate with the sledge hammer, and we got the exact spectrum we wanted. All of a sudden we got real excited about it. So, we laid it horizontally, and because we didn't have an air-impact device at that time, we just dropped an aluminum cylinder down a plastic tube; lo and behold, we were getting all kinds of good results. Then we started varying the parameters; the thickness of the plate, the type of material, the damping material, and the distance from the source. We put it on foam, we put it on sand, and we could vary the spectrum shape widely. It was very successful. I should mention that by putting it on sand, you can move the low frequency modes and steepen the slope. So that is another parameter if you ever need it. As an aside, something that came out of this is that this is a single directional-type device; but many companies who wish to use this device require three-dimensional equality. We have recently put book-end shelves on the system, and we are getting significant in-plane responses. It is still vertical, but you can rotate the box on the shelf. Another point is when data are taken on a spacecraft, or even on this plate, many times you have a tri-axis accelerometer that is mounted on a little aluminum block or some other type of device. The rocking of the plate, or the rocking of the structure in the spacecraft, can give you what you think is a longitudinal or an in-plane response that is not really there. It is not true in-plane motion. So beware if you are mounting your accelerometers above the neutral axis of the structure or plate if that is the case, because up to about 7,000 Hz and higher, just the rocking effect is equal to the normal response. Once we went back and looked at all of our spacecraft data, we realized that all the enveloping of what looked like in-plane response was really a rocking effect due to normal response due to the bending waves. So, I think many of the three-dimensional spectral requirements came from non-true three-dimensional effects.

Mr. Morse: That is a good point. I have to agree with what is mentioned in the lead-off chart: that our requirements are only for a single axis. In a previous project we had to meet the same shock requirements in all three axes. If you look at the way components are mounted in a spacecraft, shock really comes to it along a single axis. You don't get the same response in all three axes. You get a major response perpendicular to the plane on which the component is mounted. You don't get the same response in the other in-plane axes. I think that it is well recognized in vibration because many vibration specifications now require different levels in-plane, and normal to the mounting plane. I think that eventually the method should be the same for shock requirements.

Voice: The last two or three minutes of discussion satisfied the comment I was going to make. It was about the compromise that one might have to accept in a lateral axes, but I thought Ron addressed it real well by saying with book shelf-type fittings you can get the lateral axes as well.

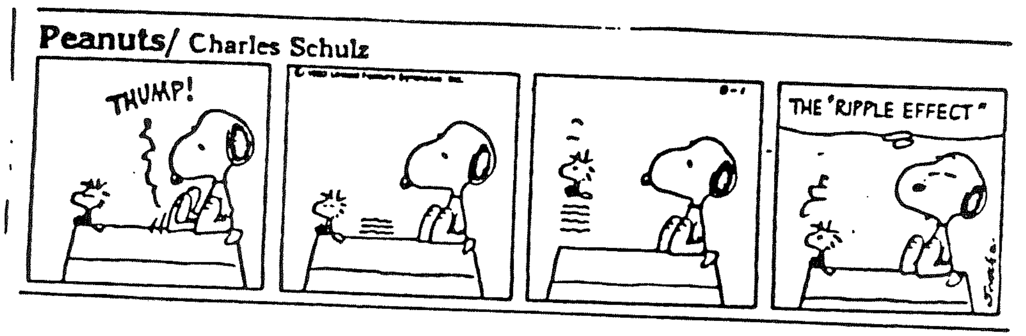

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Figure 1. Concept and Use of Resonant Plate System

