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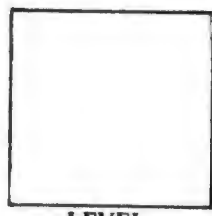
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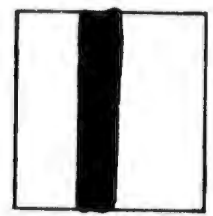
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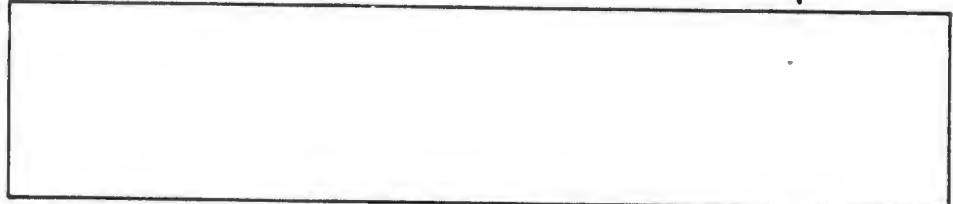
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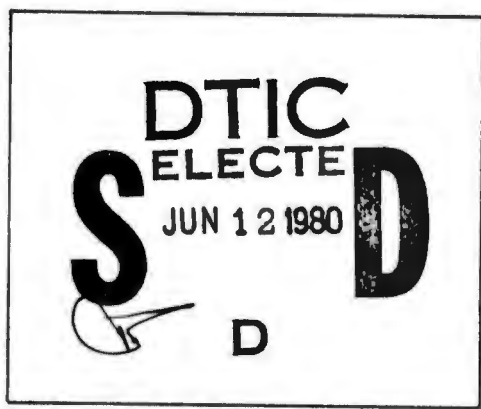
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PRELIMINARY REPORT

Operation

# WIGWAM

May 1955

Project 3.2

HULL RESPONSE AND SHOCK MOTION

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REPORT TO THE SCIENTIFIC DIRECTOR

Operation Wigwam Preliminary Report

Project 3.2

HULL RESPONSE AND SHOCK MOTION

By

H. L. RICH  
E. T. HABIB  
R. L. BORT and  
F. WEINBERGER  
David Taylor Model Basin

Approved by: H. L. RICH  
Project Officer  
Project 3.2

David W. Taylor Model Basin  
Washington 7, D. C.  
May 1955

*D. R. Saveker*  
Approved by: D. R. SAVEKER  
Commander, U.S. Navy  
Director  
Program III

*A. B. Focke*  
Approved by: Dr. A. B. FOCKE  
Scientific Director

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ABSTRACT

A total of 140 velocity meters, 12 accelerometers, 132 shock spectrum recorders and 12 displacement gages were installed in the 3 submarine and 3 surface targets for the measurement of hull response and shock motions. The oscillograph data were recorded automatically at remote recording stations.

Considerable data were obtained from all targets. These are tabulated and discussed in a preliminary way in this interim report. Some conclusions are presented.

#### ACKNOWLEDGMENTS

The planning and execution of this project were carried out by the Shock Branch of the Structural Mechanics Laboratory of the David W. Taylor Model Basin. Important contributions were made by Robert D. Ruggles, Glenn Elmer and William E. Carr.

The valuable suggestions and assistance of Dr. W. J. Sette, Commander R. C. Gooding and Commander A. F. Hancock of the David W. Taylor Model Basin and Commander D. R. Saveker, Director of Program III, Operation WIGWAM and F. J. Friel of the Norfolk Naval Shipyard, are gratefully acknowledged.

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## HULL RESPONSE AND SHOCK MOTION

### 1 INTRODUCTION

A ship may be destroyed by rupture of its hull, or it may be rendered inoperative by the destruction of vital equipment. This Project is primarily concerned with the measurement of the magnitude and character of the shock motions produced by the atomic explosion and the response of hull structure and mechanical systems which represent ship's machinery and equipment. These measurements also provide data on the secondary pulses associated with the explosion, as well as on the distance and bearing of the targets relative to the charge.

For the sake of simplicity and economy in the construction and outfitting of the special submarine targets, SQUAWS, they were not furnished with operating equipment. However, in order to make the targets more nearly representative of actual submarines, steel weights designed to simulate the major units of the propulsion system of a modern submarine were designed as a part of this Project. These were installed in each of the SQUAWS. These weights and their foundations as well as the SQUAW hulls were extensively instrumented by this Project.

Surface vessels as well as submarines may be subjected to atomic explosions, either as a result of enemy attack, or by having delivered the weapon in an attack on an enemy submarine. Consequently, a knowledge of the shock motion produced on the hull and equipment in a surface vessel is of considerable importance. Inasmuch as the YFNB Instrument Barges were the only surface ships intended to be included in the test array, they were also instrumented.

This Project includes the determination of the following:

- a. The rigid body motion of the hull as a function of time.
- b. The motion of the hull at representative locations as a function of time.
- c. The motion of simulated items of ship's heavy machinery as a function of time.
- d. Shock spectra\* at representative locations in the vessels.

In this preliminary report the test set-up, the instrumentation, and the test results are presented and discussed in an abbreviated and preliminary form.

\*See Section 3.3

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Because of the large amount of data available, and the limited amount of time available for preparation of this Interim Report, a more complete analysis and presentation must await a later report.

## 2 TEST SET-UP

### 2.1 Test Array

Plans for the conduct of this test provided for the explosion of an atomic bomb at a depth of 2,000 feet, in water having a depth of at least 10,000 feet.

