SSC-274

DEVELOPMENT OF AN INSTRUMENTATION PACKAGE TO RECORD FULL-SCALE SHIP SLAM DATA

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SHIP STRUCTURE COMMITTEE
1978

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Ship Structure Committee
An Interagency Advisory Committee
Dedicated to Improving the Structure of Ships

Address Correspondence to:
Secretary, Ship Structure Committee
U.S. Coast Guard Headquarters,(G-M/82)
Washington, D.C. 20590

SR-1235
JULY 1978

The physical and statistical properties of slamming phenomena experienced by a ship in rough seas have been examined primarily through model experiments. However, very few examples of good correlation between model experiments and full-scale trials are available due to the lack of comparable reliable data from observations at sea. This important design information deficiency has been caused by the lack of suitably rugged instrumentation to withstand the forces and pressures of a violent sea.

The Ship Structure Committee undertook a project to develop an instrumentation package that would be capable of recording simultaneously the impact pressure, acceleration, strains, and the vertical motions and velocity of the ship at the pressure transducer location relative to the impacting wave.

This report describes the work involved in developing a unit package capable of recording those quantities together with a program for proof testing and calibrating the units aboard a full-scale ship.

WM Benkert
W. M. Benkert
Rear Admiral, U.S. Coast Guard
Chairman, Ship Structure Committee

FINAL REPORT

on

Project SR-1235

"Full-Scale Ship Slam Investigation"

DEVELOPMENT OF AN INSTRUMENTATION PACKAGE TO RECORD FULL-SCALE SHIP SLAM DATA

by

E. G. U. Band
A. J. Euler

Payne, Incorporated

under

Department of the Navy
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U. S. Coast Guard Headquarters
Washington, D.C.
1978

ABSTRACT

An instrumentation set has been developed for use in investigating the slamming experience of a full-scale ship. Methods for treating both bow-flare and bottom-slamming have been considered. A radar altimeter was used to sense the relative height of the wave at the transducer location in order to determine the relative velocity between the bottom or the bow of the ship and the wave at the instant of slam.

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1. INTRODUCTION

The Ship Structure Committee has been engaged, for many years, in a systematic study of the loads, pressures and stresses experienced by commercial ships at sea. Typical of these experiments have been those carried out on the dry-cargo ships S.S. WOLVERINE STATE and S.S. HOOSIER STATE (References 1 through 5), the container ship S.S. BOSTON (References 6, 7), and the very extensive program undertaken on the SEA-LAND McLEAN (the SL-7 program) (References 8 through 12).

In most of these programs the primary emphasis has been on the measurement of midship bending stresses. It has become almost traditional in these tests to record data, for a period of twenty minutes or half an hour, at four-hour intervals. In some cases the data were recorded continuously during storms. In the SL-7 program a much wider variety of information was recorded (not necessarily simultaneously) and parallel model and analytical efforts have been undertaken. Reference 12 provides a good overview of the SL-7 program.

A study of the slamming phenomenon was conducted on the S.S. WOLVERINE STATE by locating pressure transducers in the forward part of the hull bottom. The results of these experiments have been described in References 4 and 5. The WOLVERINE STATE, being a dry cargo ship which often completed voyages at rather shallow draft, was a good subject for the study of bottom slamming. Earlier attempts had been made to identify slam events by using only the midship bending information (Reference 13).

The objective of the present program (Reference 14) is to contribute a further step in this widespread, full-scale-ship, structural-load activity in the area of slamming. One vital piece of information that has been missing from the previous programs has been the relative vertical velocity between the ship's bottom and the water surface at the time that impact occurs. The relative vertical velocity has been shown, by Ochi and others (References 15 through 18), to be a controlling factor in slam severity.

This report, therefore, describes the development of an instrumentation package designed to measure and record a number of slam-related phenomena, including relative vertical velocity, hydrodynamic pressure, bottom-plating strains at various locations, and vertical accelerations. The instrumentation is also monitored so that the onset of slamming can be predicted and so that the instrumentation signals can be recorded only while slamming is occurring.

2. DESIGN AND CONSTRUCTION OF EXPERIMENTAL INSTALLATION

2.1 OBJECTIVES

The objective of the development of the experimental installation during this program can be summarized as follows:

A. Develop a set of instruments to record the local pressures and strains experienced by the bow plating of a commercial ship when undergoing bottom of bow-flare slamming.

B. Measure the vertical velocity of the impact area relative to the water surface; in particular, the use of a Collins Radar Altimeter for this purpose was to be evaluated.

C. Adapt existing, government-owned equipment that had been used for prior experiments on the Sea-Land McLEAN as much as possible for the purposes of the present tests. The most significant item of government-furnished equipment was an Ampex, 14-channel, FM tape-recorder.

D. Assemble a centrally located control station containing the recorder, a time-signal generator, a controller/programmer and the power supplies for the individual instruments.

E. Use the controller/programmer to control the tape recorder so that it would be activated to record slams when they were expected to occur but which would keep the recorder inactive at other times. The controller/ programmer was also to provide calibration signals on all instrumentation channels.

F. Conduct laboratory tests to verify the operation of the instrumentation package.

2.2 THE INSTRUMENTATION PACKAGE

The instrumentation package is represented diagrammatically in Figure 1 and typical physical locations of the gages are shown in Figure 2. Typical mixes of the principal instruments occupying the fourteen channels of the recorder are shown in Table 1. In Table 2 the hardware items purchased during the contract are listed. Four different pressure gages were procurred so that they could be compared during laboratory drop tests and a selection made from among them.

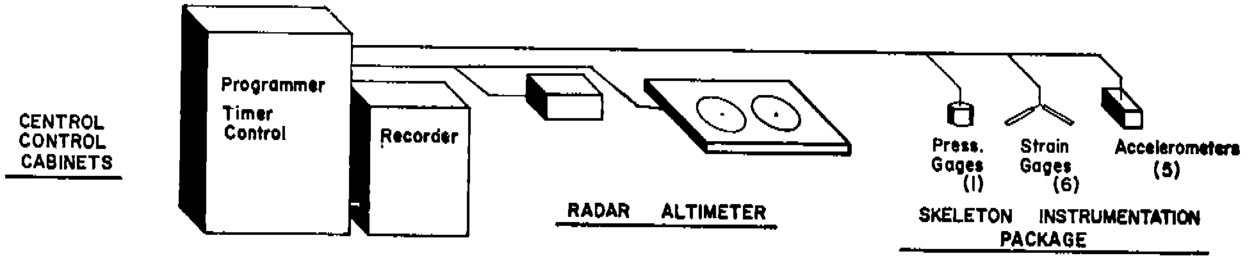
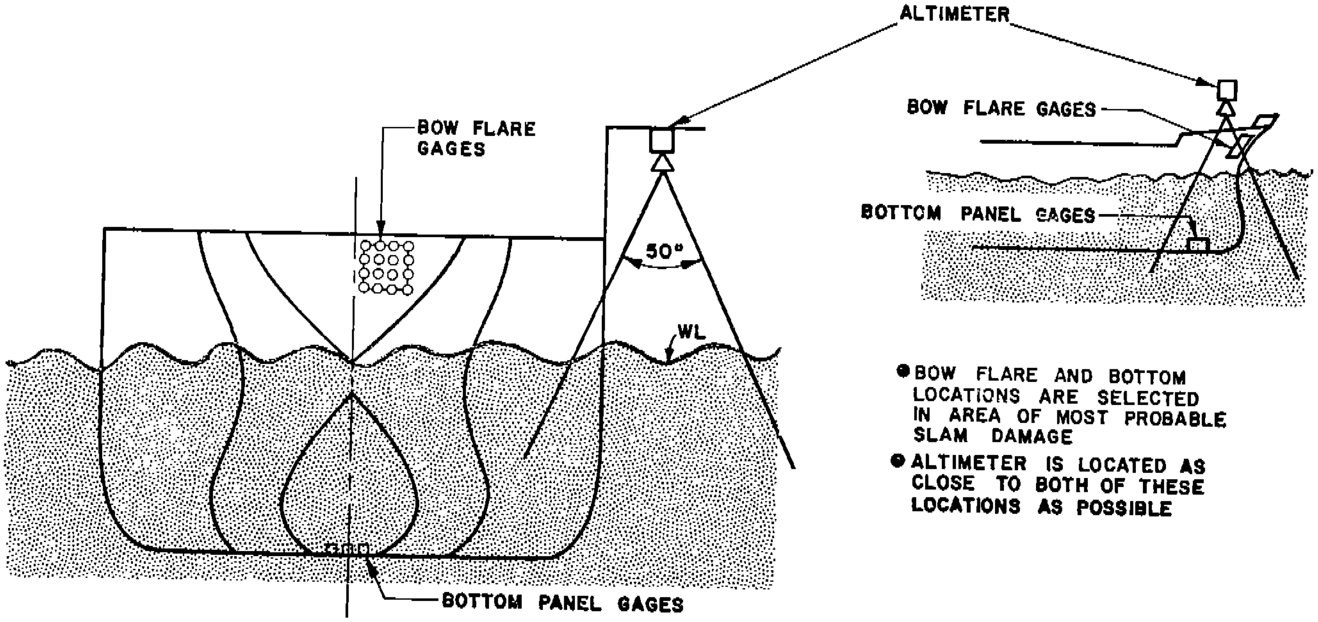


Figure 1. Diagram of Data Acquisition System.



- BOW FLARE AND BOTTOM LOCATIONS ARE SELECTED IN AREA OF MOST PROBABLE SLAM DAMAGE
- ALTIMETER IS LOCATED AS CLOSE TO BOTH OF THESE LOCATIONS AS POSSIBLE

Figure 2. Location of Gages.

Table 1. Proposed Instrumentation.

1. ACCELEROMETER (SHIP OVER-ALL RESPONSE)

BOW FLARE PANEL GAGES
5 STRAIN GAGES
6 PRESSURE GAGES
1 ACCELEROMETER

BOTTOM PANEL GAGES
5 STRAIN GAGES
6 PRESSURE GAGES
1 ACCELEROMETER

1 PROGRAMMER / TIMER / CONTROLLER

1 RADAR ALTIMETER (2 PREFERRED)

12 SIGNAL CONDITIONERS

1 14 CHANNEL RECORDER (G.F.E.)

Table 2. Updated Equipment Status List.

(10/28/76)

SYSTEM ELEMENT	*	SOURCE	POWER REQUIREMENT	INPUT SIGNAL	OUTPUT SIGNAL	COST
Radar Altimeter	P	Collins Radio Co.	28 VDC @ 0.8A Power	Altitude: 0-500-2000 Ft.	0 - 500 Ft: 10 Mv/ft 500-2000 Ft: 3 Mv/ft Linear Analog Signal	~ $2400.00 ea. [1] (1)
14 CH FM Tape Recorder	S	AMPEX FR-1300	105-125 VAC @ 4A, 48-62 Hz	1.0V RMS for 40% Deviation 2500 Hz @ 3.75 ips	1.0 V RMS into 10K Ω Load or Greater	GFE* [1] (1)
Pressure Transducer	P	BLH High Output Type DHF	10 VDC Excitation	0-350 PSIA, @ 2.5 KHZ	3 Mv/V Input	[1] $400.00ea
	P	Kulite XTMS-1-190		0-500 PSIA	7.5 Mv/V	[1] $400.00ea
	P	Sensotec 60B0564-1		0-350 PSIA	3 Mv/V	[1] $400.00ea
	P	Dynesco PT 311-B		0-500 PSIA	3 Mv/V	[1] $200.00ea (6)
Strain Gage	P	AILTECH Co. Hermetically Sealed	10 VDC Excitation	± 200 μ in/in @ less than 200 Hz	.1 Mv/V Input	~ $ 30.00 ea. [3] (6)
Accelerometer	S	Setra, Inc. Model 100	6 VDC Excitation	± 5g at 100 Hz	~ 1 Mv/V Input	[2] GFE*
		Model 100		± 2-1/2g		[2]
		Model 100		± 2g		[1] (2)
Signal Conditioner	P	Vishay Instruments 2100 System	115 VAC ±10% @ 1A, 50-60 Hz	Less than 10 Mv @ 5 KHZ from any ¼, ½ or full-bridge source	100 to 2100 gain @ 5 KHZ ± .5 db	~ $400.00 ea. [6] (16)

* CURRENT STATUS: S - Selected C - Leading Candidate U - Undefined * Government Furnished Equipment
P - Purchased N.A. - Not Applicable [ ] No. required for test ( ) No. required for system

Table 2. Updated Equipment Status List. (Continued)

(10/28/76)

SYSTEM ELEMENT		SOURCE	POWER REQUIREMENT	INPUT SIGNAL	OUTPUT SIGNAL	COST
Controller Power Supply	P	Power-One, Inc. BB 15-1.5	110 VAC	N.A.	± 15 VDC @ 1.5A	~ $ 54.00 ea. [1] (1)
Remote Switch Power Supply	P	Power-One, Inc. C24-2.4	110 VAC	N.A.	24 VDC @ 2.6A	~ $ 45.00 ea. [1] (1)
Time Code Generator/ Translator	P	DATUM Model - 9300	115 VAC @ .5A	IRIG A or B	IRIG A or B	~$1650.00 ea. [1] (1)
Frequency Counter	P	Heath/Schlumberger SM 4100	115 VAC	0-30 MHZ	Digital Display	~$ 190.00 ea. [1] (1)
Frequency Generator	P	Heath/Schlumberger SG-18A	115 VAC	N.A.	1 Hz - 100 KHZ	~$ 130.00 ea. [1] (1)
Digital VOM	P	Simpson 464D	115 VAC or Batt.		Digital Display	~$ 300.00 ea. [1] (1)

The physical dimensions of the Collins radar altimeter are indicated in Figure 3. The Collins radar altimeter was designed as a radar altimeter for light aircraft. It normally operates at altitudes of up to 2000 feet and is claimed, by the manufacturer, to have an accuracy of ± 2 feet. The antenna mounting recommended by the manufacturer is sketched in Figure 3. The ground plane is, normally, part of the aircraft structure. A similar instrument, designed for the purpose by NRL was used on the SL-7 program to provide wave height information. The Collins altimeter was selected for evaluation in the present program because of its very attractive price, which is a prime consideration in an installation that must be mounted externally on the ship and, as such, is liable to suffer accidental damage.

The Collins radar altimeter, although clearly not designed for the low-altitude, over-water operation required in a ship-board installation, was proposed for use in this application because it was known to be in use, in a very similar application, in the U.S. Navy Surface Effect Ship (SES) Program. The SES requirement was for an instrument to determine the location of the SES hull with respect to the waves so that both wave height and motion information could be generated. Considerable effort was expended on this project by the U.S. Navy* in order to improve low-level operation and, at the same time, develop a more compact and rugged antenna configuration. The configuration developed is illustrated in Figures 4 and 5. Unfortunately, this information was not available in time to incorporate it in the preliminary tests reported here, but should be considered for inclusion in any further development of this program.

2.3 OPERATING PLAN

The proposed operating plan for the instrumentation suite is shown in Table 3 and the proposed recording scheme in Figure 6. After considerable discussion it was concluded that it was more desirable to maintain all of the instrumentation system in the "on" condition throughout the voyage than to attempt to define a "stand-by" regime during which the instrumentation was "on" and a "stand-down" regime, in calm weather, for example, when the instrumentation was turned "off". The expected life of the instruments is not affected by this decision and the power consumption is very small.

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* Antenna & Avionics section of the Systems Engineering Test Directorate, Naval Air Test Center, Patuxent River, Maryland.

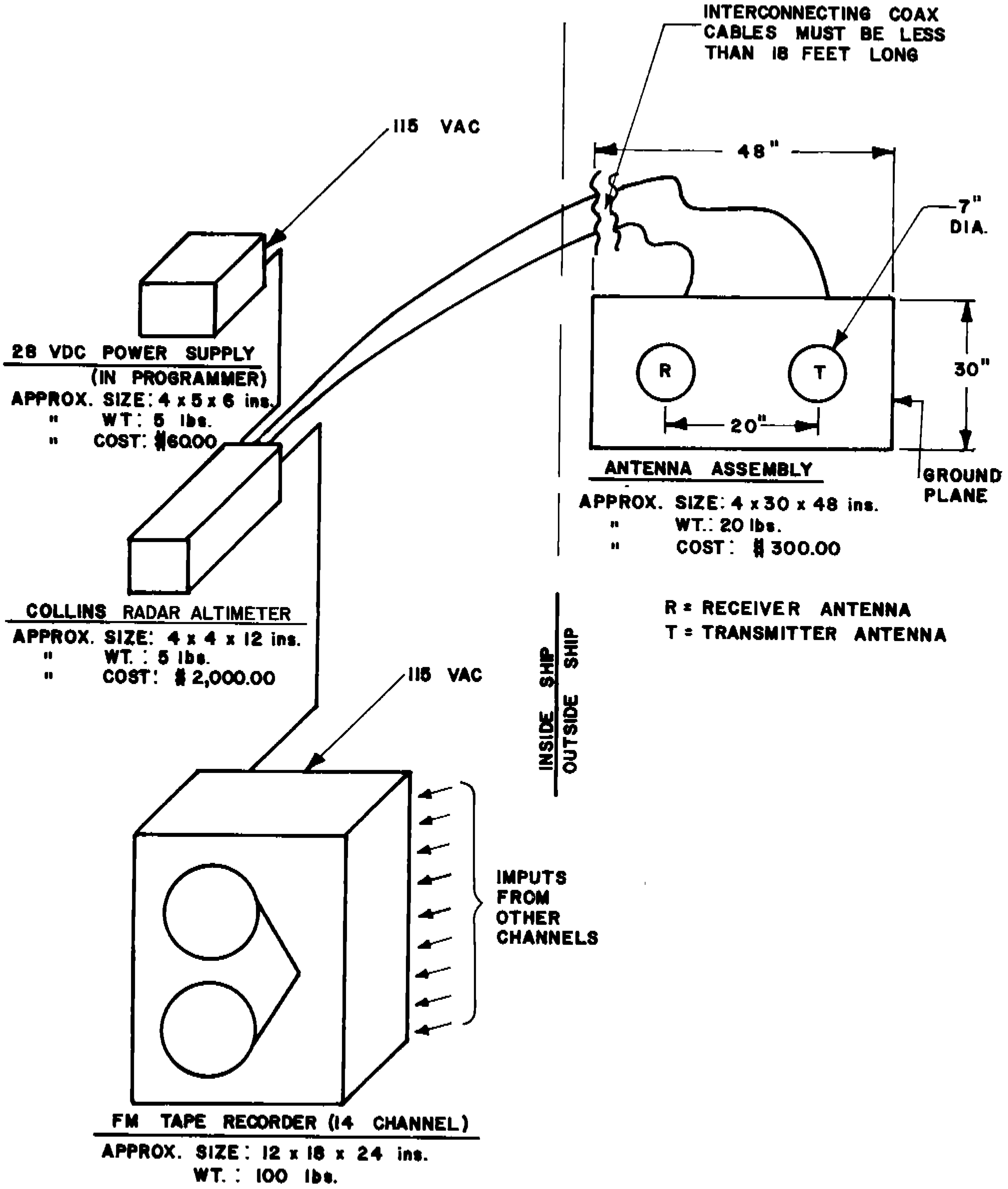


Figure 3. Block Diagram of Radar Altimeter.

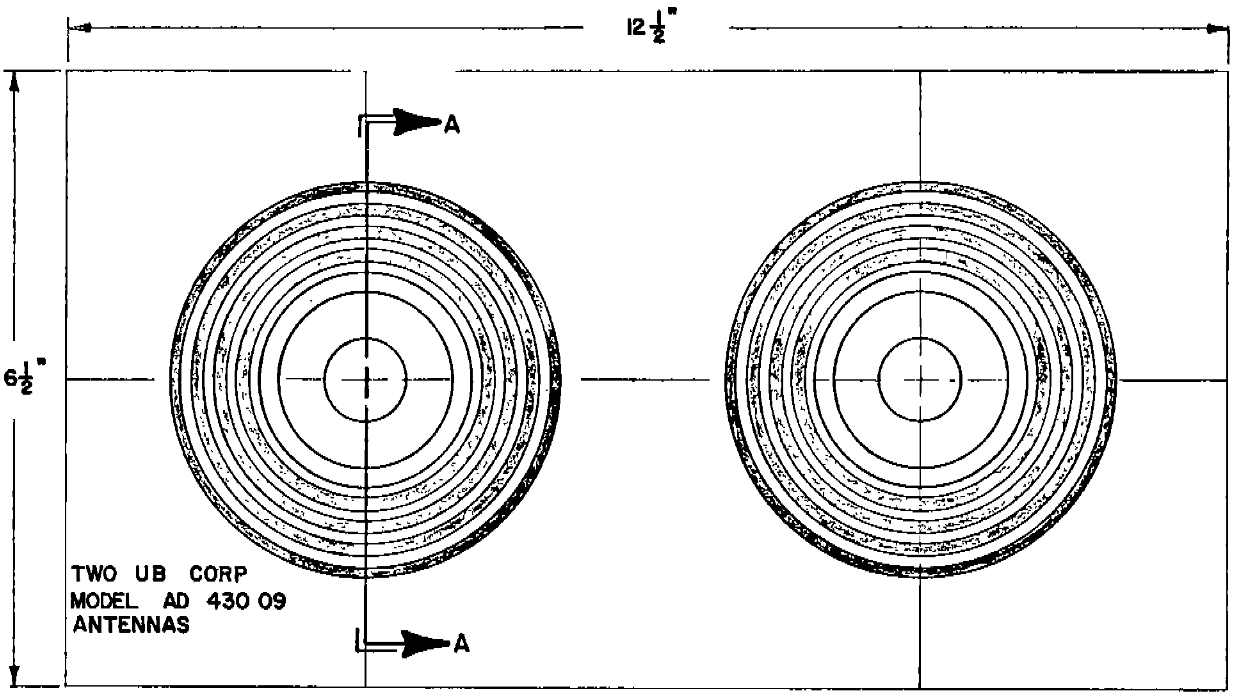


Figure 4. Alternate Altimeter Antenna Design. (By Systems Engineering Test Directorate Antenna and Avionics Section, Naval Air Test Center, Patúsent River, Maryland, as used on SES-100A).

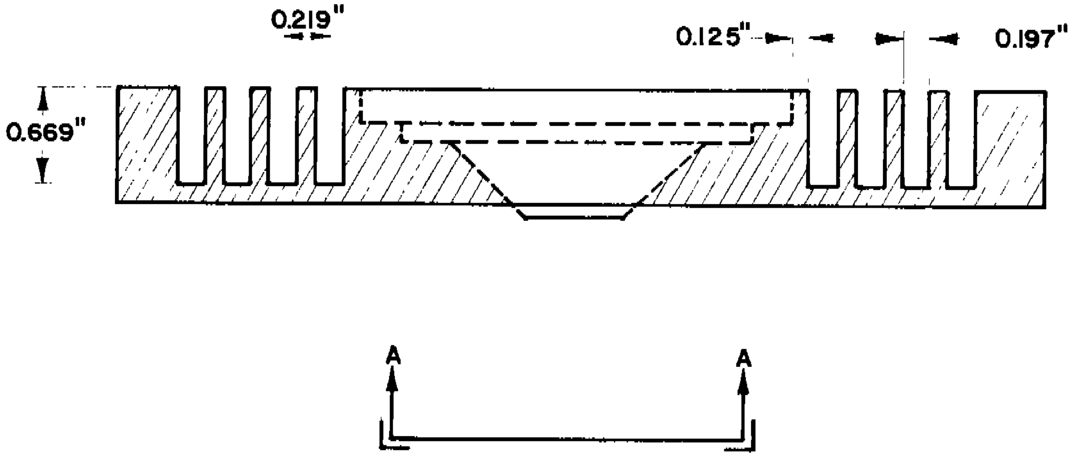


Figure 5. Alternate Altimeter Antenna Design Cross Section.

Table 3. Proposed Programming Routine.

MODE	SIGNAL CONDITIONERS AND INSTRUMENTATION	ALTIMETER	POWER CIRCUITS	TAPE DRIVE	TIMER	CAL. SIGS
"STAND-BY"	ON	ON ↓	ON	OFF		RUN ONCE PER DAY AT MIDNIGHT
"SLAM IMMINENT"	ON	ON	ON	ON	ON ↑	OFF

↓ THESE SIGNALS ARE MONITORED BY PROGRAMMER AND USED TO CHANGE MODE AS REQUIRED

EG. ↑ TIMER IS USED TO RETURN FROM "SLAM IMMINENT" TO "STAND-BY" AFTER PRESET INTERVAL UNLESS PROGRAMMER HAS PREDICTED THAT ANOTHER SLAM IS IMMINENT

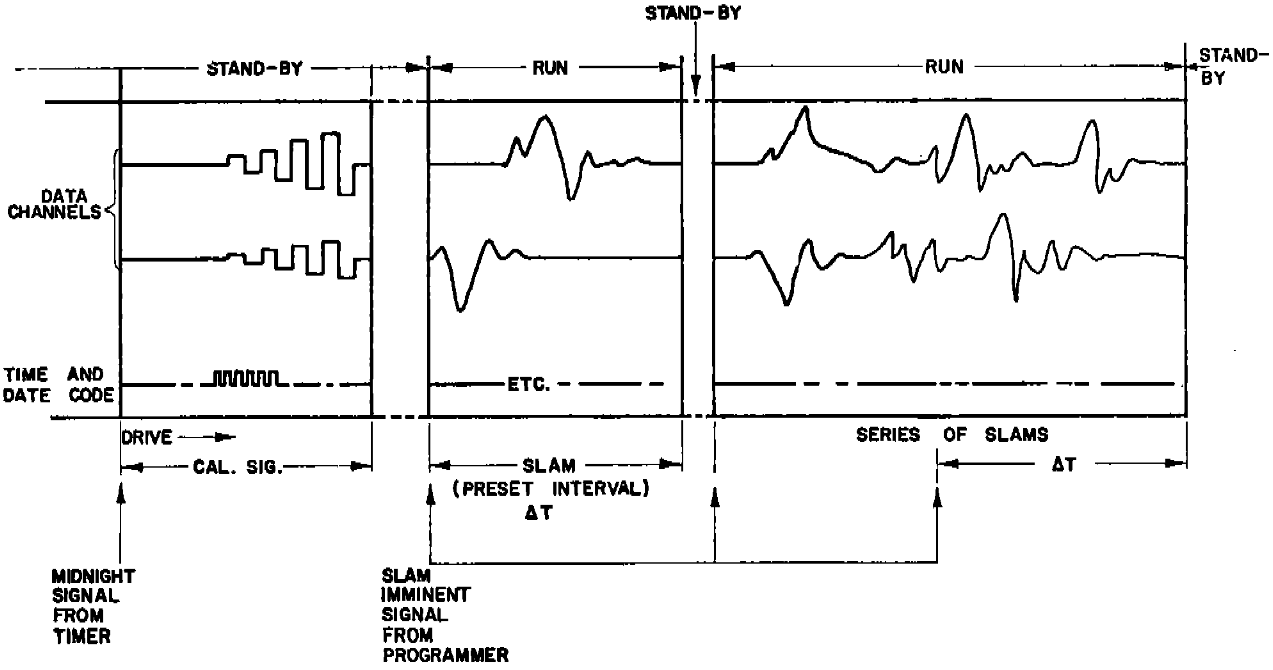


Figure 6. Data Recording Scheme.

All power circuits, therefore, are continuously in the on-condition and the only difference between the normal, "stand-by" mode and the "slam-imminent" mode is that the tape drive is activated in the latter case. The prime function of the "programmer/controller", therefore, is to monitor the altitude signal and start the tape drive whenever a slam appears to be imminent. The logic used for this determination will be described in the following paragraphs.

2.4 THE PROGRAMMER/CONTROLLER

The layout of the programmer is shown in Figure 7 together with its principal interconnections to the other system components. The four principal functions of the programmer are separated into four separate circuit boards as shown in Figure 8. These four principal functions are:

- Calibration Sequencer - once every twenty-four hours the programmer performs a calibration of a-l of the instrumentation channels. The sequence is initiated and controlled from this board in response to a time signal from the time-code generator.
- Wave Height Averager - the signal from the radio altimeter is monitored on a continuous basis and averaged to determine the mean draft level at the altimeter station. This quantity is used in the logic used to start the tape recorder drive.
- Tape Recorder Control - the current altimeter signal is compared, on a continuous basis, with the mean draft signal. Whenever the two signals vary by more than a predetermined amount, it is anticipated that a slam is imminent and the tape recorder drive is activated.
- Relay Driver - once the tape recorder drive has been activated a recording will be made for a predetermined period of time. This period is controlled by the relay driver which will deactivate the tape drive unless a further "slam-imminent" signal is received. This process is represented in Figure 6.

The logic and sequence of the various functions are represented in Figure 9. The height of the antenna above the local water surface is represented by the signal X. $\overline{X}$, the average value of X, provides a representation of the mean water level on the hull. The depth of immersion, X_2, of the impact panel above the mean draft $\overline{X}$ is computed from the known, fixed, distance X_3 of the impact panel below the altimeter by the formula:

$$X_2 = \overline{X} - X_3$$

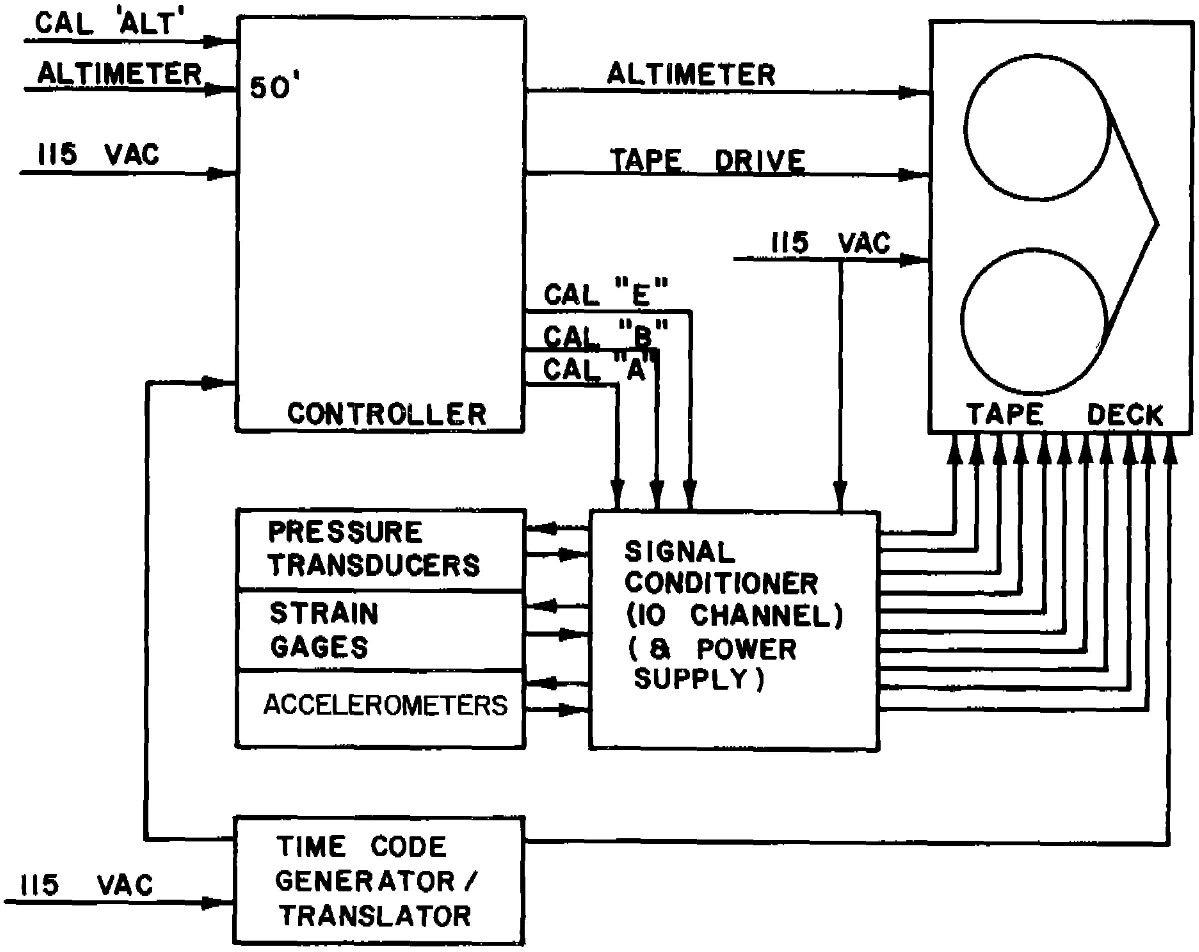


Figure 7. Instrumentation Package.