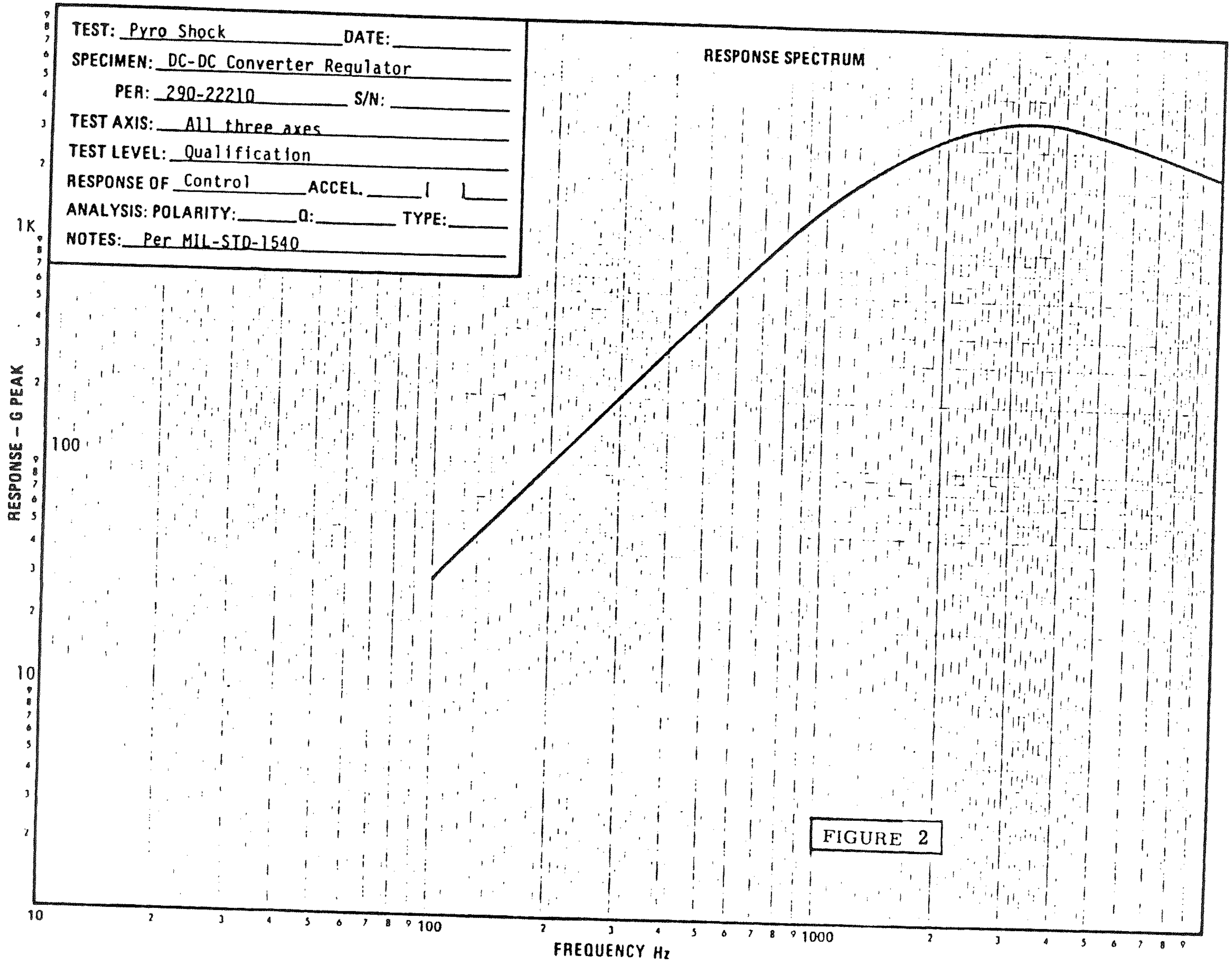


Figure 2. Component Response Spectrum

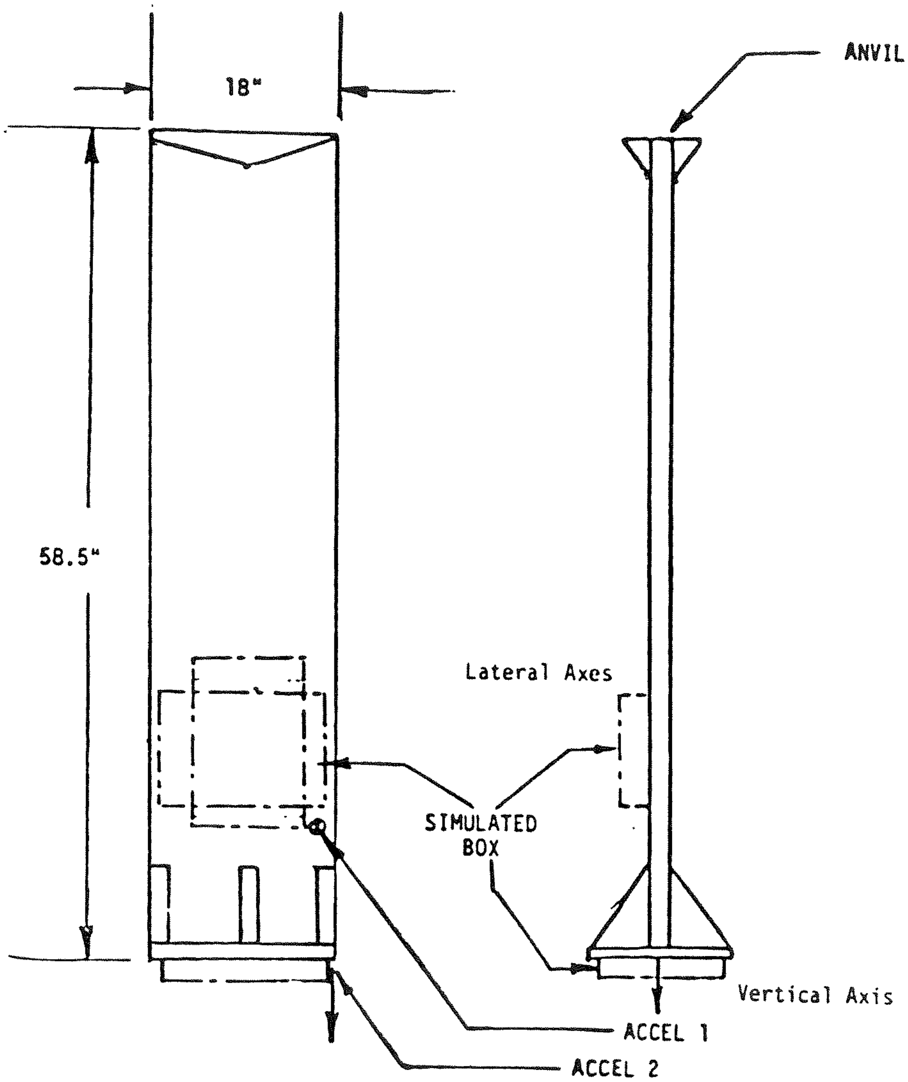


Figure 3. Resonant Plate Developed to Meet a Component Response Spectrum

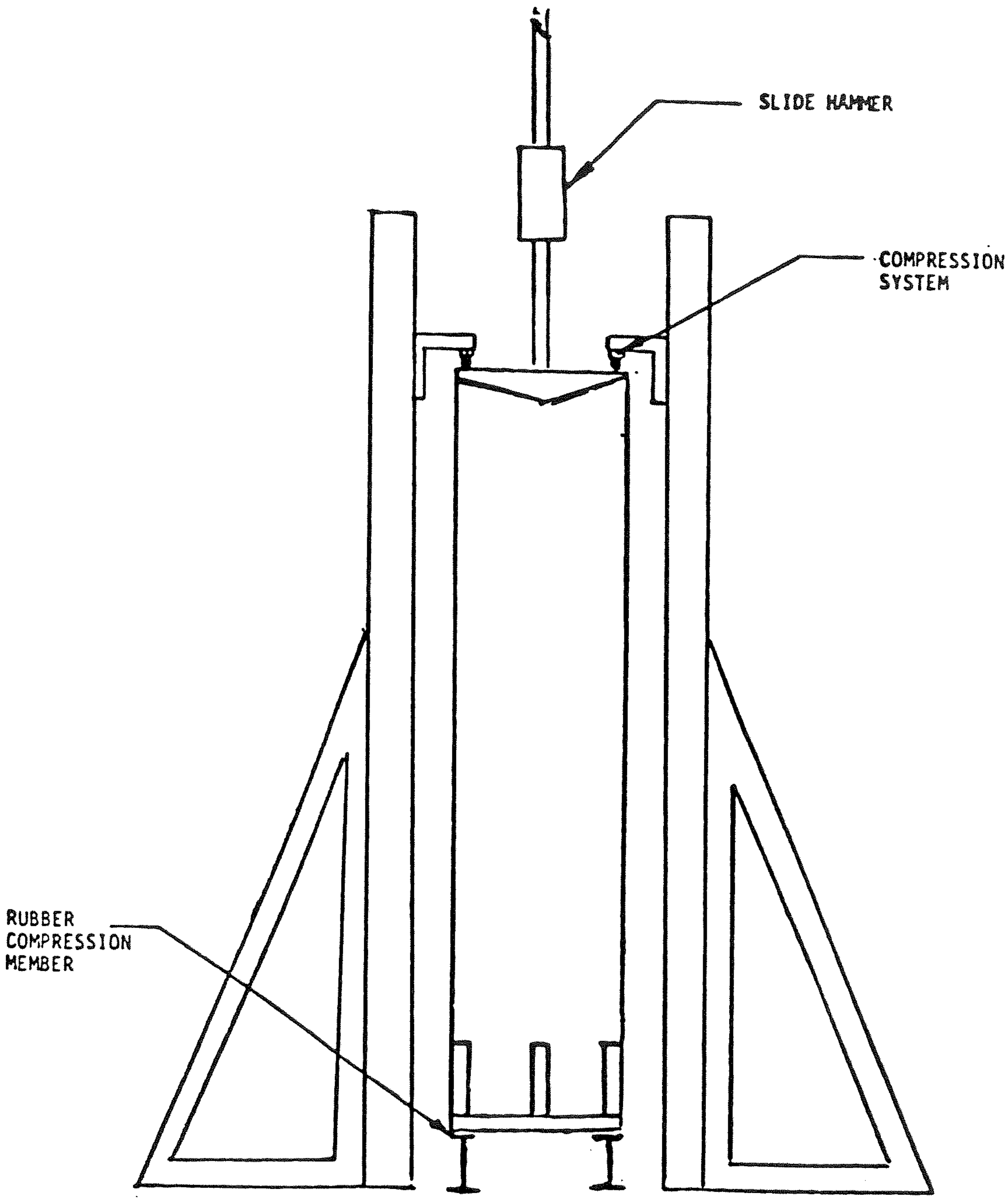


Figure 4. Test Fixture and Test Arrangement

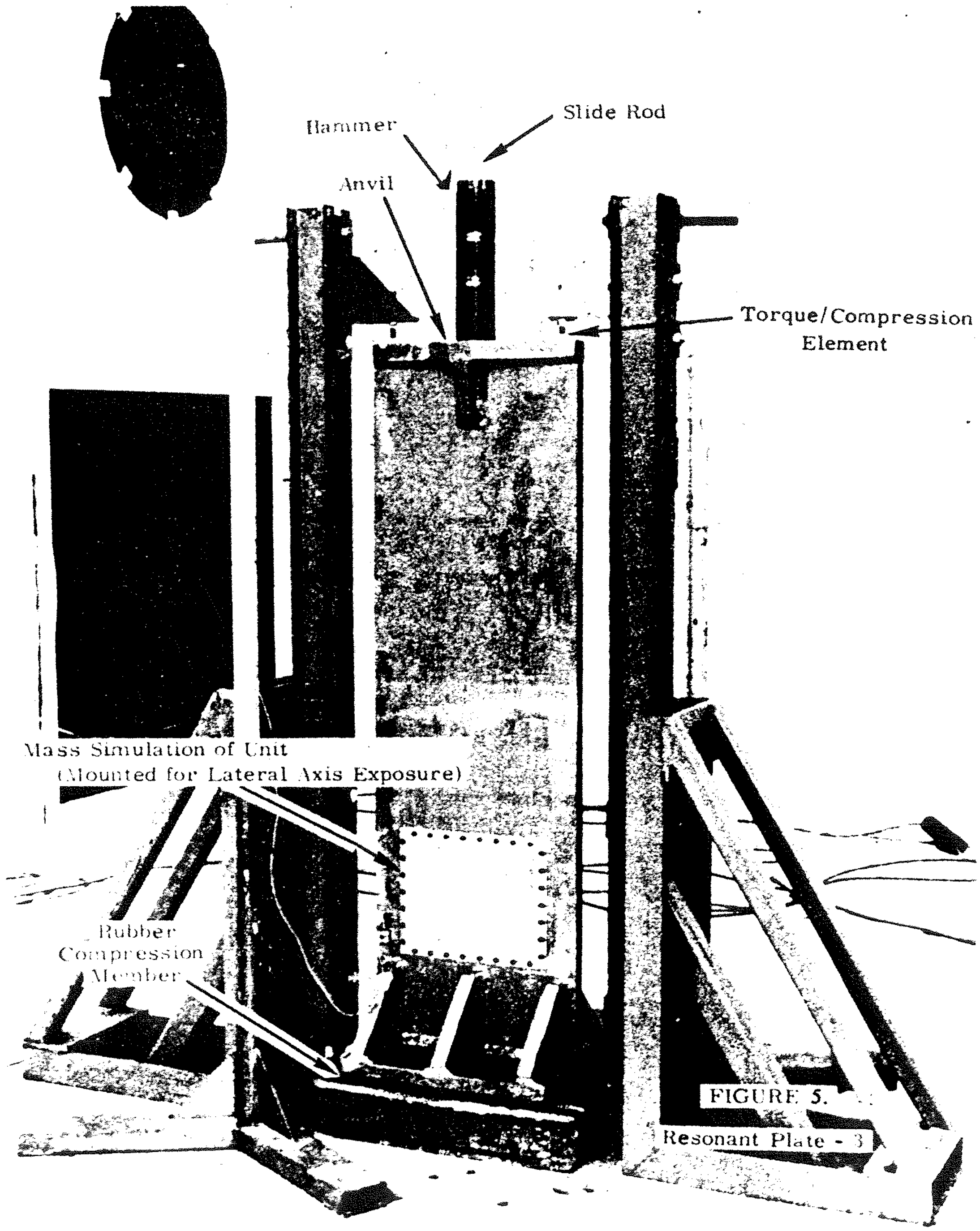
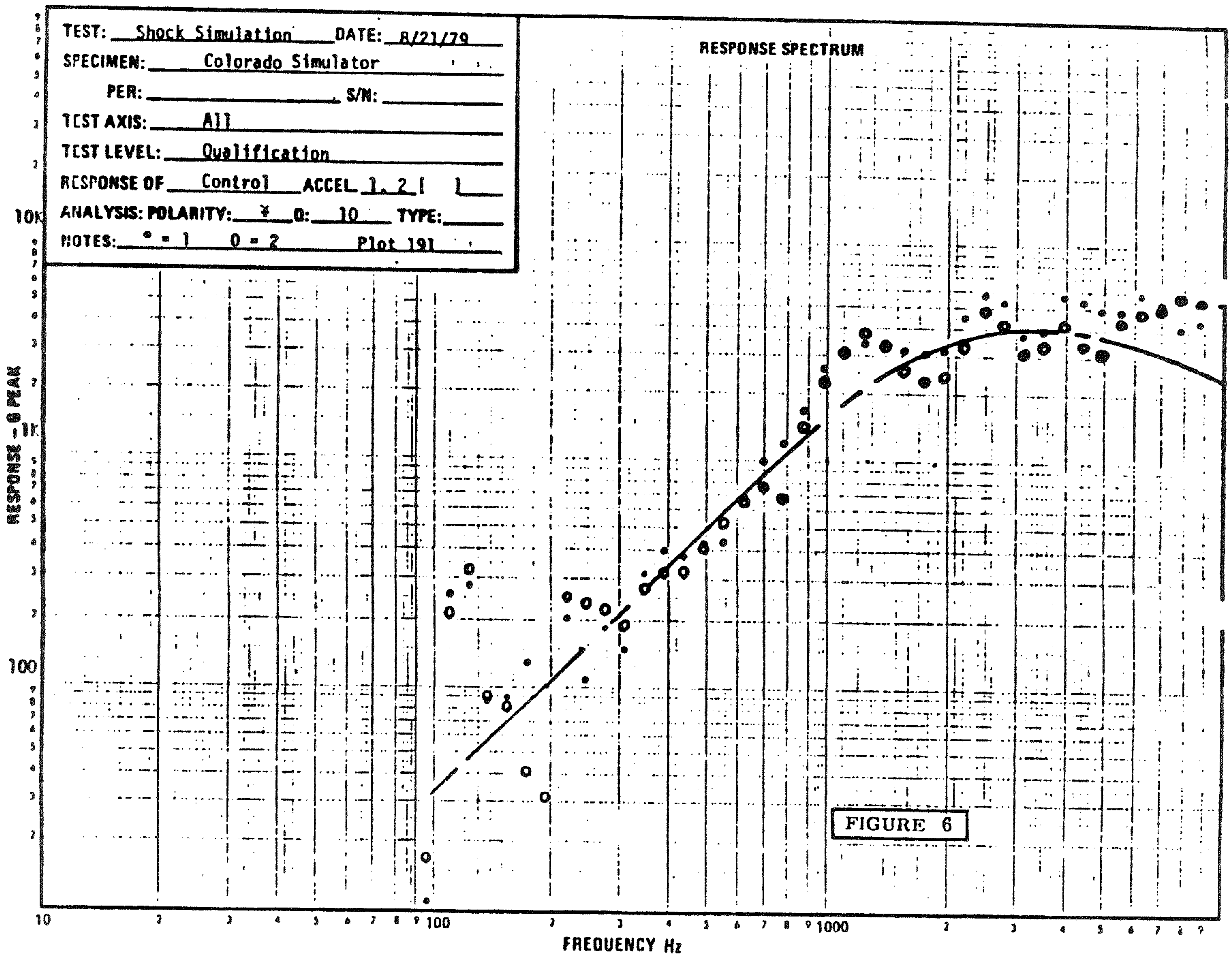
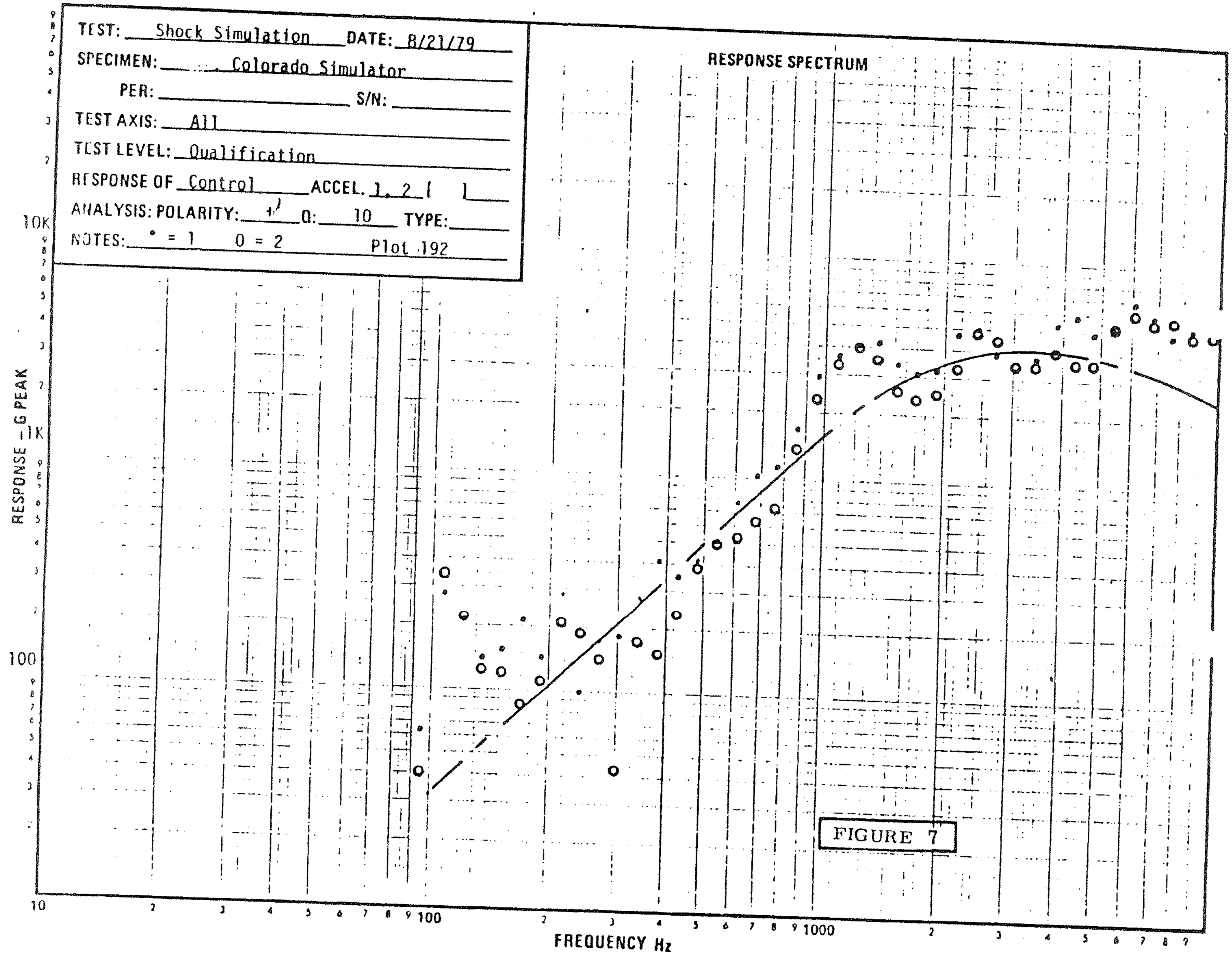