Three SQUAW targets were to be suspended by chains from pontoons, submerged to a depth of 250 feet and all were to be stern end towards the weapon. The pontoon and chain support system was intended to be capable of supporting a completely bilged target. The SQUAW closest to the bomb was to be at a distance which was less than the estimated lethal range for the weapon; the next target was to be at the lethal range, and the third target was to be beyond that range. However, severe weather conditions en route to and at the test site resulted in loss of many chains and pontoons. These losses necessitated a modification of the test arrangements.

Because of the loss of chains and pontoons prior to the test SQUAW 29, the target farthest from the weapon, was not submerged for the test.

SQUAWS 12 and 13, the two targets closest to the bomb, were submerged to test depth despite the loss of some of their supporting chains and pontoons.

As a result, the test array consisted of two submerged and four surface targets.

### 2.2 SQUAW Targets

The SQUAW was a four compartment submarine target containing two cylindrical test sections and two conical end sections. The design of the test sections was based on that of the SS-563 class of submarine. However, the diameter and scantlings in the SQUAW were  $4/5$  that of the SS-563, the hull stiffeners were internal rather than external, and the length of each test compartment was made 29 feet (twice the diameter). The weights which simulated main propulsion equipment and foundations were based on the SS-566 propulsion system. Both the weight and the location of the center of gravity of each item were simulated on  $4/5$  scale. However, unlike the SS-566, the port engine weight was isolated from its foundation by means of resilient mountings. From the data obtained the ability of the resilient mounting to isolate the engine from the shock was to be evaluated.

The frequencies and vibration characteristics of these items are given in Reference (1).

An inboard profile view through the center line of the SQUAW targets are shown in Illustration 1. These show schematically the location and outline of the simulated engine weights and instruments.

### 2.3 YFNB Targets

The three YFNB barges (whose principal function was to serve as instrument recording platforms) were instrumented to a limited degree for the measurement of hull-response shock motions. These data provide a basis for estimating the effects of deep atomic explosions on combatant-type vessels.

The YFNB is a double bottom longitudinally framed vessel 260 feet long and 48 feet wide. Illustration 2 shows inboard profile as well as the instrument locations.

## 3 INSTRUMENTATION

Thirty-five velocity meters, 4 accelerometers, 34 shock spectrum recorders and 4 mechanical displacement gages were installed on each of the three SQUAWS. Two additional velocity meters were used on SQUAW 12.

On each YFNB, 11 velocity meters and 10 shock spectrum recorders were installed.

Gages were chosen on the basis of reliability of operation and cost. Gages susceptible to damage from dampness or those types sensitive to spurious mechanical, electrical or acoustic signals were avoided.

### 3.1 Velocity Meters

A velocity meter consists essentially of a pick-up coil and a magnet. Usually the coil is fastened rigidly to the frame of the instrument while the magnet is suspended from the frame by springs. Relative motion between the coil and the magnet generates a voltage proportional to velocity. When the output voltage is applied to an oscillograph, a time history of the velocity is recorded. The velocity meters used in this test were bolted to mounting plates which were welded to the structure whose velocity was measured.

All velocity meters in each SQUAW target were connected to a terminal board in the forward compartment. Special multi-channel armored instrument cables 600 feet long connected this terminal board to a

control panel in the instrument trailer. The control unit provided a signal level attenuator, a calibration voltage control, and a field current supply and control for each velocity meter channel. The velocity meter control unit was connected to string oscillographs, which recorded the signals on a time base.

Of the total of 140 velocity meters used, 45 were of the British type, 61 were of the TMB-Bar-Magnet type and the remaining 34 were of the Hartz type.

All meters were calibrated by the "drop test". In this test the output voltage produced by the pickup is recorded as the magnet is released and falls freely in the meter case. This type of calibration permits determination of the sensitivity and its uniformity with relative position of coil and magnet. However, the test is limited to low velocities. All British and Hartz type meters and a random sampling of TMB Bar-Magnet meters were also calibrated by means of a ballistic pendulum test. In this test the meter is subjected to essentially a step change in velocity. Calibrations at velocities as great as 14 feet per second were made. Measurements of the sensitivity of a meter by these two techniques agreed within 5%.

The displacement range of a velocity meter is limited and depends on its design. If the displacement range is exceeded, the meter "bottoms". A correction for this bottoming may, in some cases, be made. This correction effectively increases the displacement range.

### 3.2 Accelerometers

Four Statham accelerometers, each having a range of 300 g, were used in each target. The accelerometer contains a mass supported by two parallel flexure plates fixed to the base of the instrument. Four pre-stretched resistance wire filaments are attached to the mass and the instrument base. These wires are connected electrically as a Wheatstone bridge. The gage is sealed in a case filled with a silicone fluid which provides damping for the system. Displacement of the mass relative to the base in a direction perpendicular to the plane of the flexure plates produces further elongation of two of the wires and relaxation of the other two. The change in resistance produced is proportional to acceleration within the operating frequency range of the gage.

The sensitivities of the gages as supplied by the manufacturer were checked against a standard crystal accelerometer (calibrated by the reciprocity method) in steady state vibration tests on an electromagnetic vibration table at low accelerations. High acceleration tests were conducted on a ballistic pendulum using a crystal accelerometer as a standard. An average deviation of about 10% in the sensitivity was obtained between the two types of calibration.

The accelerometers were connected to carrier amplifiers and recorded on string oscillographs.