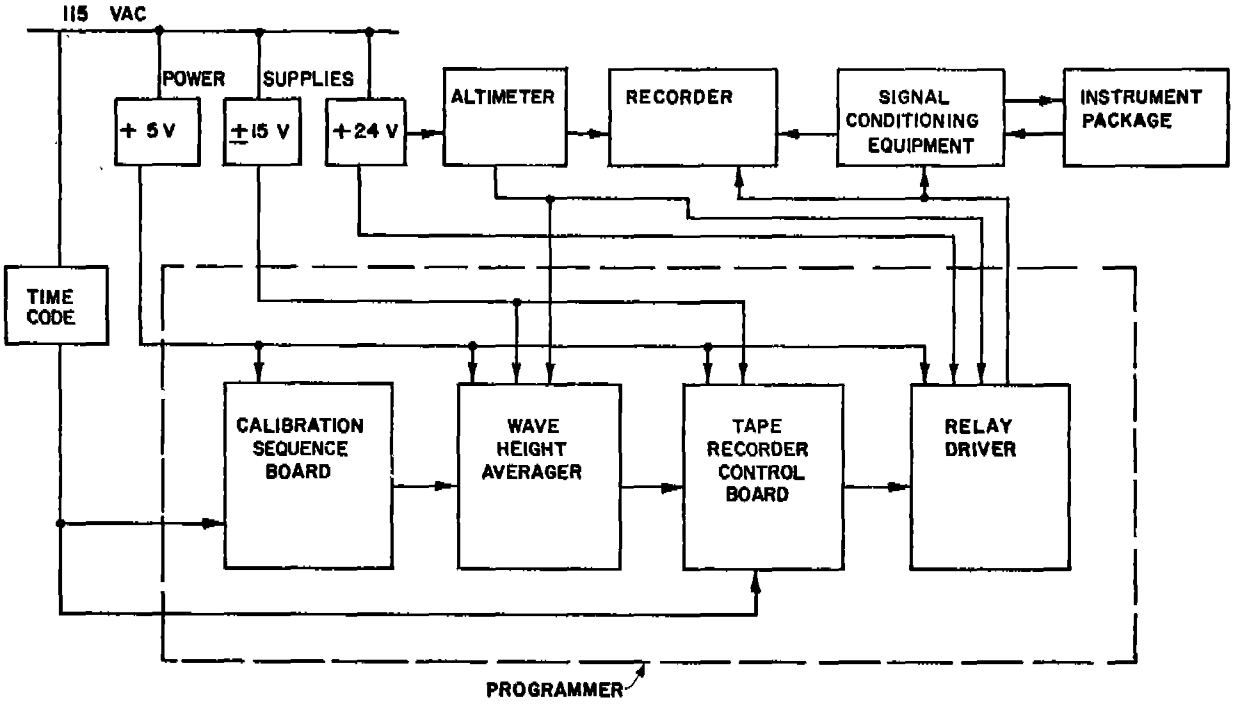
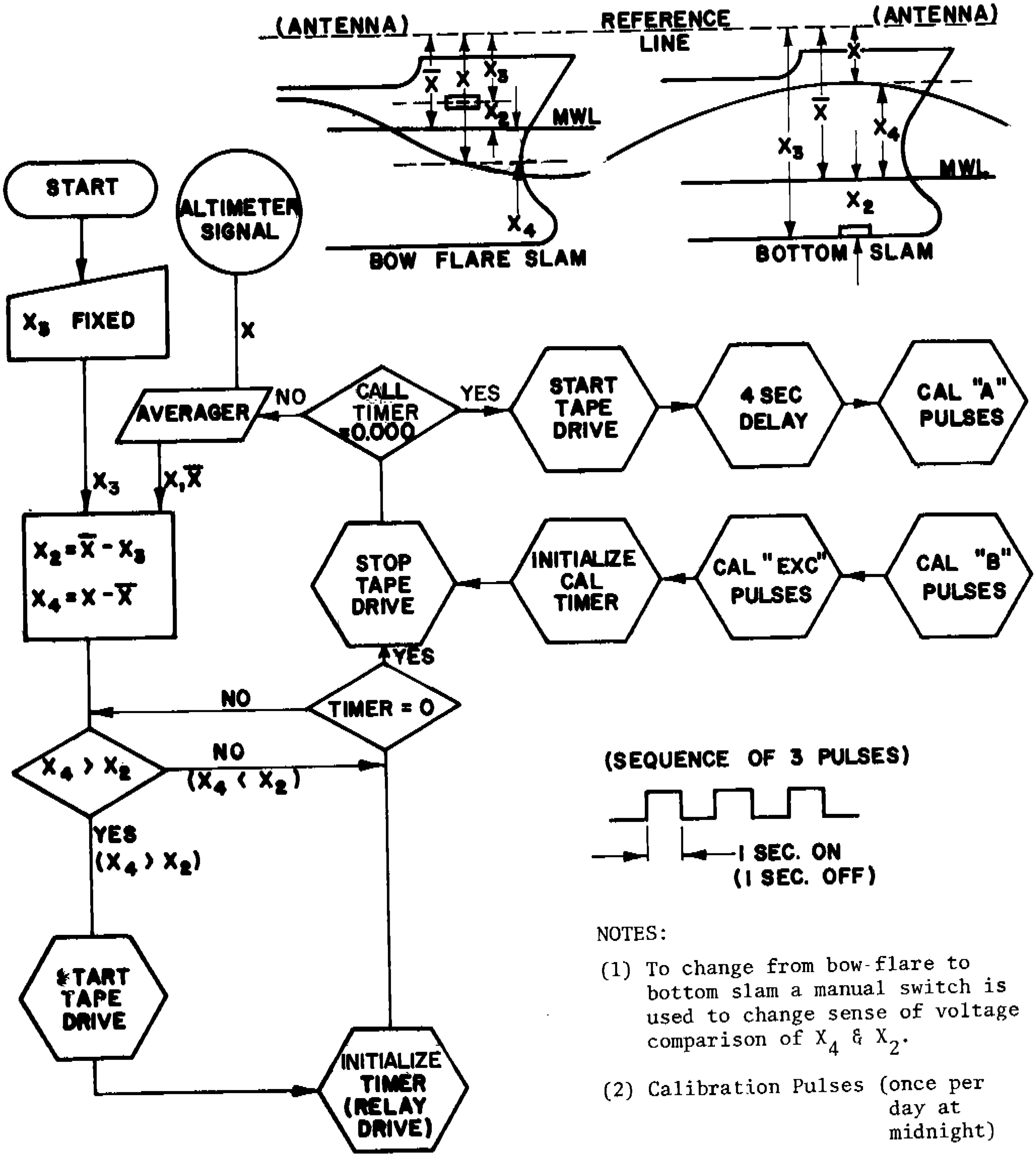


Figure 8. Layout of Programmer/Controller.



NOTES:

(1) To change from bow-flare to bottom slam a manual switch is used to change sense of voltage comparison of X_4 & X_2.

(2) Calibration Pulses (once per day at midnight)

Figure 9. Controller Logic Circuit.

If the impact panel is below the mean water line, as in the case of bottom slamming, then X_2 will be negative. The instantaneous height, X_4, of the wave surface below the mean water level is computed directly from the altimeter signal by the formula:

$$X_4 = X - \overline{X}$$

Whenever X_4 exceeds X_2, in the case of bow-flare, or is less than X_2, in the case of bottom slamming, then it is predicted that a slam is imminent within the current wave encounter cycle and the tape drive is turned on. By using this test instead of the rather more obvious direct comparison of X with X_3, it is envisaged that the slam will be predicted several seconds before it occurs which will allow the recorder adequate start-up time to achieve stable operation before the slam occurs. The exact levels at which this comparison should be made can only be determined by experience. The objective will be to attempt to err on the side of recording too often, so that a percentage of the recording sequences will be blank, rather than too seldom, in which case a percentage of slams would be missed.

The only difference between the recording of bottom slams and bow-flare slams, as far as the controller is concerned, lies in the sign of the difference between X_4 and X_2. All that is necessary to adjust the recorder to record bow-flare slams, therefore, instead of bottom slams is to include a manual switch which changes the sense of the voltage comparison between the X_2 and X_4 signals and to adjust the X_3 value to the appropriate value. This is illustrated in Table 4.

The design of the circuits used to implement these procedures is discussed in Appendix A.

2.5 OUTPUT DATA

The output information required from the instrumentation system include the following:

- Date and time of each slam or series of slams
- (Concurrent speed, sea state and heading information can be obtained from the ships log)
- Time-histories of the following measured quantities:
    - Relative height of altimeter over water
    - Strains
    - Pressures
    - Accelerations.

Table 4. Controller Settings and Computed Quantities for Bow Flare and Bottom Slams.

QUANTITY	BOW FLARE SLAM	BOTTOM SLAM
$\overline{X}$ (computed by Wave Height Averager)	Height of Altimeter above mean water level	Height of Altimeter above mean water level
X_3 (manual setting)	Height of Altimeter above lowest Bow Flare Pressure Gage	Height of Altimeter above ship bottom
$X_2 = \overline{X} - X_3$ (Computed)	Positive	Negative
$X_4 = X - \overline{X}$ (Computed)	Positive when bow is high	Negative when bow is low
Signal to Activate Tape Drive	$X_4 > X_2$	$X_4 < X_2$
V_S Relative Vertical Velocity at Instant of Slam	Computed as (dX/dt)* when $X = X_3$	

* The time derivative dX/dt may require filtering and/or averaging in order to obtain a usable value.

As well as the actual measurements a number of quantities may be derived from the measured data. Some quantities may be computed very readily from the measured data while others may require considerable further development effort:

- Relative vertical velocity is one of the most important parameters characterizing a slam. In theory it can be derived by taking the time derivative of the relative height signal but, in practice, this is not easy to do as the relative height signal is typically very noisy. By appropriate filtering of the wave-height signal and/or averaging of the derived velocity over a short time period it should be possible to obtain usable values. The alternative would be to determine relative vertical velocity by hand from the trace of relative height which is a simple operation but rather time-consuming.

  The relative vertical velocity most often used is that which corresponds to the initiation of the slam.

- Average pressures have been found to provide information which is more usable by the designer than point pressures. Perhaps the most comprehensive series of tests yet undertaken to determine slamming loads and pressures are those currently being conducted on the XR-1D test craft by the Surface Effect Ship Test Facility (SESTF) at the Patuxent River Naval Air Station (Reference 33). The majority of these tests are being run in the "hullborne" condition, so that the XR-1D has many of the characteristics of a displacement ship.

  A specially designed module equipped with nineteen 8" x 8" pressure panels and seven pressure gages has been incorporated into the bottom of this craft to allow time histories of pressure to be obtained under slam conditions. In addition to the direct measurements from each panel the signals from the panels are summed in seven different combinations so that indications of average pressures over areas of different sizes can be obtained. These pressure-area relationships provide information that can be used by the designer for the design of small areas such as plating panels or larger areas such as main frames. The pressures measured over larger areas than the individual gages should be more amenable to Froude scaling between model and full-scale experiments.

3. PRELIMINARY LABORATORY TESTS

A series of preliminary tests were carried out to evaluate the operation of the various parts of the experimental instrumentation package. These tests are described in the following paragraphs.

3.1 COMPARATIVE TESTS OF PRESSURE GAGES

In order to make a rational selection of pressure gages for the proposed ship-board installation a set of four different gages were compared. The four gages were identified in Table 2.

In order to provide the gages with a realistic environment all four were mounted in an 18-inch square panel of one-inch thick mild steel plate, as shown in Figure 10. The scale characteristics of each transducer are listed in Table 5.

3.1.1 Effect of Temperature Change

One frequently occurring problem with pressure gages in impact situations is their sensitivity to changes of temperature, in particular, to thermal shock. (See, for example, Reference 19). The thermal-shock problem could be particularly significant in the case of the bow-flare pressure gages, for example, which could suffer a sudden change in temperature, from bright sunlight to sea-water quenching in an impact situation.

The results of a simple, slow-rate variation in temperature with time is shown in Figure 11. All four of the gages exhibit satisfactory stability under these conditions as the largest recorded change is about 0.5% of the full-scale reading. The Dynesco and BLH gages show less than o.25% change.

3.1.2 Effects of Thermal-Shock

The results of two "thermal-shock" tests are shown in Table 6 and indicated pressure time-histories are shown in Figure 12. It is at once apparent that the Kulite gage is completely unsuitable for this application as a sudden, 20°F drop in temperature resulted in an apparent impact pressure of 83 psi (16.3% of full-scale). The BLH and Sensotec gages were most satisfactory from this point of view as the apparent pressures registered were less than 1% of full-scale in each case.

3.1.3 Effect of Acceleration

The sensitivity of the pressure gages to impact type accelerations was also tested by subjecting the panel to a series of mechanical impacts. The relative performance of the four gages is shown in Figure 13. The Dynesco and Kulite gages were much superior to the BLH and Sensotec gages in this regard. In view of the relatively low acceleration environment experiences during ship slamming (peak transient accelerations of up to 1g, Reference 5) this factor is not expected to be very significant. However, gage locations where local panel vibrations are probable should be avoided.

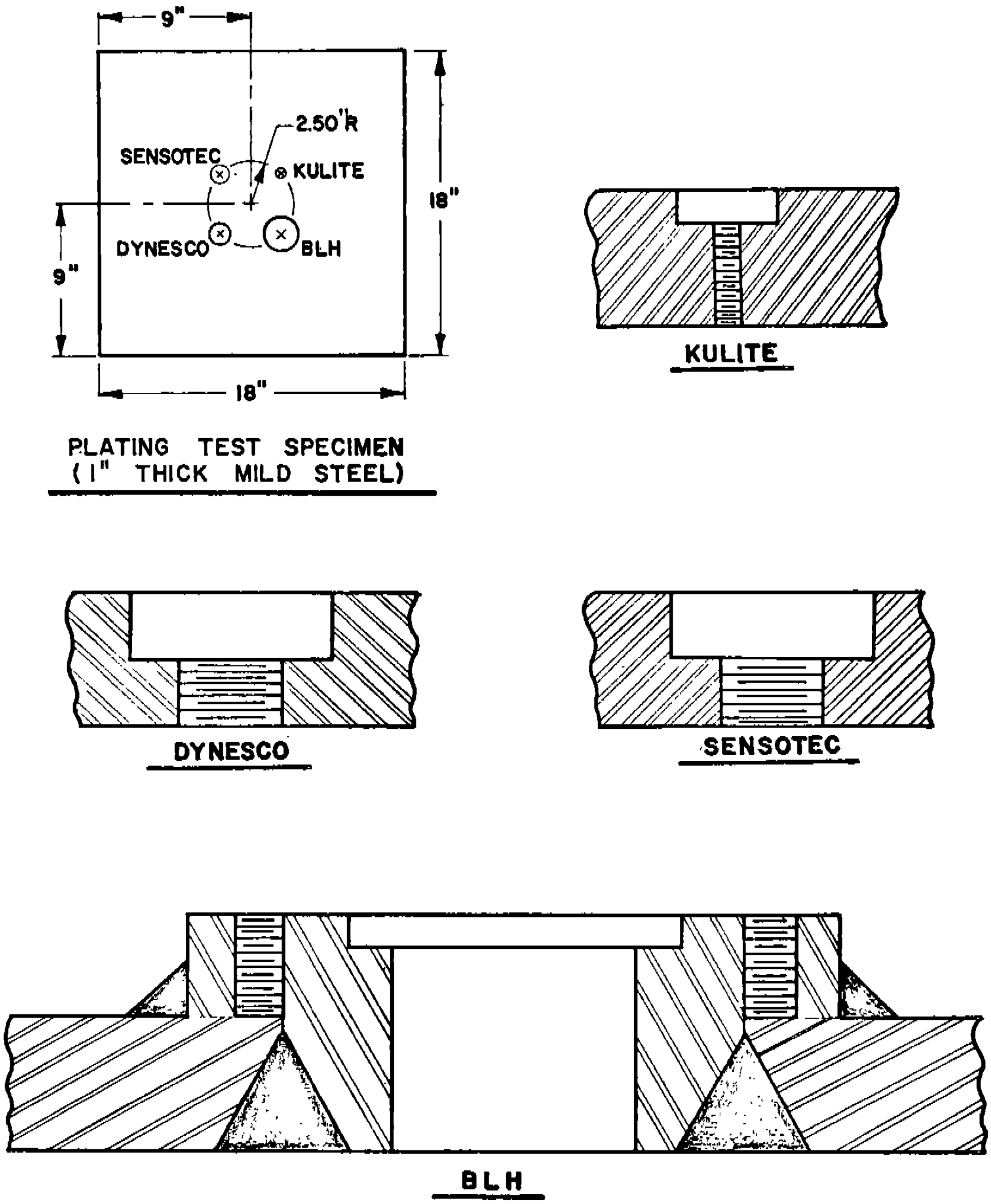


Figure 10. Test Specimen Transducer Installation Details.

Table 5. Pressure Transducer and Galvonometer Sensitivity Details.

Signal Cond. Channel	Transducer Excitation	Pressure Transducer	Transducer Range	Transducer Sensitivity	Galvonometer Channel	Galvonometer Sensitivity
1	10V	BLH	350 psi	3.0 Mv/V	1	.984 V/in
2	10V	Dynesco	500 psi	3.08 Mv/V	2	.588 V/in
3	10V	Sensotec	350 psi	2.98 Mv/V	3	.574 V/in
4	-	-	-	-	-	-
5	-	-	-	-	-	-
6	10V	Kulite	500 psi	7.45 Mv/V	4	.593 V/in

Example of data reduction:

$$\text{Output(PSI)} = \frac{(e_G)(\delta)(R)}{(G)(e_T)(E)}$$

where: e_G = Galvonometer Sensitivity (Mv/in)
δ = Galvonometer Deflection (Inches)
R = Maximum Transducer Range
G = Signal Conditioner Channel Gain
E = Transducer Excitation (Volts)
e_T = Transducer Sensitivity (Mv/V)

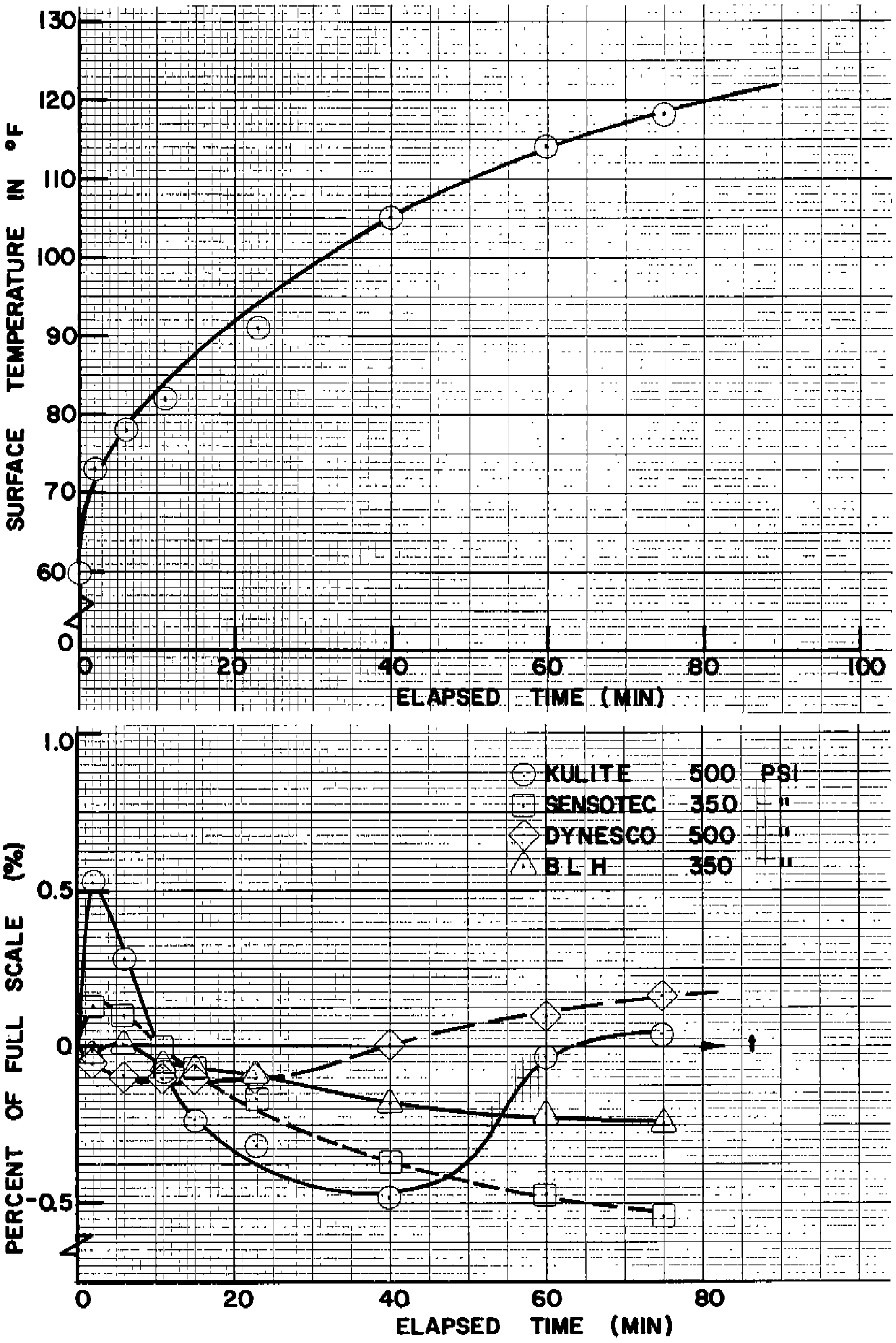


Figure 11. Pressure Gage Drift with Change of Temperature.

Table 6. Response of Transducers to a Simulated Thermal Shock.

TRANSDUCER	GALVONOMETER CHANNEL	GAIN	THERMAL SHOCK #	TRANSDUCER OUTPUT (MV)	TRANSDUCER OUTPUT (PSI)	TRANSDUCER OUTPUT % F.S.
KULITE	4	100	1	1.23	82.6	16.5
			2	1.23	82.6	16.5
SENSOTEC	3	2000	1	.115	1.4	0.4
			2	.16	1.9	0.5
DYNESCO	2	2000	1	.44	7.14	1.43
			2	.29	4.70	0.94
BLH	1	2000	1	.22	2.57	.73
			2	.28	3.27	.93

NOTE: "Thermal Shocks" were caused by quenching plate temperature of about 120°F to 98°F.

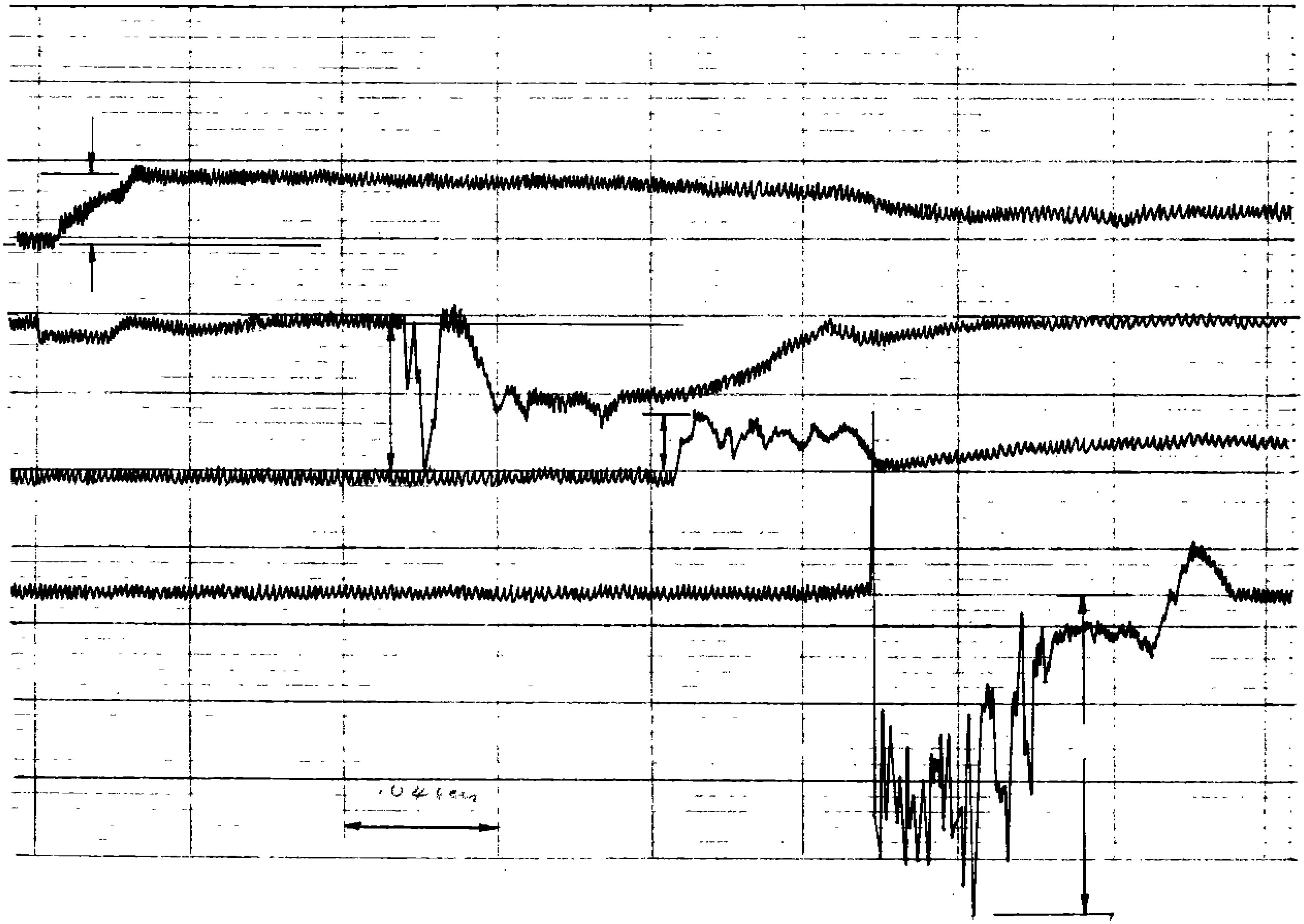


Figure 12. Response of the Pressure Transducers to a Thermal Shock. (Figure was traced from Visicorder Record)

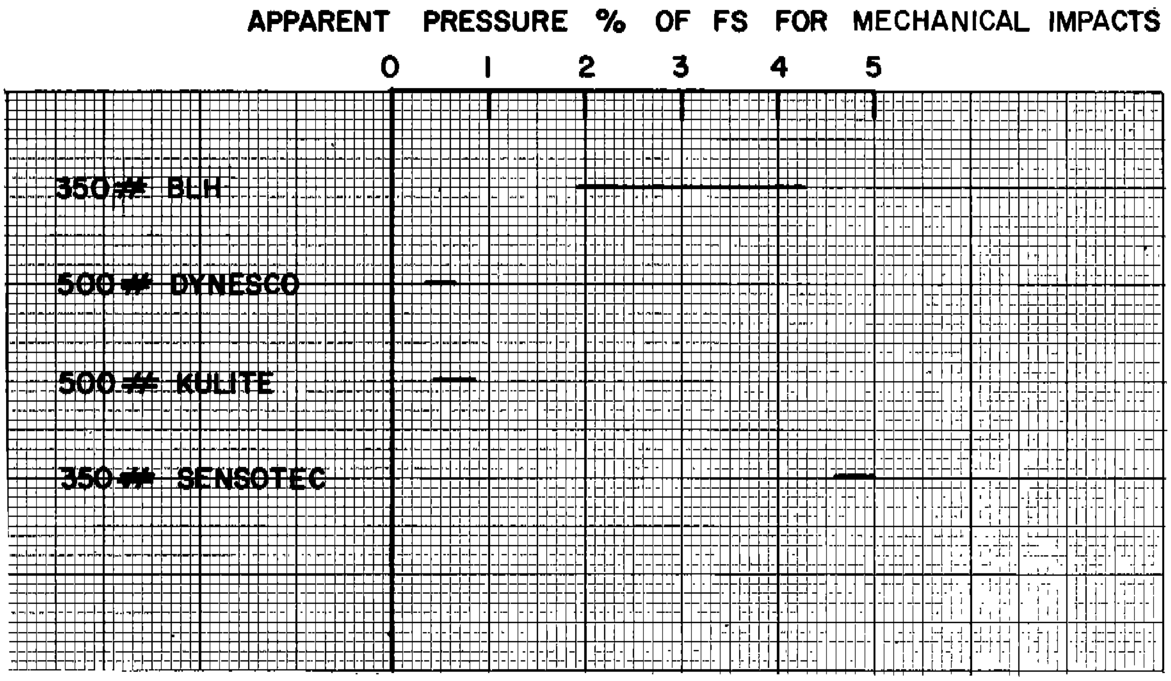


Figure 13. Pressure Gage Sensitivity to Impact Accelerations.

3.1.4 Summary of Pressure Gage Testing

On the basis of these tests there seemed to be no reason to replace the BLH gages which had given good service on the WOLVERINE STATE and which had the additional advantage of being closer to the scaled-up size of any gages that could be used in comparative model tests.

3.2 IMPACT TESTS

The purpose of the impact tests was twofold:

- to evaluate the response of the four pressure gages to transient, impact pressures
- to verify the proper functioning of the operating circuits and recording equipment.

An impact facility was constructed using a simple water tank and a drop specimen guided by a parallel linkage. The impact panel shown in Figure 10 was connected to the lower face of the drop specimen. Two different orientations were used: one in which the specimen was installed parallel to the water surface and in the other it was installed at a deadrise angle of 15°.

3.2.1 Zero-Deadrise Drop Tests

A series of drops were made from different heights above the water in each case. The zero deadrise impacts are listed in Table 7 and pressure-time histories are shown in Figures 14 - 18. In all cases some relatively low-frequency oscillation is apparent at about 100-150 Hz while in each of the two higher drop heights (Figures 17 and 18) a severe, high-frequency ringing occurs at 2-3 KHz.

The maximum pressures measured in each case are plotted in Figure 19. They exhibit a trend similar to that reported in References 20 and 21 for flat-plate impacts.

The dashed line in Figure 19 represents the maximum pressures recorded in the tests described in these references. The impirical equation for this limit line is:

$$\hat{P} = 3.69 \, V_S^{1.7}$$

where $\hat{P}$ is impact pressure in psi

and V_S is the relative vertical velocity at impact in ft/sec.

All of the measured points in the drop tests described here are seen to lie well below this impirical limit line. Frequencies calculated from the pressure rise-time are also plotted and show an approximately linear trend with increase of impact velocity, as expected.

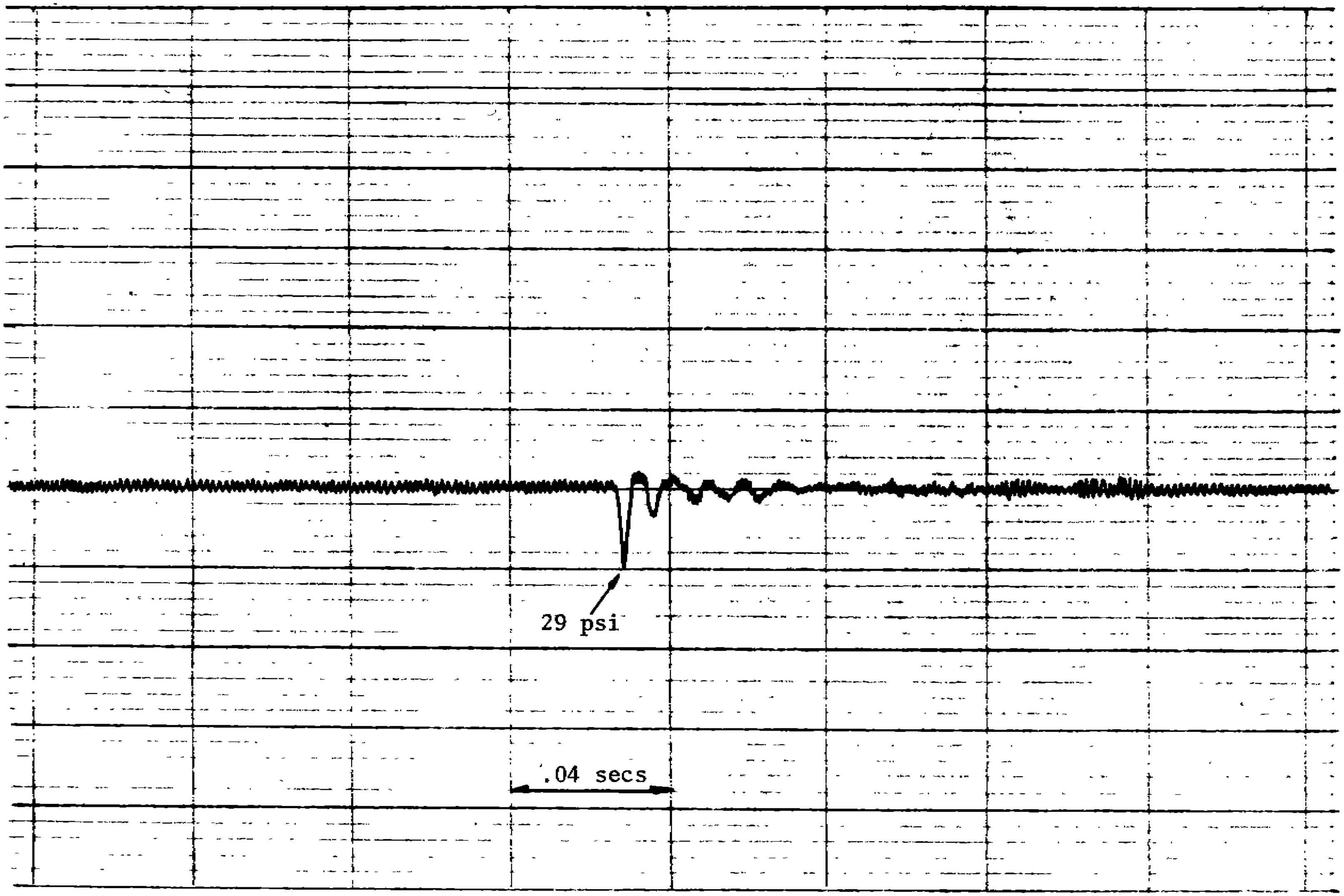
3.2.2 Fifteen-Degree-Deadrise Drop Tests

Tests were also conducted with the same test specimen mounted on one side of a 15° deadrise V-wedge. Time histories of a series of tests are shown in Figures 20-23. For comparison the accelerations predicted from simple V-wedge theory (Reference 22) are also shown. The agreement is quite good except for the fact that the measured acceleration rise-time is rather shorter than predicted by the theory in all cases. This could be due in part to the low-frequency oscillation (about 50 Hz) that continues well after the peak impact acceleration. This oscillation is probably dependent on the structural characteristics of the test rig.

Table 7. Impact Pressure and Rise Time for a Flat Plate Impact at Various Impact Velocities.