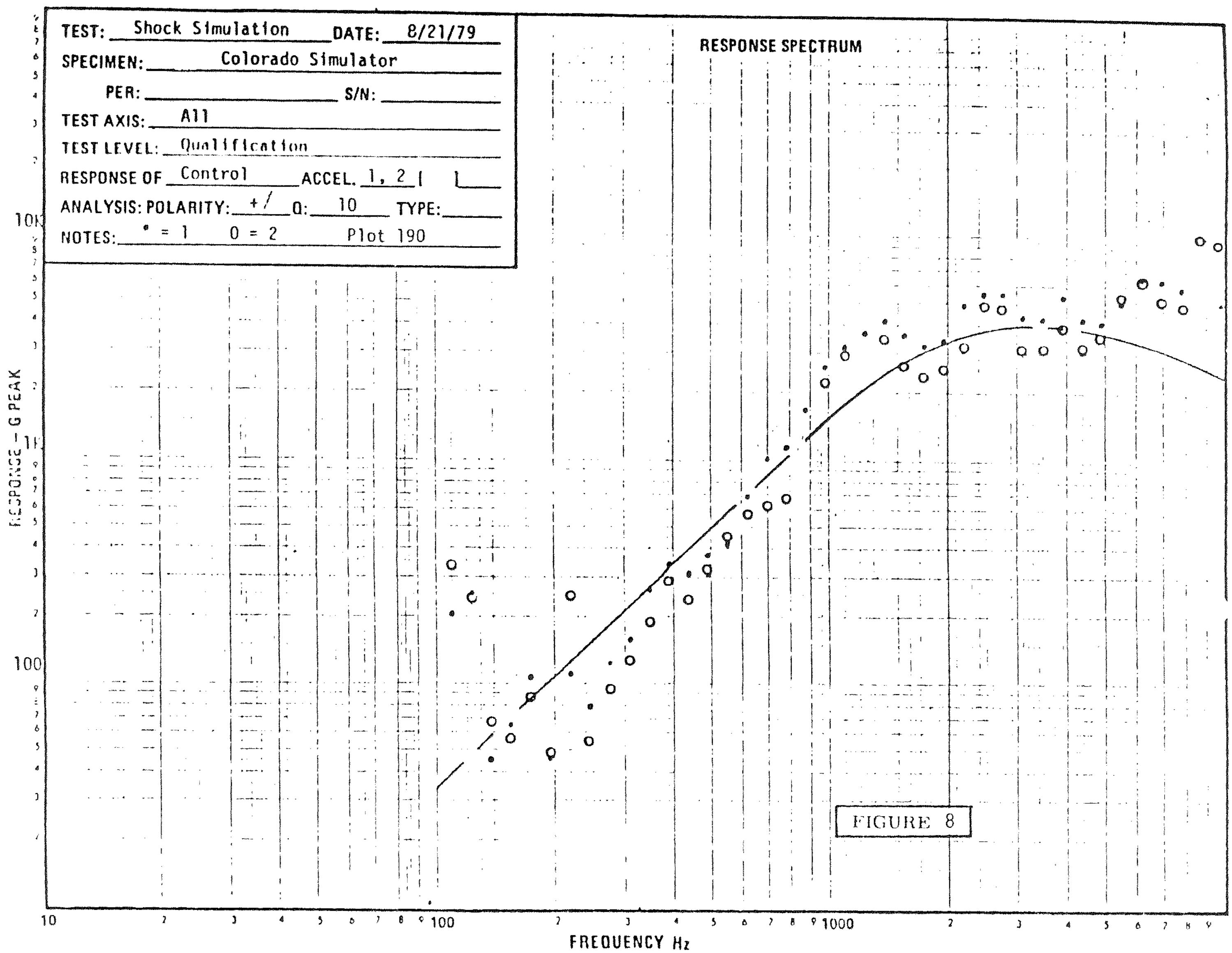
Figure 5. Labelled Test Setup



Figures 6 Results of Simulated Pyro-Shock Tests



Figures 7. Results of Simulated Pyro-Shock Tests



Figures -8. Results of Simulated Pyro-Shock Tests

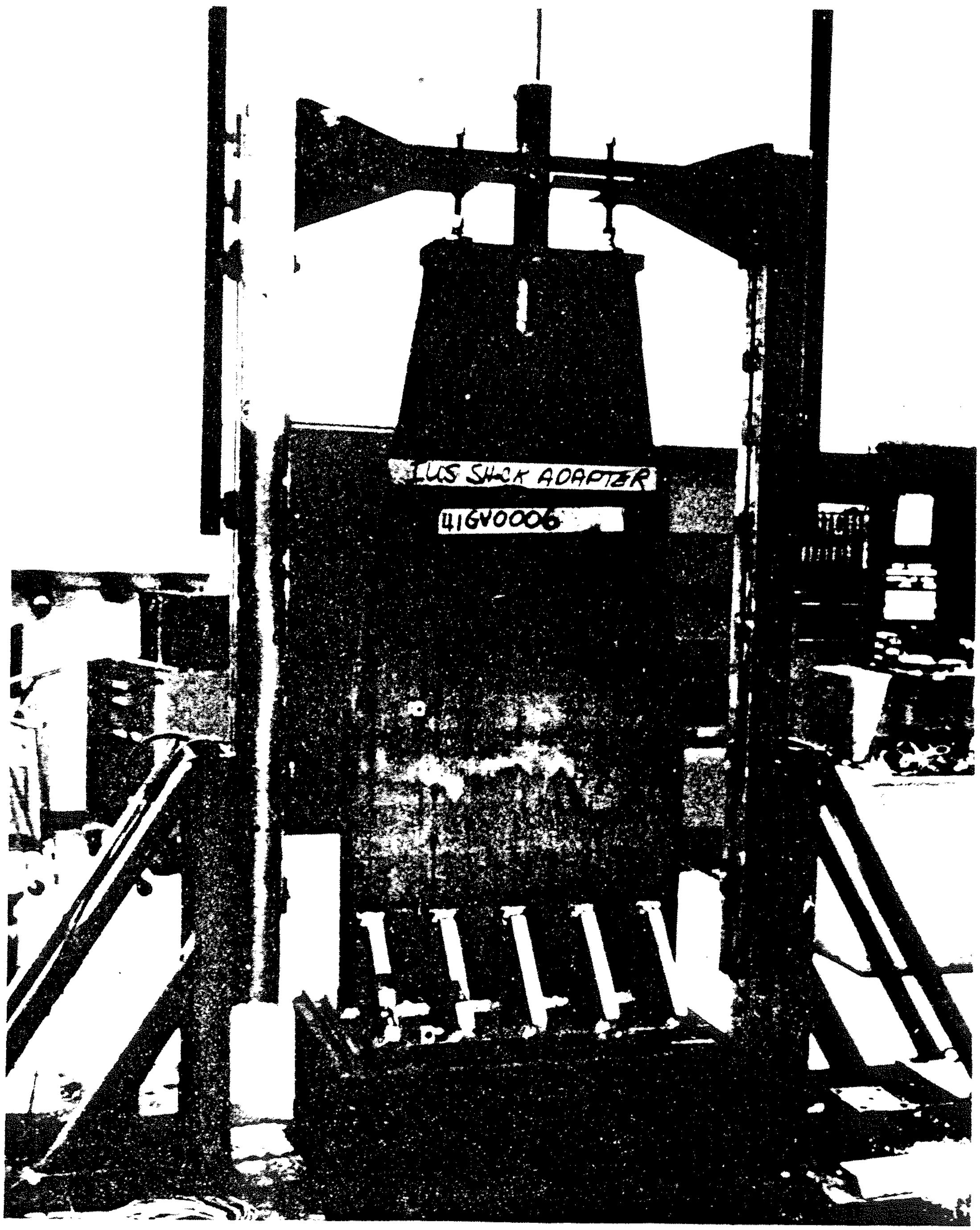


Figure 9. Resonant Plate System

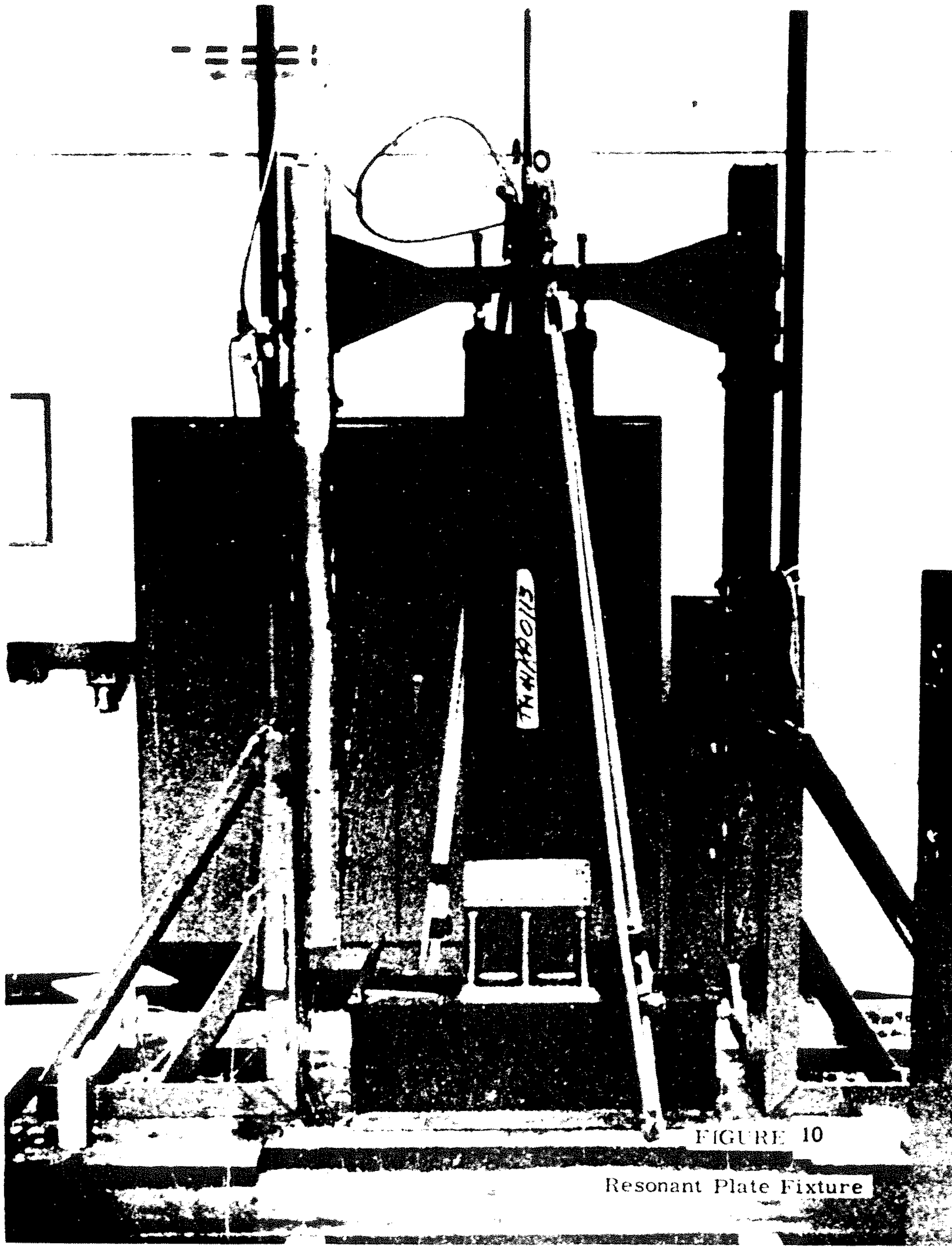


Figure 10. Resonant Plate System

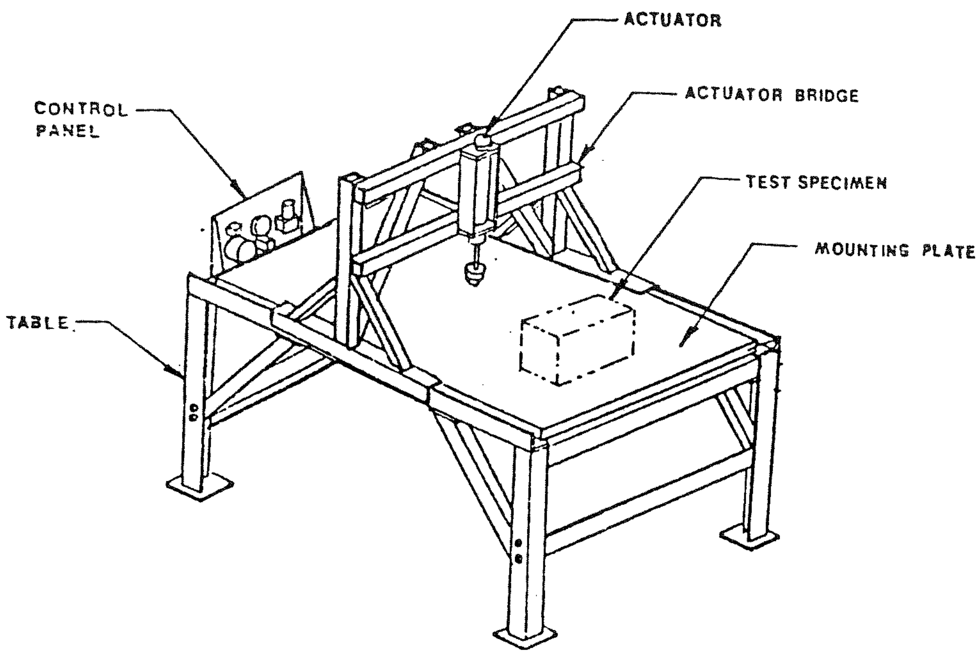