### 3.3 Shock Spectrum Recorders

The shock spectrum recorder is an autographic instrument used for obtaining shock spectra. It is completely self-contained and requires no power. It records the peak response of a series of weighted cantilever reeds, each having a different natural frequency. The response of each reed approximates that of a single degree of freedom mechanical system having the same natural frequency. From the peak displacement of each reed the corresponding peak acceleration is computed. A graph of these peak accelerations plotted as a function of reed frequency is called a shock spectrum.

Thirty-four MARK 4 shock spectrum recorders were used in each SQUAW and 10 in each YFNB. This model, designed at the Taylor Model Basin, was the result of a development program set up to improve the reliability and validity of this type of instrument.

This instrument contained ten reeds having natural frequencies of from 20 to 450 cycles per second. In this gage the reed excursions were scribed on a waxed paper. Two heavy bolts passing through the gage attach it to a mounting plate that was welded to the structure. Each gage was installed in a special watertight housing designed to withstand the hydrostatic pressure at a depth of 600 feet. The housing was provided to protect the record in case of flooding of the target.

### 3.4 Mechanical Displacement Gages

Mechanical displacement gages were used to measure maximum relative displacement between the shock-mounted engine and its foundation. This displacement gage consisted of a pointed section of thin lead sheet which was soldered to a heavy metal base. The base of the gage was rigidly attached to the shock-mounted equipment and adjusted so that the top of the gage was against the equipment foundation. Relative displacement of the equipment with respect to the foundation causes the gage to deform. The maximum displacement of the equipment is determined by measuring the set in the gage.

### 3.5 Instrument Trailers

An instrument trailer was provided in each YFNB. It housed the recording oscillographs, auxiliary control and calibrating devices, amplifiers for accelerometers, and the sequence timers. In addition it housed the recording and operating equipment for Project 3.6, and the sequence initiating relays for Project 3.4. The trailers were standard cargo hauling semi-trailers adapted for this use.

The wheels and tires were removed from the trailers on the two barges farthest from the charge. This was necessary to decrease their overall height and permit them to fit inside the barge. The springs were secured to the deck. A standard semi-trailer dolly without wheels was used to support the front of each of these trailers. The trailers, mounted on these springs, had natural frequencies of approximately 5 cycles per second. On the YFNB-12 which was closest to the explosion the entire trailer undercarriage was removed and a special plate support substituted at the front and rear. While this spring suspension did not appreciably reduce the frequency of the trailer, it greatly increased the distance through which the trailer could move in a vertical direction without causing the deck and trailer to collide.

Inasmuch as the natural frequency of all trailers was appreciably lower than structural frequencies of the deck, shock motions transmitted to the recording instruments were greatly attenuated.

### 3.6 Sequence Timer

Inasmuch as no personnel were aboard the instrument barges during the test all recording instruments were operated automatically. The operation was controlled by two sequence timers in each trailer which were activated by radio telemetered signals supplied by E.G.&G., Inc. Each sequence timer consists of a series of motor driven, cam operated switches. The first sequence timer was started by a signal transmitted at -15 seconds and the second at -5 seconds. The two sequence timers paralleled each other so that either would operate the equipment.

### 3.7 Timing Signals

Fiducial time markers supplied by E.G.&G., Inc. were recorded on each oscillograph record. These fiducial signals indicated the time of detonation of the bomb and each 0.5 second interval thereafter.

In addition, each oscillograph had its own built-in timing system which recorded 10 millisecond intervals.

## 4 LOCATION OF INSTRUMENTS

The location of each pickup on the SQUAW targets is given in Table 1 and is shown schematically on the inboard profile view, Illustration 1A, and in the four sectional views, Illustrations 1B, 1C, 1D, and 1E.

The location of each pickup on the YFNB targets is given in Table 2 and is shown schematically on the inboard profile view, Illustration 2.

TABLE 1 LOCATION OF INSTRUMENTS - SQUAW TARGETS

Position	Instrument	Component	Structure to which attached	Vertical Position	Transverse Position	Longitudinal Position
<b>FWD COMPARTMENT</b>						
A1	VM* SSR** VM	Axial Vertical	Fwd Trim Tank Bulkhead Fwd Trim Tank Bulkhead	Near Top of Tank Near Top of Tank	Stbd side 1 ft from Hull Port side 1 ft from Hull	Fwd side of Tank (Fr 2) Fwd side of Tank (Fr 2)
A2	***					
<b>BATTERY COMPARTMENT</b>						
B-1	VM SSR	Radial (Vert)	Hull Stiffener Flange	Top of hull (1200 O'clock)	Center Line	Fr 21
B-2	VM SSR	Radial (45°)	Hull Stiffener Flange	1030 O'clock	45° to Port from top	Fr 21
B-3	VM SSR	Axial	Midships Bulkhead	Center Line	1 ft Stbd of Center Line	Fwd side Midship Bulkhead (Fr 26½)
B-4	VM SSR	Vertical	Midships Bulkhead	Center Line	Center Line	Midships Bulkhead (Fr 26½ & 27)
B-5	VM SSR	Axial	Midships Bulkhead	Center Line	Port side 1 ft in-board from hull	Fwd side Midship Bulkhead (Fr 26½)
<b>ENGINE COMPARTMENT</b>						
C-1	VM SSR	Radial (Vert)	Hull Stiffener Flange	Top of Hull (1200 O'clock)	Center Line	Fr 28
C-2	VM SSR	Radial (45°)	Hull Stiffener Flange	1030 O'clock	45° to Port from top	Fr 28
C-3	VM SSR	Radial (Vert)	Hull Stiffener Flange	Top of Hull (1200 O'clock)	Center Line	Fr 32
C-4	VM SSR	Radial (45°)	Hull Stiffener Flange	1030 O'clock	45° to Port from top	Fr 32
C-5	VM SSR	Radial (Horiz.)	Hull Stiffener Flange	Horizontal Plane (0900 O'clock)	Port side	Fr 32