VELOCITY (Ft/Sec)	PRESSURE (PSI)	RISE TIME (SEC)	FREQUENCY* (Hz)
5.66	29	.0018	139
8.00	49	.0016	156
11.31	103	.0014	179
13.86	212	.0008	313
14.97	277	.0008	313

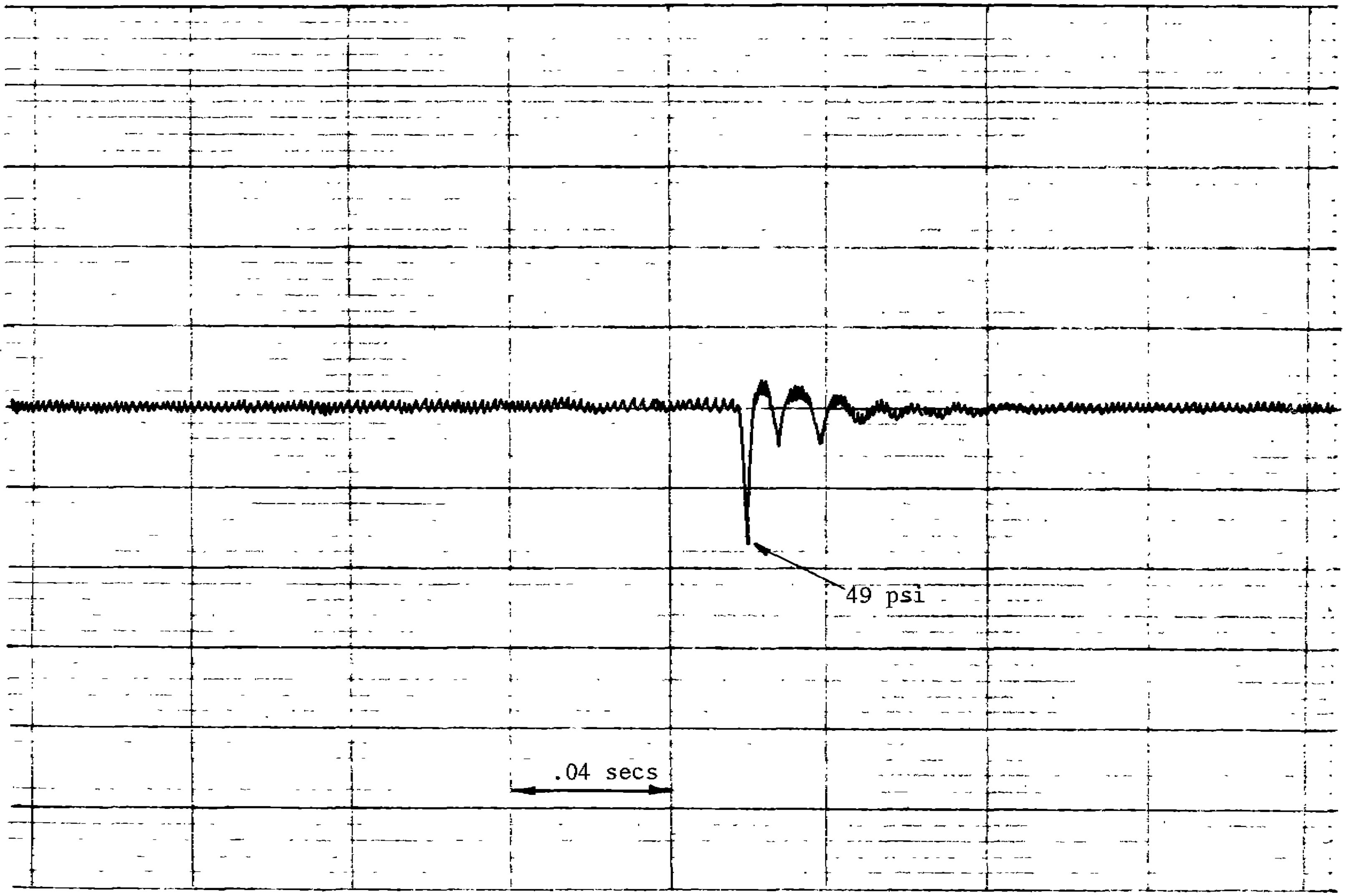
* "Frequency" is calculated as 1/(4 x Rise Time)



TRANSDUCER: BLH DHF-350
SIGNAL CONDITIONER: VISHAY; GAIN 200
GALVONOMETER: M1650; 0-1000 HZ

PAPER SPEED: 25 ips
DROP HEIGHT: 1/2 Ft.

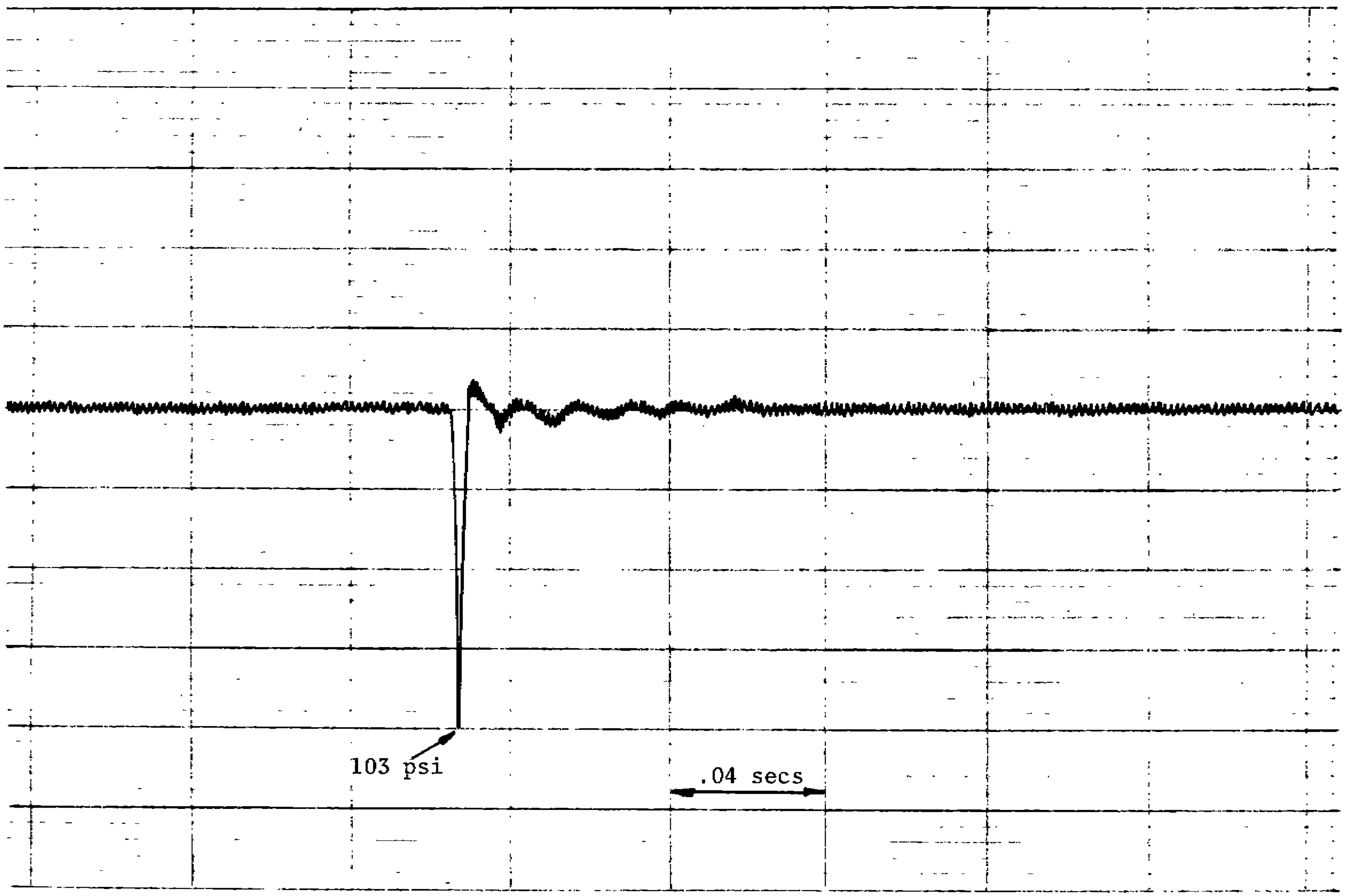
Figure 14. Pressure-Time History for Zero Deadrise Impact for Six-Inch Drop Height. (Figure was traced from Visicorder Record)



TRANSDUCER: BLH DHF-350
SIGNAL CONDITIONER: VISHAY; GAIN 200
GALVONOMETER: M1650; 0-1000 HZ

PAPER SPEED: 25 ips
DROP HEIGHT: 1 Ft.

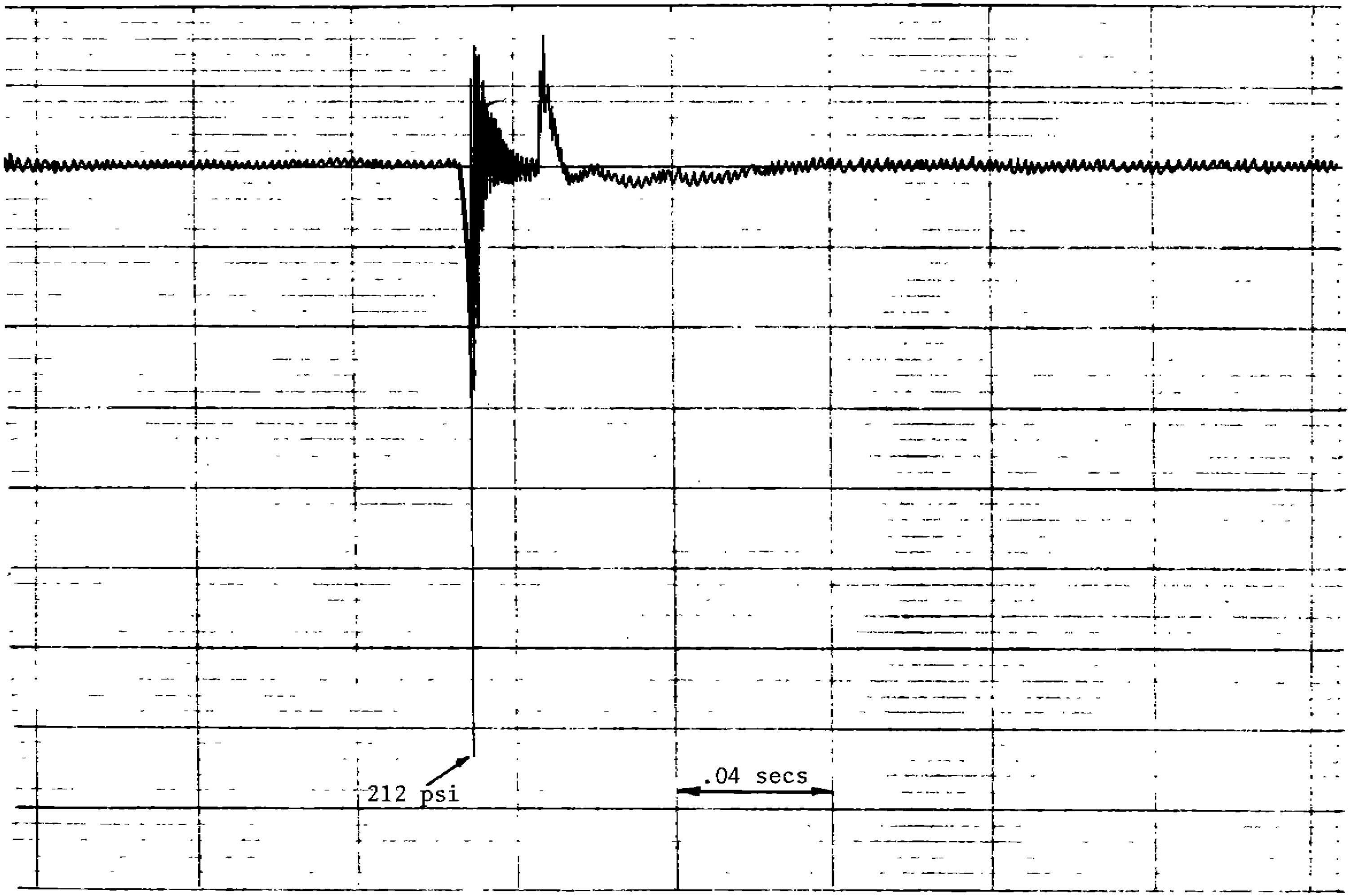
Figure 15. Pressure-Time History for Zero Deadrise Impact for Twelve-Inch Drop Height. (Figure was traced from Visicorder Record)



TRANSDUCER: BLH DHF-350
SIGNAL CONDITIONER: VISHAY; GAIN 200
GALVONOMETER: M1650; 0-1000 HZ

PAPER SPEED: 25 ips
DROP HEIGHT: 2 Ft.

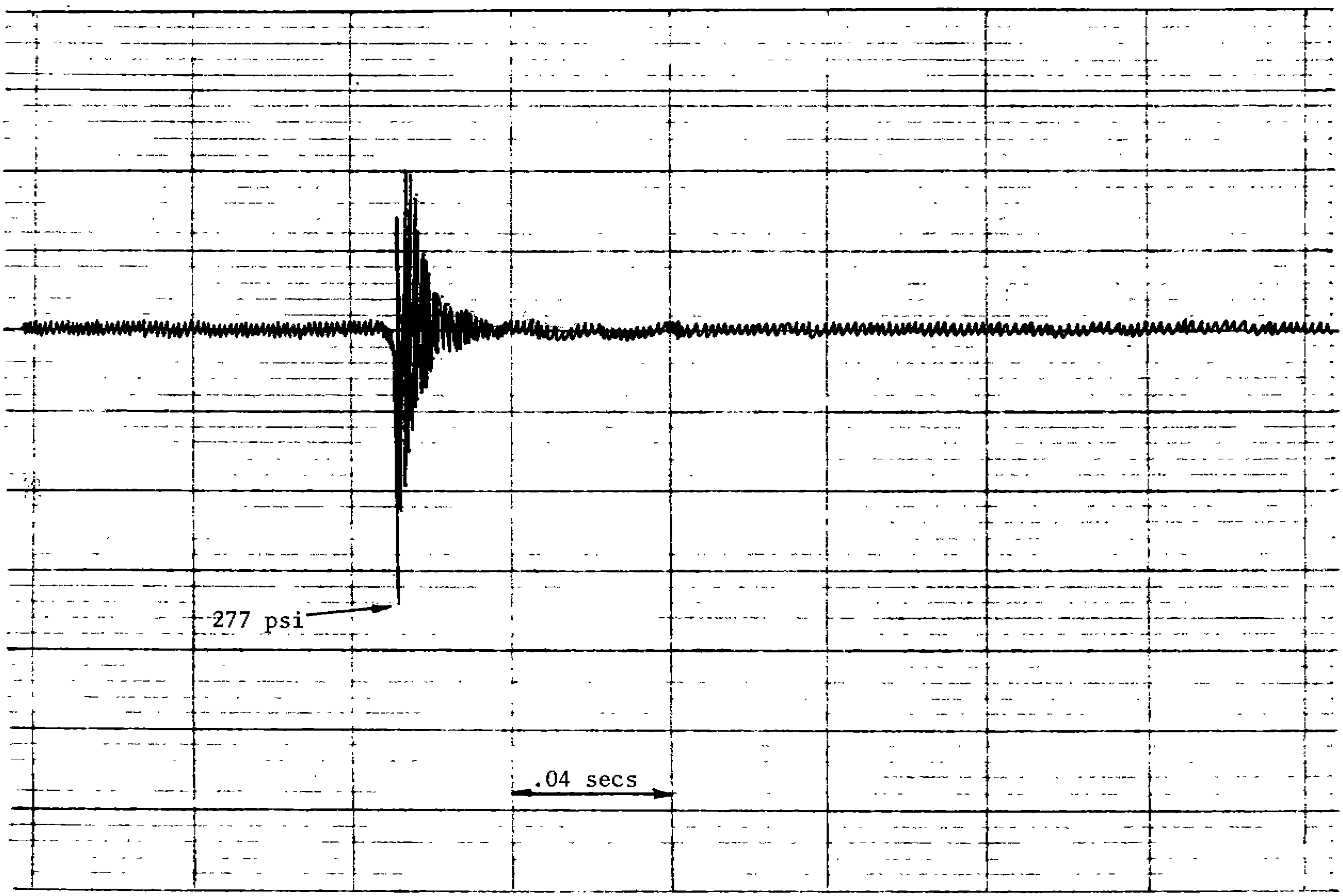
Figure 16. Pressure-Time History for Zero Deadrise Impact for Twenty-Four Inch Drop Height. (Figure was traced from Visicorder Record)



TRANSDUCER: BLH DHF-350
SIGNAL CONDITIONER: VISHAY; GAIN 200
GALVONOMETER: M1650; 0-1000 HZ

PAPER SPEED: 25 ips
DROP HEIGHT: 3 Ft.

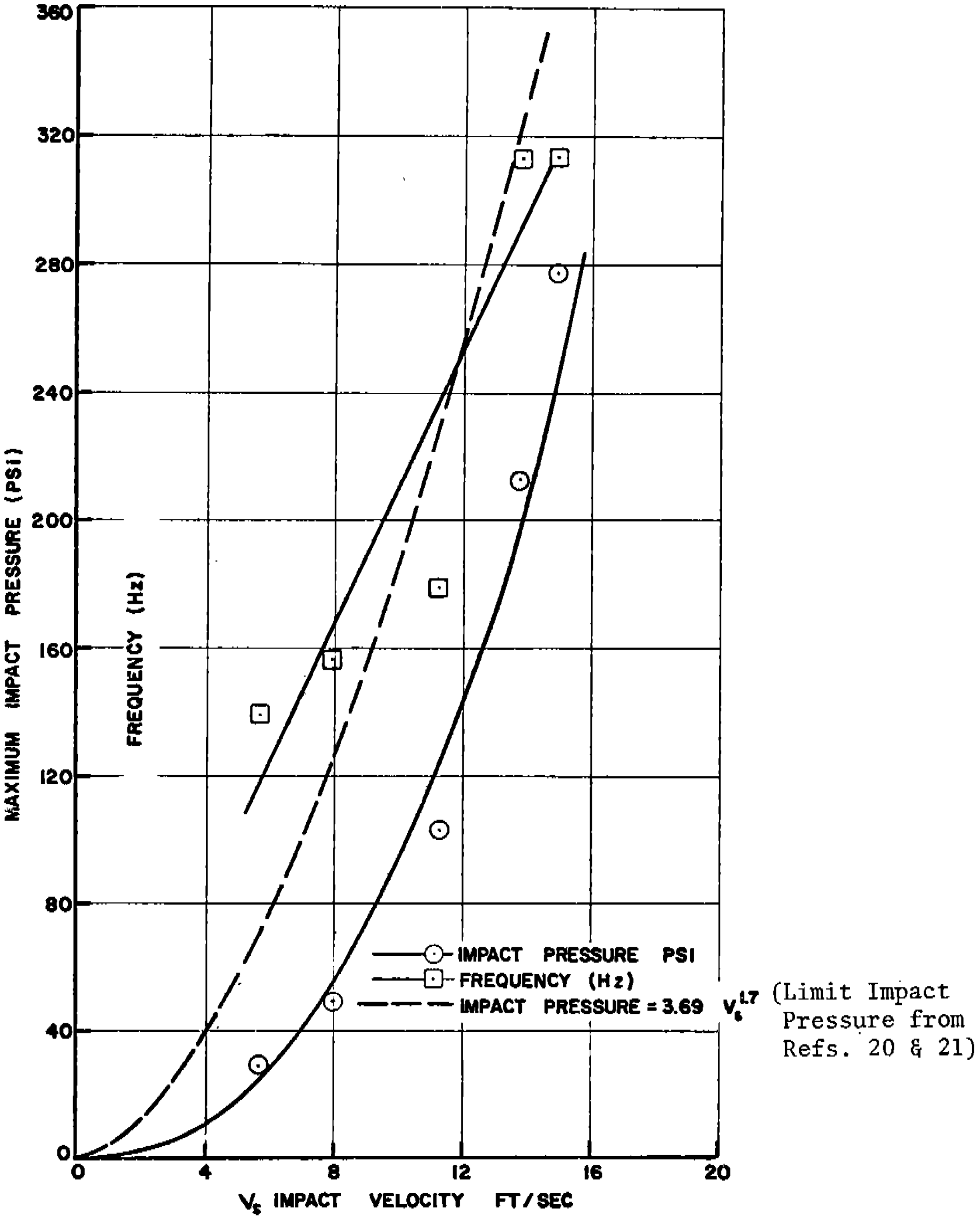
Figure 17. Pressure-Time History for Zero Deadrise Impact for Thirty-Six Inch Drop Height. (Figure was traced from Visicorder Record)



TRANSDUCER: BLH DHF-350
SIGNAL CONDITIONER: VISHAY; GAIN 200
GALVONOMETER: M1650; 0-1000 HZ

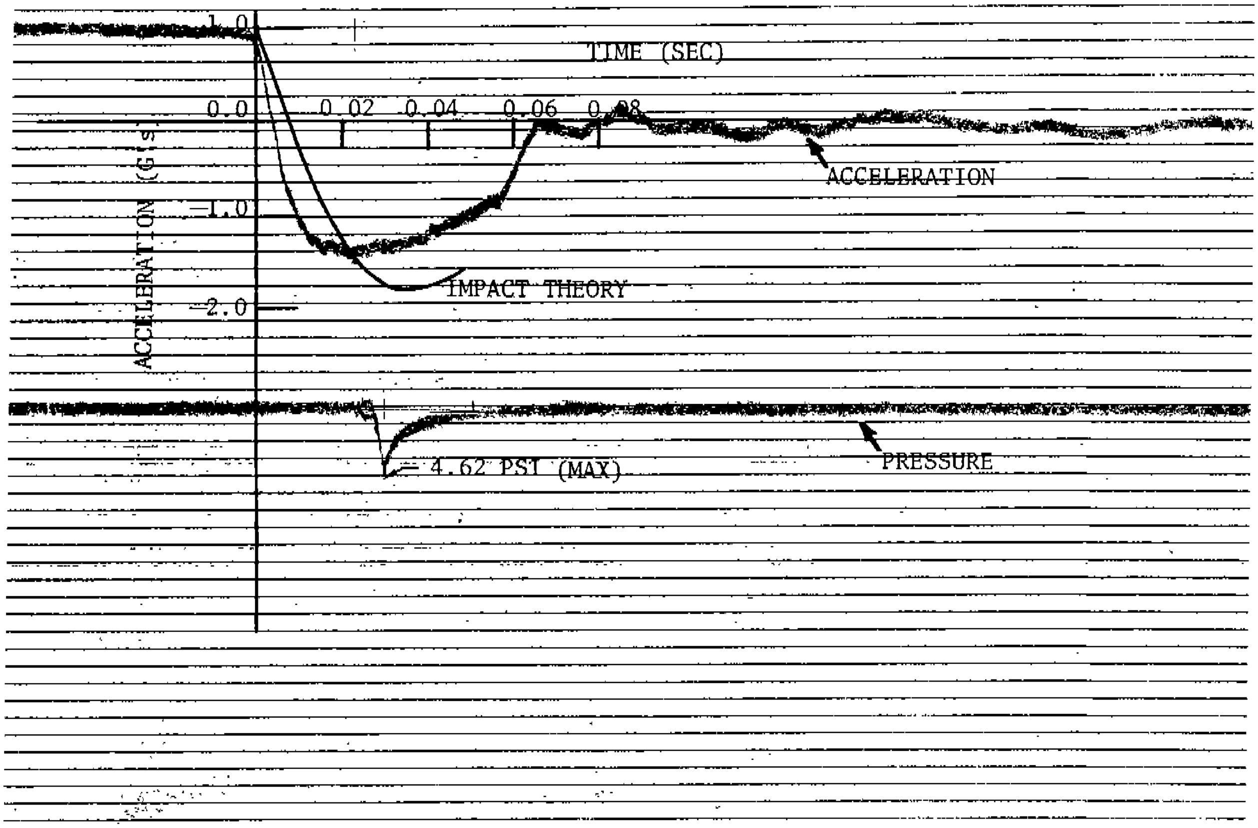
PAPER SPEED: 25 ips
DROP HEIGHT: 3-1/2 Ft.

Figure 18. Pressure-Time History for Zero Deadrise Impact for Forty-Two Inch Drop Height. (Figure was traced from Visicorder Record)



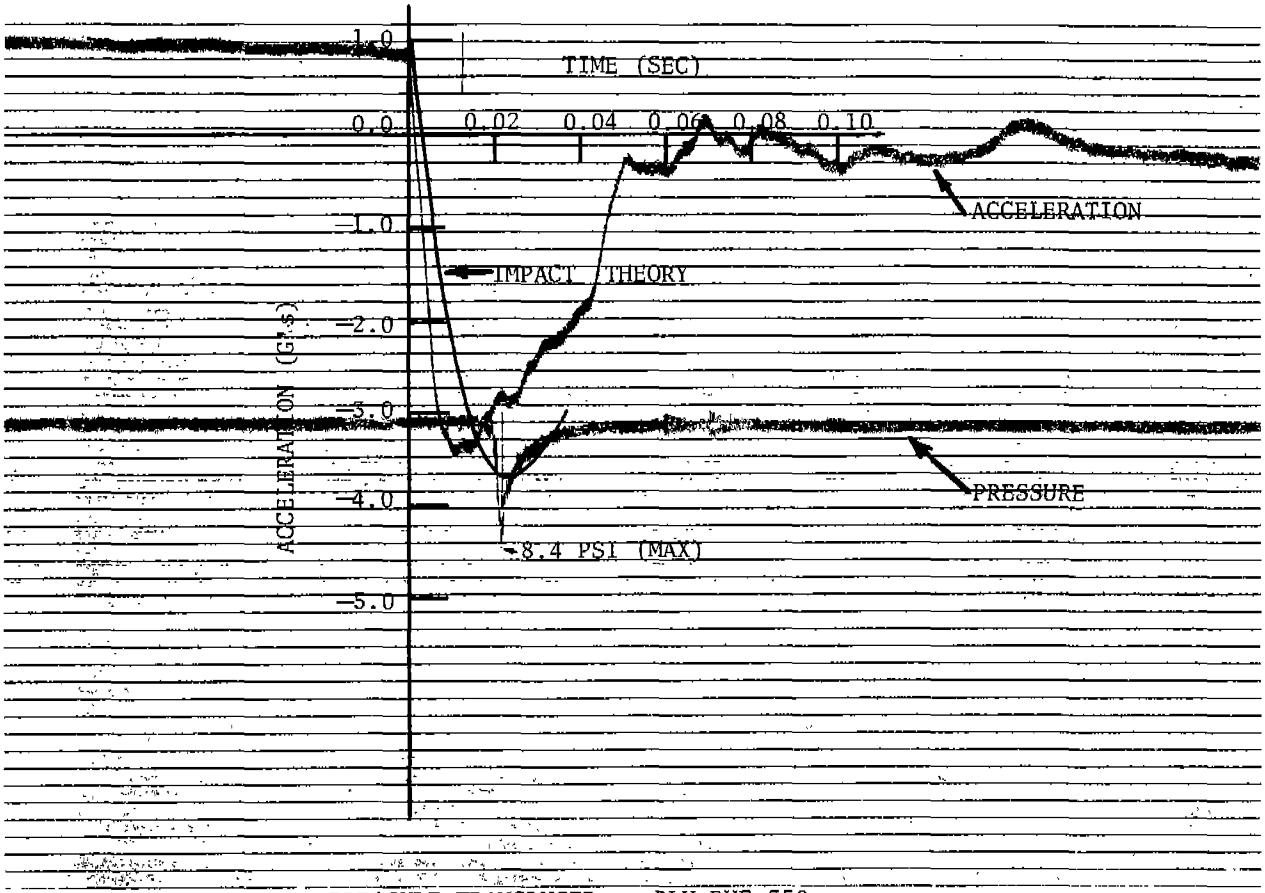
(Limit Impact Pressure from Refs. 20 & 21)

Figure 19. Maximum Impact Pressures Measured in Zero Deadrise Drop Tests.



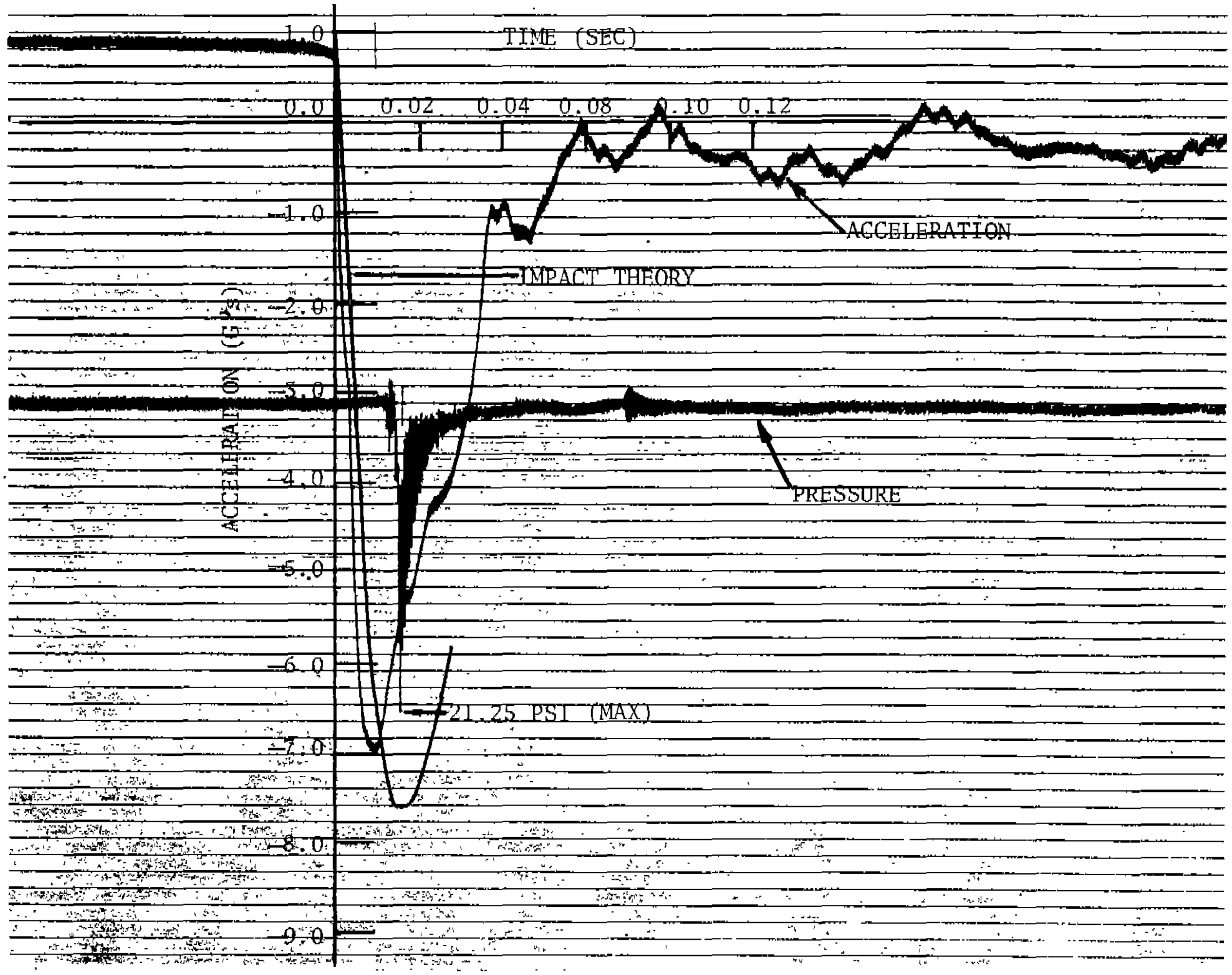
PRESSURE TRANSDUCER:	BLH DHF 350
ACCELEROMETER:	SERTA MODEL 100
PANEL WEIGHT:	450 LB.
DEADRISE ANGLE:	15 DEGREES
PLANFORM AREA:	9 SQ. FT. (3 FT x 3 FT)
IMPACT VELOCITY:	5.67 FT/SEC
CHART SPEED:	25 IPS

Figure 20. Time-History of Acceleration and Pressure During Vertical Drop Tests of a 15° Deadrise V-Wedge. (Impact Velocity = 5.67 ft/sec.)