Figure 11. General Test Arrangement Using the Lockheed Resonant Plate

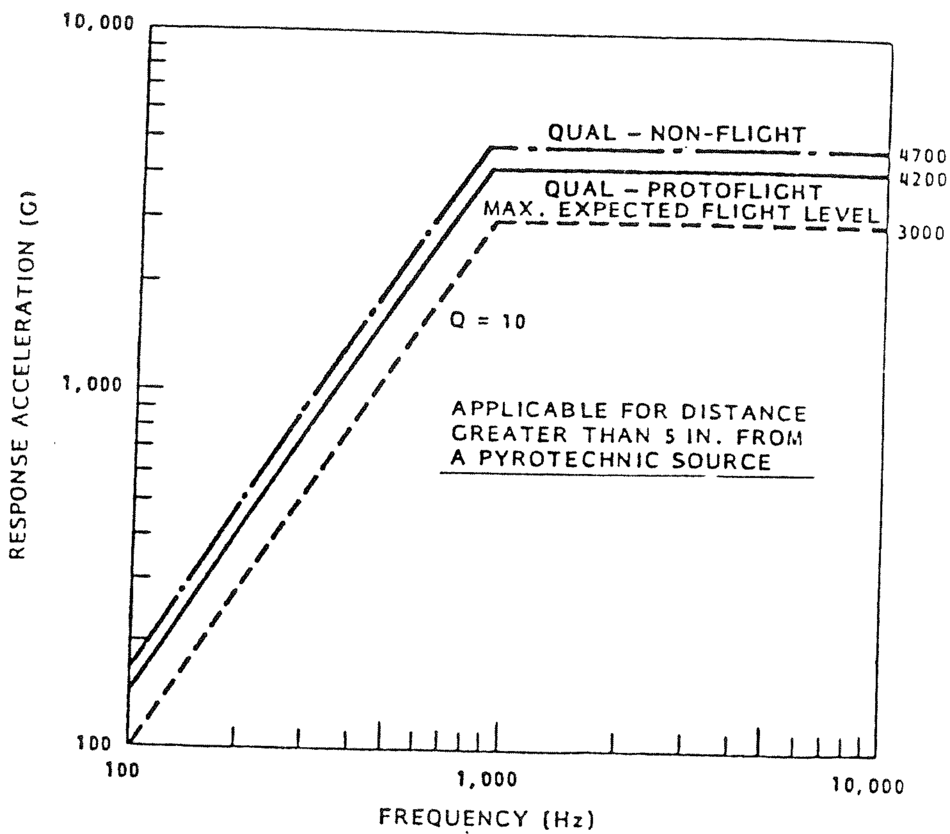


FIGURE 11A PYROTECHNIC SHOCK ENVIRONMENT

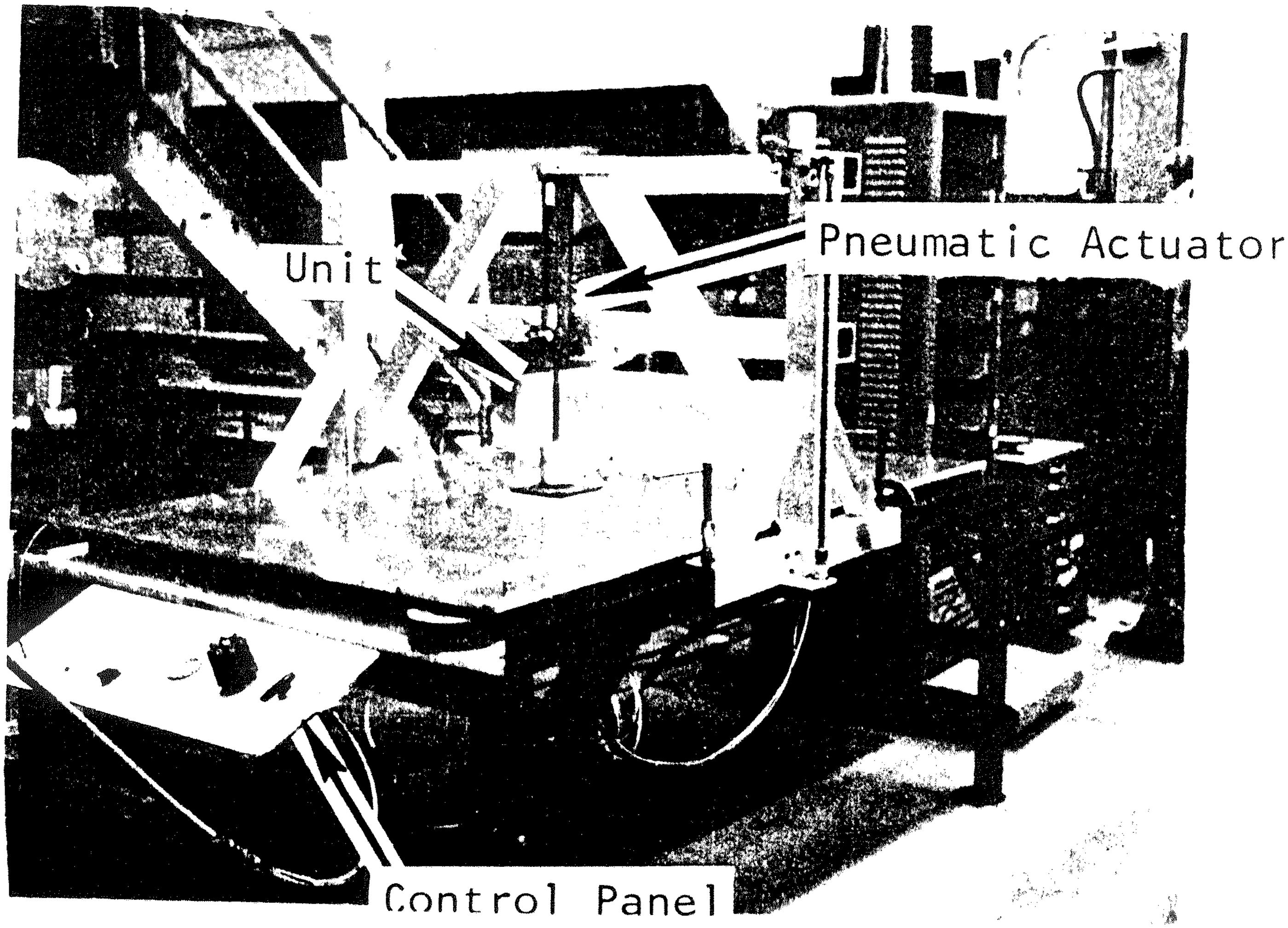


Figure 12. Proto-Qual Test Setup on Lockheed Resonant Plate System

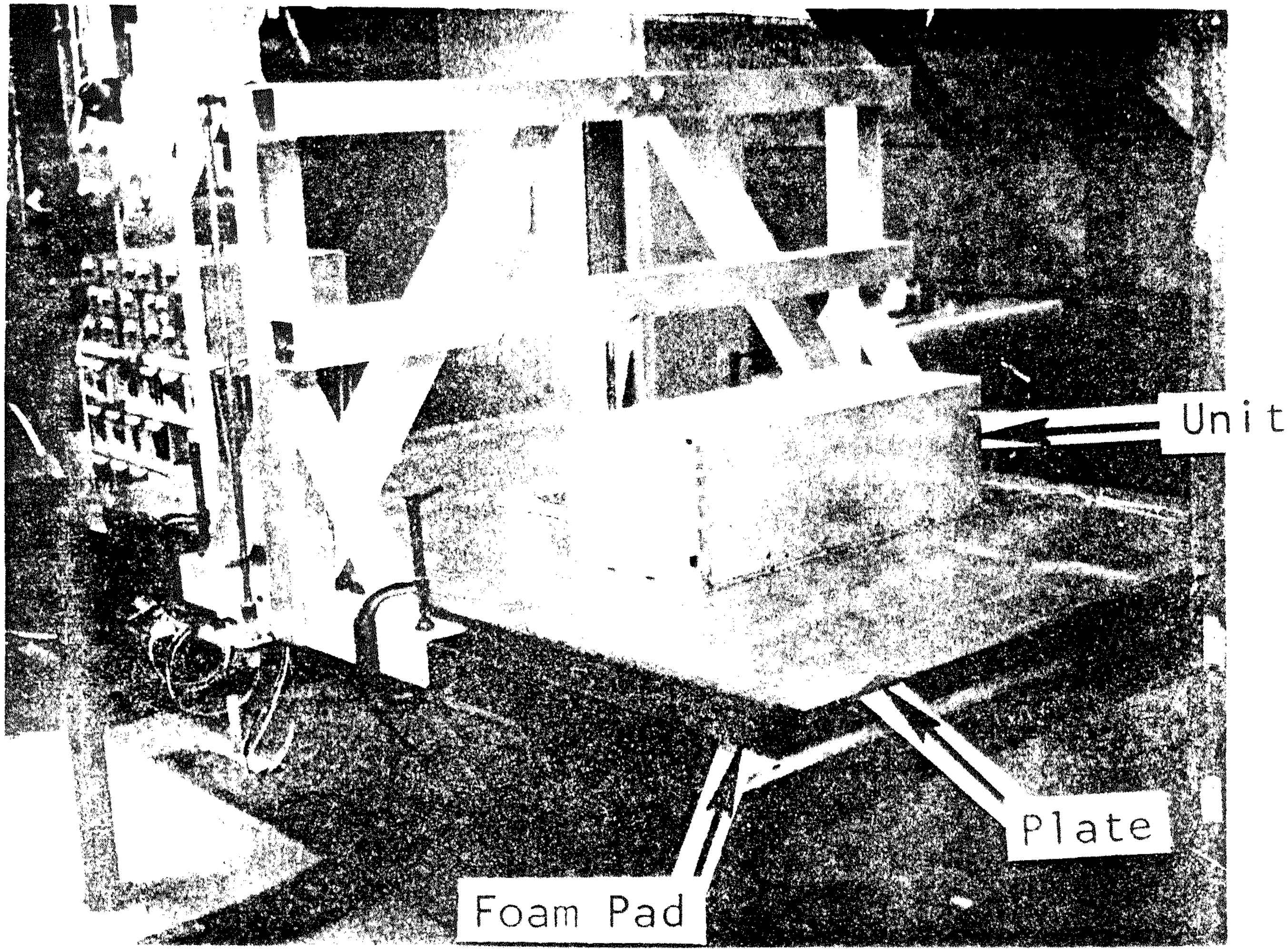


Figure 13 Other Views of the Proto-Qual Test Setup on the Lockheed Resonant Plate

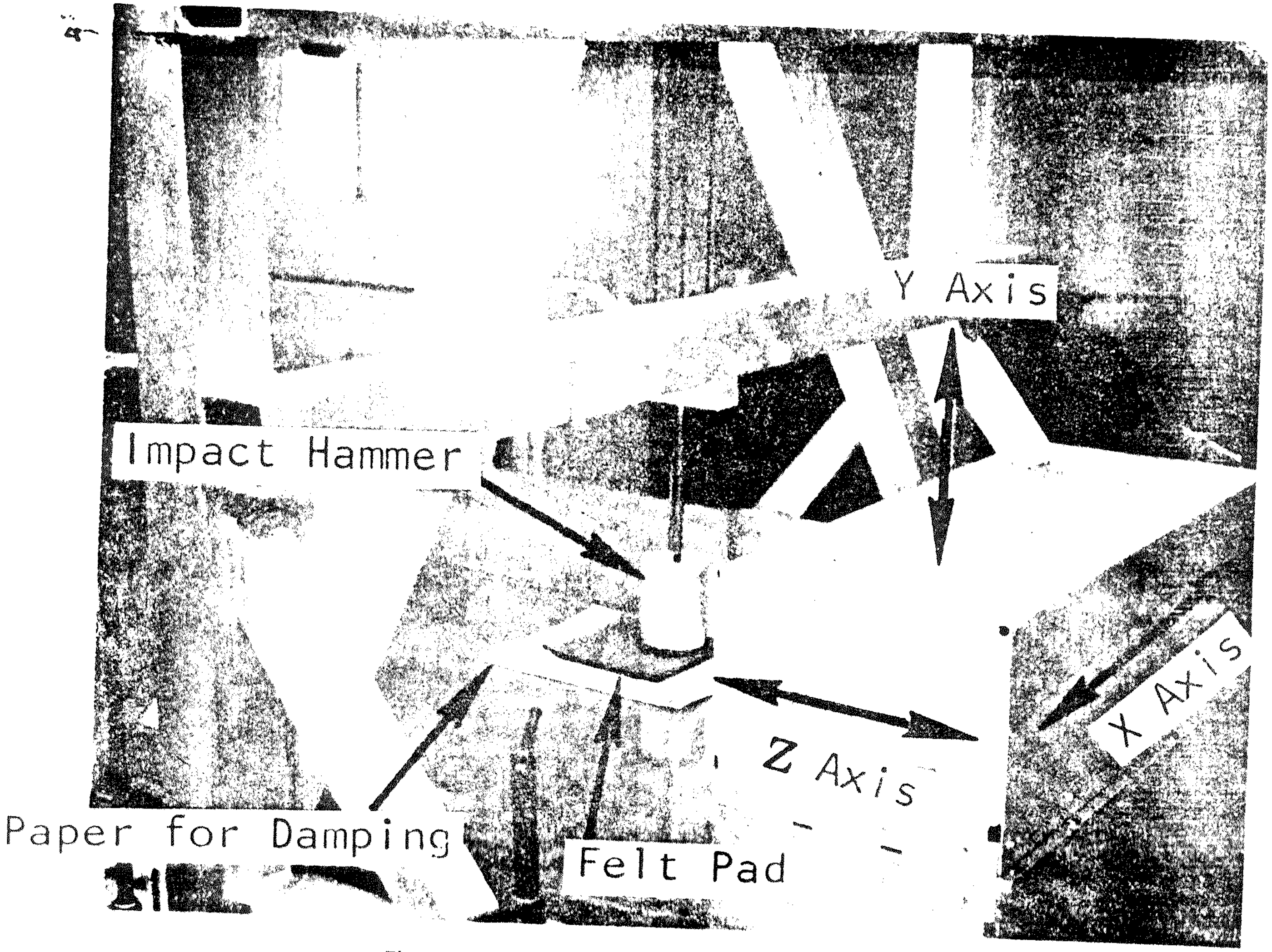
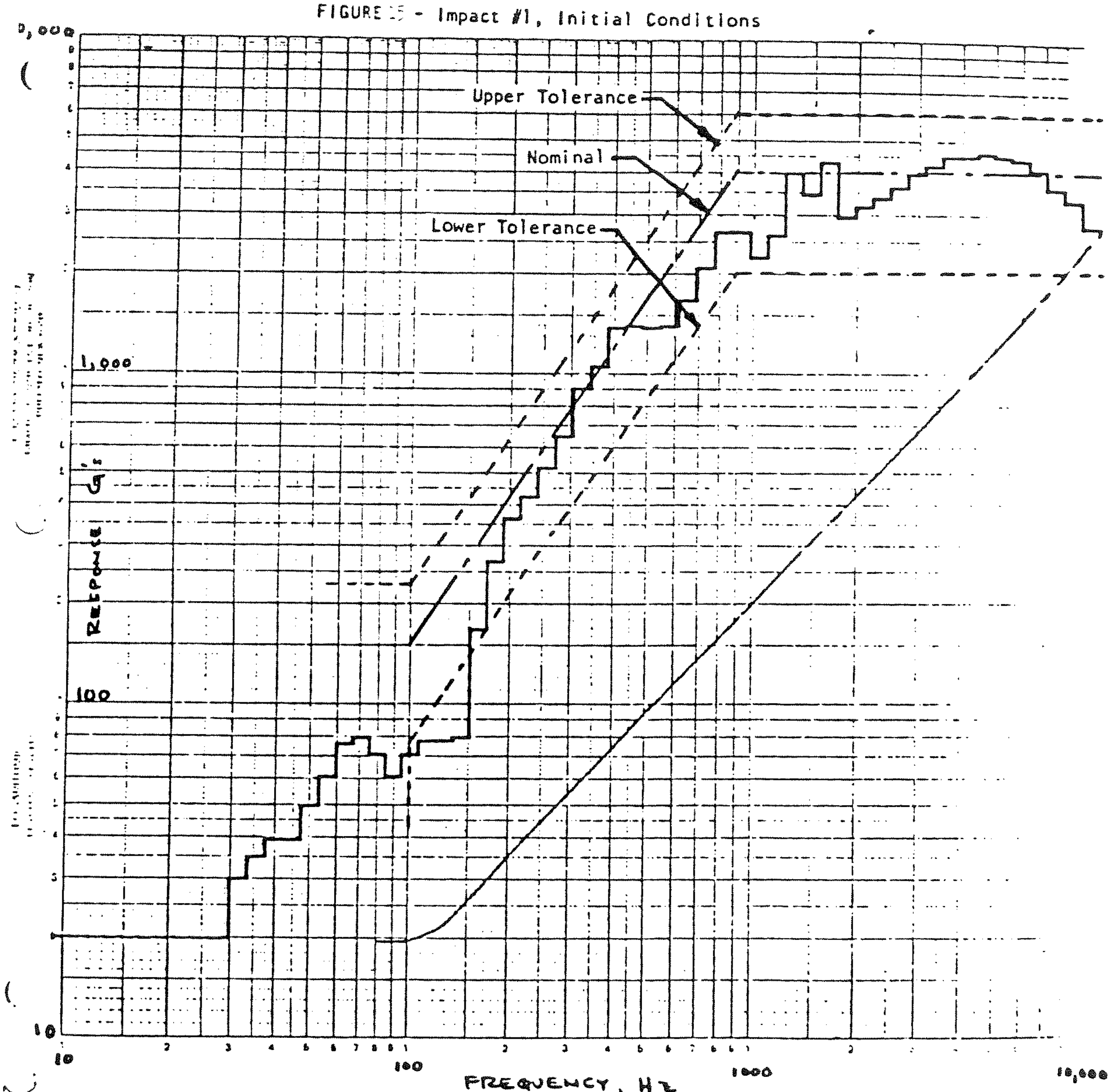