Position	Instrument	Component	Structure to which attached	Vertical Position	Transverse Position	Longitudinal Position
C-6	VM	Axial	Foundation of Port Engine	Below Engine Mount	Inboard Stiffener of foundation	Fr 30 (VM)
C-7	SSR	Athwart-ship	Foundation of Port Engine	Below Engine Mount	Inboard stiffener of foundation	Fr 28 (SSR)
C-8	VM	Vertical	Foundation of Port Engine	Below Engine Mount	Inboard stiffener of foundation	Fr 29
C-9	SSR	Axial	Port Engine	Engine Weight	Engine Weight	Fr 28
C-10	VM	Athwart-ship	Port Engine	Engine Weight	Engine Weight	Fr 30½
C-11	SSR	Vertical	Port Engine	Engine Weight	Engine Weight	Fr 31
C-12	VM	Vertical	Foundation of Center Engine	On hull Stiffener	Center Line	Fr 31
C-13	SSR	Axial	Foundation of Stbd Engine	Below Engine Mount	Inboard stiffener of foundation	Fr 29½
C-14	VM	Athwart-ship	Foundation of Stbd Engine	Below Engine Mount	Inboard stiffener of foundation	Fr 30½
C-15	SSR	Vertical	Foundation of Stbd Engine	Below Engine Mount	Inboard stiffener of foundation	Fr 29
C-16	VM	Axial	Stbd Engine	Engine Weight	Engine Weight	Fr 28
C-17	SSR	Athwart-ship	Stbd Engine	Engine Weight	Engine Weight	Fr 30
C-18	VM	Vertical	Stbd Engine	Engine Weight	Engine Weight	Fr 30½
C-19	SSR	Axial	Center Engine	Engine Weight	Engine Weight	Fr 31
C-20	VM	Vertical	Center Engine	Engine Weight	Engine Weight	Fr 29½
C-21	SSR	Athwart-ship	Port Generator	Generator Weight	Generator Weight	Fr 30
						Fr 30
						Fr 30½
						Fr 30
						Fr 30½
						Fr 29
						Fr 28½
						Fr 32
						Fr 31

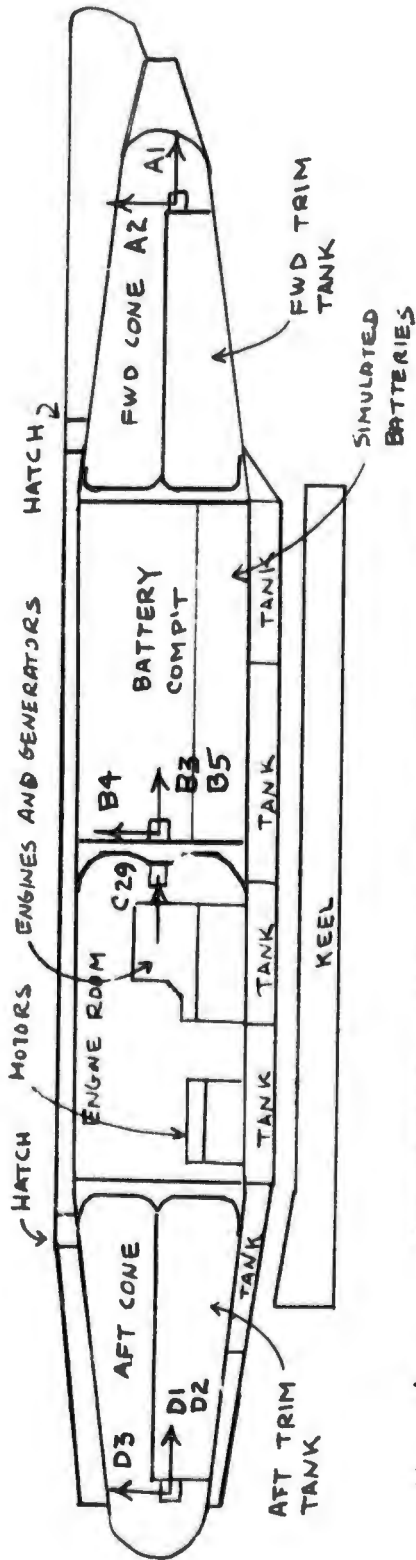
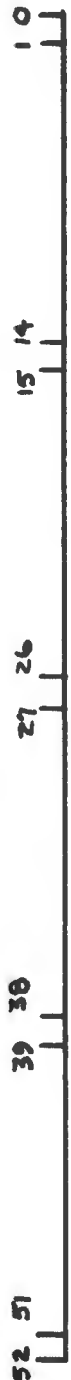
TABLE 1 (Continued)