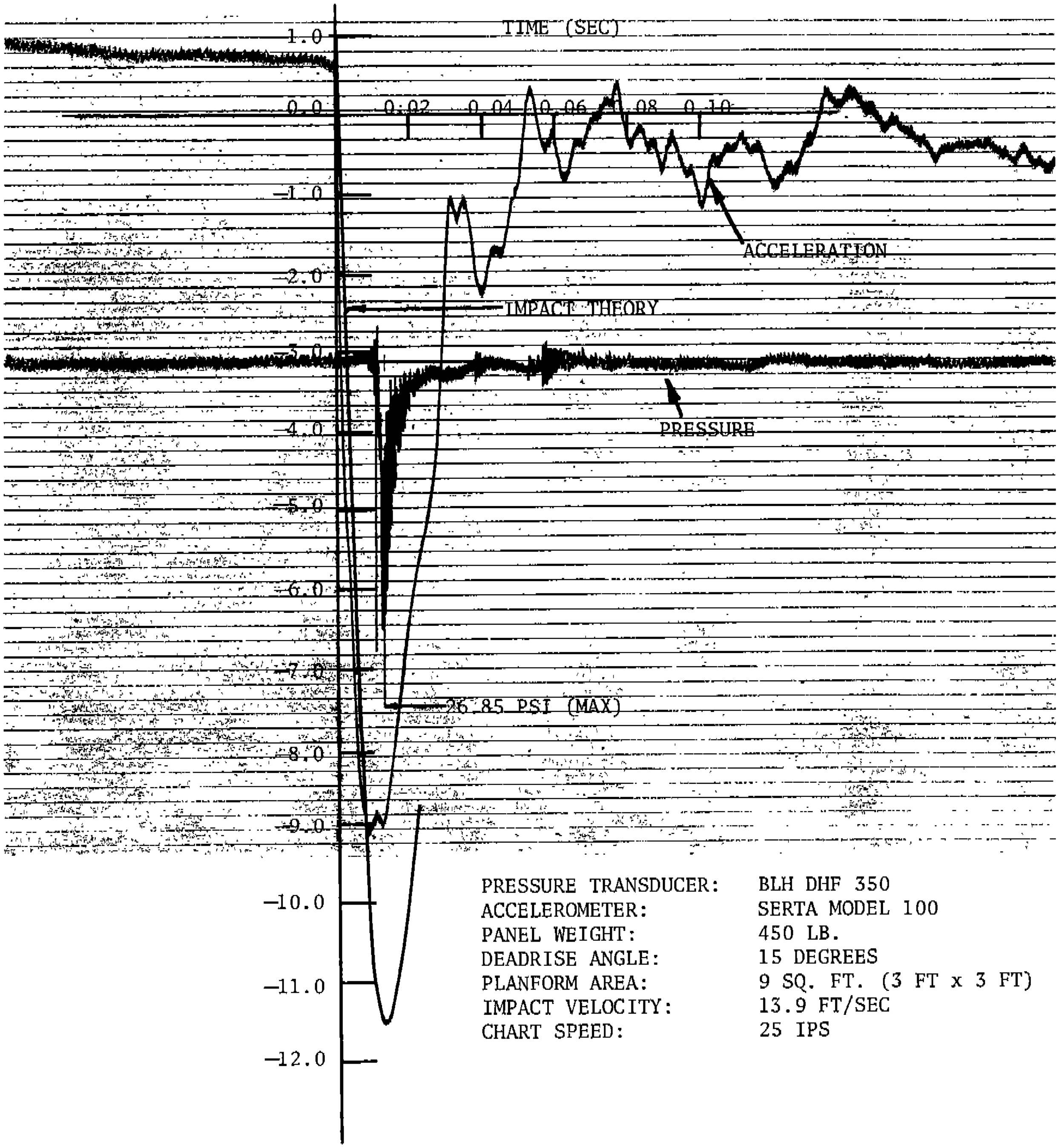
PRESSURE TRANSDUCER:	BLH DHF 350
ACCELEROMETER:	SERTA MODEL 100
PANEL WEIGHT:	450 LB.
DEADRISE ANGLE:	15 DEGREES
PLANFORM AREA:	9 SQ. FT. (3 FT x 3 FT)
IMPACT VELOCITY:	8.02 FT/SEC
CHART SPEED:	25 IPS

Figure 21. Time-History of Acceleration and Pressure During Vertical Drop Tests of a 15° Deadrise V-Wedge. (Impact Velocity = 8.02 ft/sec.)



PRESSURE TRANSDUCER:	BLH DHF 350
ACCELEROMETER:	SERTA MODEL 100
PANEL WEIGHT:	450 LB.
DEADRISE ANGLE:	15 DEGREES
PLANFORM AREA:	9 SQ. FT. (3 FT x 3 FT)
IMPACT VELOCITY:	11.34 FT/SEC
CHART SPEED:	25 IPS

Figure 22. Time-History of Acceleration and Pressure During Vertical Drop Tests of a 15° Deadrise V-Wedge. (Impact Velocity = 11.34 ft/sec)

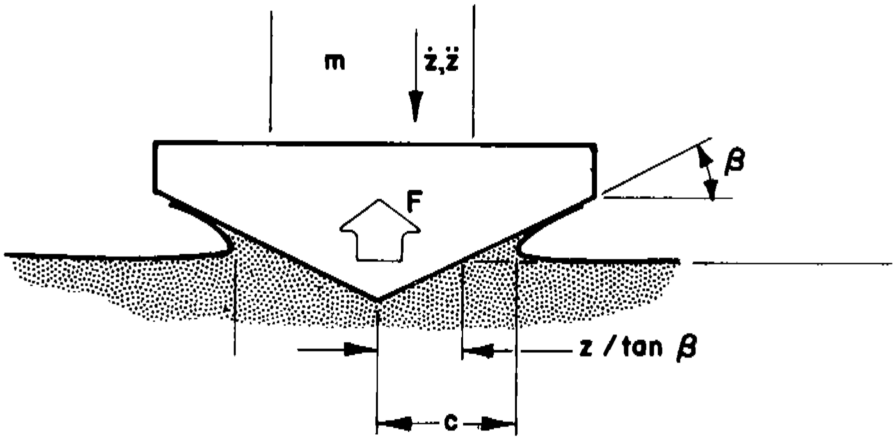


PRESSURE TRANSDUCER: BLH DHF 350
ACCELEROMETER: SERTA MODEL 100
PANEL WEIGHT: 450 LB.
DEADRISE ANGLE: 15 DEGREES
PLANFORM AREA: 9 SQ. FT. (3 FT x 3 FT)
IMPACT VELOCITY: 13.9 FT/SEC
CHART SPEED: 25 IPS

Figure 23. Time-History of Acceleration and Pressure During Vertical Drop Tests of a 15° Deadrise V-Wedge. (Impact Velocity = 13.9 ft/sec.)

The maximum impact pressures measured are compared with those predicted for the pressure-gage location in Figure 24. In this case, (with deadrise), the pressures are more readily calculated by V-wedge theory and the agreement between theory and experiment in Figure 24 is very good. Frequencies, calculated from the rise-time to maximum pressure are also shown in Figure 24.

The theoretical impact accelerations and time histories were calculated by using conventional hydrodynamic theory.



The upward force, F, on an impacting wedge is given by:

$$F = C_p \cdot \frac{1}{2} \rho \dot{z}^2 \, 2cb \, f_b \qquad (1)$$

where C_p is the average pressure coefficient

$C_p = 2.16 \tan\beta \left(\frac{\pi}{2\beta} - 1\right)^2$ (Ref. 23)

ρ = mass density of water (lb. $\sec^2/\text{ft}^4$)

$\dot{z}$ is the vertical, downward velocity, ft/sec

c is the semi-wetted width, between spray roots, in feet

b is the width measured perpendicular to c in feet

f_b is a correction factor to allow for the model's finite width.

($f_b \simeq$ .88 based on Reference 24)

β is the deadrise angle in radians.

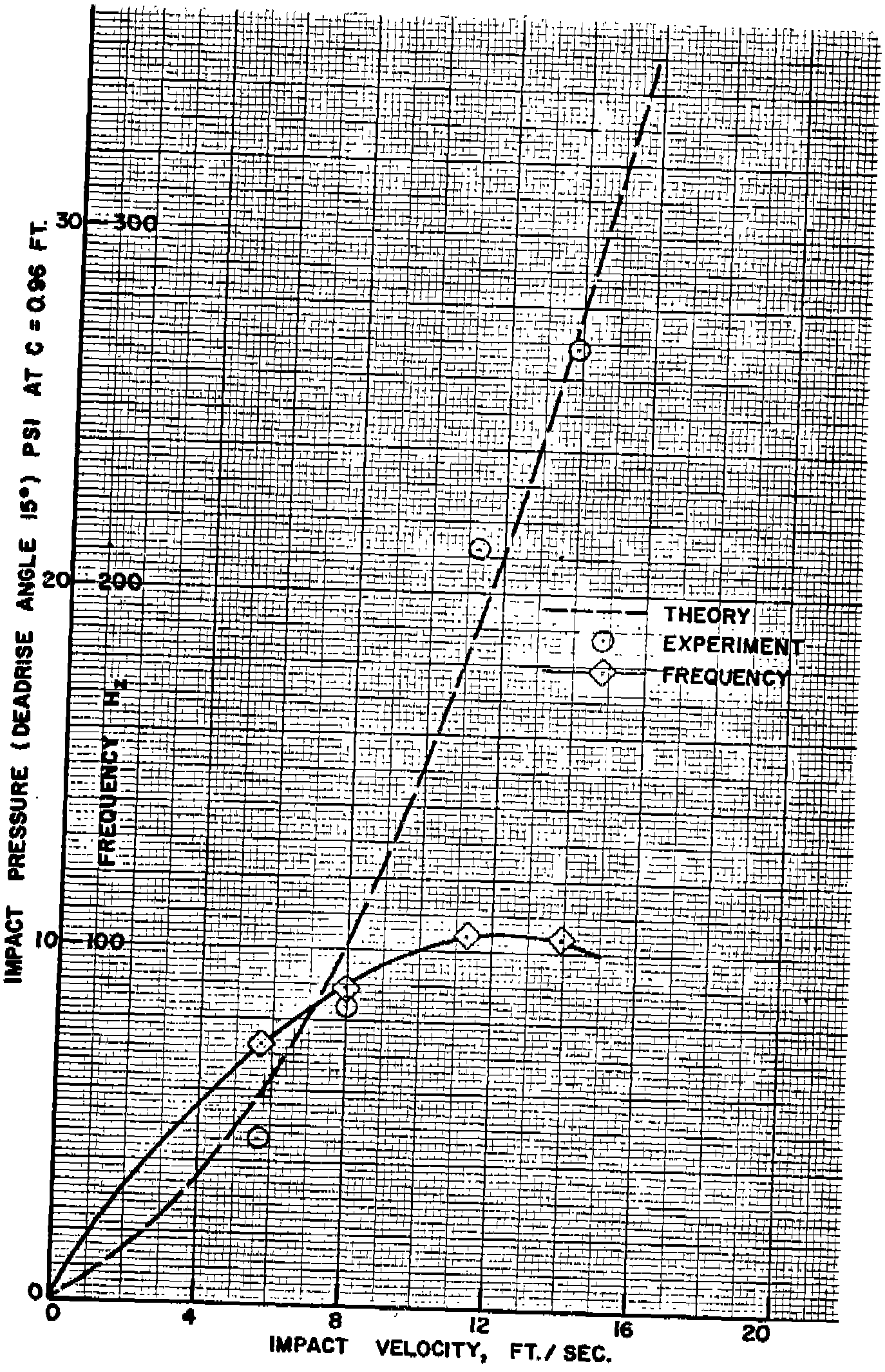


Figure 24. Variation of Maximum Pressure with Impact Velocity for an Inclined Plate Compared to Impact Theory; Weight of Plate = 450 Lbs., Deadrise Angle = 15°, Area = 9 Ft^2.

Also $$F = -m(\ddot{z} - g) \tag{2}$$

and $$c = k_s\, z/\tan\beta \tag{3}$$

where k_s is the "splash-up" factor

$$ks \simeq \pi/2 - \beta(1 - 2/\pi) \qquad \text{(Reference 25)}$$

By combining equations (1), (2) and (3):

$$\ddot{z} + K\,\dot{z}^2\,z = g \tag{4}$$

where $K = C_p\,\rho\dot{z}^2\,cbf_b/(m \tan\beta)$

The peak pressure, $\hat{p}$, at any instant of time can be assumed to be equal to $1/2\rho V_s^2$ where V_s is the true velocity of the stagnation point in space (Reference 25). The stagnation point, for small angles of deadrise (less than say 20°) can be assumed to be above the spray root (Reference 23) so that $\hat{p}$ is given by:

$$\hat{p} \approx \frac{1}{2}\rho\,\dot{c}^2$$

$$= \frac{1}{2}\rho(k_s\,\dot{z}/\tan\beta)^2 \tag{5}$$

Equations (4) and (5) can be evaluated numerically.

The results obtained from these computations were used to plot the theoretical curves shown in Figures 20 thru 23.

3.2.3 Impact Instrumentation

In view of the reasonable agreement obtained between impact theory and experimental measurements it was assumed that the behavior of the BLH pressure gages and Setra accelerometers were satisfactory for the purposes of measuring slam incidents.

In all cases the pressure gages were powered in a manner simulating the proposed shipboard installation and the signals were recorded on the F.M. tape recorder in the manner in which they would be when installed on board ship. The visual signals shown in Figures 14 - 18 and 20 - 23 were obtained by playing back the magnetic tape record to a paper-tape visicorder.

It was considered that, in this way, the feasibility of the signal conditioning and recording equipment was demonstrated as well as the functioning of the instruments themselves.

3.3 TESTS OF THE COLLINS RADAR ALTIMETER

One objective of the current program is to implement the Collins radar altimeter as a wave height sensor. Data from the altimeter is to be recorded, together with the other instrumentation, to provide a time-history of relative wave height and velocity. The programmer/controller will also use inputs from the altimeter to predict the occurrence of relative motions sufficiently large to cause slams, so that the recorder can be activated.

3.3.1 Apparatus Used in Laboratory Tests

The objective of the test was to simulate a shipboard installation of the altimeter as the transmit and receive antenna pair. Since an important consideration in the final shipboard installation will be to minimize the size of the structure supporting the antennas, thus minimizing vulnerability and cost, a ground plate was constructed using Collins' minimum recommended dimensions. (see Figure 25).

As a preliminary check on the altimeter's utility in this application a simple, guide-rail apparatus was constructed to allow moving the antenna plate relative to a reflecting surface, thus simulating the passage of a wave beneath the antennas. The rail was mounted on the side of a wall, 22 feet high, 60 feet wide, of plain cement-block construction, and with one window in the center. The window was used to brace the apparatus and provide access to the recording equipment. Ground around the base of the wall and extending outwards for more than 70 feet was gravel covered. This area was kept clear of vehicles or other reflecting surfaces during the tests. The track was used in two configurations, one for testing at distances from 18 to 30 feet and another for testing between 12 and 24 feet. (See Figure 26).

The carriage allowed for mounting the antenna from 2 to 10 feet out from the wall and at angles of beam inclination (measured from the vertical along an axis parallel to the roofline) ±40° (positive outwards).

3.3.2 Preliminary Tests

A large number of calibration points were taken. These are summarized as Figures 27, 28 and 29. Figure 27 was data produced using a 20 x 40-inch ground plane plate while the data of Figures 28 and 29 were produced using side extensions which nearly double the plate area. (See Figure 25).

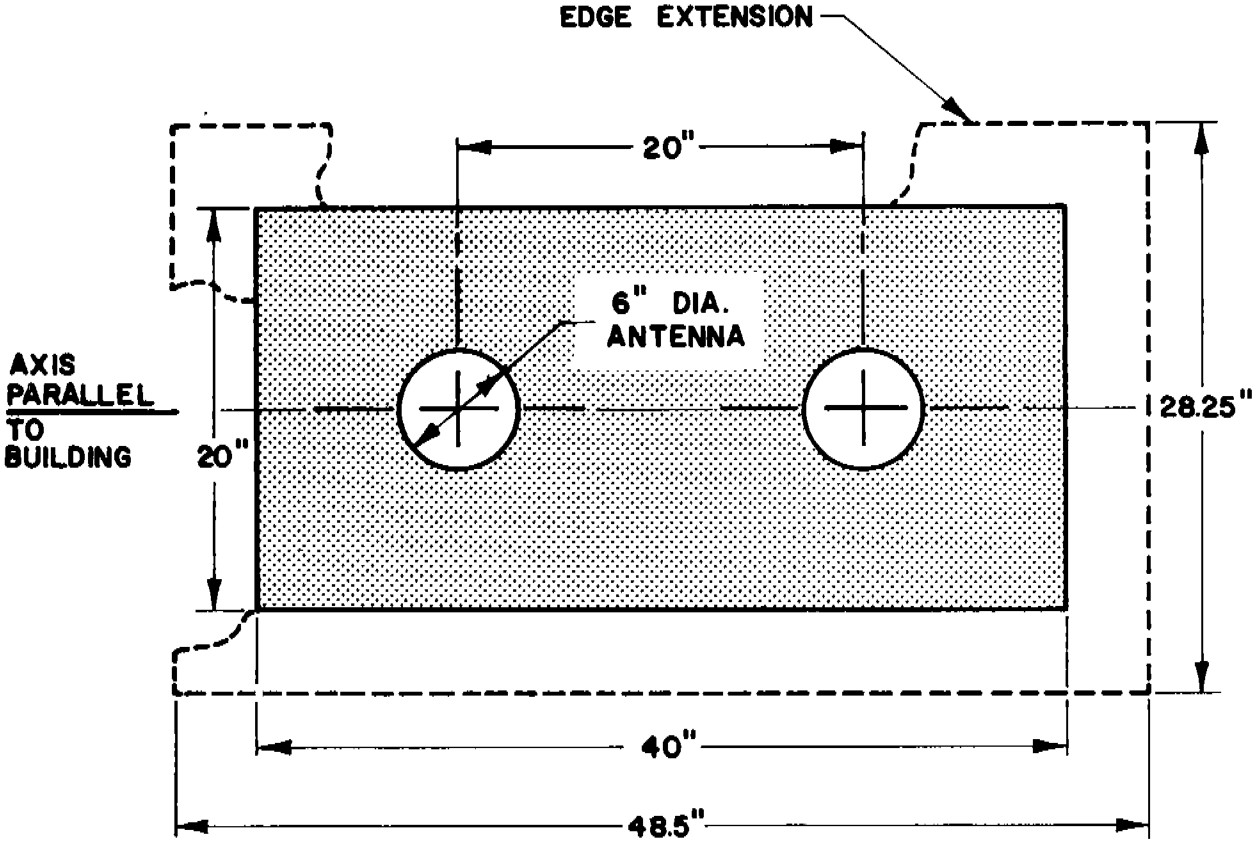


Figure 25. Ground Plane Plate with Antenna Locations and Edge Extension Shown.

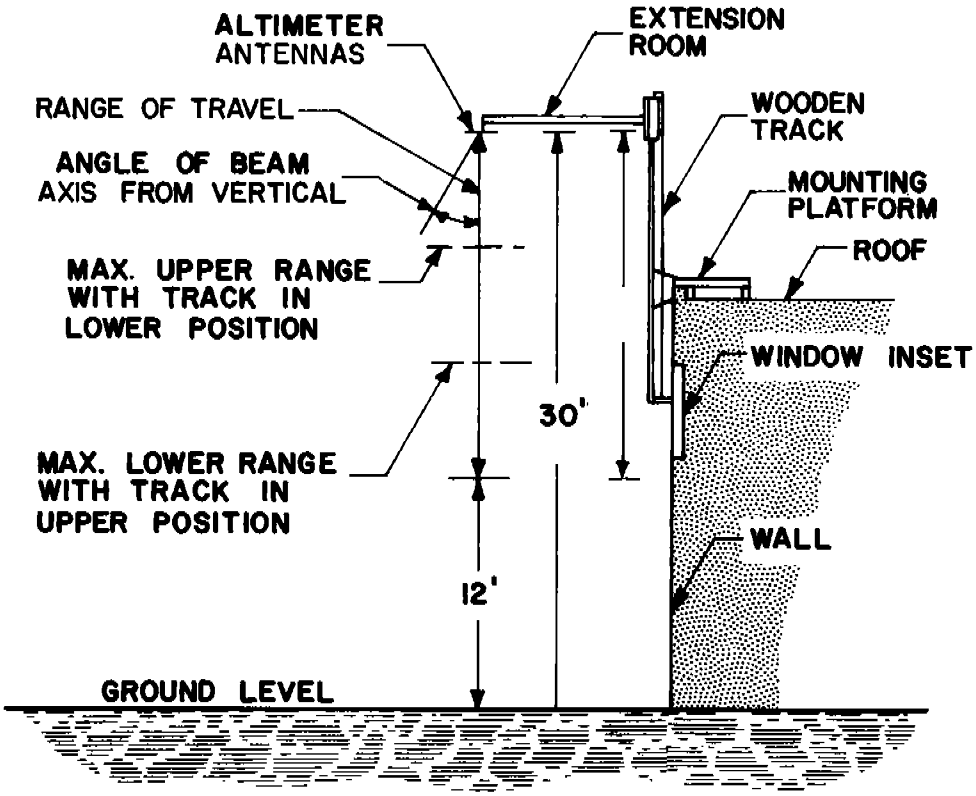


Figure 26. Test Track Mounted in Upper Position on the Building Wall.

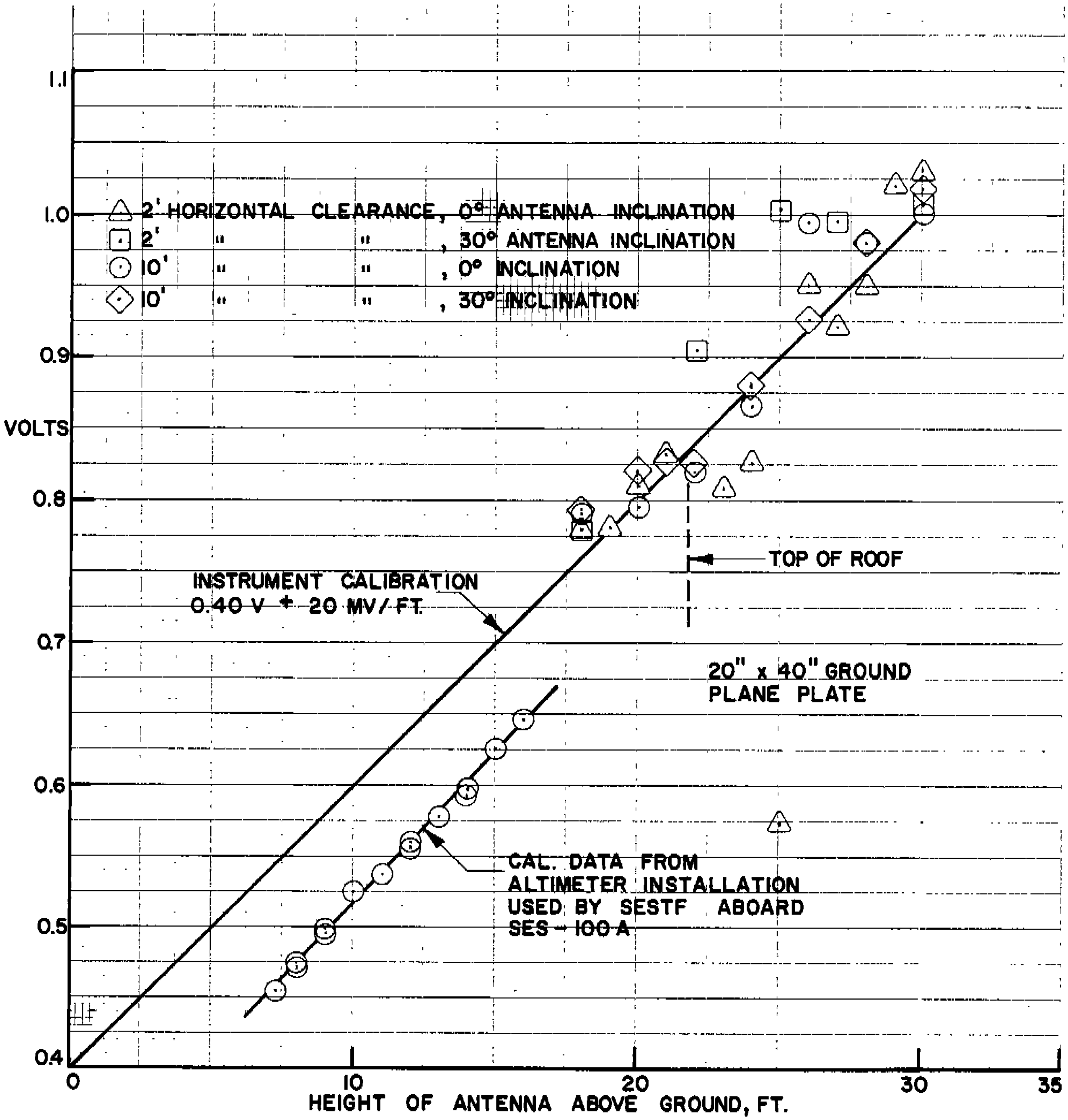


Figure 27. Preliminary Radar Altimeter Calibration Data, 20" x 40" Ground Plate.

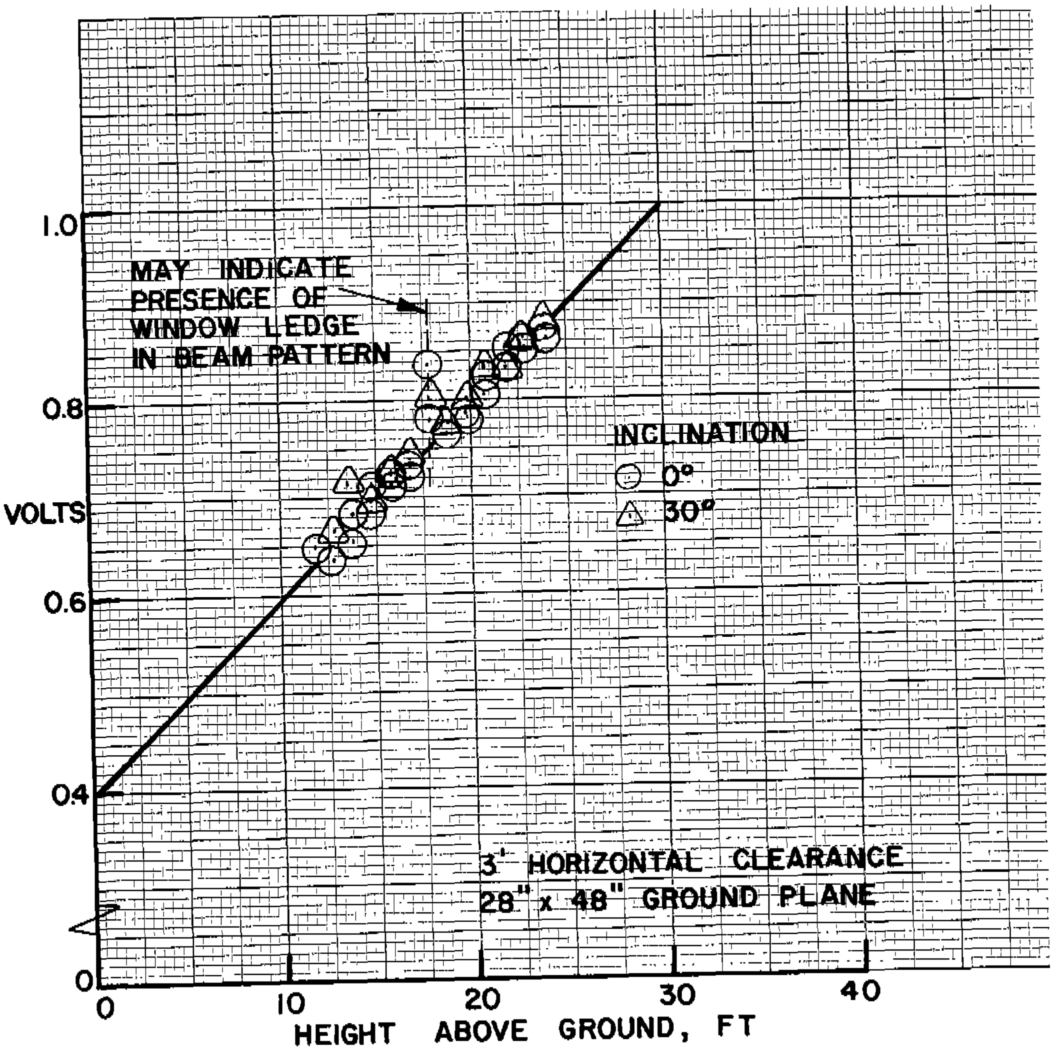


Figure 28. Preliminary Radar Altimeter Calibration, 3 Ft. Clearance.

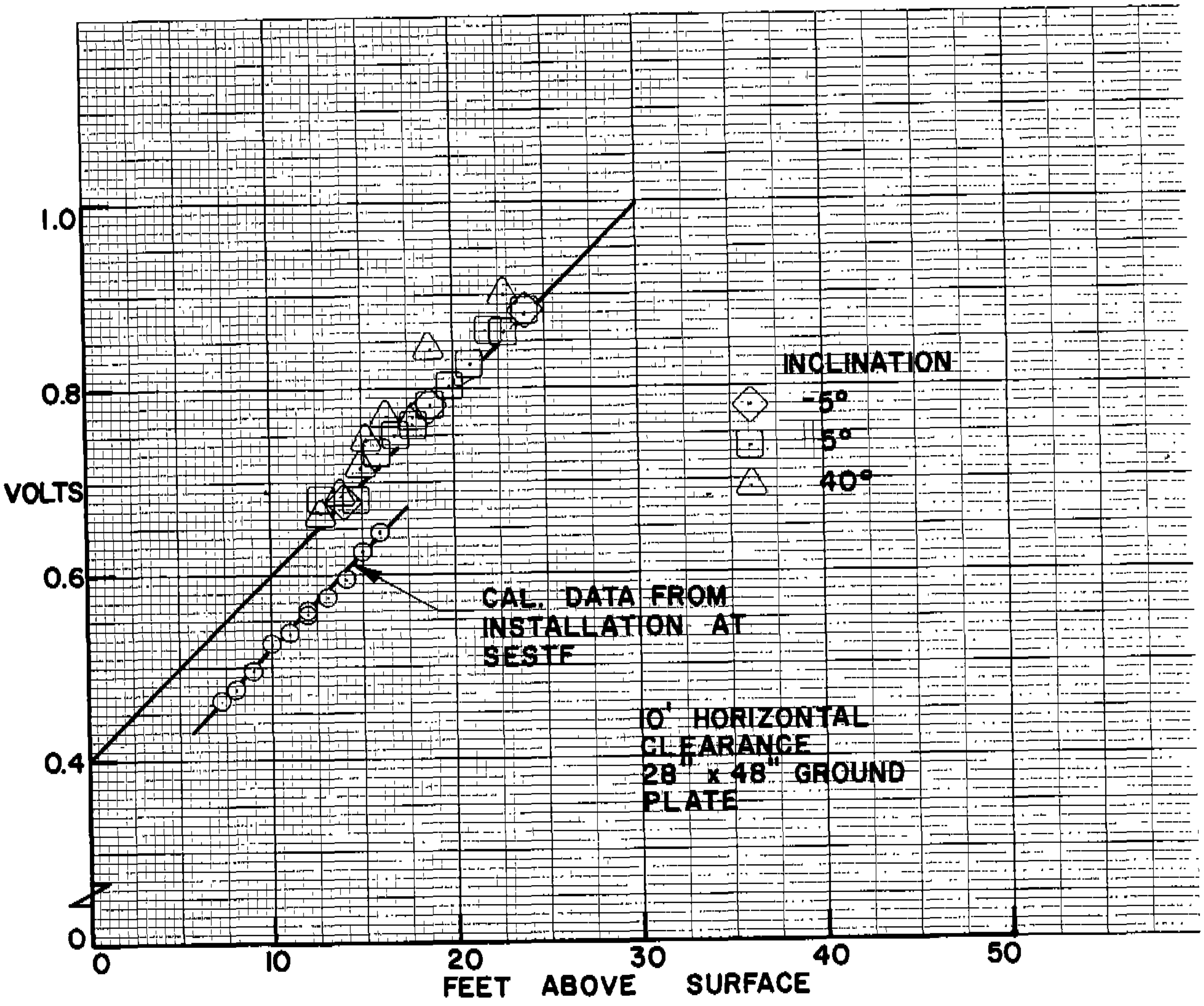


Figure 29. Preliminary Radar Altimeter Calibration, 10 Ft. Clearance.

There was considerable data scatter; much more than was expected from the data obtained from the engineers at SESTF.* These data have been plotted for comparison purposes on Figures 27 and 29. As can be seen, these calibration points are considerably less scattered. It is interesting to note that this data was obtained with an unmodified Collins altimeter and a ground plane plate and antenna installation of 1/3 the size of that shown in Figure 25. This point will be discussed further in the next section.

Much of the scatter may be attributed to the geometry of the test stand installation. Several discontinuties were present which would have produced multi-path reflections or local reflections, the window-sill and frame, the roof and the cap strip along its edge or metallic components of the building's structure.

Increasing the horizontal clearance to 10 feet (Figure 29) improved the data scatter, particularly for small angles of antenna inclination. The antenna has a 50° beam width. Tilting the beam axis beyond 25° appears to increase scatter when a "clean" return signal is being received.

The instrument, as originally installed, also showed what appeared to be internal instability. On several occasions apparently spontaneous variations in output voltage were observed. These amounted to as much as ±2 feet and were sufficiently puzzling that visicorder strip charts were produced. Figure 30 is a chart which was taken when the altimeter was at a fixed height of about 18 feet. There was a breeze blowing and the antenna was oscillating torsionally (about an axis normal to the wall) during the test. The problem was not consistent, however.

Figure 31 illustrates altimeter output as the antenna plate is being raised from 12 to 23 feet. While there is considerable noise the output did not exhibit the "wild" swings seen earlier.

Instrument checks showed that the unit was functioning properly, however, several details in apparatus design and procedure were implemented to improve the operation.

1) The parking lot soil was thoroughly wetted during testing. This improved soil conductivity and thus provided a sharper return for the altimeter to process. This improved performance indicated that the altimeter should give a much clearer signal when operating over water.

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* Surface Effect Ship Test Facility, U.S. Naval Air Station, Patuxent River, Maryland. A similar Collins Radar Altimeter has been installed on the SES-100A testcraft (see Figure 34).