Figure 14. Other Views of the Proto-Qual Test Setup on the Lockheed Resonant Plate



Distance - Unit to Measurement	=	2.5 inches
Distance - Measurement to Impact Point	=	6.5 inches
Actuator Pressure	=	150 psi
Damping	=	15 sheets paper

Figure 15. Response Spectra Measured on Lockheed Resonant Plate System

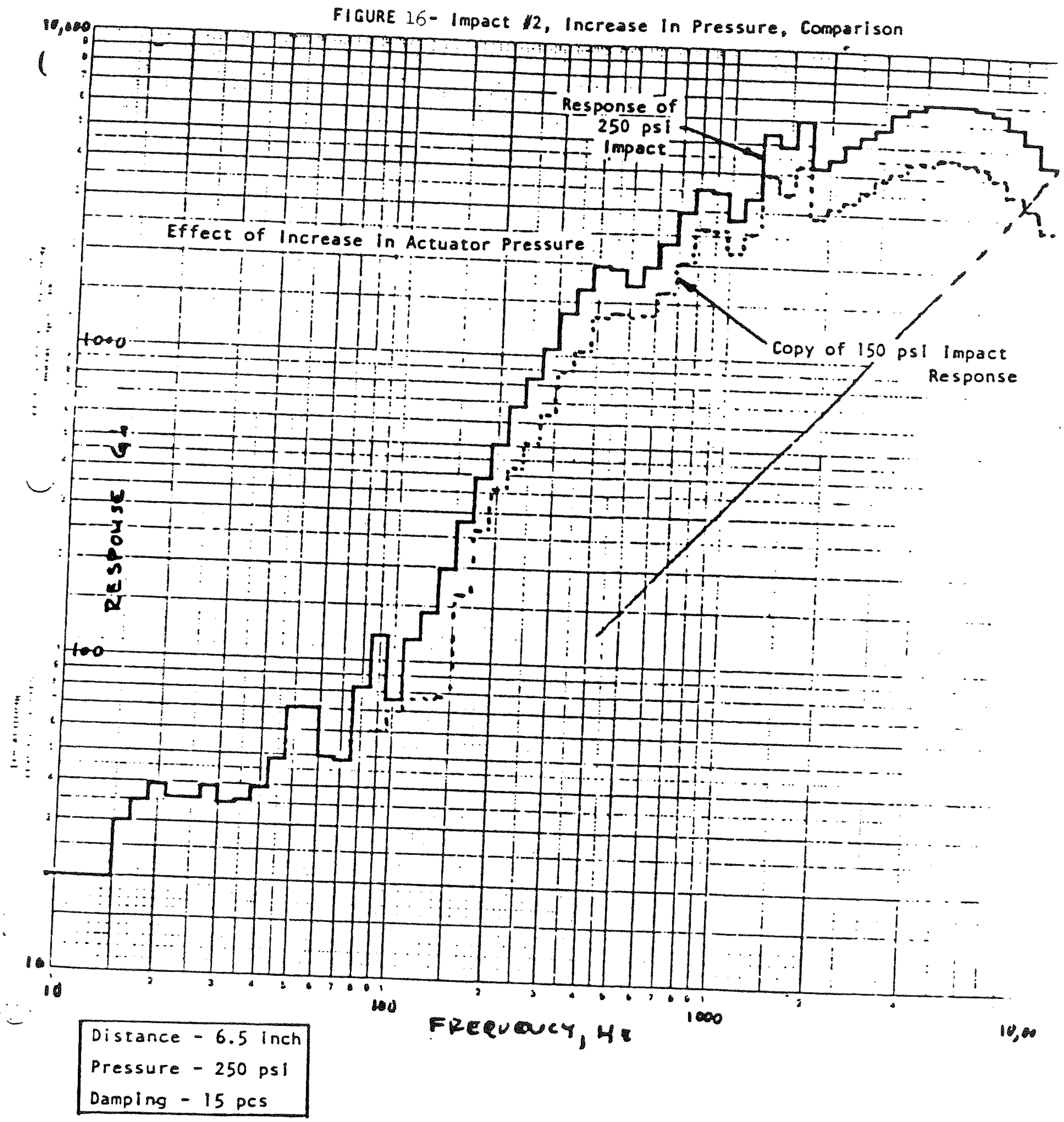


Figure 16. Effect of Change in Actuator Pressure on Response of Lockheed Resonant Plate System

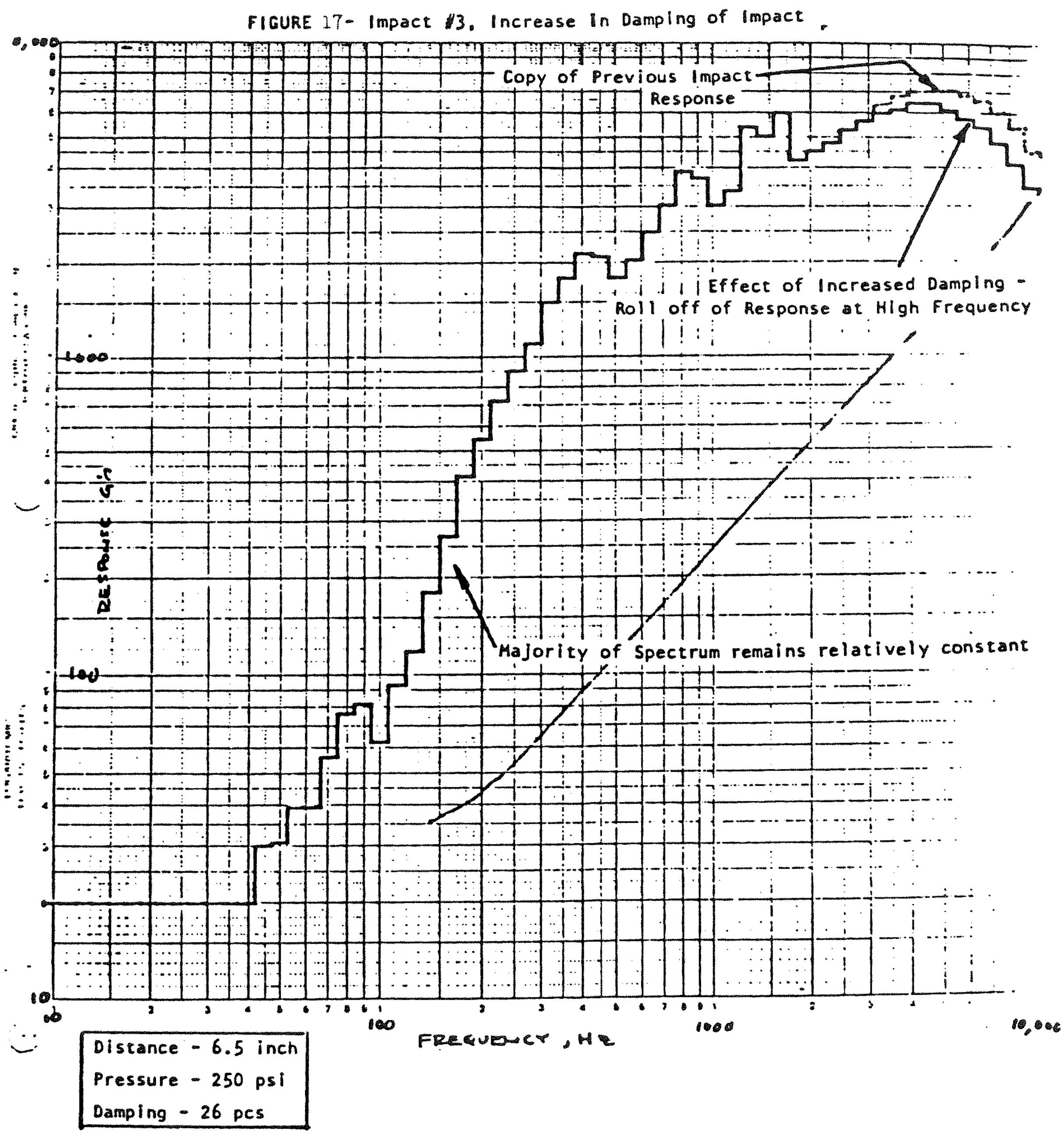


Figure 17. Effect of Change in Damping on Response of Lockheed Resonant Plate System

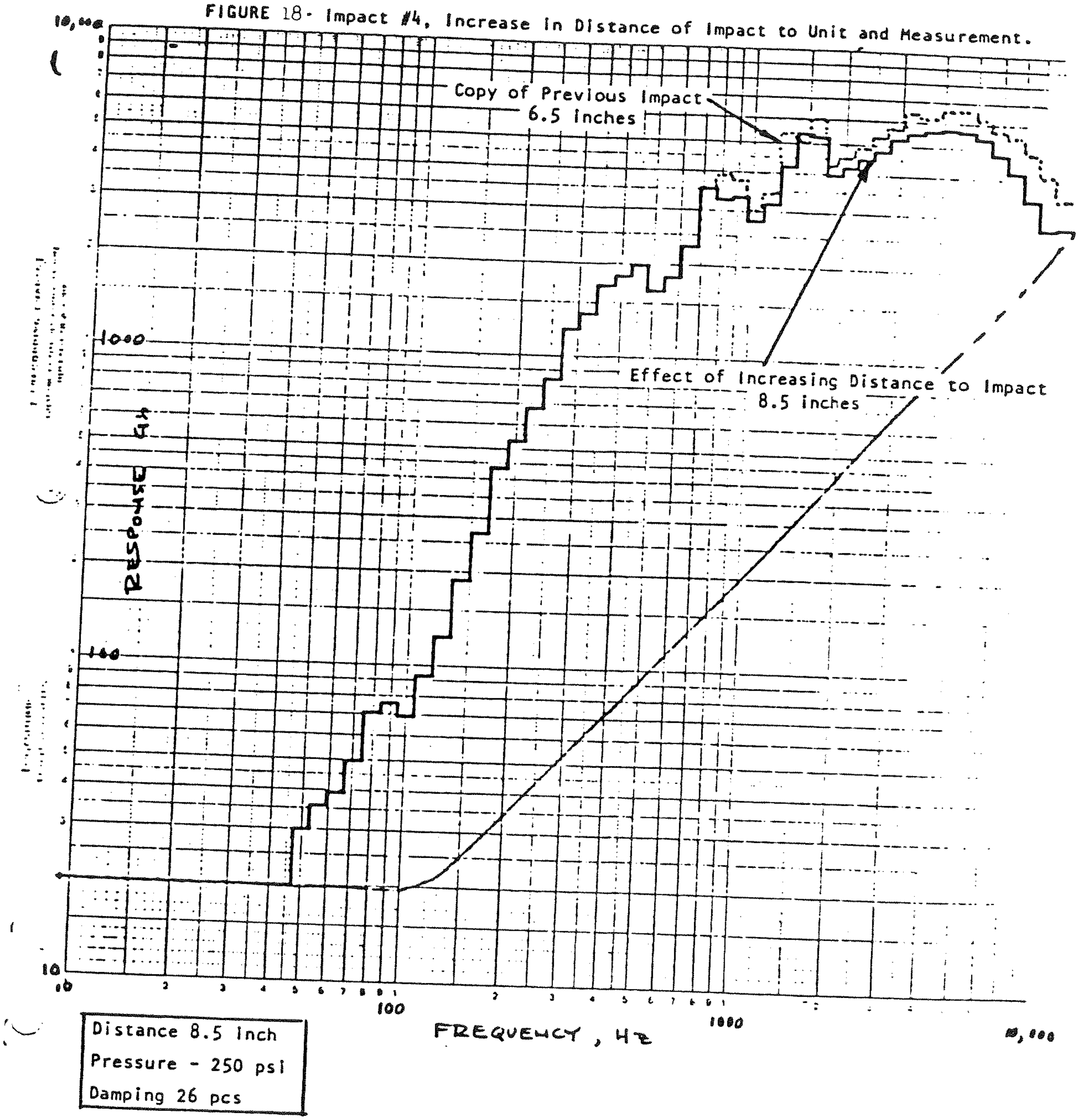


Figure 18 Effect of Change in Distance from Impact Point on Response of Lockheed Resonant Plate System