Position	Instrument	Component	Structure to which attached	Vertical Position	Transverse Position	Longitudinal Position
C-22	VM	Vertical	Port Generator	Generator Weight	Generator Weight	Fr 32 $\frac{1}{2}$
C-23	SSR	Athwart-ship	Stbd Generator	Generator Weight	Generator Weight	Fr 32
C-24	VM	Vertical	Stbd Generator	Generator Weight	Generator Weight	Fr 31 $\frac{1}{2}$
C-25	SSR	Axial	Foundation of Port Motor	Below Motor Mount	Inboard Stiffener of Foundation	Fr 31
C-26	VM	Vertical	Foundation of Stbd Motor	Below Hull Stiffener	Inboard Stiffener of Foundation	Fr 32
C-27	SSR	Axial	Stbd Motor	Motor Weight	Motor Weight	Fr 34 $\frac{1}{2}$
C-28	VM	Vertical	Stbd Motor	Motor Weight	Motor Weight	Fr 34
C-29	Accelerometer	Axial	Bulkhead Stiffener	Center Line	Center Line	Fr 35 $\frac{1}{2}$
C-30	Accelerometer	Axial	Stbd Engine	Engine Weight	Engine Weight	Fr 36
C-31	Accelerometer	Axial	Port Engine	Engine Weight	Engine Weight	Fr 35
C-32	Displacement Gage	Three	Across Port Engine Mount	At Engine Mount	Outboard corner of engine	Fr 36
C-33	Displacement Gage	Three	Across Port Engine Mount	At Engine Mount	Inboard corner of Engine	Aft side of Stiffener (Fr 27)
C-34	Displacement Gage	Three	Across Port Engine Mount	At Engine Mount	Outboard corner of engine	Aft end of Engine (Fr 31)
C-35	Displacement Gage	Three	Across Port Engine Mount	At Engine Mount	Inboard corner of Engine	Aft end of Engine (Fr 31)

TABLE 1 (Continued)

Position	Instrument	Component	Structure to which attached	Vertical Position	Transverse Position	Longitudinal Position
AFT COMPARTMENT						
D-1	VM SSR	Axial	Aft Trim Tank head	Near top of Tank	Near stbd side of Hull	Aft side of tank (Fr 51)
D-2	Accelerometer	Axial	Aft Trim Tank Bulkhead	Near top of Tank	Near Stbd side of Hull	Aft side of tank (Fr 51)
D-3***	VM	Vertical	Aft Trim Tank Bulkhead	Near top of Tank	Near port side of Hull	Aft side of tank (Fr 51)
	* Velocity Meter					
	** Shock Spectrum Recorder					
	*** SQUAW-12 only					
TABLE 1 (Continued)						

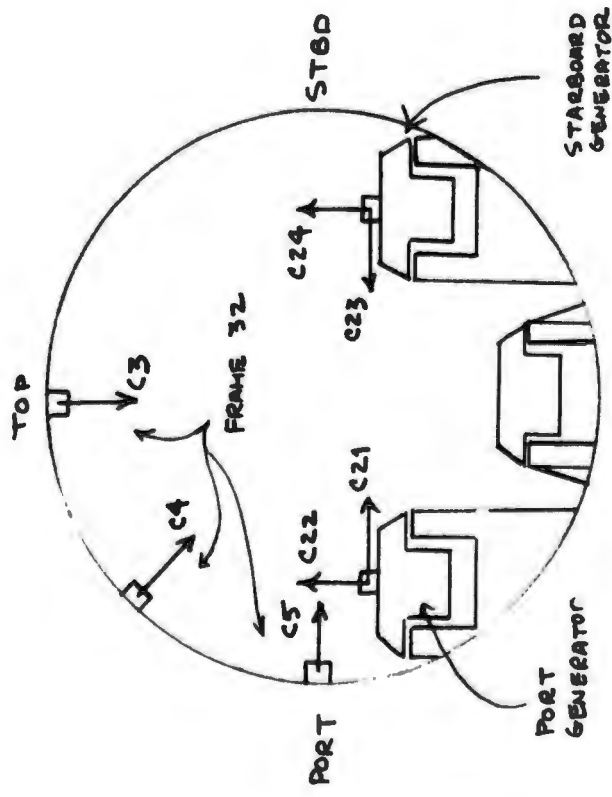
FRAME NO.