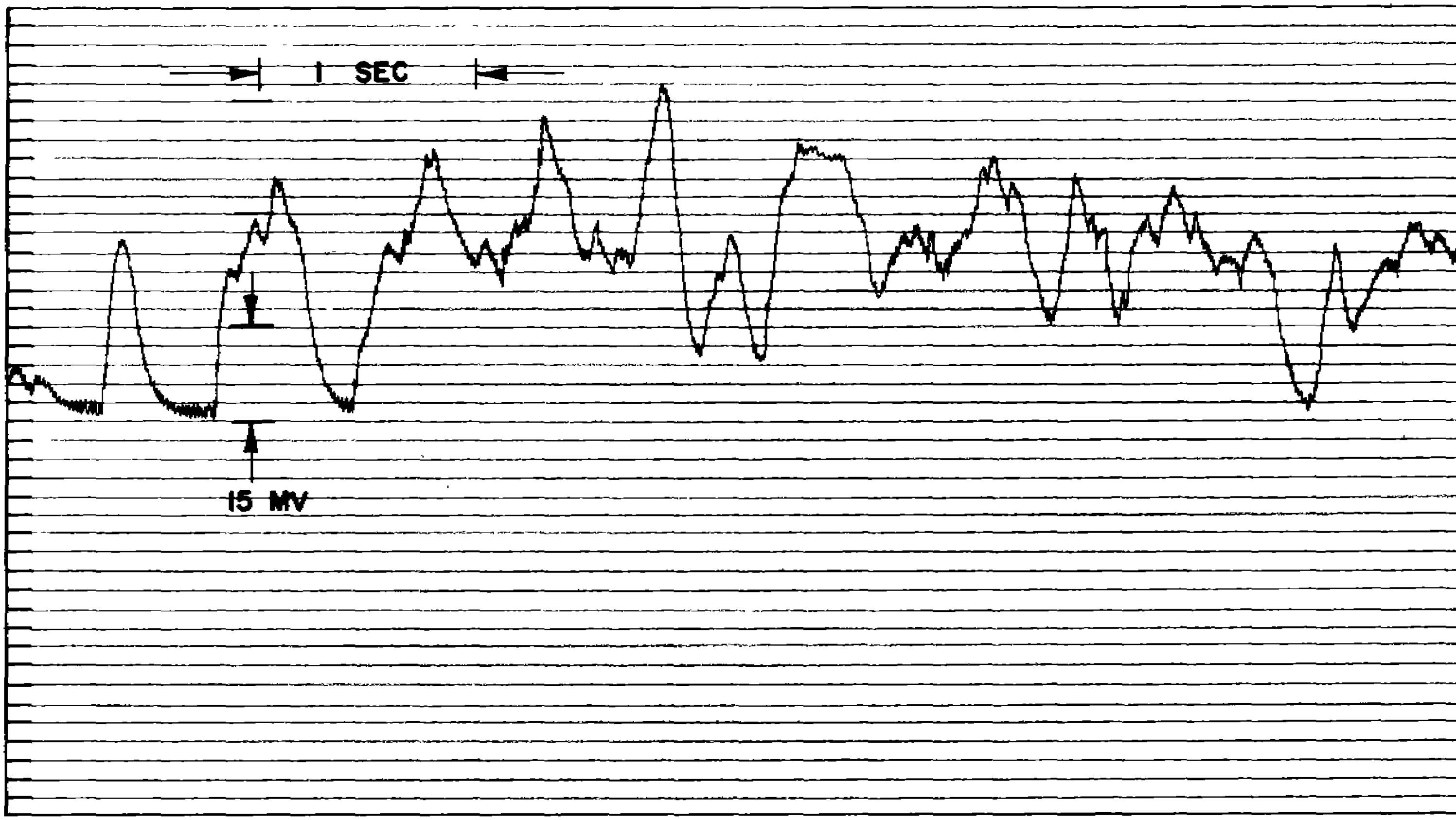


Figure 30. System Instability.

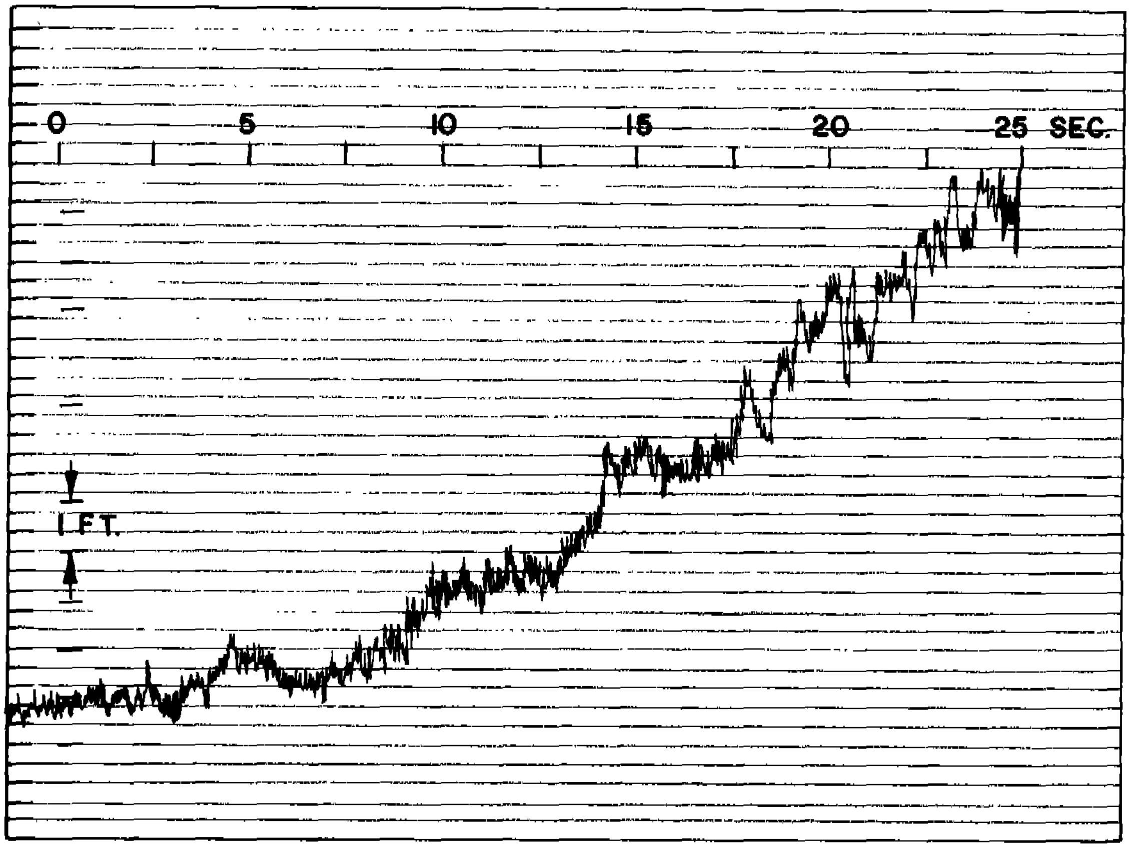


Figure 31. Raising the Altimeter Along the Track.

2) One of the performance limiting factors of the radar altimeter was determined to be the mounting of the transmit and receive antennas on a suitable ground plane. The aluminum ground plane was therefore covered with a sheet of copper to improve conductivity between the antenna horns and the ground plane. Although excellent results were obtained using a copper sheet ground plane, good engineering practice (and the manufacturer's recommendations) requires that the cast aluminum antennas with their aluminum mesh gaskets be mounted against aluminum (chromate finish) for resistance to electrochemical corrosion. In addition, it is recommended that the ground plane and antenna housings be well coated with a high quality epoxy finish to further enhance resistance to the salt water environment. It is important, however, not to coat the dielectric face-plates.

3) Laboratory Calibration Procedures -- After the antennas had been mounted against the copper ground plane and after the ground in the test area had been well watered, it was observed that a quite smooth (noise-free) analog output was obtained (Figure 32). When the antennas swung in a breeze (or when caused to oscillate manually) a transient appeared in the output (Figure 33) as if a good reflector, well above ground level, were being brought into the field of view during a portion of the antennas' excursion. Since there was no visible object which could have caused such an effect, there is probably a metallic structure within the building which produces a spurious response. In subsequent tests the test location was moved to a concrete parking area and no further trouble was experienced with sway or transient signals.

In the final condition of antenna and location the instrument was found to perform within specifications and without "spontaneous" instability. The calibration is linear.

3.3.3 Recommendations

After the initial tests were conducted, details were obtained of the altimeter ground plane plate in use at SESTF on the SES-100A (see Figure 34). This is a very much more compact design as illustrated in Figures 4 and 5. It was developed by the Patuxent Naval Air Station, Antenna Range Group using NASA derived design criteria. The mounting plate is of 1-inch thick aluminum and has a series of deeply machined grooves located concentrically about each antenna horn. The antennas are UB Corporation, 3-inch diameter, conical horns and have a very good isolation from crosstalk. The plate dimensions are approximately 6" x 12" leading to a very compact installation. Figure 35 shows a time-history obtained from the installation of this equipment on the SES-100B during a high-speed run, which demonstrates an ability to generate a clearly defined signal. One of the recommendations resulting from this study will be to adapt the Collins radar altimeter with an antenna array rebuilt to reproduce the SESTF design.

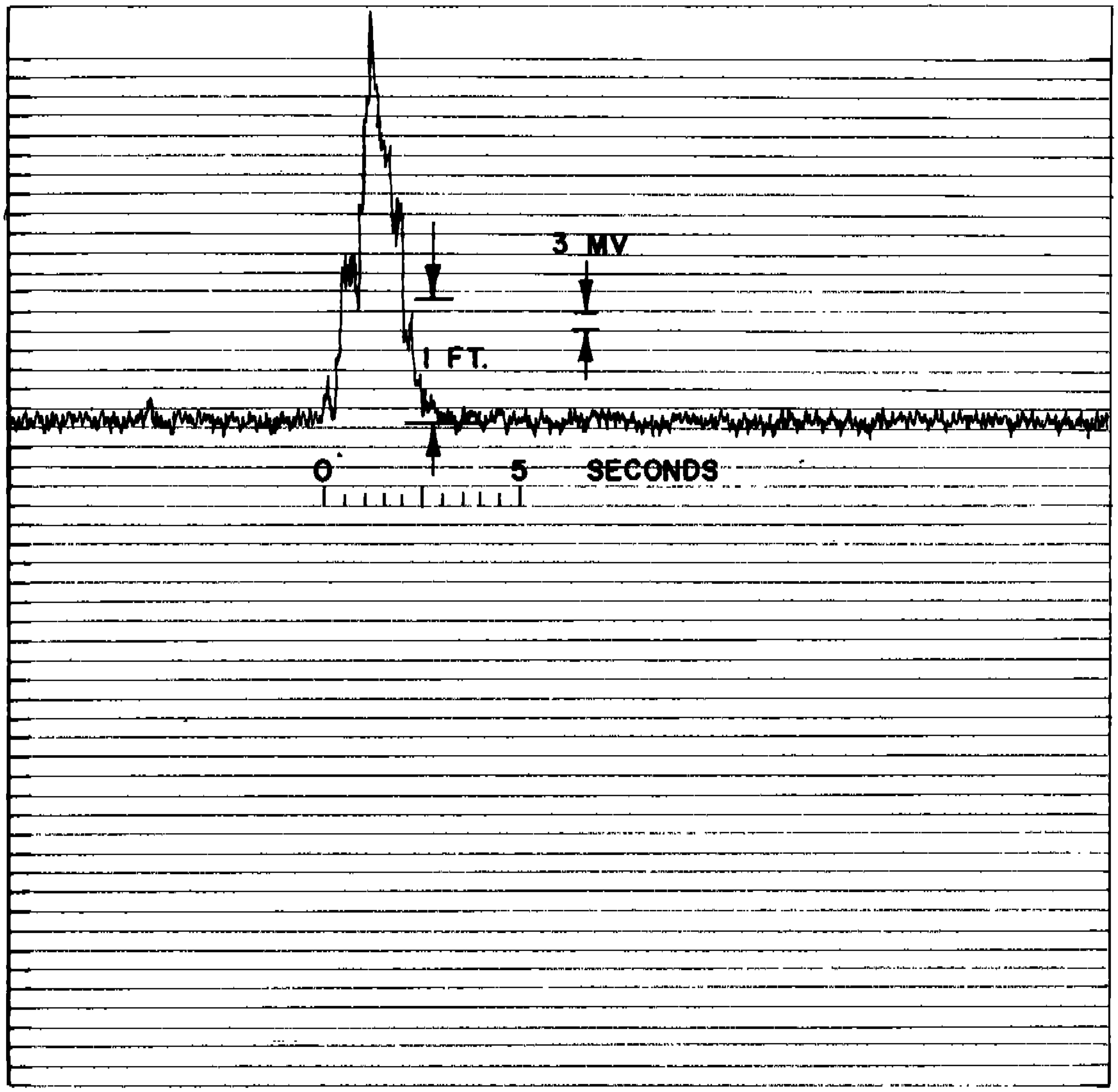


Figure 32. Altimeter Signal Produced by a Car Passing Under the Antenna.

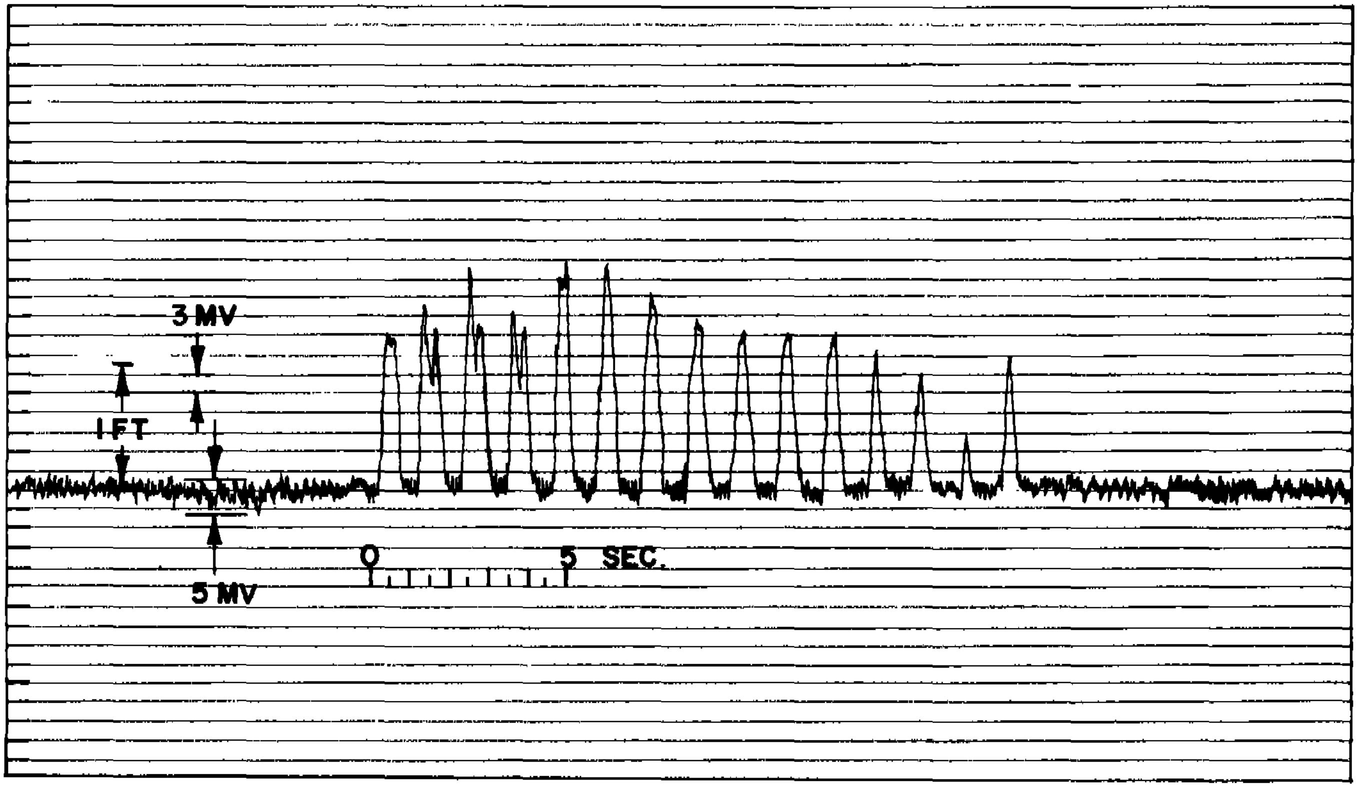


Figure 33. Antenna Sway.

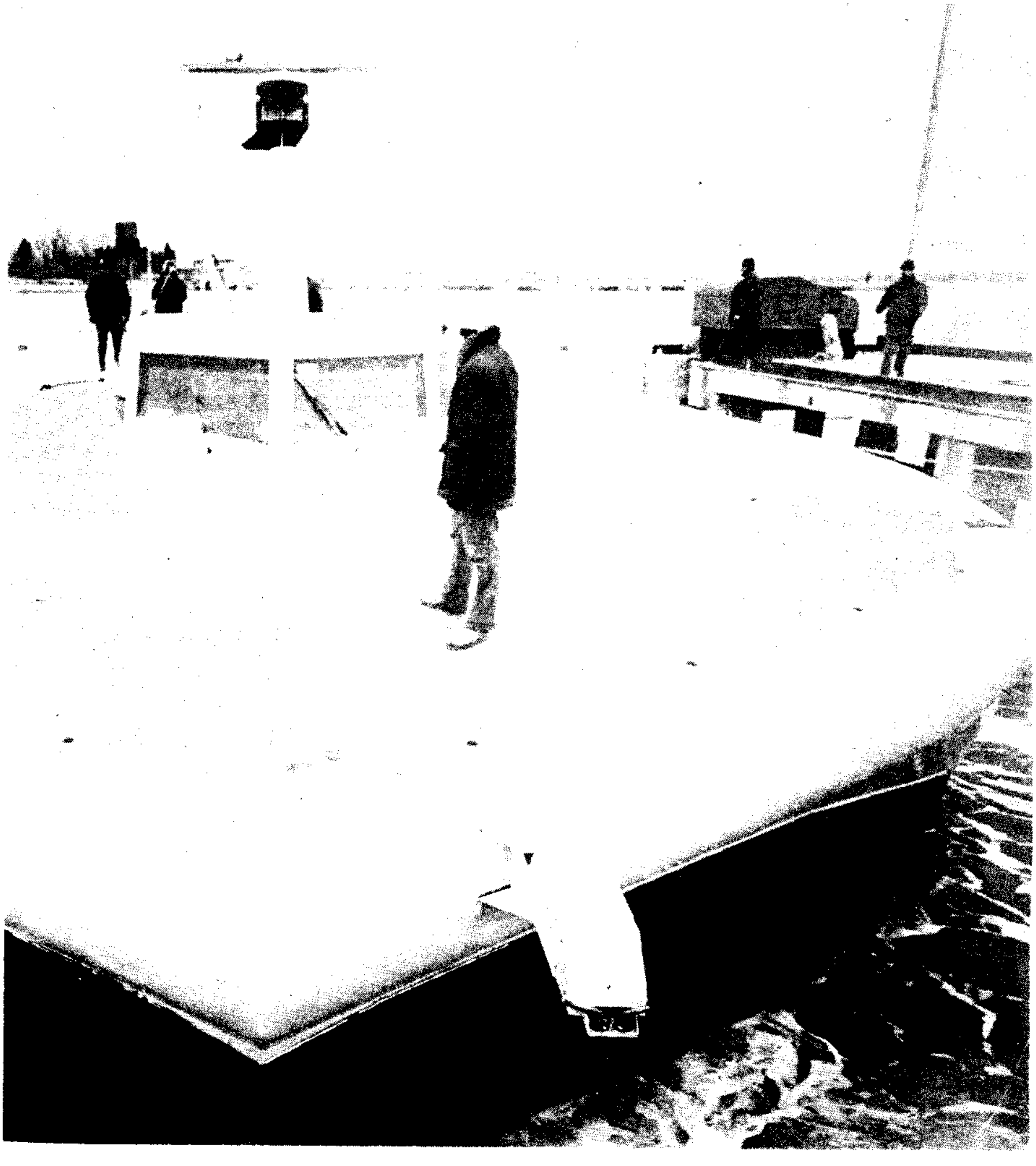


Figure 34. Collins Radar Wave Height Sensor Mounted on SES-100A.

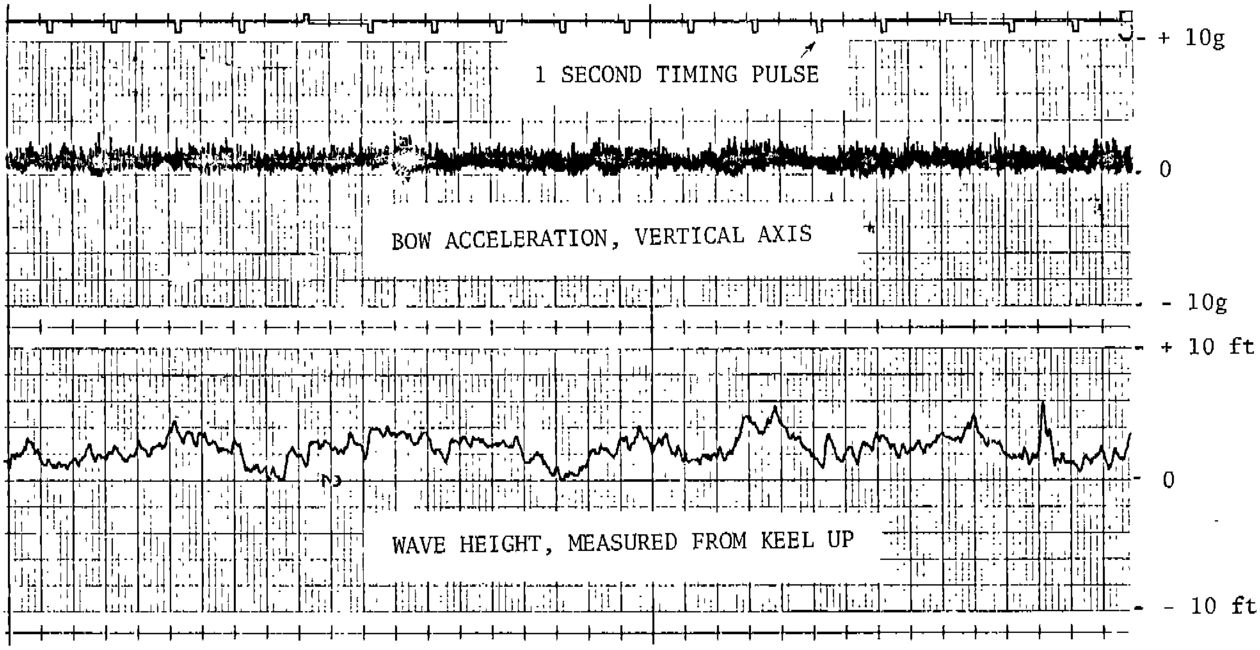


Figure 35. Typical Accelerometer (Top Trace) and Relative Bow Height (Lower Trace) Signals of the SES-100B taken with the Collins Radar Altimeter During High-Speed (> 75.0 Knots) Runs in Waves. Paper Speed = 10 mm/sec., Accelerometer Range ±10 g's, Altimeter Range ±10 Feet.

3.3.4 Operational Calibration

Since the radar altimeter is provided with an internal calibration capability which tests the entire electronic circuitry (except the antennas and external cabling) it is recommended that this feature be incorporated into the overall system calibration which is to be performed on a daily basis. The operation of this "one-point" calibration function involves shorting to ground one pin on the main altimeter connector, and produces an analog output corresponding to a fifty-foot altitude.

If it is desired to obtain an additional calibration point, as is done with the other transducers in the system, either of two techniques may be used. The simplest, shown in Figure 36, inserts a known length (electrical length - not physical length) of transmission line into the cabling from the receive antenna to the altimeter. The additional components for this feature are two single-pole, double-throw, coaxial relays (rated for low power at the altimeter carrier frequency) or one double-pole, double-throw relay, and the appropriate length of coaxial cable. When the relay is energized, the analog output of the altimeter will be displaced an amount corresponding to one-half of the electrical length of the inserted cable.

Figure 37 illustrates the second calibration scheme. In this case, a known electrical length of transmission line is connected via an attenuator, directly between the transmitter and the receiver. Since the antennas are thus removed from the circuit during calibration, there can be no confusion caused by varying sea height. The radar altimeter specifications claim a 0.1 second time constant for the transfer function: altitude to analog output. If the unit can be described as a linear first order system (very possibly not true for large step inputs), then 4.6 time constants (=0.46 seconds) will be needed for the output to settle to within 1% of its asymptotic value following a step input. Since it seems reasonable that wave action could produce sea height variations of at least several feet during this half second settling time, it is probably preferable to use this second calibration technique.

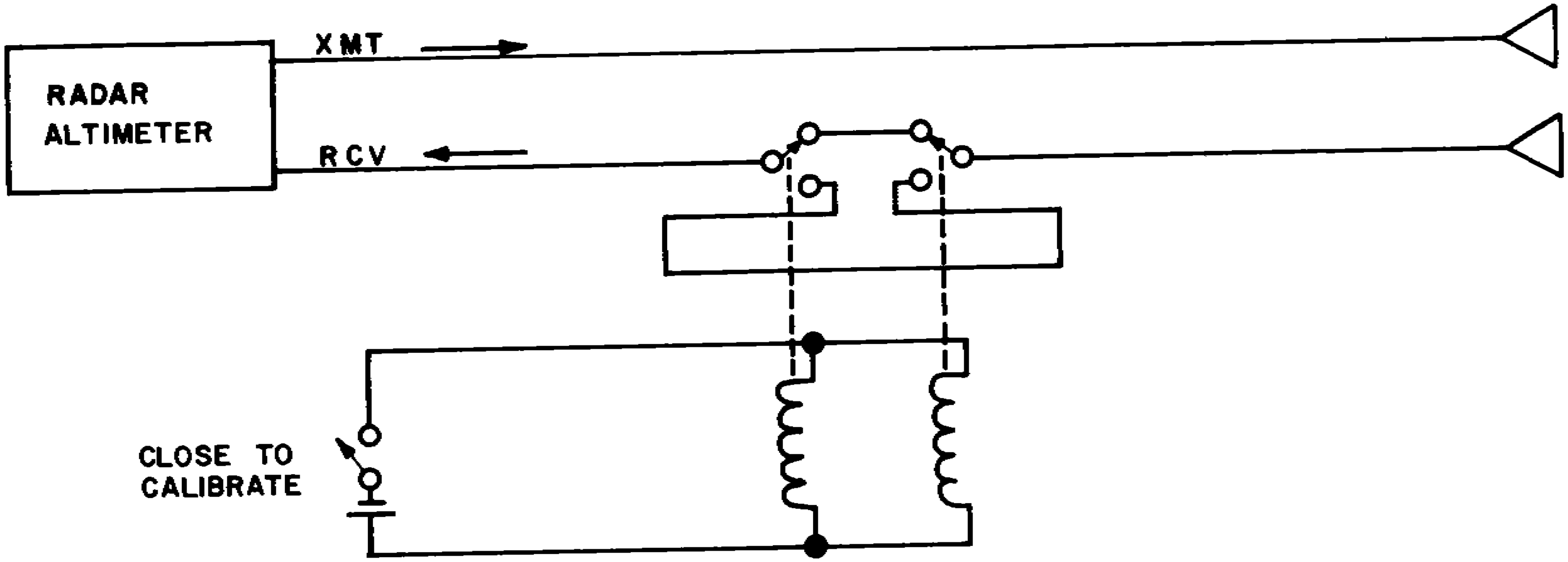


Figure 36. Altimeter Calibration Circuit.

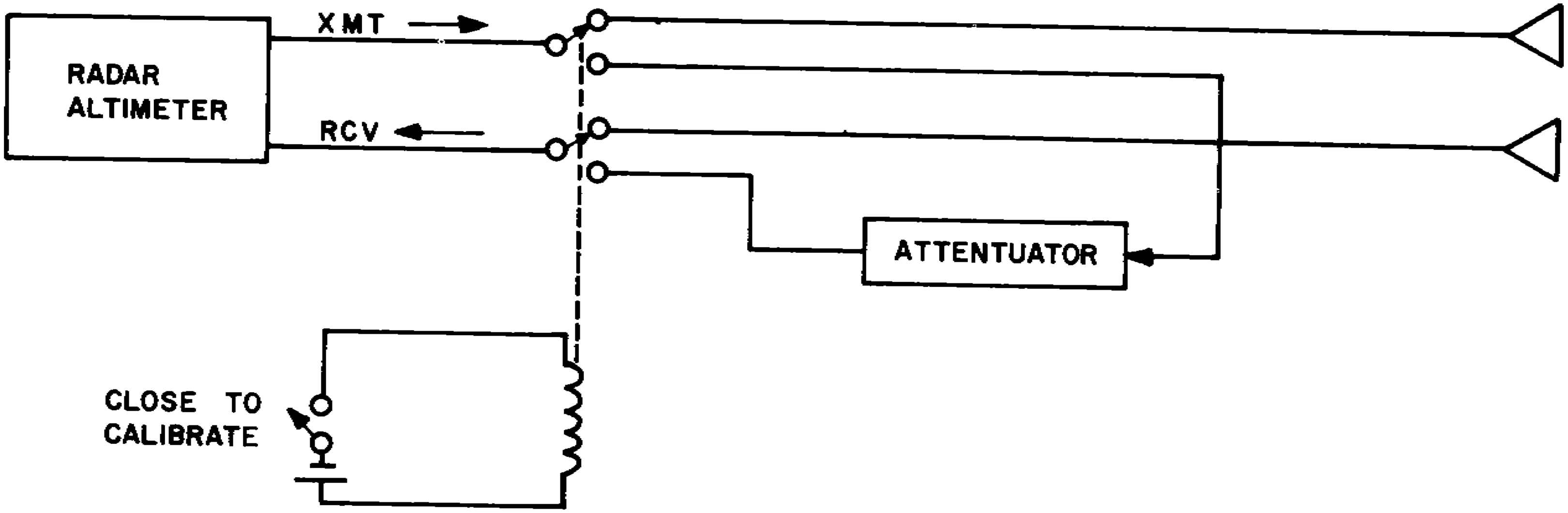


Figure 37. Alternate Altimeter Calibration Circuit.

3.4 PROGRAMMER/CONTROLLER SYSTEM TESTS

The purpose of the programmer/controller systems tests was to verify, through simulated, and where possible, actual input signals, the proper operation of the system. The total system consists of six major components plus a power supply (ship's power). Figure 38 is a block diagram of the overall system showing the interconnecting cabling.

The Collins radar altimeter (ALT-50) was tested separately as already described. A complete description of the Collins radar altimeter is given in the operating and maintenance manual (Reference 26). Subsequent testing of the slam data acquisition system was done with a simulated altimeter signal; either a dc signal corresponding to a fixed altitude or a varying signal from a laboratory signal generator.

The Vishay 2100 system signal conditioner was checked out thoroughly during the transducer selection phase of the program. At our request Vishay added a remote calibration capability which interfaces with the programmer/controller. The system is very simple to set-up and adjust. It has a gain range of from 100 to 2000 and built in circuitry to handle 1/4-, 1/2- and full-bridge transducers. A complete description of the Vishay 2100 system is given in the operating and maintenance manual (Reference 27).

The Datum 9300 time-code generator is a basic unit capable of furnishing an IRIG-B, time-code, pulse train which is used within the programmer/controller for event sequencing as well as being recorded simultaneously with the slam. This unit is not capable of decoding IRIG-B or tape searching as it is planned to perform these tasks ashore during the data reduction process.

All data are recorded by the Ampex FR-1300 portable tape recorder. This unit is equipped with a remote-control capability which is controlled by the programmer/controller.

During tests with the unit it was found that the original design for the remote-controlled switching was not adequate, and the system was redesigned to include a system of relays, which have not yet been installed.

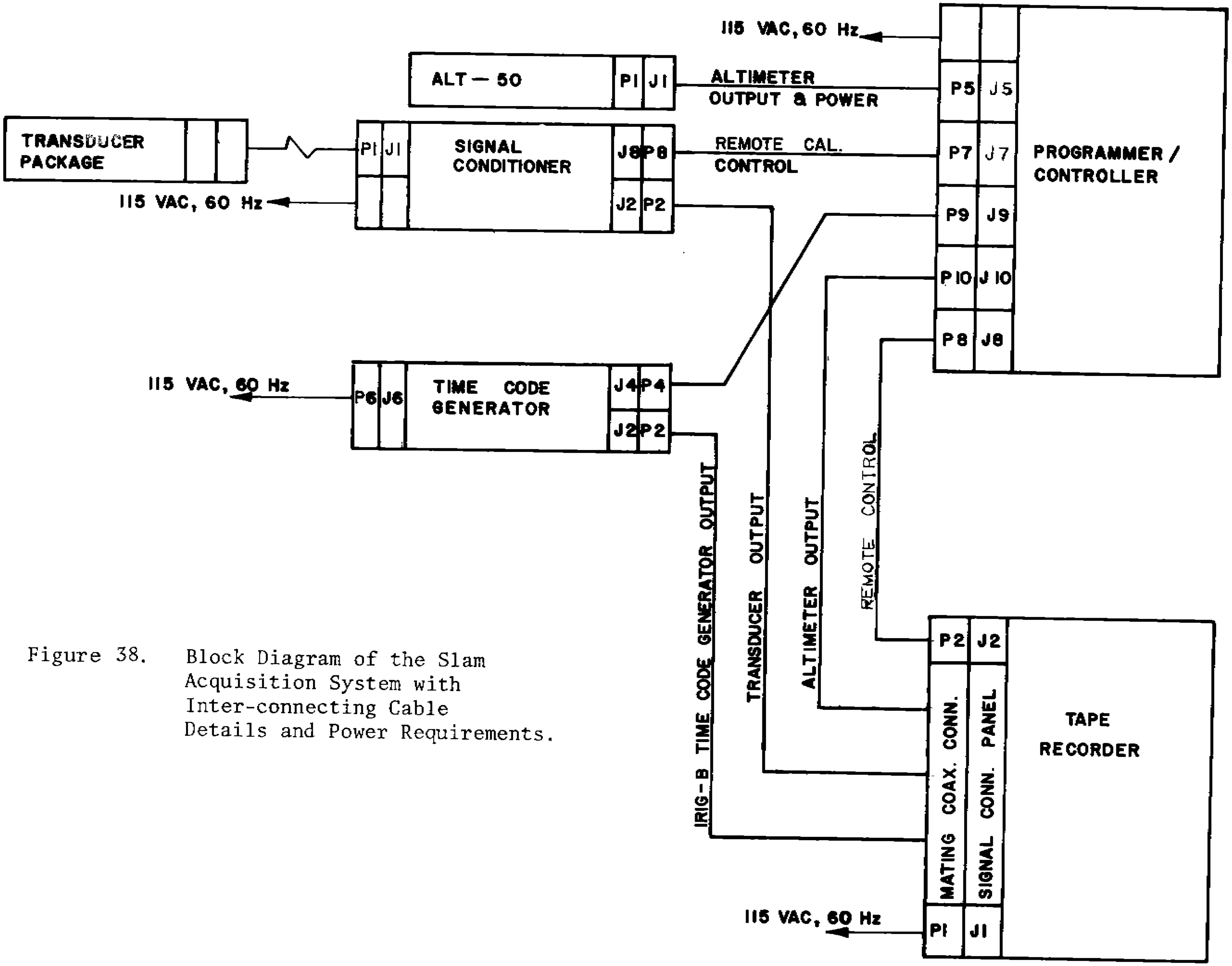


Figure 38. Block Diagram of the Slam Acquisition System with Inter-connecting Cable Details and Power Requirements.