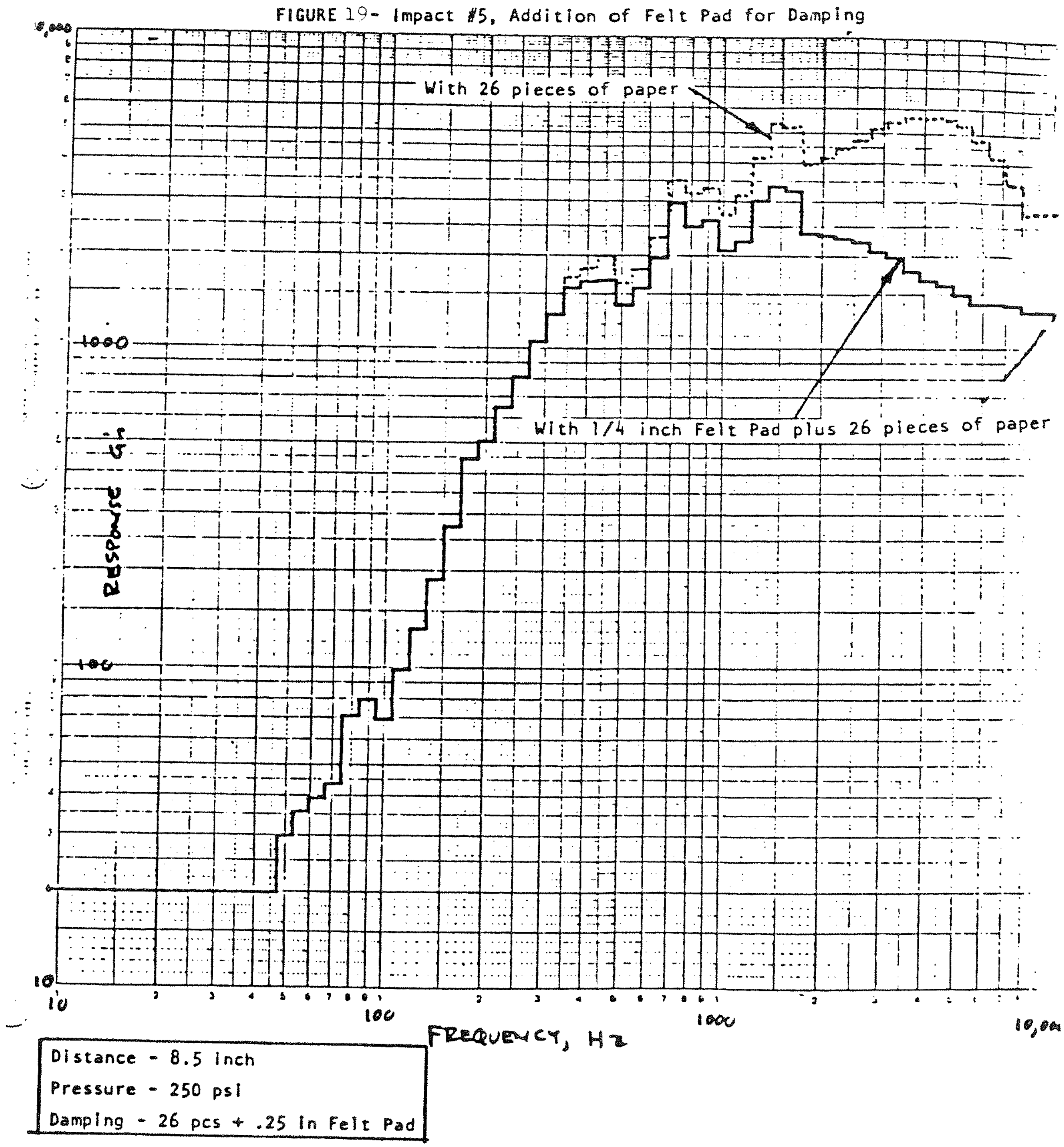


Figure 19 Effect of Addition of Felt Pad on Response of Lockheed Resonant Plate System

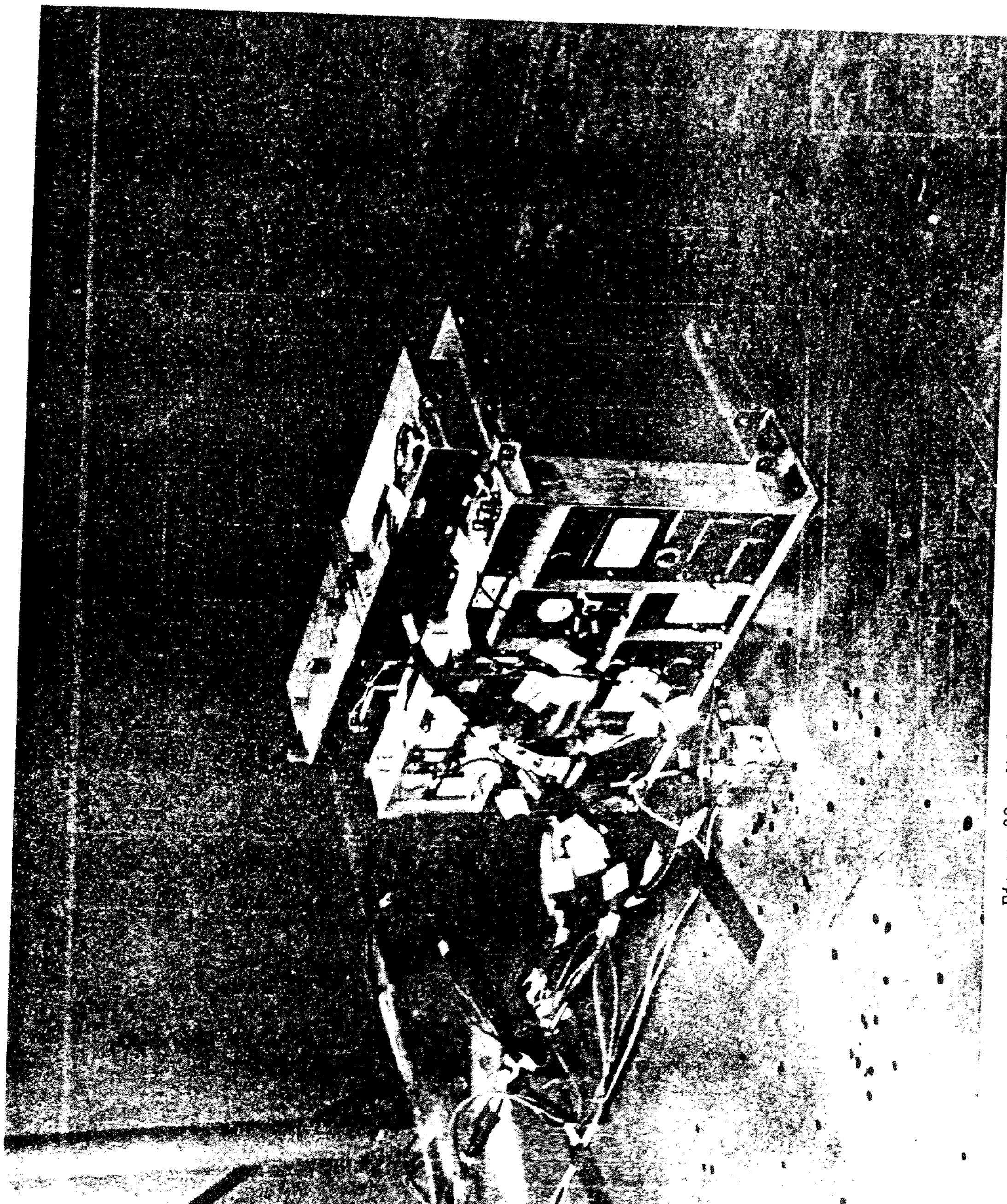


Figure 20. Mockup of Electronic Equipment

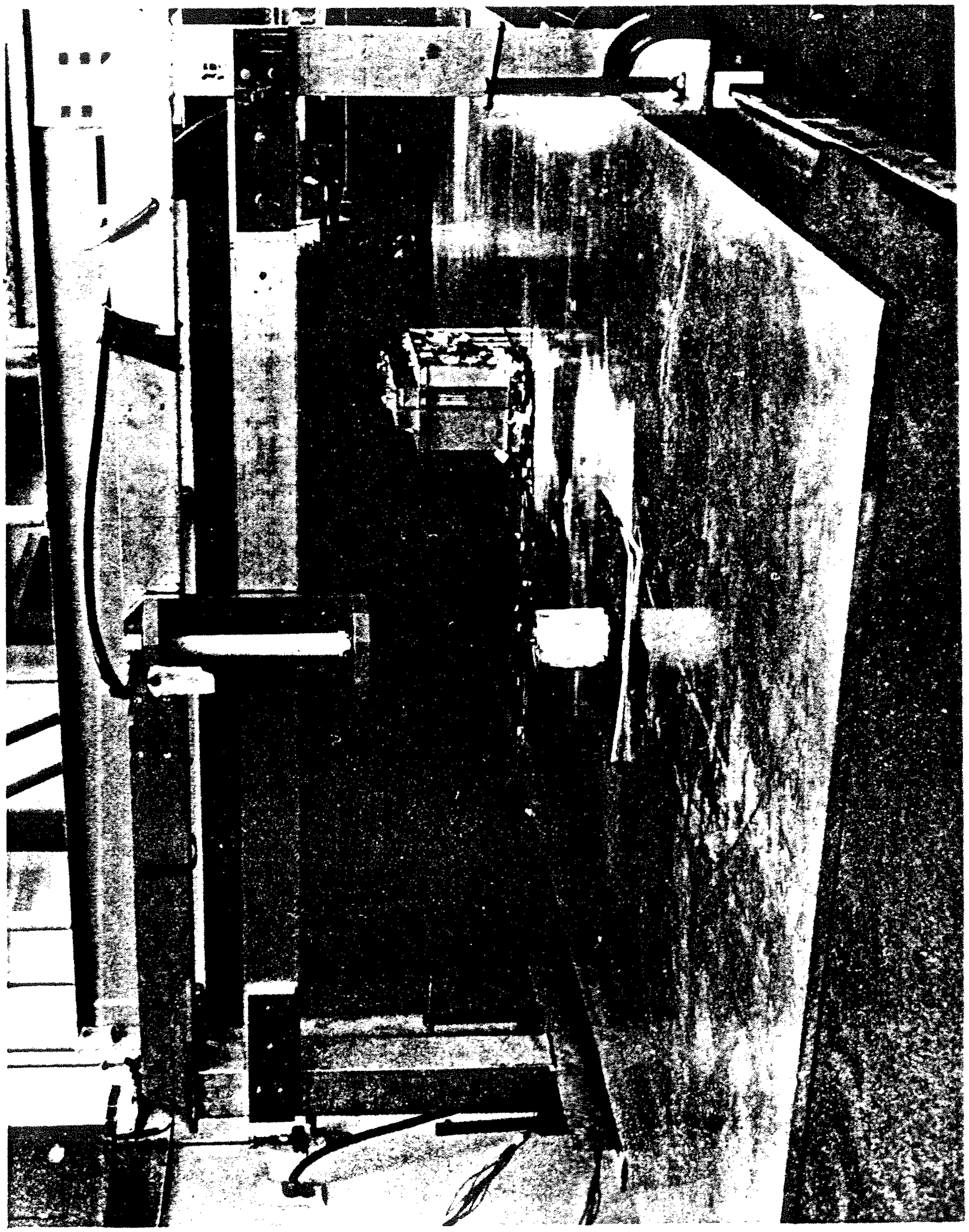


Figure 21. Prototype Electronic Equipment Test Setup
Side-on to the Wave Transmission