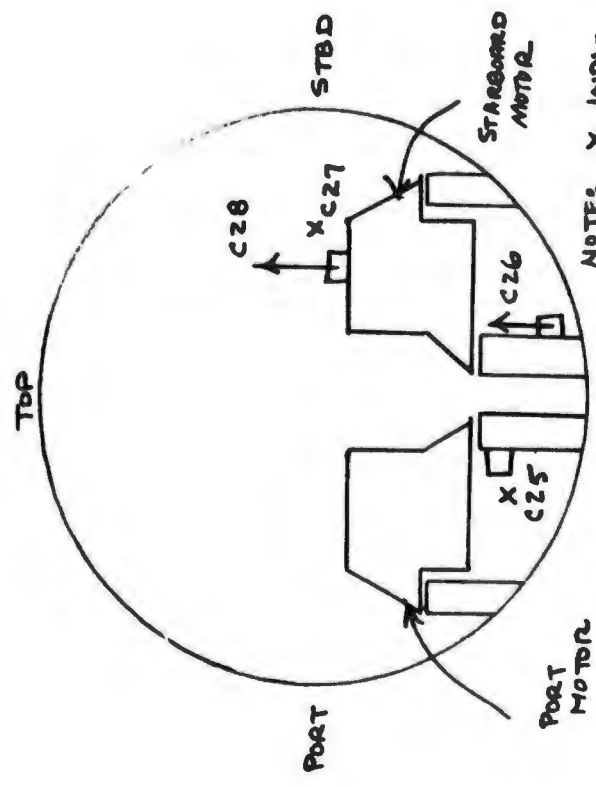
ILL. 1A. INSTRUMENT LOCATIONS ON SQUAW TARGETS, INBOARD PROFILE VIEW

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ILL. 1D. SECTION THROUGH GENERATORS, LOOKING FORWARD



NOTE: X INDICATES CAT'S AXIAL DIRECTION  
ILL. 1E. SECTION THROUGH MOTORS, LOOKING FORWARD

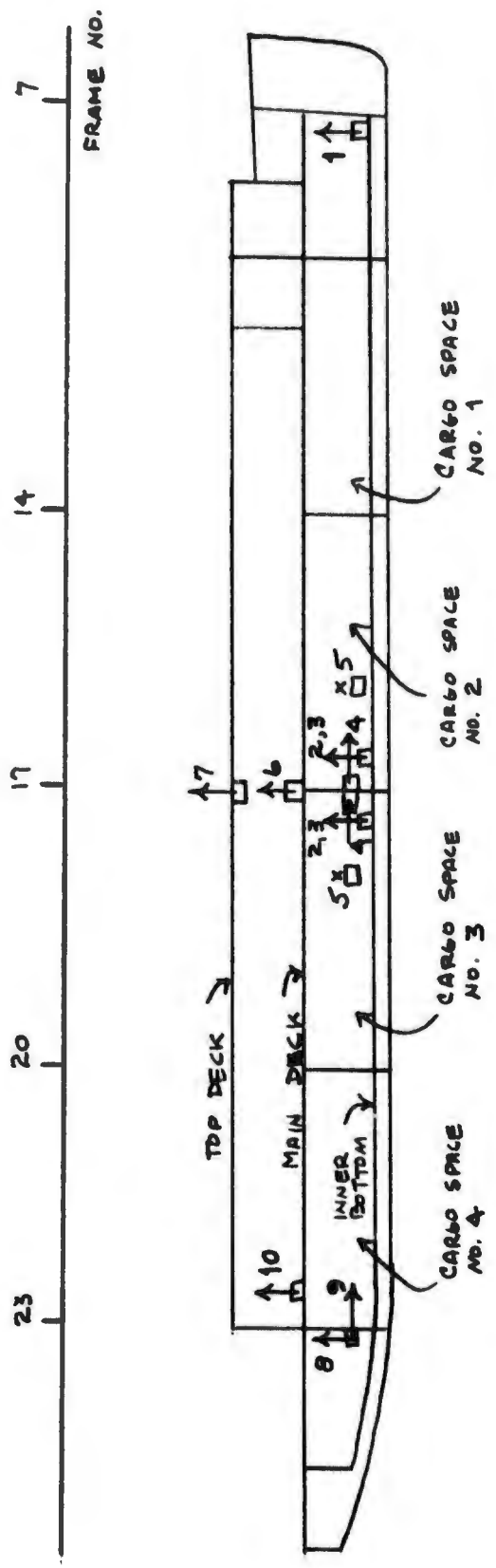
ILL. 1D AND 1E. INSTRUMENT LOCATIONS ON SQUAW TARGETS

TABLE 2 LOCATION OF INSTRUMENTS - YFNB TARGETS

Position	Instrument	Component	Structure to which attached	Vertical Position	Transverse Position	Longitudinal Position
1	VM SSR	(Vert)	Inner Bottom	Top of Inner Bottom	Center Line	2 ft aft of Fr 7
2*	VM SSR	(Vert)	Inner Bottom	Top of Inner Bottom	2 ft from port inner hull Center Line	2 ft aft of Fr 17
3*	VM SSR	(Vert)	Inner Bottom	Top of Inner Bottom	Center Line	2 ft aft of Fr 17
4*	VM SSR	Axial	Transv. Bulkhead	2 ft above inner hull	Center Line	Aft side of bulkhead (Fr 17)
5*	VM SSR	Athwart-ship (Vert)	Vert. stiffener of center bulkhead Main Deck	2 ft above inner hull	1 ft port center line Center Line	Fr 18 Fr 17
6	VM SSR	(Vert)	Transv. stiffener of top deck	1 ft below top deck	Center Line	Fr 17
7	VM SSR	(Vert)	Longitudinal stiffener of center bulkhead	2 ft above inner hull	1 ft stbd of Center Line	Fr 23 (VM) Fr 24 (SSR)
8	VM* SSR	Axial	Transv. Bulkhead Vert stiffener of center bulkhead	4 ft above inner hull 2 ft above inner hull	Center Line	Fr 23 Fr 24
9	VM SSR	(Vert)	Main Deck	Top of Main Deck	Center Line	3 ft forward of Fr 23 2 ft fwd of Fr 17
10	VM SSR	(Vert)	Inner Bottom	Top of Inner Bottom	2 ft from port inner hull Center Line	2 ft fwd of Fr 17
2**	VM SSR	(Vert)	Inner Bottom	Top of Inner Bottom	Center Line	2 ft fwd of Fr 17
3**	VM SSR	(Vert)	Inner Bottom	Top of Inner Bottom	Center Line	2 ft fwd of Fr 17
4**	VM SSR	Axial	Transv. Bulkhead	2 ft above inner bottom	Center Line	fwd side of Fr 17

Position	Instrument	Component	Structure to which attached	Vertical Position	Transverse Position	Longitudinal Position
5**	VM SSR	Athwartship Axial	Vert stiffener of Center Bulkhead	2 ft above inner bottom	1 ft port of center line	Fr 16
9**	VM		Vert stiffener of Center Bulkhead	1 ft above inner hull	1 ft port of center line	Aft side of Fr 24
* YFNB 12 and 13 ** YFNB 29 only						