4. FULL-SCALE SHIP TEST PLAN

4.1 SELECTION OF SHIP

Numerous factors have to be borne in mind in the selection of a ship as a subject for a slamming investigation.

- The ship should be in normal, commercial operation in an area, such as the North Atlantic, in which severe sea states are likely to occur.
- The ship should be of a type that is prone to either bottom slamming (such as the WOLVERINE STATE) or bow-flare slamming (such as full-formed tankers, bulk freighters, and high-speed containerships) or to both.
- The ship should be of modern design and construction so that the information generated by the tests will be of direct application to current design technology.
- It would be advantageous if the ship was concurrently being used for recording other types of structural data such as midship bending stresses, wave heights, etc. These data would provide valuable corroborative information for cross-correlation and would allow considerable economies to be achieved in installation, data retrieval, periodic maintenance and crew training.
- It would also be advantageous if the ship had been subjected to previous model-scale evaluations. This would allow full advantage to be taken of the previous test results and would provide useful guidance in model design, model tank selection and model test planning.
- The most important consideration in ship selection is to obtain the acquiescence of the owners and the cooperation of the crew. The previous experience of the Ship Structures Committee will be most useful in this connection.

4.2 FINAL DESIGN OF INSTRUMENTATION PACKAGE

a) Instrumentation Location -- Once a ship has been selected, the final design of the instrumentation package can be initiated. The first step will be to determine the most probable sites for slamming to occur and to select locations for the pressure gages, strain gages and accelerometers. At this stage consideration should be given to installing a considerably larger array of gages than can be monitored at one time. The cost of the extra gages will not be large compared with the cost sharing of installing the extra gages at the same time as the basic set. The purpose of the extra instruments will be to allow various areas of the plating to be examined at different times in different degrees of detail, and will also provide a set of ready-to-use spares in case some of the individual instruments fail.

b) Location of Control Consoles -- Once the instrumentation site has been selected, both from the point of view of the experimental coverage required and the interior layout of the ship, a suitable location for the control and record consoles will be selected. These should be located as close to the instruments as possible to prevent unnecessary lengths of cabling, but should be located where they are accessible to the operating personnel, well protected from exposure to weather and to accidental damage, and where they cause the least possible interference to the crew in the performance of their normal, shipboard duties.

A typical shipboard instrumentation console system is shown in Figure 39. The one shown in this figure is that used on the SL-7 container ship and is, in fact, considerably more extensive than that contemplated for the slam investigation.

c) Altimeter Location -- The location of the altimeter antenna will be selected to correspond as closely as possible to the station of the ship in which the gages are located, so that the relative wave height measured will represent, as closely as possible, the wave height at the instrumented station.

It is strongly recommended that two altimeters be used, one on each side of the ship, and that the signals be averaged to provide a signal representing relative wave height at the ship center line. This is represented diagrammatically in Figure 40. The use of two altimeters should compensate for errors caused by roll or transverse wave slope; the assumption must be made however that the water surface is flat between the areas covered by each altimeter. The shortcomings of this latter assumption can be studied by statistical analyses of the data.

d) Cabling -- A cabling plan similar to that used on the SL-7 (Reference 8) is visualized. The cabling on the SL-7 was divided into two categories: ship cabling and transducer cabling. The ship cabling provided the main run of the cabling from the instrumentation location to the control room, following the routing of other ship wiring wherever possible and using a series of junction boxes and multiconductor cables. The transducer cabling connected the instruments to the ship cabling junction boxes via intermediate junction boxes which were used to allow the actual transducer and strain gage lead lengths to be standardized. Connections into half and full-bridge circuits were made with the intermediate junction boxes.

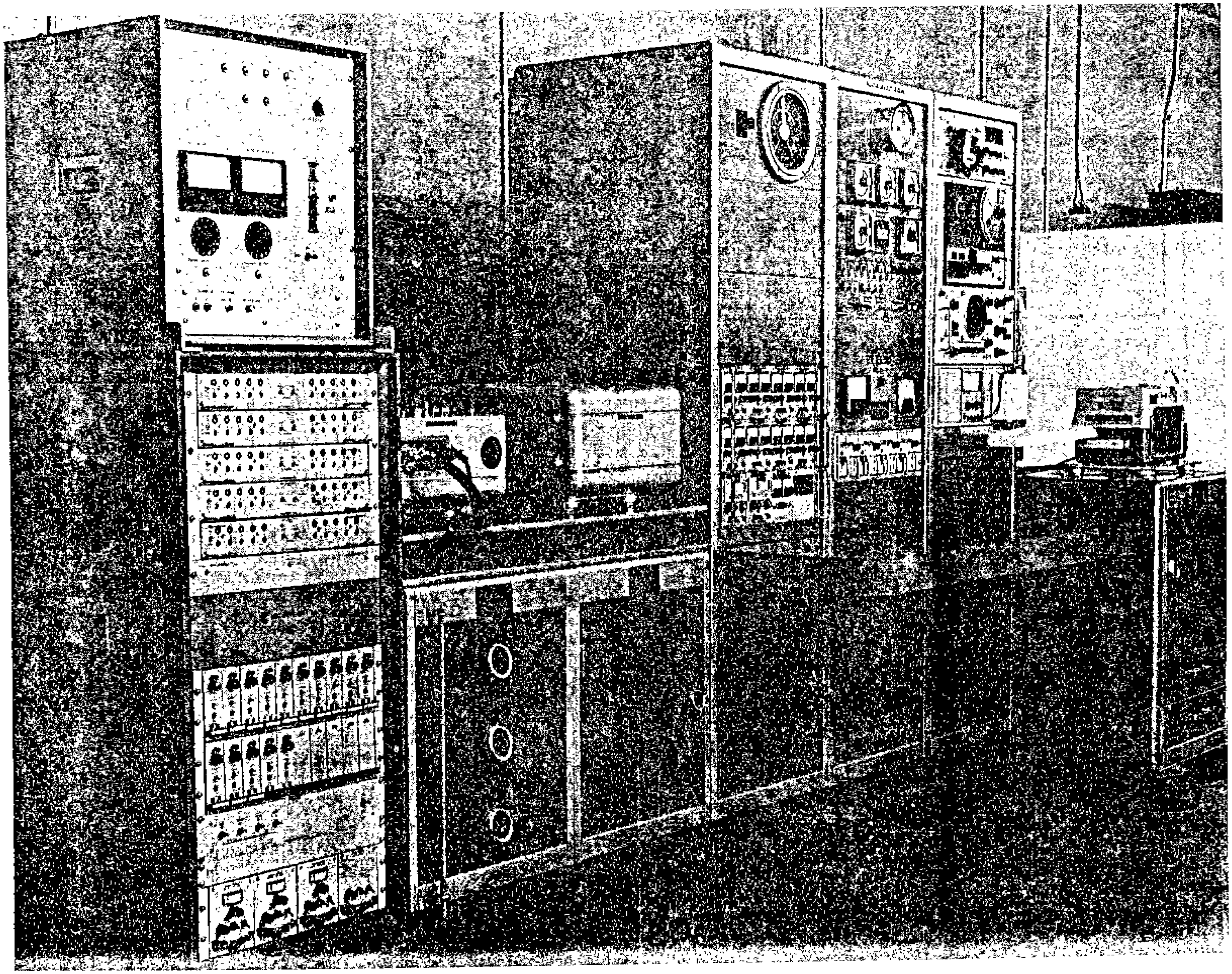
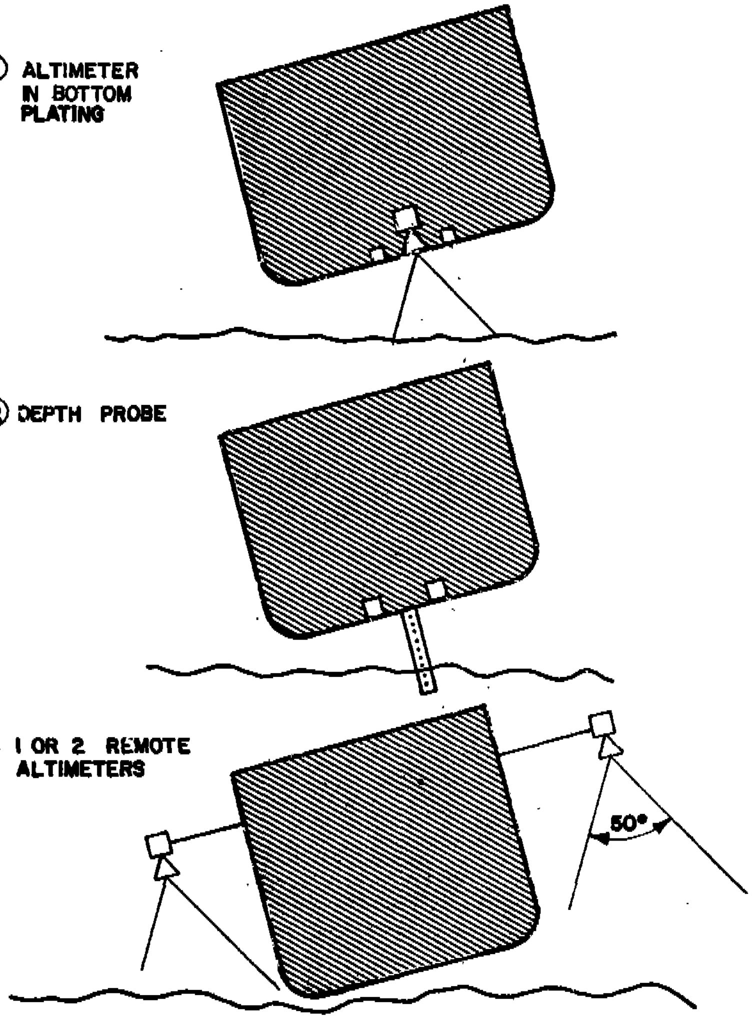


Figure 39. SL-7 Instrumentation System. (Reference 8)



	DIFFICULTIES	ADVANTAGES
① ALTIMETER IN BOTTOM PLATING	• PROBABILITY OF DAMAGE • DIFFICULT ACCESS & REPAIR • RANGE TOO SMALL FOR COLLINS RADAR ALTIMETER • SWITCH ON PROBLEM	• DIRECT MEASUREMENT
② DEPTH PROBE	• VULNERABLE TO DAMAGE • VULNERABLE TO FOULING • SENSITIVE TO SPRAY & RUN-UP	• DIRECT MEASUREMENT
③ 1 OR 2 REMOTE ALTIMETERS	• INACCURACIES DUE TO ROLL, WAVES, ETC. (INACCURACY COULD BE REDUCED BUT NOT ELIMINATED, BY USING TWO INSTRUMENTS)	• ACCESSIBILITY • PROPER RANGE FOR COLLINS RADAR ALTIMETERS • LOWER DAMAGE PROBABILITY

Figure 40. Alternative Methods of Measuring Vertical Velocity at Point of Impact.

4.2.1 Acquisition and Construction of Instrumentation System

The complete ship set of instruments would require acquisition of the items in the following list. Where known, the current list prices are included in parentheses.

1	(extra) Collins Radar Altimeter	($2,300)
4	UB Corp. Model AD43009 Antennas	($ 200 ea.)
2	Grooved Aluminum Ground Planes	(~$ 360 ea.)
20	BLH DHF-S Pressure Gages (Special per BLH Drawing No. 400887-1)	($ 400 ea.)
10	Signal-Conditioning Channels (1 Vishay Instruments 2100 System)	(~$ 400 per channel)
2 or 3	Ailtech Hermetically-Sealed, Strain Gages per location (2 will suffice if prinicpal axes of stress are known) (number of locations is dependent on type of ship and extent of the investigation)	(~$ 30 ea.)
20	Pressure-Transducer Mounting Blocks (see Figure 10). Will require manufacture.	
2	Antenna mounting brackets will require design and manufacture to suit the ship configuration and available local structure. These brackets should be adjustable, at least during the first voyages, in order that the most effective antenna orientation can be optimized.	
	Miscellaneous cabling, connectors, etc.	

The balance of the equipment, purchased as part of the current task, is listed in Table 2.

4.2.2 Installation of Instrumentation System

All of the instrumentation system, with the exception of the bottom plating pressure gages, can be installed with minimal interference to the ship's normal operation. The items to be brought on board are relatively small and once on board, can be installed while the ship is in harbor or underway. The bottom-plating pressure gages, however, require hull penetration below the waterline and welding of the hull plating, and will have to be installed while the ship is in drydock. It may prove to be convenient to install and check out the rest of the instrumentation system prior to the installation of the pressure gages, dependent upon the drydock schedule.

For design purposes it is more important to measure plating stress than impact pressure. Maximum hydrodynamic pressures generally show poor correlation with plating stress measurements due to the fact that the stress depends on the pressure time history and spatial distribution as well as the pressure magnitude. It may prove to be more useful to concentrate on strain gage measurements on the ship and to relate these to pressures by laboratory tests. This would have the additional advantage that strain gages are very much easier to install and service on a ship than pressure gages. In any case the design of plating instrumentation should be carefully matched to that used on the model.

4.3 PRELIMINARY TRIALS

Once the instrumentation has been installed and checked out,final adjustment of the system will be completed during the first one or two voyages. It will be necessary to plan for one or two technicians to travel on board the ship during this period.

The altimeter operation will be reviewed and the signal received will be compared with actual water level. The response of the altimeter to wave action will also be monitored for a range of antenna positions and orientations in order that a position can be selected in which the signal is as free as possible from disturbances caused by the hull structure, or the bow wave.

The functioning of the programmer/controller will be reviewed under operational conditions to ensure that the proper response to the altimeter signal is achieved and that the recorder does, in fact, record the instrumentation signals during the majority of slam events. The cut-off points on the controller may require adjustment to achieve this.

During these initial voyages the operational procedures will be worked out with the ship's crew and the responsible crew members will be instructed in the operation and minor maintenance of the system, how and when to change tapes, what records should be kept, etc.

4.4 SHIP DATA REDUCTION PLAN

4.4.1 Collection of Magnetic Tape Record

After each voyage the tapes and data logs used will be collected and returned for data processing. The instrumentation system will be checked out for proper functioning and will be refurbished as necessary.

4.4.2 Quick-Look Data Analysis

The magnetic tape will be played back through a simple data reduction system that will be designed to extract the following information:

- Date and time of each slam or series of slams
- Maximum signal (pressure, strain or acceleration) recorded during each slam event
- Time elapsed since last slam
- Relative vertical velocity at time of slam
- Indicated relative wave height at time of slam.

This preliminary analysis will enable a judgment to be made as to the value of the data and the correct functioning of the system. It will also provide the basis for a statistical analysis.

4.4.3 Statistical Analysis

The slam information obtained from the quick-look analyses will be examined for statistical significance. If the number of slams is sufficient, histograms will be prepared of such quantities as:

- slam severity (in terms of pressure and/or strain signals)
- number of occurrences per unit time
- time between slams
- relative vertical velocity at time of slam

As far as possible these analyses should be performed automatically in order that a large number of slams can be analyzed in a consistent manner.

4.4.4 Detailed Analysis

As the data accumulates from a number of voyages more detailed analyses will be carried out; these will include:

- Studies of the time histories of individual slams, including the interrelationships between relative velocity, pressure, strain and acceleration.

- Analysis of the relationship, between relative vertical velocity and impact pressures, including a comparison with the theory described in References 15 and 17.

- Analysis of the effects of the ship operational parameters on the severity and frequency of slamming. These operational parameters include ship speed (r.p.m.), reported sea state, heading relative to the sea and condition of loading.

- Comparison of experience with this system with those of previous experiments (Reference 5, for example).

5. MODEL TEST PLAN

One of the major objectives of the overall full-scale ship slamming program is to determine what degree of correlation can be achieved between model tests and full-scale experience in the area of slamming. If it can be demonstrated that slam severity and frequency of occurrence can be predicted reliably from model tests, then this will provide an invaluable design tool for future ships. The process of planning a model test series consists of the following steps:

- Selection of a test facility

- Design of model

- Design of model instrumentation system

- Design of model data acquisition system

- Development of matrix of test runs.

These steps must be carried out with a clear understanding of budget and schedule limitations as well as the specific objectives of the test. The steps are discussed, in turn, in the following paragraphs.

5.1 SELECTION OF TEST FACILITY

There are a large number of ship model test facilities available in the U.S. and overseas capable of performing tests in irregular, two-dimensional, head seas with structurally instrumented models. Two of the best equipped facilities in the U.S. are those at the Davidson Laboratory of Stevens Institute of Technology and various tanks at the David W. Taylor Naval Ship Research & Development Center at Carderock, Maryland. The only facility, in this country, which is capable of conducting tests in irregular, two-dimensional, oblique seas is the Maneuvering and Seakeeping Basin at DTNSRDC, Carderock. The extra cost involved in conducting tests in the oblique sea facility is probably not justified at this time, particularly as the severe bottom slam conditions are usually encountered in head seas.

To a large extent the selection of the facility determines the scale of the model as each facility has well-defined limitations on physical size, maximum carriage speed and the maximum size of wave that can be generated in a stable and repeatable manner. In an investigation of full-scale slamming it is probably the latter (sea-state) limitation which will be found to be critical.

5.2 DESIGN OF THE MODEL

The model will be designed to represent the subject ship geometrically and dynamically. As the emphasis of the tests will be on slamming and wave-induced structural loading it will not be necessary to employ a self-powered model. Consideration should be given to using a free-to-surge, sub-carriage, towing system if this is available at the test facility. The model should be mounted in such a way that it is free to heave, pitch, surge and roll. If tests are only conducted in head seas the roll freedom may not be necessary. The model should be of light construction so that the center-of-gravity and pitch moment of inertia can be properly adjusted to correspond to all of the ship's operational loading conditions. In bottom slam, for example, the light-loaded condition is likely to be particularly significant.

Two types of models have been used with success in structural load tests:

- Rigid vinyl models - Rigid vinyl has the special property that its elastic modulus is 1/30th of that of steel so that models can be built to model each component of the structure of the ship in such a way that model strain approximates the strain of the same component of the ship under similar conditions. Disadvantages of these models are that they are comparatively expensive and the instability of the material requires specialized handling and testing techniques (References 28 and 29).

- Segmented models - In a number of test programs for conventional (References 8 and 30) and for advanced marine vehicles (Reference 31), segmented models have been used. These models are built in two or more pieces, divided by vertical cuts at selected sections (if there is one cut it is usually as close to amidship as can be arranged). The cuts in the model are bridged by strain gauged structural members. Non-load-carrying flexible seals are usually used to fair the gaps hydrodynamically. In some cases (Reference 31, for example) the structural bridge members are so designed that the ship's fundamental frequencies of vibration are modelled. In this way wave-induced and slam-induced shears and bending moments can be measured at the locations of the transverse cuts.

  It is recommended that a model of this type be constructed for the proposed, model-scale, slam investigation.

5.3 DESIGN OF THE MODEL INSTRUMENTATION SYSTEM

As far as possible, the model instrumentation system should model the instrumentation of the full-scale ship. The pressure gages, relative velocity measuring devices and accelerometer locations on the model should correspond to those on the ship. If the ship is equipped with strain gages to sense midship bending moment then the model should be segmented at the corresponding station or stations. In particular, the model should be equipped with a wave-height measuring device as closely similar in location and type, to that on the ship. At DTNSRDC, for example, a Western Marine Electronics, Inc. sonic-type, relative wave-height sensor has been used; consideration should be given to the use of this meter during the model tests. Alternatively, a simple probe-type height sensor could be used effectively although the point reading obtained in this way would not correspond exactly to the averaged data sensed by the altimeter on the ship.

Model-scale pressure gages have to be selected and tested with great care (Reference 19). Their small size and the comparatively low values of the pressures to be measured combine to make the pressure pulse signals difficult to distinguish from noise produced by thermal shock and impact acceleration. It is often found that the accelerometers and strain gages yield more usable information than the pressure gages.

Recent experience with the XR-1D surface effect ship test craft (Ref. 33) suggests that much larger pressure gages than have been used previously can give information that is of more use to the designer than the very transient peak-pressure information provided by small pressure gages. On the XR-1D eight-inch-square, strain-gaged pressure panels are used; the size was selected to correspond, approximately, to the size of a plating panel on the full-scale ship of which the XR-1D is a one-fifth-scale manned model. Consideration should be given to using appropriately sized pressure panels on the model that would be representative of an equivalent, larger area on the full-scale ship.

5.4 DESIGN OF MODEL DATA ACQUISITION SYSTEM

The data acquisition system for the model should, again, closely model that proposed for the full-scale ship. Sufficient data should be recorded to allow meaningful statistical analyses to be carried out and also to allow detailed time histories of selected slams to be examined. The advantage of model-scale tests is that considerably more information is available during a slam event; the pitch, heave, wave height and model speed are all known quantities.

5.5 DESIGN OF MODEL TEST MATRIX

The model will be tested over a range of speeds, sea-states and loading conditions that at least cover all conditions that the ship is likely to encounter. The model should be run at slightly higher combinations of speed and sea-state than those sustained by the full-scale ship to ensure that a full parametric study can be made. It is often necessary, in seakeeping tests, to conduct a number of repeat runs in each condition to ensure that a sufficiently large statistical sample is obtained. Once the model and full-scale tests have been conducted a considerable correlation effort remains to be performed. The model and full-scale tests should be matched and compared both deterministically, in individual cases, and statistically for grouped data.

6. CONCLUSIONS AND RECOMMENDATIONS

An instrumentation set has been developed for use in investigating the slamming experience of a full-scale ship. Methods for treating both bow-flare and bottom-slamming have been considered. The instrumentation set comprises a set of selected instruments, an FM tape recorder, and a programmer/controller used to calibrate the instruments and used for sensing the onset of slamming.

A particular feature of the instrumentation set is the use of a Collins radar altimeter to sense the relative height of the wave at the transducer location and to allow relative velocity at the instant of slam to be measured.

The various components of the instrumentation set have been designed, assembled and checked out in a series of laboratory tests.

A plan has been outlined for the installation of this equipment on board ship, for the processing of the resulting data and for the performance of a parallel set of model tests.

The following recommendations are made:

1. That plans be made to install the instrumentation on-board ship in two phases. The first phase should include the installation of the radar altimeter, the control and recording consoles and a simplified instrumentation suite consisting of selected accelerometers and strain gages.

2. The objective of the first phase of testing would be to study the performance of the radar altimeter as a device to measure relative height and relative velocity. The proper functions of the control and recording systems could be determined at the same time.

3. Once assurance had been acquired that the altimeter provided adequate information and that the system was functioning properly then the second phase could be initiated comprising the installation of the full set of pressure gages when the ship is dry-docked, and the complete set of strain gages and accelerometers.

4. It is recommended that a series of corresponding model tests be performed using a model of the instrumented ship. The model instrumentation set should be designed to record the same information as that obtained on the full-scale ship.

5. Individual recommendations as to the equipment to be included in the instrumentation set have been described in the body of this report.

REFERENCES

1. Fritch, D.J., Bailey, F.C. and Wise, N.S., "Results from Full-Scale Measurements on Midships Bending Stresses on Two C4-S-B5 Dry Cargo Ships Operating in North Atlantic Service," Ship Structure Committee, Report No. SSC-164, AD No. 605-535, September 1964.

2. Fritch, D.J., Bailey, F.C. and Wheaton, J.W., "Results from Full-Scale Measurements of Midship Bending Stresses on Two Dry-Cargo Ships - Report #2," Ship Structure Committee, Report No. SSC-181, March 1967.

3. Band, E.G.U., "Long-Term Trends of Hull Bending Moments," American Bureau of Shipping Report, 1966.

4. Wheaton, J.W., Kano, C.H., Diamant, P.T. and Bailey, F.C., "Analysis of Slamming Data from the S.S. WOLVERINE STATE," Ship Structure Committee Report No. SSC-210, AD No. 713-196, 1970.

5. Wheaton, J.W., "Further Analysis of Slamming Data from the S.S. WOLVERINE STATE," Ship Structure Committee, Report No. SSC-255, 1976.

6. Fain, R.A., Cragin, J.Q. and Schofield, B.H., "Ship Response Results from the First Operational Season Aboard the Container Vessel, S.S. BOSTON," Ship Structure Committee, Report No. SSC-212, 1970.

7. Cragin, J.Q., "Ship Response Instrumentation Aboard the Container Vessel S.S. BOSTON: Results from Two Operational Seasons in North Atlantic Service," Ship Structure Committee, Report No. SSC-214, 1970.

8. Fain, R.A., "Design and Installation of a Ship Response Instrumentation System Aboard the SL-7 Class Containership S.S. SEA-LAND McLEAN," Ship Structure Committee, Report No. SSC-238, AD No. 780-090, 1973.

9. Dalzell, J.F. and Chiocco, M.J., "Wave Loads in a Model of the SL-7 Containership Running at Oblique Headings: In Regular Waves," Ship Structure Committee, Report No. SSC-239, AD No. 780-065, 1973.

10. Elbatouti, A.M., Liu, D. and Jan, H.Y., "Structural Analysis of SL-7 Containership Under Combined Loading of Vertical, Lateral and Torsional Moments Using Finite Element Techniques," Ship Structure Committee, Report No. SSC-243, AD No. A002-620, 1974.

11. Kaplan, P., Sargent, T.P. and Cilmi, J., "Theoretical Estimates of Wave Loads on the SL-7 Containership in Regular and Irregular Seas," Ship Structure Committee, Report No. SSC-246, AD No. A004-554, 1974.

12. Siekierka, W.J., Johnson, R.A. and Loosmore, C.S., "SL-7 Instrumentation Program Background and Research Plan," Ship Structure Committee, Report No. SSC-257, 1976.

13. Band, E.G.U., "Note on Detailed Bending Stress Records of Slams Experienced by S.S. WOLVERINE STATE," Webb Institute of Naval Architecture, February 1965.

14. "Review and Recommendations for the Interagency Ship Structure Committee's Fiscal 1978 Research Program." Report prepared by the Ship Research Committee, National Research Council, National Academy of Sciences, 1977.

15. Ochi, M.K., "Prediction of Occurrence and Severity of Ship Slamming at Sea," Office of Naval Research, Fifth Symposium of Naval Hydrodynamics, 1964.

16. Ochi, M.K., "Extreme Behavior of a Ship in Rough Seas--Slamming and Shipping of Green Water," SNAME Transactions 1964, pp. 143-202.

17. Ochi, M.K. and Motter, L.E., "A Method to Estimate Slamming Characteristics for Ship Design," Marine Technology, April 1971.

18. Ochi, M.K., "Ship Slamming-Hydrodynamic Impact Between Waves and Ship Bottom Forward," Symposium on Fluid-Solid Interaction, ASME Winter Meeting, Pittsburgh, November 1967.

19. Krachman, H.E., Lindsey, L.G. and Caplan, W.F., "Two Media Low Pressure Transient Measurements," ISA Transactions, Vol. 15, No. 1, 1976, pp. 17-21.

20. Chuang, Sheng-Lun, "Experiments on Slamming of Wedge-Shaped Bodies," Journal of Ship Research, September 1967.

21. Chuang, Sheng-Lun, "Investigation of Impact of Rigid and Elastic Bodies with Water," NSRDC Report No. 3248, February 1970.

22. Pierson, J.D., Dingee, D.A. and Neidinger, J.W., "A Hydrodynamic Study of the Chines-Dry Planing Body," Stevens Institute of Technology, Experimental Towing Tank Report No. 492, May 1954.

23. Pierson, J.D., "The Penetration of a Fluid Surface by a Wedge," Stevens Institute of Technology, Experimental Towing Tank Report No. 381, July 1950.

24. Korvin-Kroukovsky, B.V. and Chabrow, F.R., "The Discontinuous Fluid Flow Past An Immersed Wedge," Stevens Institute of Technology, Experimental Towing Tank Report No. 334, October 1948.

25. Band, E.G.U., "Study of Bow Impact Loads for 100 Ton Surface Effect Ship," Wyle Laboratories, Payne Division Working Paper No. 18008-2 for Aerojet General Corporation, 11 December 1969.

26. "Collins Instruction Book - ALT-50 Radio Altimeter System", Collins Radio Group/Rockwell International, Cedar Rapids, Iowa, Manual No. 523-0764281-10111A, (1 November 1973), with 2nd Edition updates No. 523-0765194-002118 dated 1 December 1974.

27. "2100 System Strain Gage Conditioner and Amplifier System - Instruction Manual", Vishay Instruments, Malvern, Pennsylvania (No Date).

28. Austin, S.L., "Rigid Vinyl Modelling An Efficient Technique for Predicting Ship Structural Response", NSRDC Report, February 1973.

29. Rodd, J.L., "Verification of the Rigid Vinyl Modeling Technique: The SL-7 Structure", Ship Structures Committee, Report No. SSC-259, 1976.

30. Compton, R.H. and Zubaly, R.B., "Further Study of the Use of Model Test Data to Predict Statistical Trends of Wave Bending Moments", Webb Institute of Naval Architecture Progress Report No. 7, for American Bureau of Shipping, March 1964.

31. "Loads Criteria Model Tests Test Data Analysis and Correlation Report", Rohr Industries, Inc. CDRL No. SOOG(H-10)A, ID No. AP2-004114, Doc. No. DH10SOOG02, 31 January 1976.

32. "Slamming Pressures on a Barge Model", SNAME T & R Report R-12.

33. "XR-1D Interim Test Data Analysis and Correlation Report", Rohr Marine, Inc., (March 1978).

APPENDIX A

DESIGN OF THE PROGRAMMER/CONTROLLER

A. DESIGN OF THE PROGRAMMER/CONTROLLER

A.1 PROGRAMMER - CALIBRATION SEQUENCER BOARD

General Description

The primary function of this circuit board is two-fold. Every 24-hour period the board generates a signal which starts an integration process designed to yield a new mean-water line reference. While the above is taking place, the necessary commands are generated to start the recorder and introduce a three B-step, calibration process. The automatic calibration process is initiated along with the mean-water line determination at a reading of zero hours, zero minutes, and zero seconds on the time-code generator.

Functional Description

The programmer board receives a parallel, binary-coded, decimal time from the time code generator. U1 through U6 are TTL one-of-ten decoders. Each decoder decodes those decimal numbers within each decade required to generate the timing signals listed below. Each output used is a negative going pulse, the duration of which is one second.

Time	Signal
00:00:00 00:00:01	A-one second, recorder-start pulse (pin D) together with its complement (pin C).
00:00:04 00:00:10	A 0.5 Hz, square-wave, Cal "A" command is generated for a period of 6 seconds. This 5 volt signal available on pin E will cycle a calibration resistor into one leg of each strain-gage transducer 3 times during the 6-second period.
00:00:10 00:00:16	A 0.5 Hz, square-wave Cal "B" command is generated for a period of 6 seconds. This 5 volt signal available on pin F will cycle a calibration resistor into another leg of each strain gage transducer 3 times during the 6-second period.
00:00:16 00:00:22	A 0.5 Hz, square wave Cal "C" command is generated for a period of 6 seconds. This 5 volt signal available on pin H will cycle the bridge power to each transducer 3 times during the 6-second period.
00:00:22 00:00:23	A one-second, negative-going recorder stop pulse (pin J).

Time	Signal
00:00:00 00:01:00	A one-minute, positive-going pulse (pin P) together with its complement (pin K) which enables the wave height integrator for a determination and storage in memory of the mean-water line reference.
00:00:00 00:02:00	A low-going, two-minute, integration signal to be used in the event a one-minute integration is insufficient.

Note: If a two-minute integration is required, make the following changes to the programmer board:

1) Disconnect wire on pin K of card and wire pin K to U9 pin 6.
2) Disconnect wire between pin P of card and U9 pin 4 and connect pin P of card to U9 pin 5.

The outputs of the decimal decoders are inverted by the hex inverters U7 and U8. U10, U11, U12, (triple 4 input nand gates) and parts of U9 (hex inverter) do the necessary decoding to yield set and reset pulse that mark the beginning and ending of each of the 6-second calibration periods. These set and reset pulses toggle the dual flip-flops U13 and U14 to yield the 6-second-long, positive level corresponding to each cal mark. The flip-flop outputs are used to gate the .5 Hz square wave through the dual-input nand gates in U15.

The .5 Hz square wave is derived from a 1 Hz time-code generator output by dividing it in half with a J-K flip-flop wired from 1/2 of U13.

The integration commands are similarly decoded from the outputs of the BCD to decimal decoders.

The tuning wave forms illustrated in Figure A1 shows the functions of the various circuit elements. Figure A2 shows the calibration arrangement used for the radar altimeter.