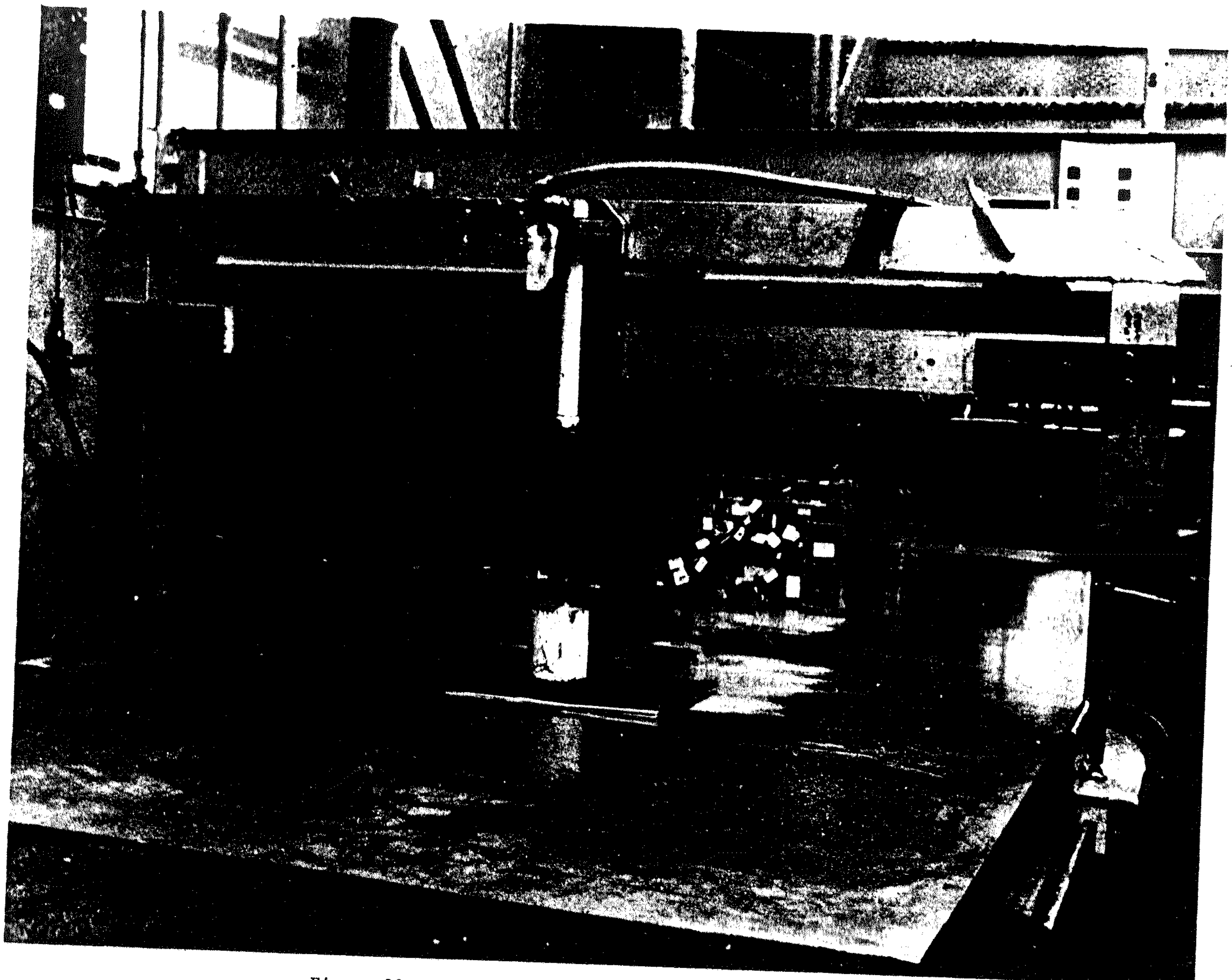


Figure 22. Prototype Electronic Equipment Test Setup Face-on to the Wave Transmission

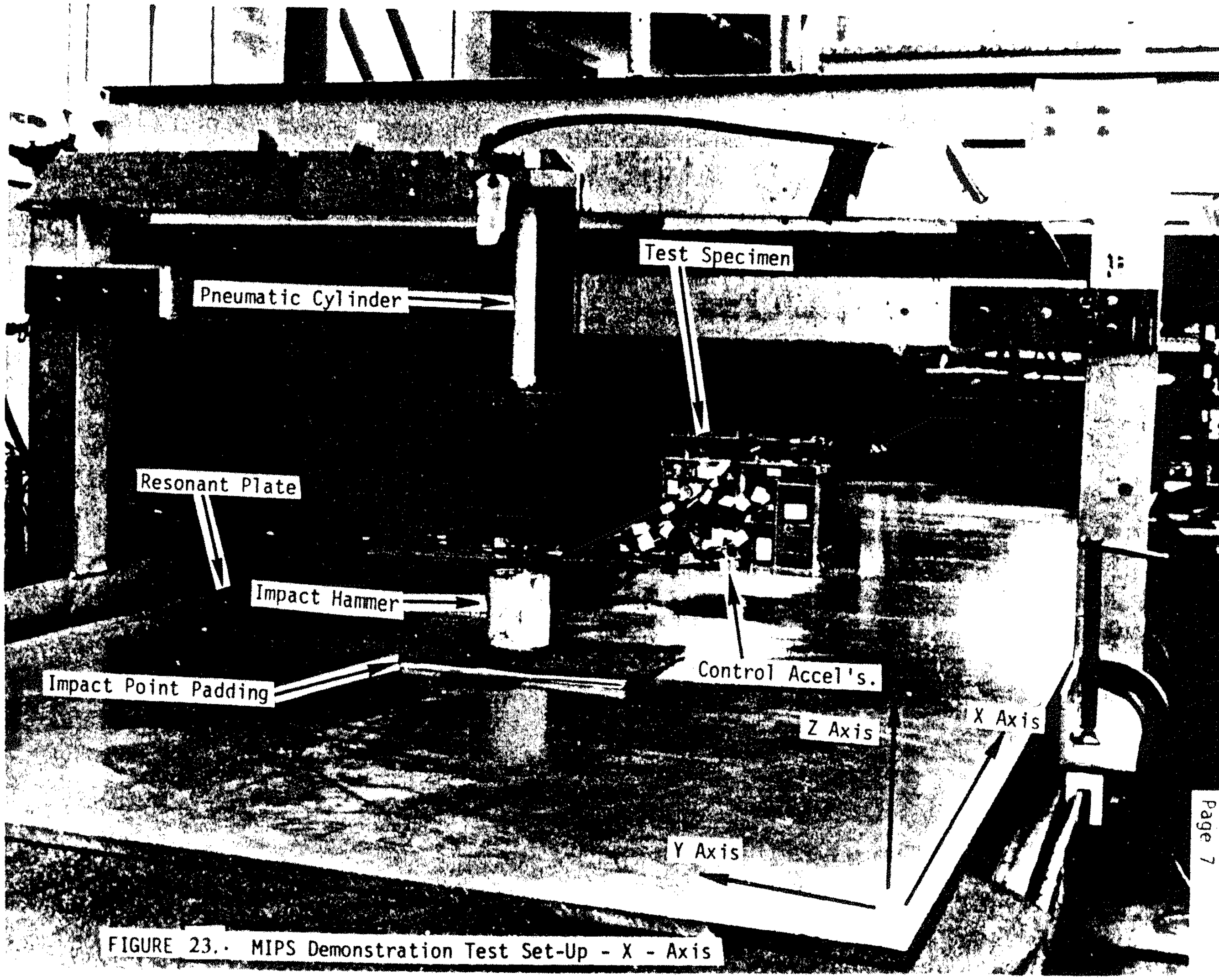


Figure 23. Prototype Electronic Equipment Labeled Test Setup Face-on to the Wave Transmission