TABLE 2 (Continued)



- NOTES
1. X INDICATES ATWARTSHIP ORIENTATION OF METER
  2. METERS 2, 3, 4, AND 5 IN CARGO SPACE NO. 2 ON YFNB-29 ONLY
  3. METERS 2, 3, 4, AND 5 IN CARGO SPACE NO. 3 ON YFNB-12 AND YFNB-13 ONLY

ILL. 2. INSTRUMENT LOCATIONS ON YFNB'S

## 5 TEST RESULTS

Oscillograph recordings of the transient velocity produced by the detonation of the device were made at 37 locations in SQUAW 12, at 35 locations in SQUAWS 13 and 29 and at eleven locations in each of the three YFNB instrument barges. In addition, the outputs of 4 accelerometers installed on each SQUAW were recorded.

Recordings were obtained successfully with 70% of the above instruments, from -2 seconds to as late as +25 seconds after the detonation. Records were obtained from every pickup installed on each YFNB, and from 60% of the pickups installed on the SQUAW targets. From the results of instrument checks made at the test site prior to the test, it is apparent that all failures were due to open circuits in the instrument cable joining the SQUAWS and the YFNB's. This conclusion is substantiated by the fact all recordings made from pickups on the YFNB's, where the special instrument cable was not necessary, were successful. The severe and continuous flexing and chafing of the instrument cable due to the rolling and pitching of the SQUAW targets in the high swell which persisted at the test site, doubtlessly produced the damage.

### 5.1 Oscillograph Measurements

Because of the preliminary nature of this report and the difficulty of making reproductions from the oscillograms, only small sections of several oscillograph records are reproduced, Illustrations 3, 4, and 5. However, data read and tabulated from all oscillograph records are included in this report, Tables 3, 4, and 5. The actual oscillograms are available at the Taylor Model Basin and will be more completely reproduced in the final report.

The peak velocity, average acceleration (ratio of peak velocity to rise time), and the duration of the peak velocity pulse measured with velocity meters on the SQUAWS are listed in Table 3. The peak acceleration and the duration of the initial acceleration pulse measured with accelerometers on the SQUAWS are given in Table 4. Peak velocity, average acceleration and the duration of the first velocity pulse measured with the velocity meters on the YFNB's are given in Table 5.

Examination of the oscillograph records shows that several distinct periods of excitation of the accelerometers and velocity meters occurred. The time of arrival of the major pulses which produced these shock motions at selected gage positions were measured on the oscillograms; these arrival times are tabulated in Table 6. These times were measured with an accuracy of  $\pm 1$  millisecond from the "Zero Time" fiducial marker. They were corrected for error in the fiducial marker.<sup>2</sup> From these times, the distances of each target from the explosion may be calculated. The angle made by the longitudinal axis of the target and the direction of propagation of the shock wave

Illustration 3 - Oscillograph 7, SQUAW-12, Velocity Meter and Accelerometer Records