A.2 WAVE-HEIGHT-AVERAGER BOARD

General Description

The function of this board is to receive and utilize the output of the altimeter to determine an average waterline reference denoted here by $\overline{x}$. This reference is the average distance in feet from the altimeter to the water. The analog output from the altimeter is buffered and filtered prior to being integrated for a period of 60 seconds. (The integration time is determined by the programmer board and will occur every 24 hours). The analog averaged waterline reference $\overline{x}$ is sampled and held long enough to be converted to a parallel digital word which is stored for 24 hours. A digital to analog converter outputs the stored word through an inverting amplifier to yield the final output $\overline{x}$ of proper polarity for computations performed by the recorder control board. There are facilities to input any desired $\overline{x}$ value manually in the event the stored data are not used.

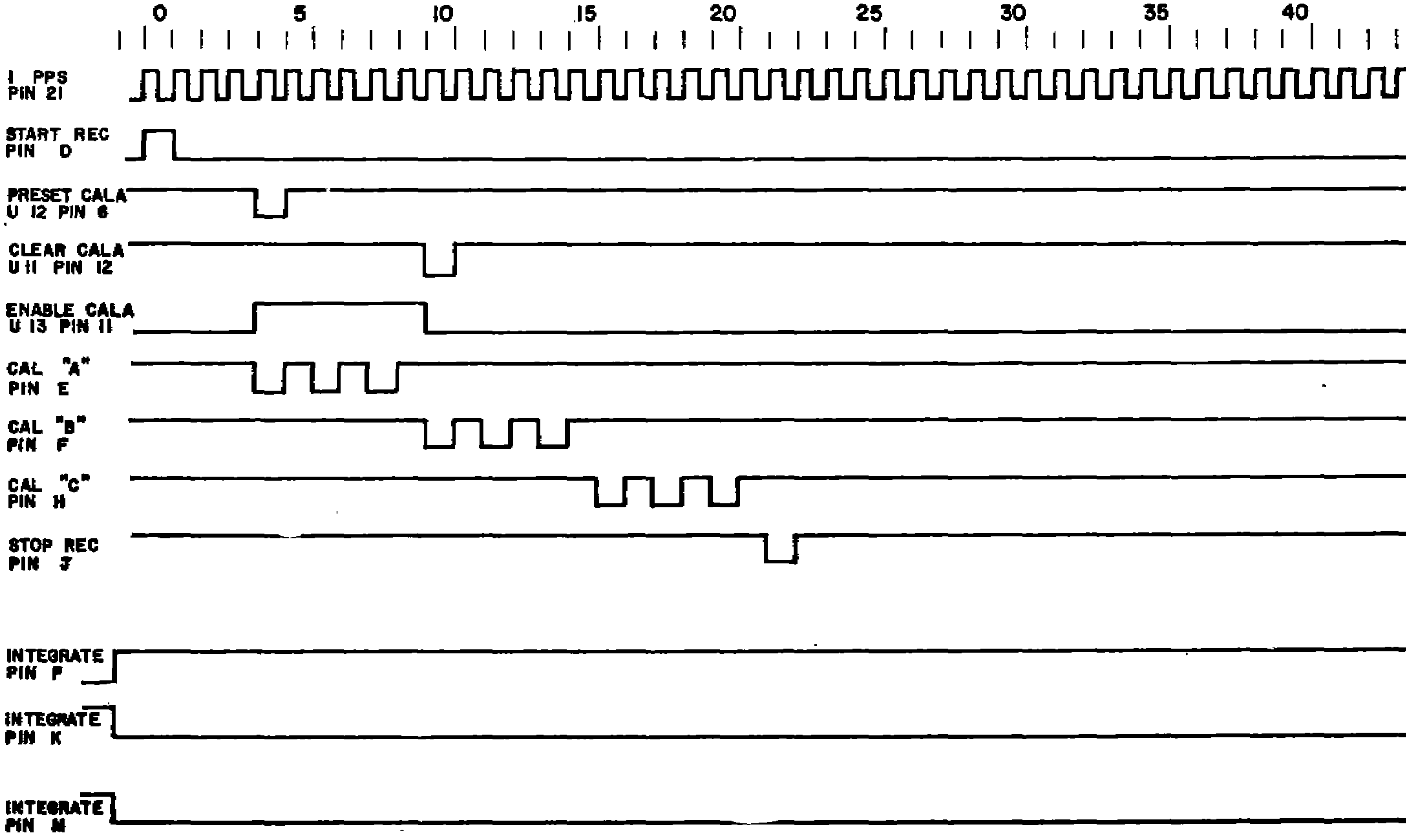


Figure A1.(a). Calibration Sequence.

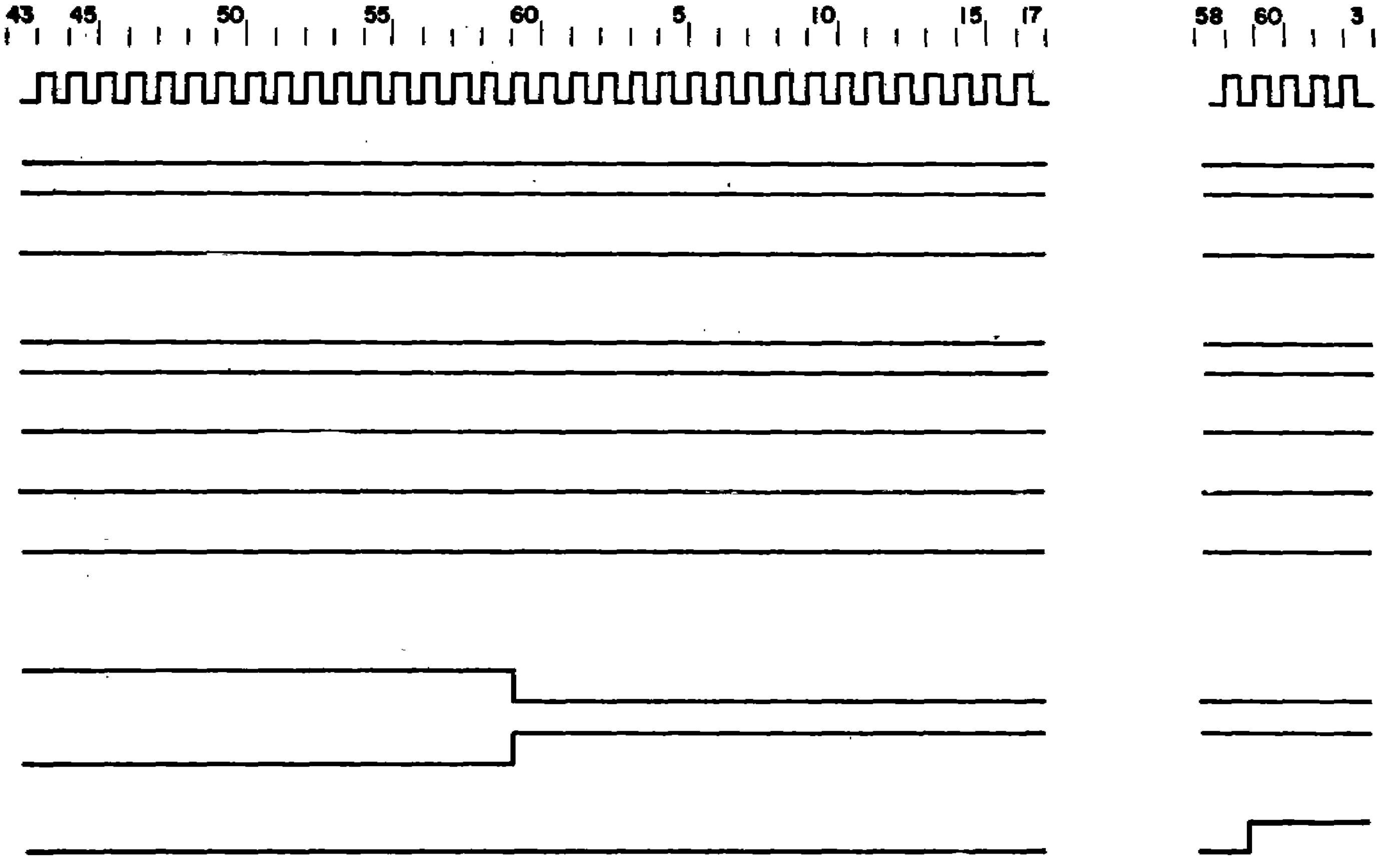


Figure A1.(b). Calibration Sequence.

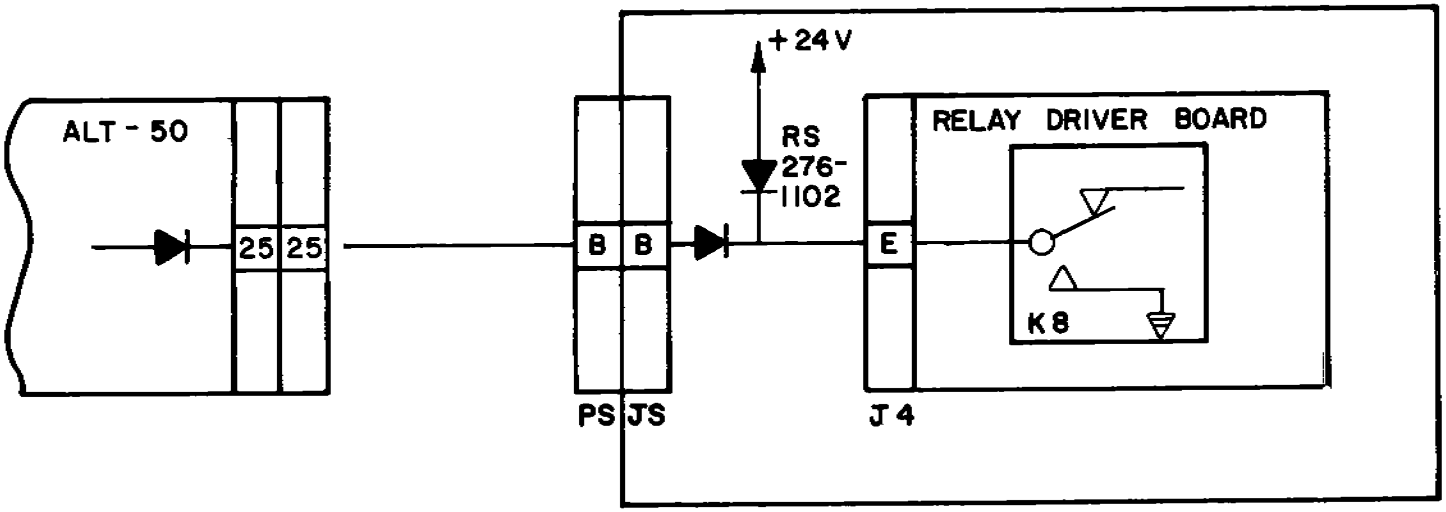


Figure A2. Altimeter Calibration Fix.

Functional Description

The output signal from the altimeter is buffered by a 747 operational amplifier contained within integrated circuit U1. This amplifier performs two main functions. It provides a D.C. offset to compensate for the 0.4 VDC level always present on the altimeter output and it provides a two-pole, low pass filter with $f_c = 5$ Hz. The overall low frequency gain of this buffer is unity. The buffered altimeter output x is routed to the Recorder Control Board via pin 5 and to an integrator U2. The integrator output is normally clamped to zero by the solid-state, two-pole switch U3 which shorts the integrating capacitor C (see Figure A3) . Upon receiving an integrating command from the programmer board, U3/S1 opens allowing U2 to integrate for the programmed time. Since,

$$e_o = -\frac{1}{RC}\int_{t=0}^{t=60} e_i dt$$

The value of RC is set to yield a scale factor of 0.1 v/ft at the output of the integrator.

A.3 RECORDER-CONTROL BOARD

General Description

The basic function of this board is to determine when the wave trough drops to some predetermined threshold (indicative of a forthcoming flare or bottom slam), start the recorder, stop the recorder, recycle or delay shutdown in a manner to capture on tape all transient data associated with every slam. In order to understand the run criteria, the general parameters and their relationships are shown in Figure A4.

Prior to running, a decision must be made as to which type of slams will be recorded (i.e. flare or bottom). A switch on the front panel must be set accordingly. When the proper threshold criteria has been recognized, a recorder start signal is generated and maintained for a variable time after the criteria is no longer met (i.e. the wave trough having risen above the threshold). The entire cycle is retriggerable in the event the wave trough once more exceeds the criteria even if the recorder is still in the delayed stop portion of the previous cycle.

Functional Description (see Figure A5)

$\overline{x}$ and x' are buffered in the dual, op-amp circuits of U1. The buffer for $\overline{x}$ is unity gain since the scale factor has been established as 0.1 v/ft by the Wave-Height-Averager Board or the manual, draft-control potentiometer. The x' parameter is given a gain of 5 to make it compatible with the $\overline{x}$ signal. In addition, a 3-Hz, low-pass, filter function is also provided for x' by feedback capacitor in its buffer amplifier. The buffered x' signal is now denoted as -x.

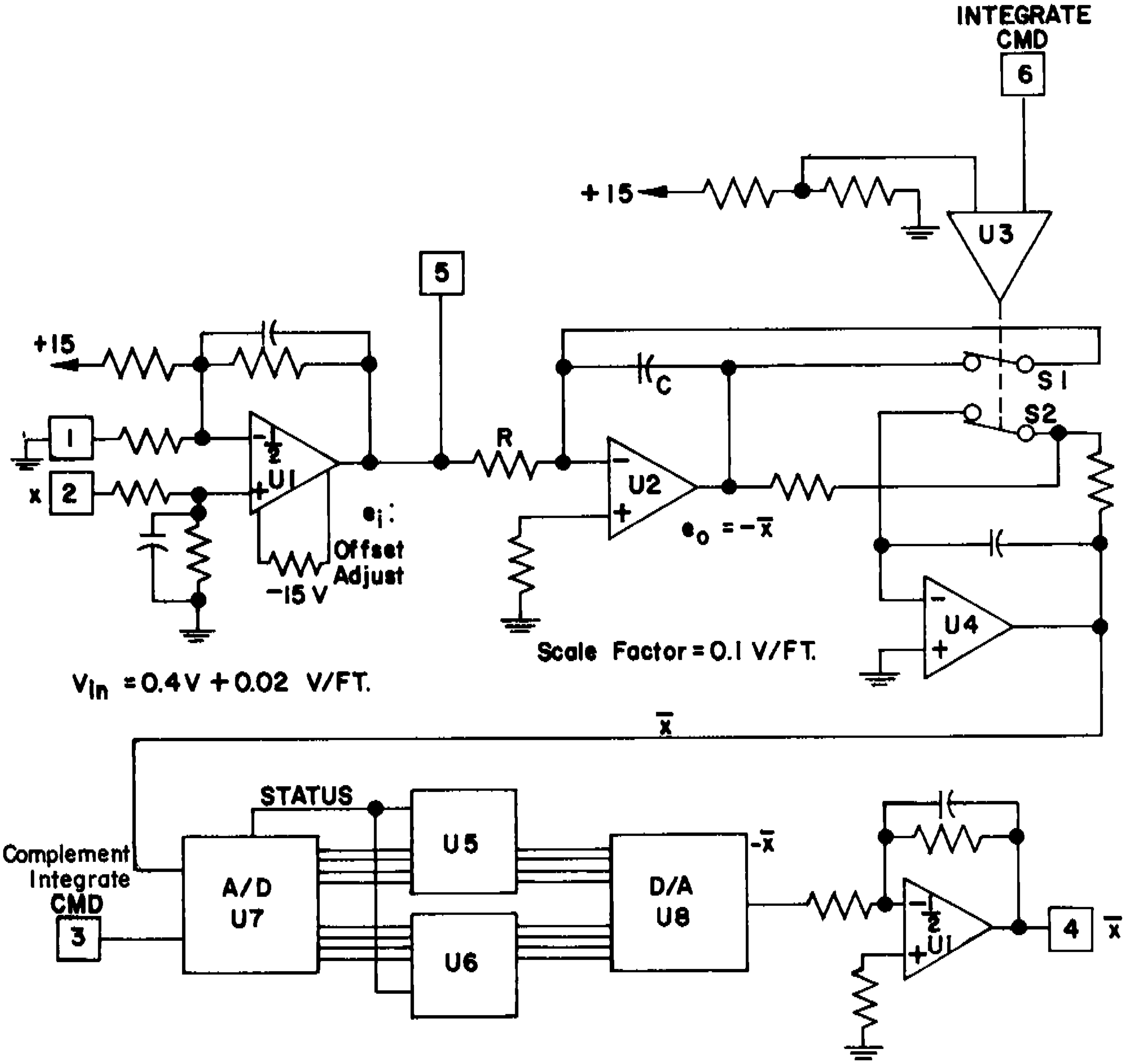
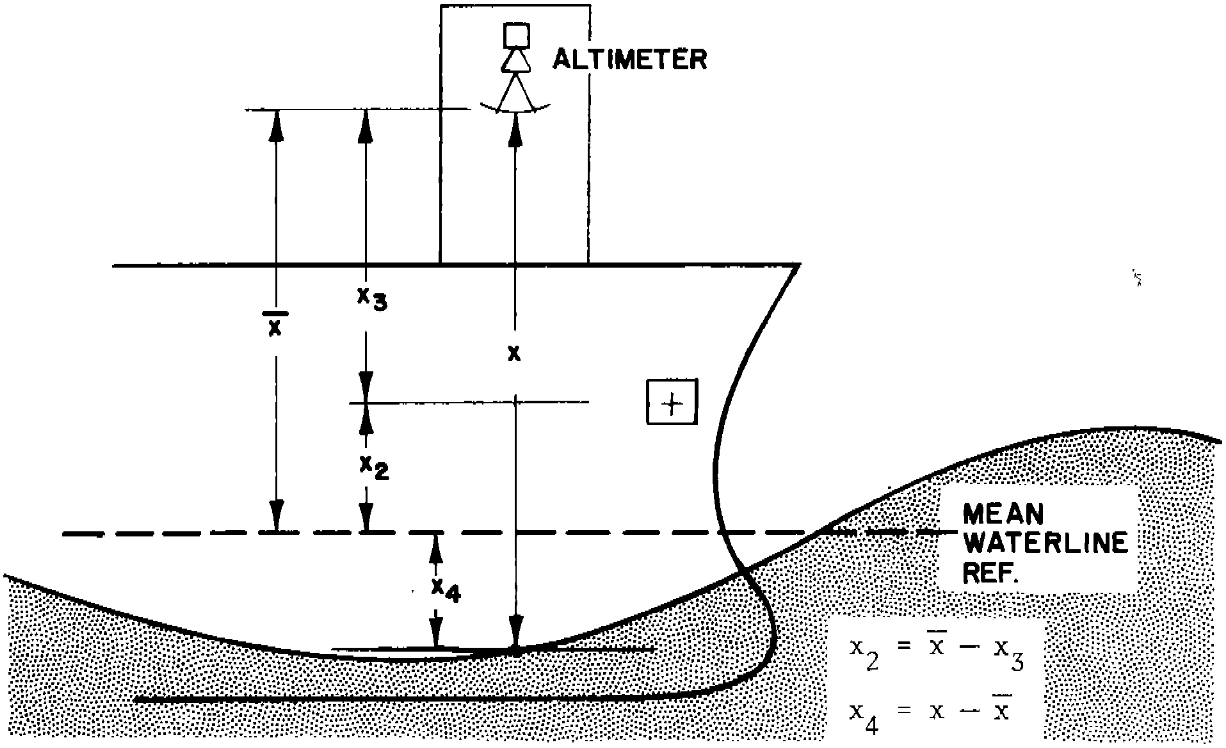


Figure A3. Wave Height Averager Board, Functional Block Diagram.



$$x_2 = \bar{x} - x_3$$

$$x_4 = x - \bar{x}$$

Flare Slam Criterion ← $x_4 > x_2$

Bottom Slam Criterion — $x_4 < x_2$

Figure A4. Definition of Altitudes Measured by Radar Altimeters.

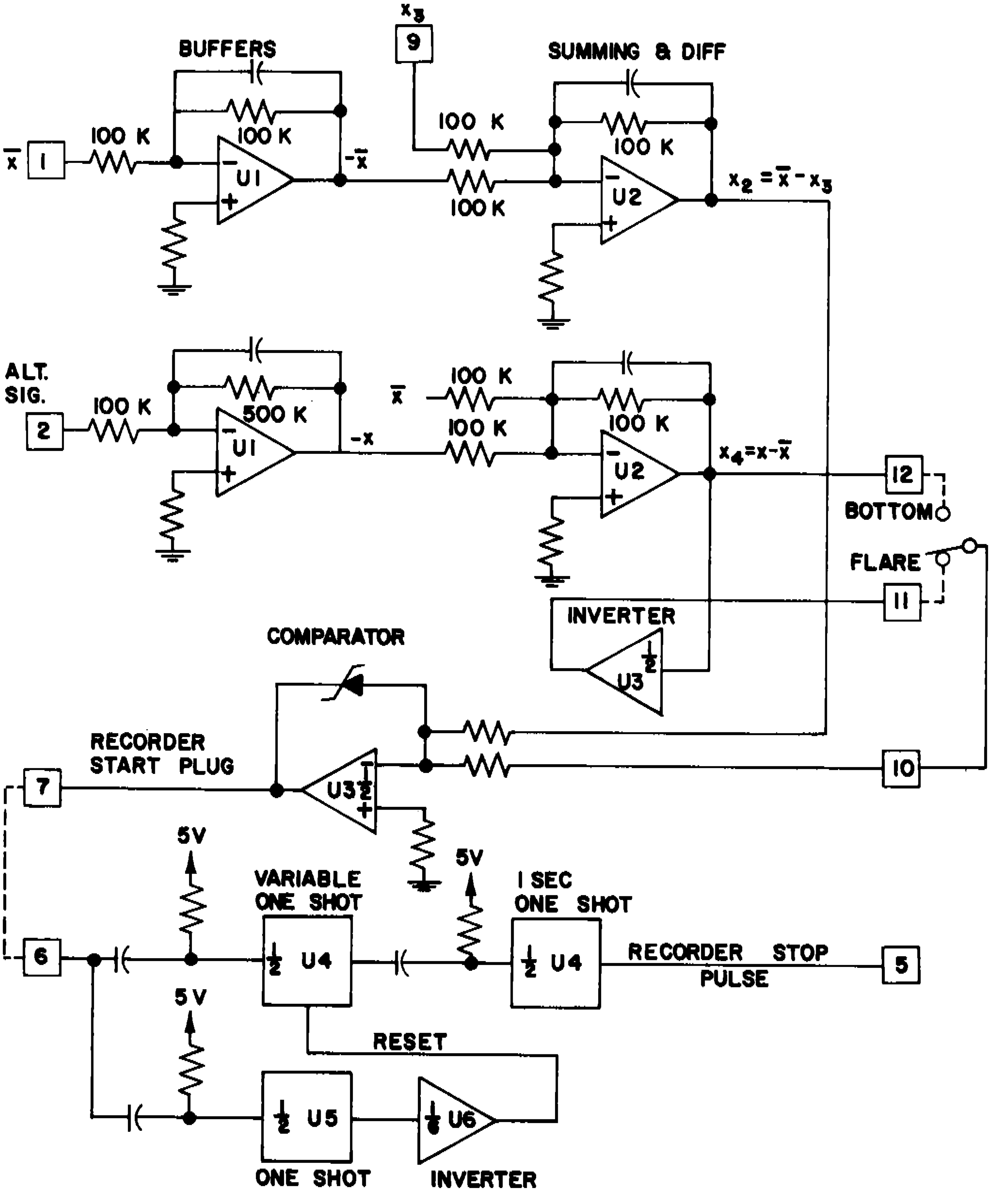


Figure A5. Functional Block Diagram of the Recorder-Control Board.

The two 747 op amps in U2 operate on x_3, $-\bar{x}$, and $-x$ as differencing circuits to yield the two outputs x_2 and x_4.

x_2 is routed to one input of a comparator made up of 1/2 of U3. Either x_4 or $-x_4$ (depending on which slam mode is being investigated) is routed to the other input. Thus for the case of the flare mode when $|x_4| > |x_2|$, the polarity of the x_4 input at the comparator is negative and since the two parameters are summed at the negative input the output goes positive.

It is this positive level at pin 7 that is used as the recorder start signal. The start signal performs relay drive functions on the Driver Board and is routed back to the Control Board via pin 6. The start pulse will stay positive as long as $x_4 > x_2$. When this criteria is no longer met, the negative-going edge of the start signal is capacity coupled into the trigger input of 1/2 of U4. U4 is a dual, 555 timer, each half of which is wired as a one shot. The first one-shot generates a positive-going pulse of variable length (depending on the stop-delay-potentiometer setting) upon the input falling edge of the recorder-start signal. It is this one shot that determines the length of time that the recorder will run after the wave trough has risen above the threshold. After the appropriate delay, the negative going edge of the first one shot triggers the second half of U4. This one shot outputs a one-second-long, stop pulse sufficient to stop the recorder. It is a feature of the 555 timer that if the reset line (pin 4 of U4) is momentarily held at ground simultaneous to the application of a trigger signal, the entire timing cycle is repeated. U5 and U6 provide the recycle pulse to enable the recycle feature.

A.4 RELAY-DRIVER BOARD

General Description

The Relay-Driver Board provides the interface between the low level drive signals generated by the other boards in the system and the Ampex FR1300 and strain gage amplifiers. It consists of a number of 5 VDC dip relays which perform a number of functions such as applying 28 VDC to the calibrate relays in the strain gage amplifiers as well as making circuit closures on the Ampex remote control lines.

Examination of the schematic indicates that only three basic circuits are used. Some 7400 series nand gates provide some simple logic and signal conversion where necessary. Open collector 7406 inverters are used as current sinks for the third elements on the board which are the drive relays.

Since some conversion time is required of the A/D converter, U4 in conjunction with U3/S2 provides a sample and hold circuit to hold the value $\bar{x}$ sufficiently long. During the integration period U4 acts as an inverter. S2 opens with the disappearance of the integrate command signal holding the output of U4 at the determined average value $\bar{x}$.

The 8-bit A/D converter U7 is a successive approximation converter operating from its internal clock and initiated by the negative going edge on the inverse of the integrate command. This edge coincides with the maximum output of the integrator. When conversion is complete, the converter status output (pin 3 of U7) goes low setting the binary data bits into the two, 4-bit latches U5 and U6. It is U5 and U6 that provide the memory function for the averaged waterline reference.

U8 is a 10 bit D/A converter which is being used in an 8 bit configuration. It continually outputs in analog form, the binary data it received from the two, 4-bit latches. Another 747 op amp is utilized in the second half of U1 to invert the negative output from the D/A converter and provide $\overline{x}$ for use by the Recorder-Control Board.

A.5 WIRING DIAGRAMS

The following wiring diagrams are attached as Figures A6 through A10:

Figure A6: Programmer-Calibration - Sequencer Board Logic and Wiring Diagram.

Figure A7: Wave-Height Averager Board.

Figure A8: Recorder-Controller Board.

Figure A9: Relay-Driver Board

Figure A10: Vishay Relay Board Installation.

Figure A11: Chassis Wiring Diagram, System Programmer.

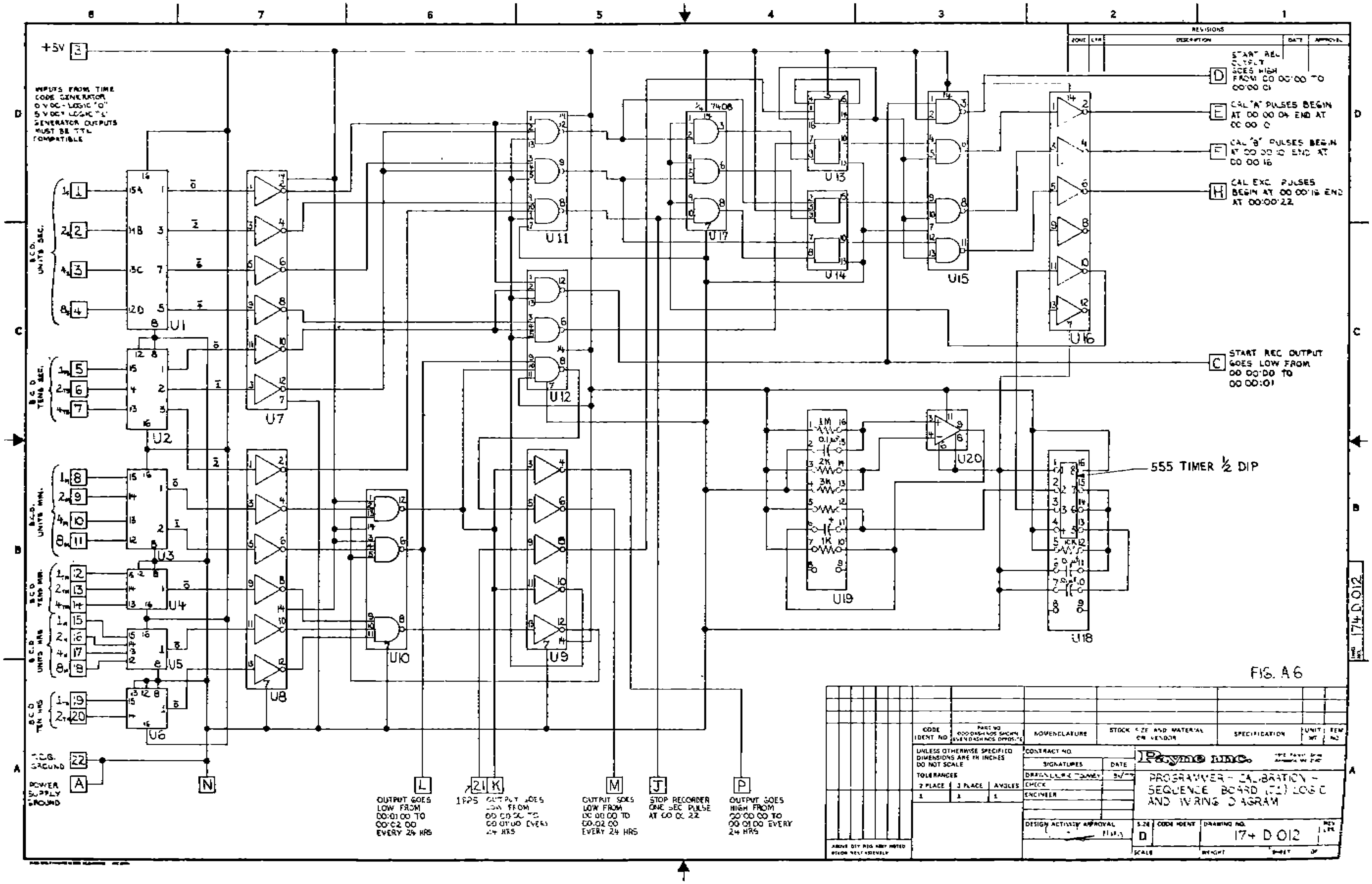

+5V 3
INPUTS FROM TIME CODE GENERATOR
0 V DC - LOGIC "0"
5 V DC - LOGIC "1"
GENERATOR OUTPUTS MUST BE TTL COMPATIBLE
B.C.D. UNITS SEC.
B.C.D. TENS SEC.
B.C.D. UNITS MIN.
B.C.D. TENS MIN.
B.C.D. UNITS HRS
B.C.D. TENS HRS
T.C.G. GROUND 22
POWER SUPPLY GROUND A
U1
U2
U3
U4
U5
U6
U7
U8
U9
U10
U11
U12
U13
U14
U15
U16
U17
U18
U19
U20
¼ 7408
555 TIMER ½ DIP
1M
0.1µF
2K
3K
1K
10K
N
START REC OUTPUT GOES HIGH FROM 00 00'00 TO 00'00 01
CAL "A" PULSES BEGIN AT 00 00 04 END AT 00 00 0
CAL "B" PULSES BEGIN AT 00 00 10 END AT 00 00 16
CAL EXC. PULSES BEGIN AT 00 00'16 END AT 00'00'22
START REC OUTPUT GOES LOW FROM 00 00:00 TO 00 00:01
L
OUTPUT GOES LOW FROM 00:01 00 TO 00'02 00 EVERY 24 HRS
21
1PPS
K
OUTPUT GOES LOW FROM 00 00 00 TO 00 01'00 EVERY 24 HRS
M
OUTPUT GOES LOW FROM 00 00 00 TO 00:02 00 EVERY 24 HRS
J
STOP RECORDER ONE SEC PULSE AT 00 00 22
P
OUTPUT GOES HIGH FROM 00'00 00 TO 00 01 00 EVERY 24 HRS
REVISIONS
ZONE
LTR
DESCRIPTION
DATE
APPROVAL
CODE IDENT NO
PART NO
NOMENCLATURE
STOCK SIZE AND MATERIAL OR VENDOR
SPECIFICATION
UNIT WT
ITEM NO
UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES DO NOT SCALE
TOLERANCES
2 PLACE
3 PLACE
ANGLES
CONTRACT NO.
SIGNATURES
DATE
DRAWN
CHECK
ENGINEER
DESIGN ACTIVITY APPROVAL
Payne inc.
PROGRAMMER - CALIBRATION - SEQUENCE BOARD (Z1) LOGIC AND WIRING DIAGRAM
SIZE D
CODE IDENT
DRAWING NO. 174 D 012
REV LTR
SCALE
WEIGHT
SHEET
OF
174 D 012