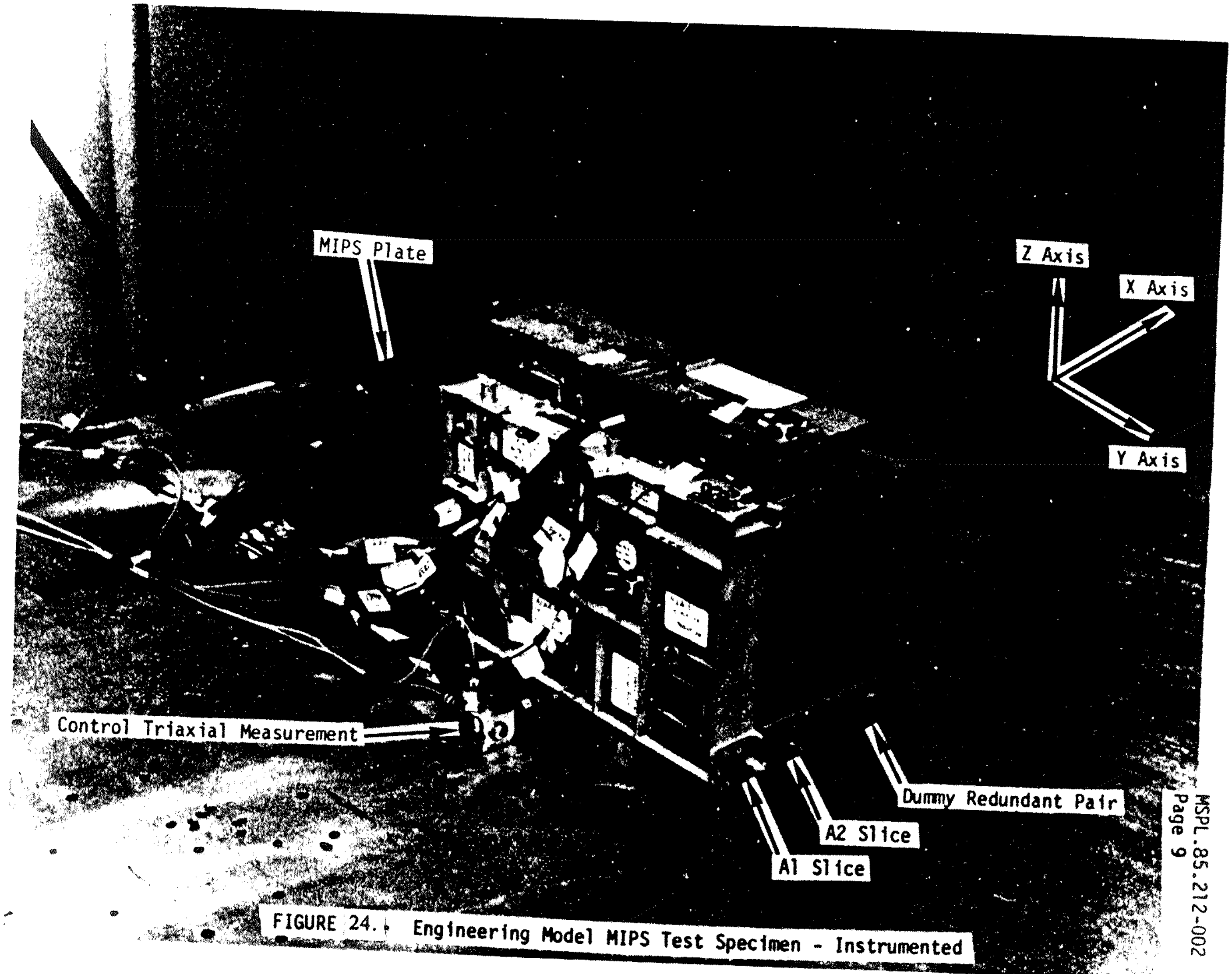


FIGURE 24. Engineering Model MIPS Test Specimen - Instrumented

Figure 24. Instrumented Test Unit

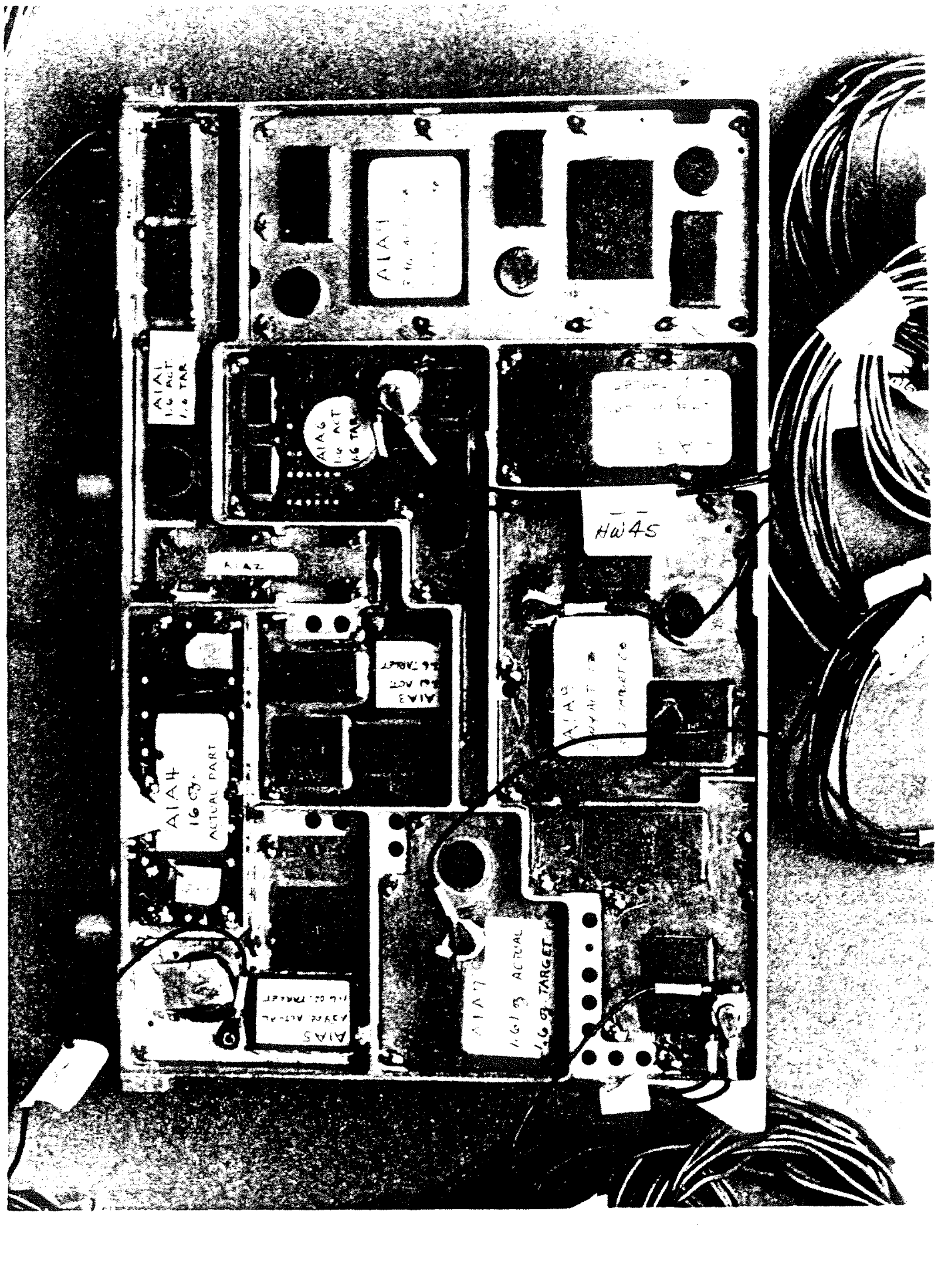


Figure 25. Instrumentation Locations Inside Instrumented Test Unit

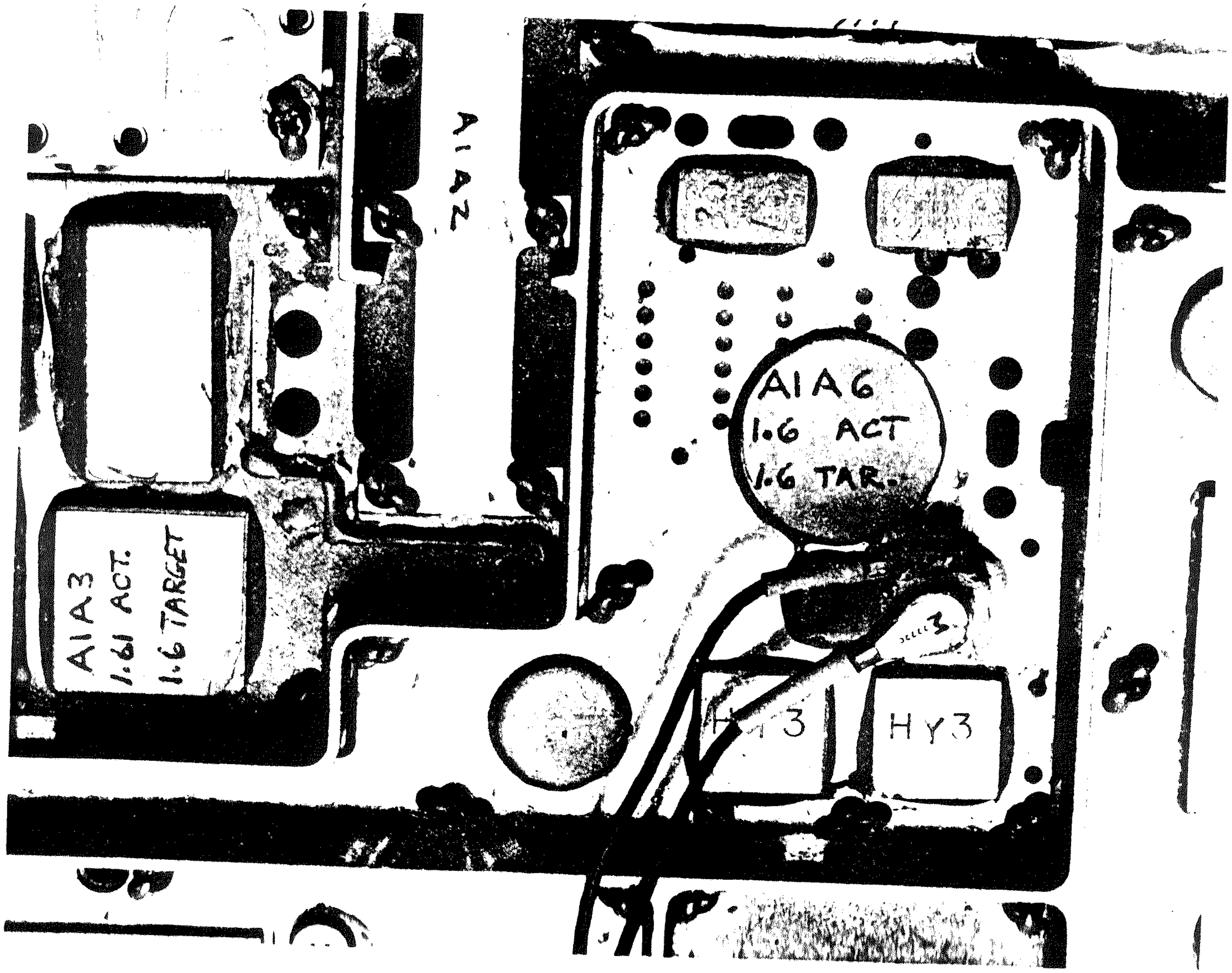


Figure 26. Closeup of Accelerometers Inside Instrumented Test Unit at Mockup of the Circuit Boards

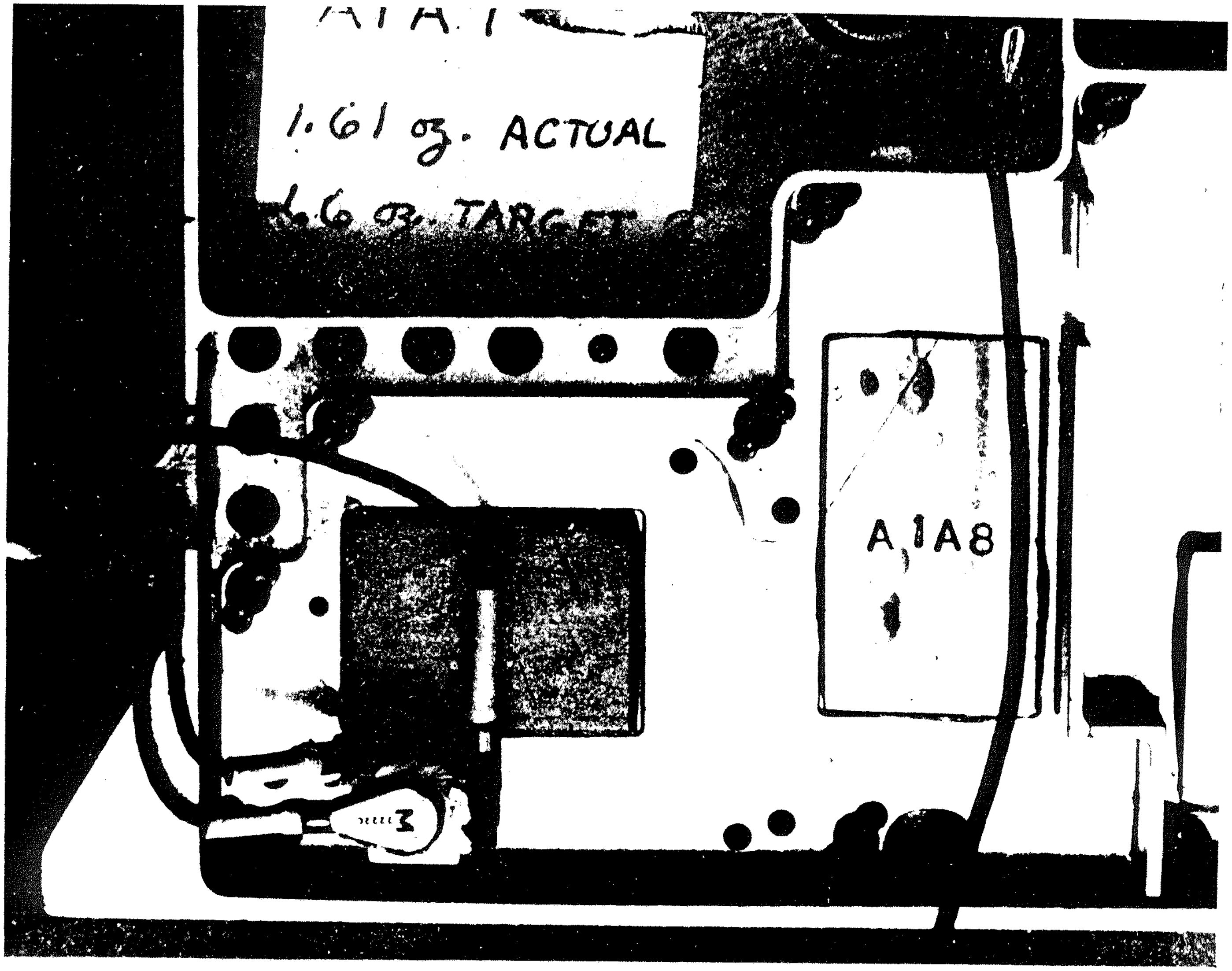


Figure 27. Instrumentation Mounted at the Corners of the Instrumented Test Unit

Discussion

Mr. Mardis (General Dynamics - Pomona Division): I had seen this apparatus before. How much did it cost? How did you establish your material selection and the contact geometry between the hammer and the plate?

Mr. Morse: I don't have an exact answer on the cost. You can see from the material we used to put it together, it is not expensive. However, quite a few dollars were involved in the development work to arrive at the system that is there. We did quite a bit of work on several programs with it, so the cost to TRW, to develop the three particular plates that we showed, probably does not represent what somebody like you might have to do to go into a program now, because you have a pretty good idea of where to start. With regard to material selection, we initially tried steel plates, and they ring much more than aluminum. Probably, if you use magnesium you can get more damping . So, you would have to look at your particular requirements and try to tailor the materials that you want to use toward the spectrum that you have and the levels that you have from the other parameters. "The details are left to the student." About the contact geometry, each of those hammers that you saw are slightly curved so it is not a pointed impact point, but it is rounded in a fairly small area. In many cases we did use a Delrin washer at the impact point. We tried different thicknesses, and different thicknesses gave us different levels. So you would probably end up doing a lot of development work to develop your particular spectrum with that impact point and using very different materials. We used a steel hammer and an aluminum anvil.

Mr. Rosenbaum (General Dynamics - Convair): I guess we at General Dynamics should talk to each other more because we have been using an impact tester for seven or eight years that we made out of an old HYGE machine which we use for the pneumatic hammer. We have done a similar type of testing for electronic components for a long time.

Mr. Morse: Many years ago I was very irritated, and I thought, "Boy, the Navy is really unscientific with their high-impact medium weight shock machine, they just have a hammer hitting a plate." I thought, "How could anybody be so unscientific as to just hit a plate with a hammer and expect to get the right shocks." Yet, the Navy stuck with that system, and the equipment that went into submarines and ships passed those tests, and never had problems. In retrospect, it was not a bad system. They didn't have much data on it. They didn't know exactly why they were doing it, but they were doing it right maybe for the wrong reasons, but probably for a lot of the right reasons. So you have to temper some of the judgements you make as a young fellow as you get older.

Mr. Rosenbaum: In retrospect, talking about what Henry Luhrs was talking about this morning, we found "off-the-shelf" 250-g relays that would barely pass drop-table or drop-tower shocks but they would easily pass orders of magnitude more than that on a resonant-type table like this.

Mr. Morse: I discussed the advantages of the resonant plate in a paper that I presented three years ago. The advantages of the resonant plate are the transmission path and the fact that the shock arrives at the box in a similar way to the real world; you do not overcorrelate the input as you do on a drop table or on a shaker. That is the best portion of the resonant plate simulation that you can do. The mounting impedance is still not good because you are using a plate instead of a honeycomb panel, a spacecraft structure, or what have you. Although the compliance still is not matched, you at least match the transmission path in some respects.

Mr. Rosenbaum: Like you, we have used felt, rubber, Delrin, and all kinds of things by trial and error to vary the widths of the pulse.

Mr. Morse: Again, this just shows a couple of ways to solve problem. You have a problem. You want to perform a shock test. How do you do it? "Resonant plate" techniques are not too bad. You have a few things that you can vary; you can vary some of the parameters and get where you want by using paper for damping or whatever works.

Mr. Dotson (Lockheed): I was involved in the development of this system. One reason we tried this approach was we were trying to develop a system that would cover a particular spacecraft that had many of items mounted on honeycomb panels, and which had very similar characteristics to a flat plate. It was also a system that had a lot of low frequency response. We started off trying to use explosive joints to excite this plate. It was hung vertically at the time, and we found we couldn't generate the low frequencies. In checking one of the accelerometers one of the technicians happened to hit the plate with the sledge hammer, and we got the exact spectrum we wanted. All of a sudden we got real excited about it. So, we laid it horizontally, and because we didn't have an air-impact device at that time, we just dropped an aluminum cylinder down a plastic tube; lo and behold, we were getting all kinds of good results. Then we started varying the parameters; the thickness of the plate, the type of material, the damping material, and the distance from the source. We put it on foam, we put it on sand, and we could vary the spectrum shape widely. It was very successful. I should mention that by putting it on sand, you can move the low frequency modes and steepen the slope. So that is another parameter if you ever need it. As an aside, something that came out of this is that this is a single directional-type device; but many companies who wish to use this device require three-dimensional equality. We have recently put book-end shelves on the system, and we are getting significant in-plane responses. It is still vertical, but you can rotate the box on the shelf. Another point is when data are taken on a spacecraft, or even on this plate, many times you have a tri-axis accelerometer that is mounted on a little aluminum block or some other type of device. The rocking of the plate, or the rocking of the structure in the spacecraft, can give you what you think is a longitudinal or an in-plane response that is not really there. It is not true in-plane motion. So beware if you are mounting your accelerometers above the neutral axis of the structure or plate, if that is the case, because up to about 7,000 Hz and higher, just the rocking effect is equal to the normal response. Once we went back and looked at all of our spacecraft data, we realized that all the enveloping of what looked like in-plane response was really a rocking effect due to normal response due to the bending waves. So, I think many of the three-dimensional spectral requirements came from non-true three-dimensional effects.

Mr. Morse: That is a good point. I have to agree with what is mentioned in the lead-off chart, that our requirements are only for a single axis. In a previous project we had to meet the same shock requirements in all three axes. If you look at the way components are mounted in a spacecraft, shock really comes to it that way. You don't get the same response in all three axes. You get a major response perpendicular to the plane in which the component is mounted. You don't get the same in the other in-plane axes. I think that is well recognized in vibration because many vibration specifications now require different levels in-plane, and normal to the mounting plane. I think that eventually should be the same for shock requirements.

Voice: The last two or three minutes of discussion satisfied the comment I was going to make. It was about the compromise that one might have to accept in a lateral axes, but I thought Ron addressed it real well by saying with book shelf-type fittings you can get the lateral axes as well.