FIG. A6

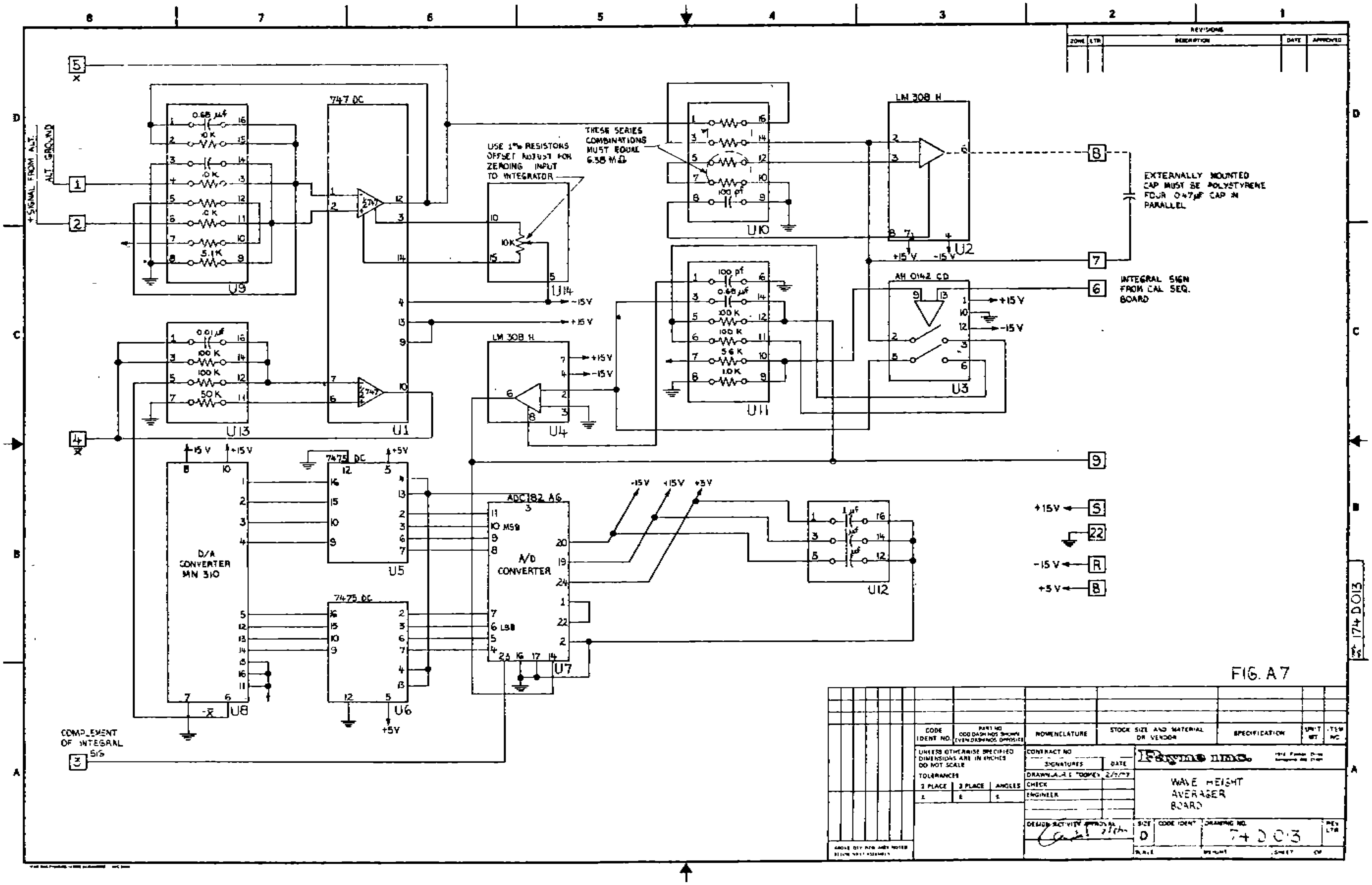

+SIGNAL FROM ALT.
ALT. GROUND
0.68 µf
10 K
5.1 K
U9
747 DC
747
U1
U13
0.01 µf
100 K
50 K
USE 1% RESISTORS OFFSET ADJUST FOR ZEROING INPUT TO INTEGRATOR
10K
U14
-15 V
+15 V
THESE SERIES COMBINATIONS MUST EQUAL 6.38 MΩ
100 pf
U10
LM 308 H
U2
EXTERNALLY MOUNTED CAP MUST BE POLYSTYRENE FOUR 0.47µF CAP IN PARALLEL
AH 0142 CD
U3
INTEGRAL SIGN FROM CAL SEQ. BOARD
100 K
56 K
1.0 K
U11
LM 308 H
U4
D/A CONVERTER MN 310
U8
7475 DC
U5
U6
ADC 182 AG
MSB
LSB
A/D CONVERTER
U7
1 µF
U12
+5 V
COMPLEMENT OF INTEGRAL SIG
+15 V
-15 V
+5 V
CODE IDENT NO.
PART NO ODD DASH NOS SHOWN EVEN DASH NOS OPPOSITE
NOMENCLATURE
STOCK SIZE AND MATERIAL OR VENDOR
SPECIFICATION
UNIT WT
ITEM NO
UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES DO NOT SCALE
TOLERANCES
2 PLACE
3 PLACE
ANGLES
CONTRACT NO
SIGNATURES
DATE
DRAWN A.A.E. TOOMEY 2/7/77
CHECK
ENGINEER
DESIGN ACTIVITY APPROVAL
Payne inc.
WAVE HEIGHT AVERAGER BOARD
SIZE D
CODE IDENT
DRAWING NO. 74D013
REV LTR
SCALE
WEIGHT
SHEET
OF
REVISIONS
ZONE
LTR
DESCRIPTION
DATE
APPROVED
174 D013

FIG. A7

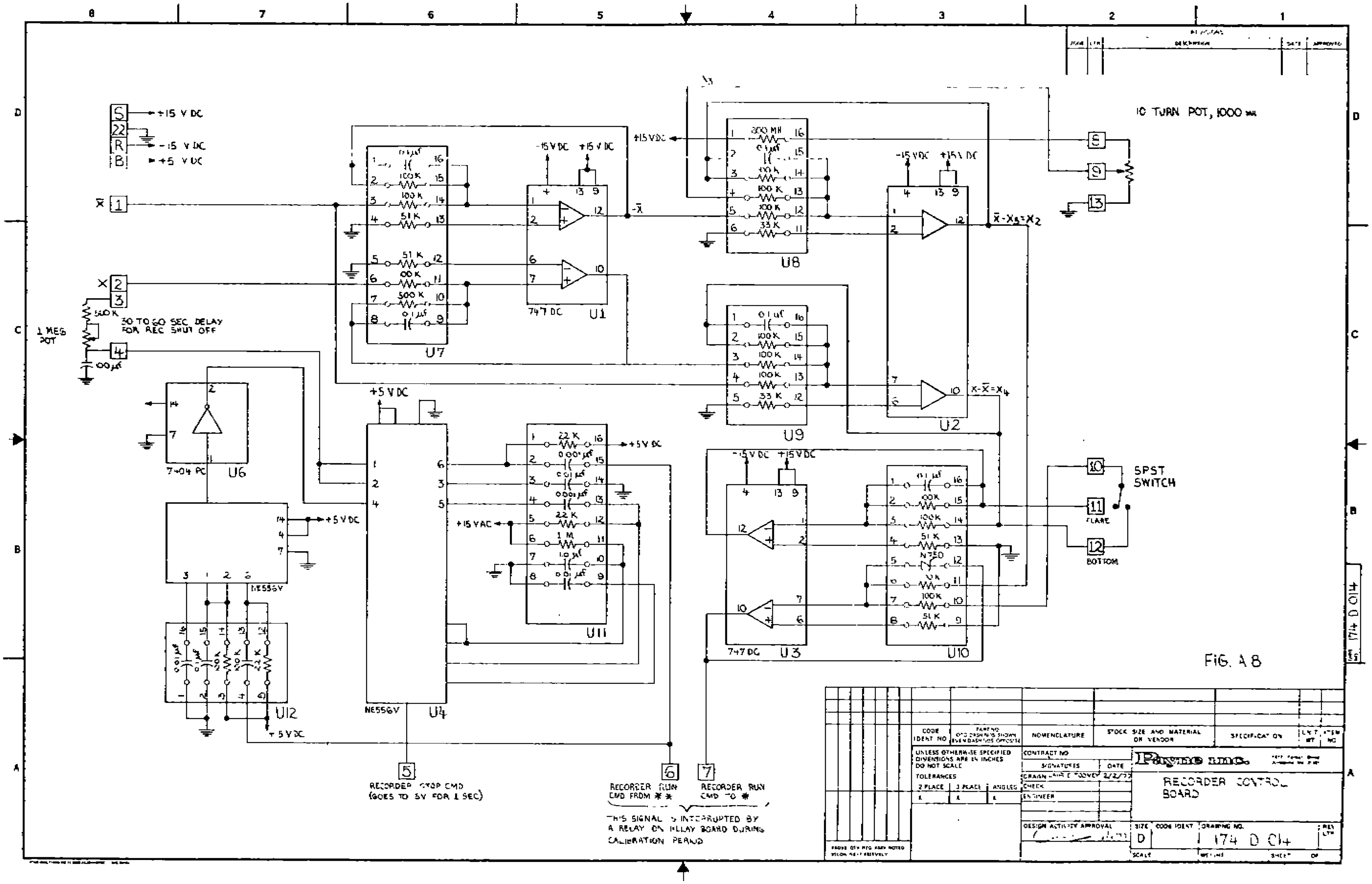

S +15 V DC
22
R -15 V DC
B +5 V DC
X̄ 1
X 2
3
500 K
1 MEG POT
30 TO 60 SEC DELAY FOR REC SHUT OFF
4
100 μf
U7
U1
747 DC
-15 V DC
+15 V DC
-X̄
+15 VDC
U8
200 MH
0.1 μf
100 K
33 K
U9
U2
X̄-X₃=X₂
X-X̄=X₄
10 TURN POT, 1000
5
9
13
10
11
12
SPST SWITCH
FLARE
BOTTOM
U3
747 DC
U10
N750
51 K
U6
7404 PC
NE555V
U12
+5 VDC
U4
NE556V
U11
22 K
1 M
0.001 μf
0.01 μf
1.0 μf
+15 VAC
RECORDER STOP CMD (GOES TO 5V FOR 1 SEC)
6
RECORDER RUN CMD FROM **
7
RECORDER RUN CMD TO *
THIS SIGNAL IS INTERRUPTED BY A RELAY ON RELAY BOARD DURING CALIBRATION PERIOD
CODE IDENT NO
PART NO
NOMENCLATURE
STOCK SIZE AND MATERIAL OR VENDOR
SPECIFICATION
UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES DO NOT SCALE
TOLERANCES
2 PLACE
3 PLACE
ANGLES
CONTRACT NO
SIGNATURES
DATE
DRAWN
2/2/77
CHECK
ENGINEER
DESIGN ACTIVITY APPROVAL
Payne inc.
RECORDER CONTROL BOARD
SIZE D
CODE IDENT
DRAWING NO. 174 D 014
SCALE
SHEET
OF

FIG. A8

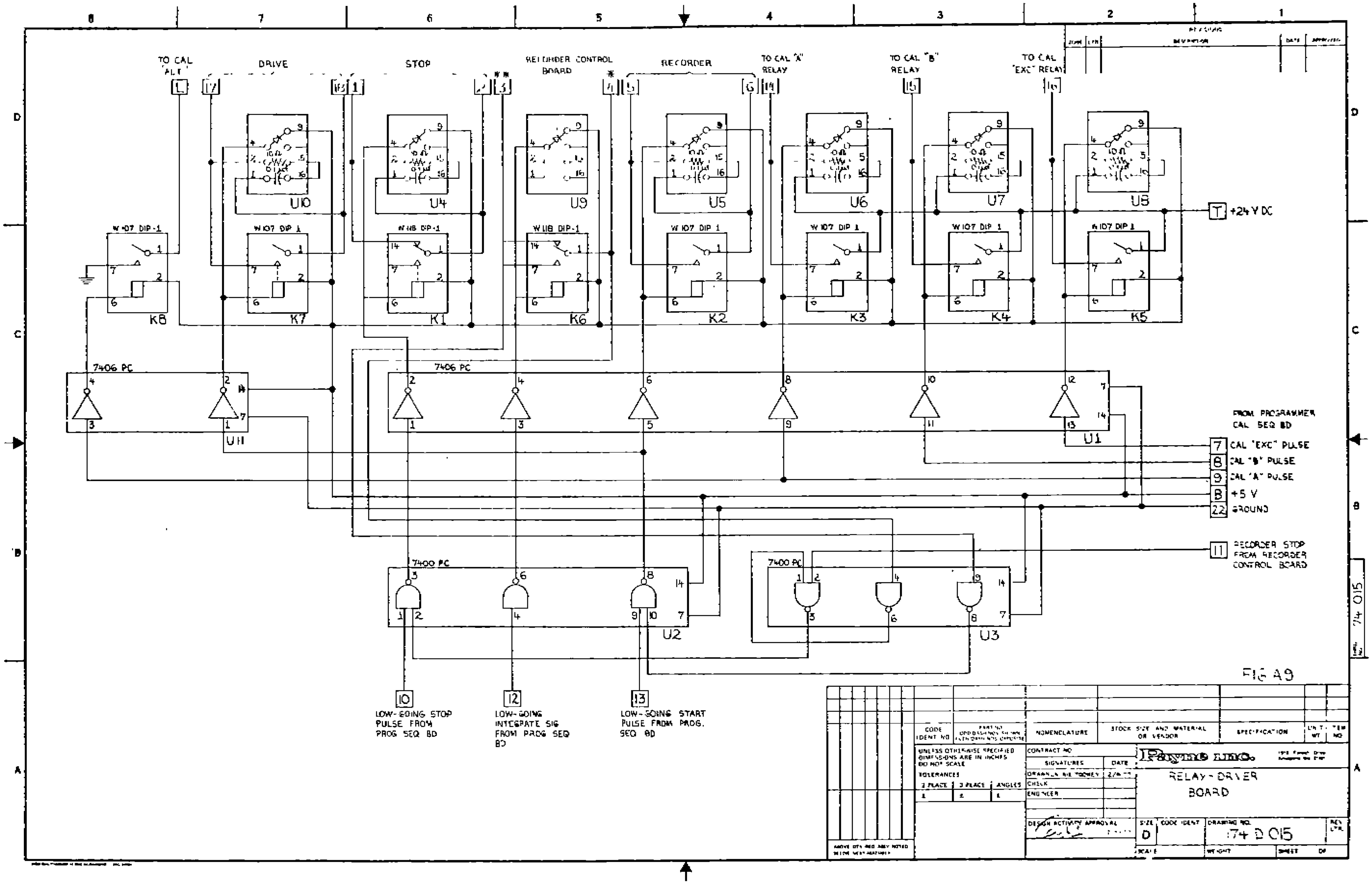

TO CAL "ALT"
DRIVE
STOP
RECORDER CONTROL BOARD
RECORDER
TO CAL "A" RELAY
TO CAL "B" RELAY
TO CAL "EXC" RELAY
L
17
18
1
2
3
4
5
G
14
15
16
U10
U4
U9
U5
U6
U7
U8
W107 DIP-1
W118 DIP-1
K8
K7
K1
K6
K2
K3
K4
K5
T
+24 V DC
7406 PC
U11
U1
FROM PROGRAMMER CAL SEQ BD
7 CAL "EXC" PULSE
8 CAL "B" PULSE
9 CAL "A" PULSE
B +5 V
22 GROUND
11 RECORDER STOP FROM RECORDER CONTROL BOARD
7400 PC
U2
U3
10 LOW-GOING STOP PULSE FROM PROG SEQ BD
12 LOW-GOING INTEGRATE SIG FROM PROG SEQ BD
13 LOW-GOING START PULSE FROM PROG. SEQ BD
REVISIONS
ZONE
LTR
DESCRIPTION
DATE
APPROVED
CODE IDENT NO
PART NO
NOMENCLATURE
STOCK SIZE AND MATERIAL OR VENDOR
SPECIFICATION
UNIT WT
ITEM NO
UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES DO NOT SCALE
TOLERANCES
2 PLACE
3 PLACE
ANGLES
CONTRACT NO
SIGNATURES
DATE
CHECK
ENGINEER
DESIGN ACTIVITY APPROVAL
Payne Inc.
RELAY-DRIVER BOARD
SIZE
D
CODE IDENT
DRAWING NO.
174 D 015
REV LTR
SCALE
WEIGHT
SHEET
OF
174 D 015

FIG A9

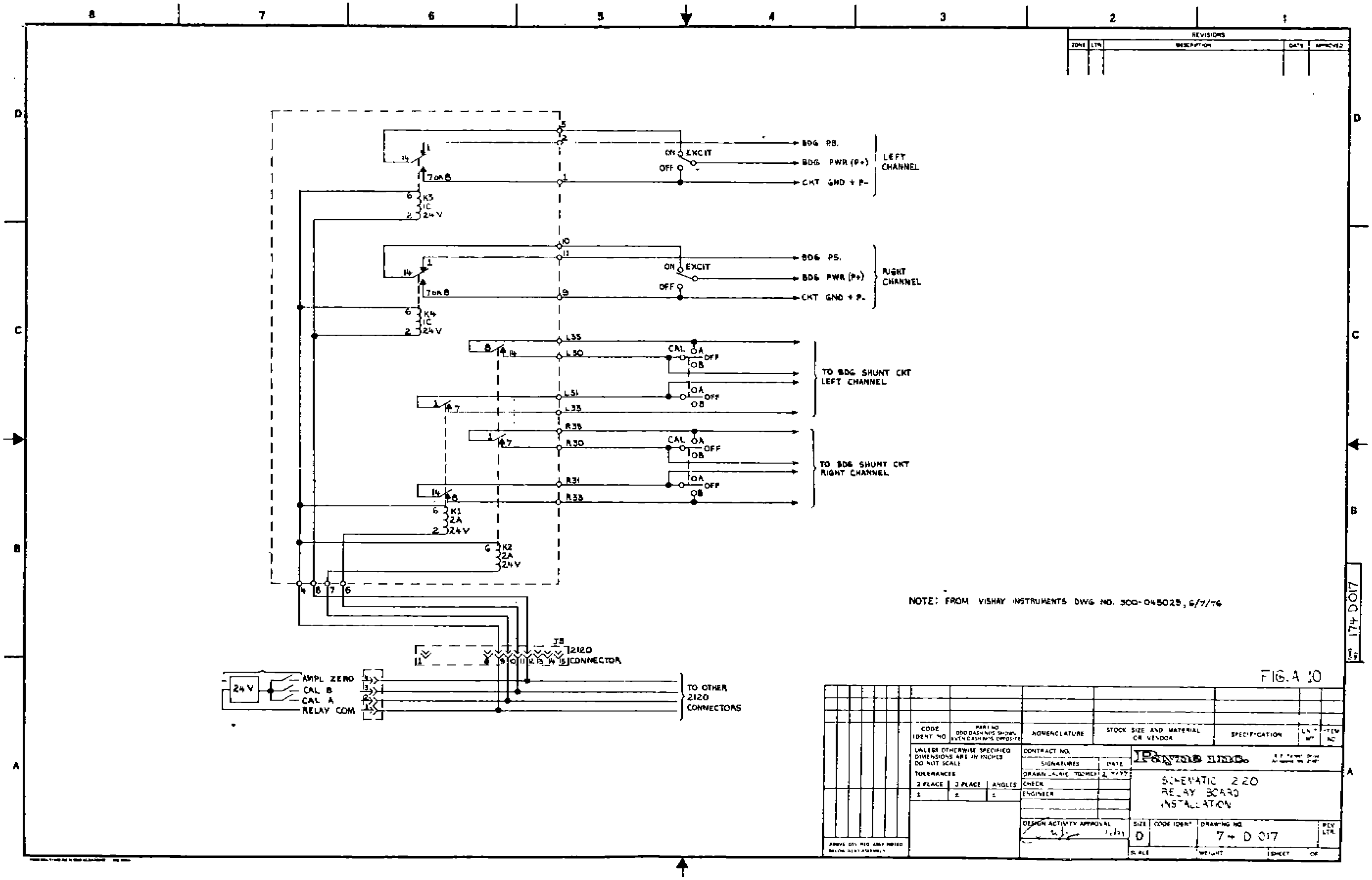


FIG. A 10

NOTE: FROM VISHAY INSTRUMENTS DWG NO. 300-045025, 6/7/76

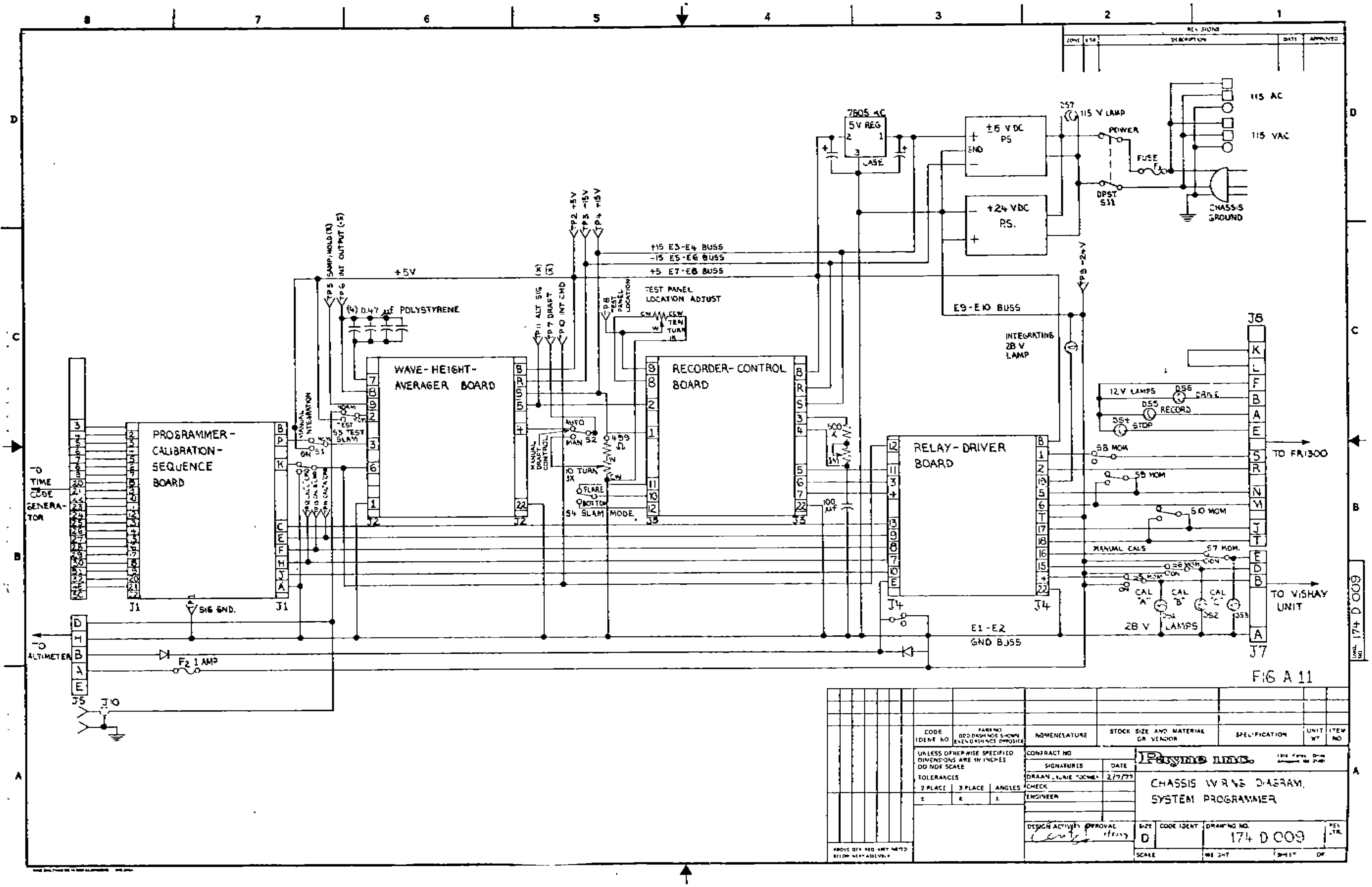

PROGRAMMER - CALIBRATION - SEQUENCE BOARD
WAVE-HEIGHT-AVERAGER BOARD
RECORDER-CONTROL BOARD
RELAY-DRIVER BOARD
±15 VDC PS
+24 VDC PS.
7805 AC
5V REG
CASE
115 V LAMP
POWER
FUSE
DPST S11
115 AC
115 VAC
CHASSIS GROUND
+15 E3-E4 BUSS
-15 E5-E6 BUSS
+5 E7-E8 BUSS
E9-E10 BUSS
E1-E2 GND BUSS
+5V
TP2 +5V
TP3 -15V
TP4 +15V
TP5 SAMP/HOLD (X)
TP6 INT OUTPUT (-X)
TP11 ALT SIG (X)
TP7 DRAFT (X)
TP10 INT CMD
TP8 TEST PANEL LOCATION
TP9 -24V
(4) 0.47 µf POLYSTYRENE
TEST PANEL LOCATION ADJUST
TEN TURN
MANUAL INTEGRATION
ON S1
S3 TEST SLAM
AUTO
MAN S2
MANUAL DRAFT CONTROL
10 TURN
FLARE
BOTTOM
S4 SLAM MODE
499 Ω
500
100 µf
INTEGRATING 28 V LAMP
12 V LAMPS
DS6 DRIVE
DS5 RECORD
DS4 STOP
S8 MOM
S9 MOM
S10 MOM
MANUAL CALS
S7 MOM.
CAL "A"
CAL "B"
CAL "C"
28 V LAMPS
TO FR1300
TO VISHAY UNIT
J1
J2
J3
J4
J5
J6
J7
J10
SIG GND.
F2 1 AMP
TO TIME CODE GENERATOR
TO ALTIMETER
174 D 009
CODE IDENT NO
PART NO
NOMENCLATURE
STOCK SIZE AND MATERIAL OR VENDOR
SPECIFICATION
UNIT WT
ITEM NO
UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES DO NOT SCALE
TOLERANCES
2 PLACE
3 PLACE
ANGLES
CONTRACT NO
SIGNATURES
DATE
DRAWN
2/7/77
CHECK
ENGINEER
DESIGN ACTIVITY APPROVAL
Payne inc.
CHASSIS WIRING DIAGRAM, SYSTEM PROGRAMMER
SIZE D
CODE IDENT
DRAWING NO. 174 D 009
SCALE
SHEET
OF

FIG A 11

APPENDIX B

LIST OF GOVERNMENT FURNISHED EQUIPMENT

(MATERIAL RECEIVED FROM TELEDYNE)
(7/28/76)

Payne, Inc.

Material Received from Teledyne 7/28/76

Contract No. N00024-76-C-4399

Full-Scale Slam Investigation - Ship Structures Committee

Item	Description	Unit of Issue	Comments
1	C222 B&F Signal Cond. Equipt	1	Mounted in cabinet but not currently being used. Recommend they not be used.
	Consists of:		
	4 B&F Input Cond. PC-2423	S/N's 2560, 3696, 3699, 2590	
	4 B&F Power Supplies 30-100F	S/N's 1626, 2261, 1994, 2471	
	4 B&F Amplifiers 600-100	S/N's 7619, 1486, 3644, 1489	
	1 B&F Model 15-200F Power Supply Instrumentation Manual		
2	C240 Ampex Portable Tape Recorder 14 Track	1	Incorporated in system as principal recording device.
	Consists of:		
	1 Ampex FR-1300 Recorder/ Reproducer System 9435 208000	S/N 9170584	
	6 FM Reproduce cards		
	1 Voice Log card		
	13 FM Record cards		
	1 Direct Record Card		
	6 Ampex FM Reproduce Filter Units (60 IPS) Cat.# 46390-11		
	6 Ampex FM Reproduce Filter Units (3-3/4 IPS) # 46390-51		
	6 Ampex FM Reproduce Filter Units (1-7/8 IPS) # 46390-61		
	1 Ampex Direct Reproduce Equalizer (60 IPS)Cat.# 69117-11		
	1 Ampex Direct Reproduce Equalizer (3-3/4 IPS) # 69117-51		
	1 Ampex Direct Reproduce Equalizer (1-7/8 IPS) # 69117-61		
	1 Ampex 69650 ES-100 Signal Electronics Operation and Maintenance Manual		
	1 Ampex 24036 FR-1300 Recorder/Reproducer Operation and Maintenance Manual		
3	C249 Humphrey Pendulums	2	
	Consists of:		
	2 Model CP17-0601-1 Humphrey Pendulums	S/N's H2095, H3390	
4	C250 Setra Linear Accelerometers	5	Incorporated in instrumentation package.
	Consists of:		
	2 Model 100 ±5g	S/N's 2074, 072	
	2 Model 100 ±2.5g	S/N's 1360, 070	
	1 Model 100 ±2.0g	S/N 068	

Material Received from Teledyne (Con't.)

Item	Description	Unit of Issue	Comments
5	C299 Ingersol Instrument Cabinets Consists of: 3 77" High Cabinets	3	Serviceable but incomplete. Used in assembly of components.
6	C304 Automation Ind. Digital Strain Indicator Portable Consists of: 1 Automation Ind. (BUDD) Digital Strain Indicator Model No. P-350 S/N 004541 1 Automation Ind. Model P-350 Digital Strain Indicator (Portable) Instruction Manual	1	
7	C317 Hewlett-Packard Electronic Voltmeter Consists of: 1 Hewlett-Packard Electronic Voltmeter Model 410C S/N 550-07532 1 Hewlett-Packard 410C Operating and Service Manual	1	Inoperative.
8	C342 Lambda Power Supplies/Rack Adapter Consists of: 2 LP411FM Power Supplies S/N's 2914, A2955 1 Instruction Manual (LP400 series)	2	
9	C342 Lambda Power Supplies/Lock Controls Consists of: 2 LP412FM Power Supplies S/N's A2549, A1800 1 Instruction Manual (LP400 Series)	2	
10	C351 Seth-Thomas Ships Clock Consists of: 1 Seth-Thomas Ships Clock	1	
11	C376 Simpson Electric Volt Omhmyst 17" Scale Consists of: 1 Simpson Model 269, Series 2 Portable VOM and Leads	1	

Material Received from Teledyne (Con't.)

Item	Description	Unit of Issue	Comments
12	C393 Textronic Oscilloscope Model RM15	1	Used for checkout of programmer/ controller.
	Consists of:		
	1 Tektronix Oscilloscope Type RM15	S/N 003584	
	1 Type RM15 Instruction Manual		
13	C404 Lambda FM Power Supplies/ Rack Adapter	4	
	Consists of:		
	4 LP411FM Power Supplies (0-20 VDC)	S/N's 2488, A2067, 2741, A2963	
	1 Instruction Manual (LP400 series)		
14	C414 API/Instr. Micrommeter Control Relay	1	
	Consists of:		
	1 API Instruments Co. Micrommeter Control Relay		
15	Eastech, Ltd. Wavebuoy Recorder System	1	
	Consists of:		
	1 Eastech Ltd. Model 440 Wave Data Acquisition Unit		
	1 Sony Model 250 Stereo Tape Deck		
	1 Model 440 Wave Data Acquisition System Operating Manual		
16	B&F Differential Amplifier (Spare)	1	
	Consists of:		
	1 B&F Model 600-10D Amplifier	S/N 1219 1	
17	Tool Box with Set of Small Hand Tools	1	
	Consists of:		
	1 Tool Box w/assorted hand tools		
18	C1333 Wind Speed and Direction Instrument	1	
	Consists of:		
	1 Wind Direction Indicator Sending Unit		
	1 Cup Anemometer Sending Unit		
	1 Danforth/White Apparent Wind Direction Indicator		
	1 Danforth Wind Speed Indicator (MPH)		

NOT ON INVENTORY

Item	Description	Unit of Issue	Comments
	2 29-1/2" High Ingersol Instrument Cabinets	2	
	1 Formica Bench Top	1	
	1 Tork Timer Model 1M8001	1	

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

An instrumentation set has been developed for use in investigating the slamming experience of a full-scale ship. Methods for treating both bow-flare and bottom-slamming have been considered. A radar altimeter was used to sense the relative height of the wave at the transducer location in order to determine the relative velocity between the bottom or the bow of the ship and the wave at the instant of slam.

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

LENGTH

Symbol	When You Know	Multiply by	To Find	Symbol
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km

AREA

Symbol	When You Know	Multiply by	To Find	Symbol
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha

MASS (weight)

Symbol	When You Know	Multiply by	To Find	Symbol
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t

VOLUME

Symbol	When You Know	Multiply by	To Find	Symbol
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3

TEMPERATURE (exact)

Symbol	When You Know	Multiply by	To Find	Symbol
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

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*1 in ≡ 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.

*U.S. GOVERNMENT PRINTING OFFICE : 1978 0-724-244/512

Approximate Conversions from Metric Measures

LENGTH

Symbol	When You Know	Multiply by	To Find
mm	millimeters	0.04	inches
cm	centimeters	0.4	inches
m	meters	3.3	feet
m	meters	1.1	yards
km	kilometers	0.6	miles

AREA

Symbol	When You Know	Multiply by	To Find
cm^2	square centimeters	0.16	square inches
m^2	square meters	1.2	square yards
km^2	square kilometers	0.4	square miles
ha	hectares (10,000 m^2)	2.5	acres

MASS (weight)

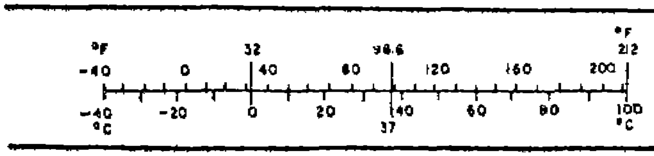
Symbol	When You Know	Multiply by	To Find
g	grams	0.035	ounces
kg	kilograms	2.2	pounds
t	tonnes (1000 kg)	1.1	short tons

VOLUME

Symbol	When You Know	Multiply by	To Find
ml	milliliters	0.03	fluid ounces
l	liters	2.1	pints
l	liters	1.06	quarts
l	liters	0.26	gallons
m^3	cubic meters	35	cubic feet
m^3	cubic meters	1.3	cubic yards

TEMPERATURE (exact)

Symbol	When You Know	Multiply by	To Find
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature



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