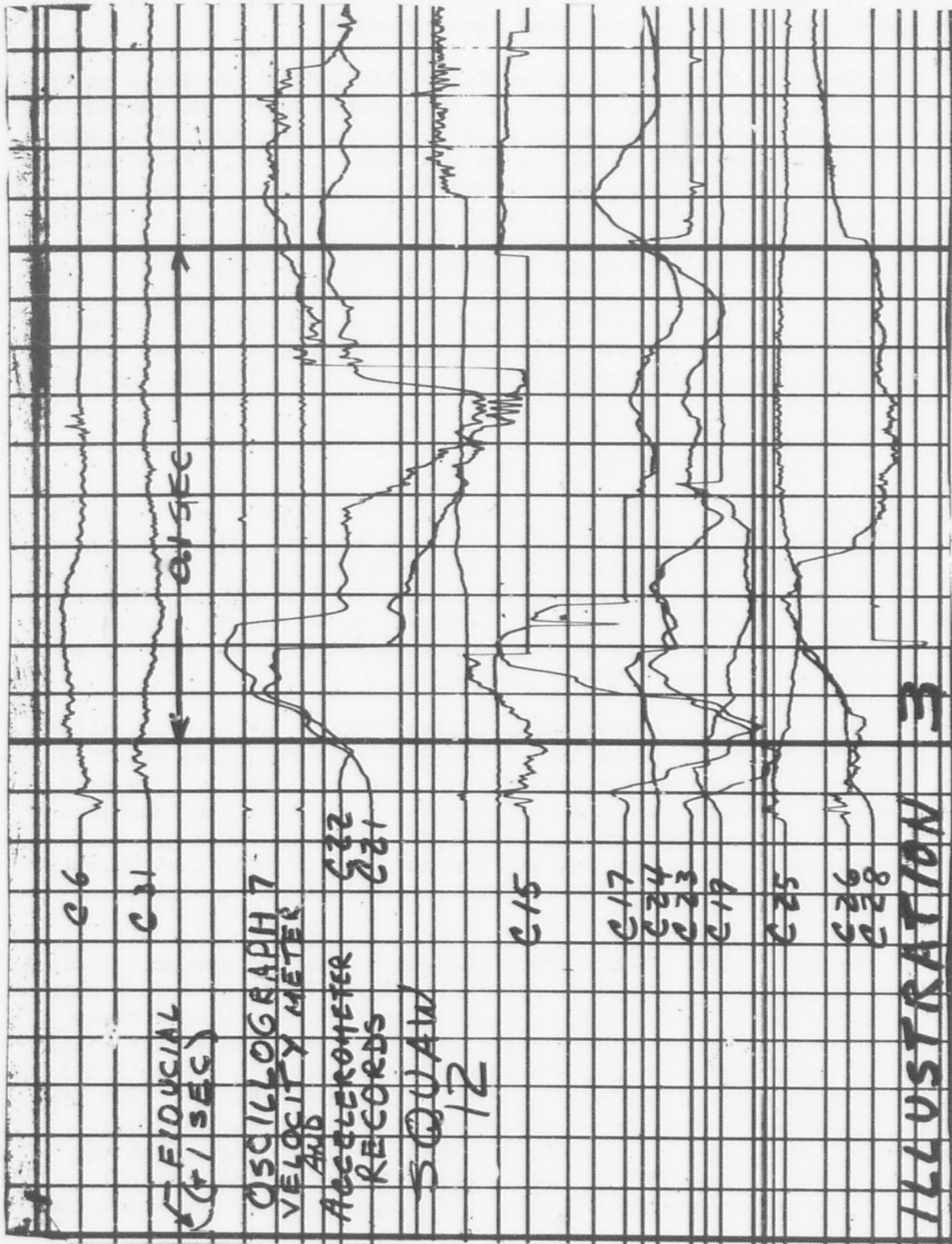


Illustration 4 - Oscillograph 8, SQUAW-12 and YFNB-12, Velocity Meter Records

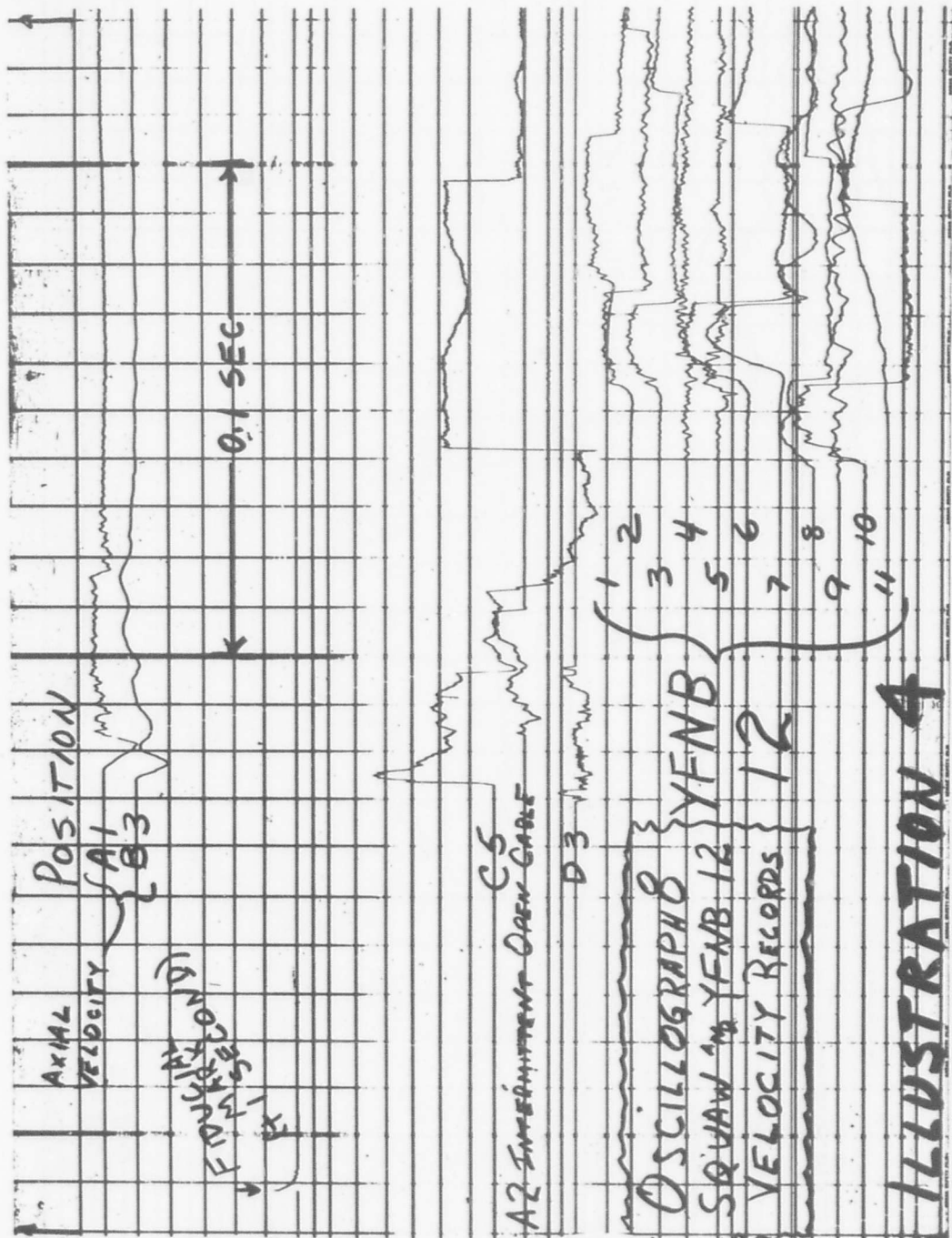


Illustration 5 - Oscillograph 4, SQUAW-13, Velocity Meter and Accelerometer Records

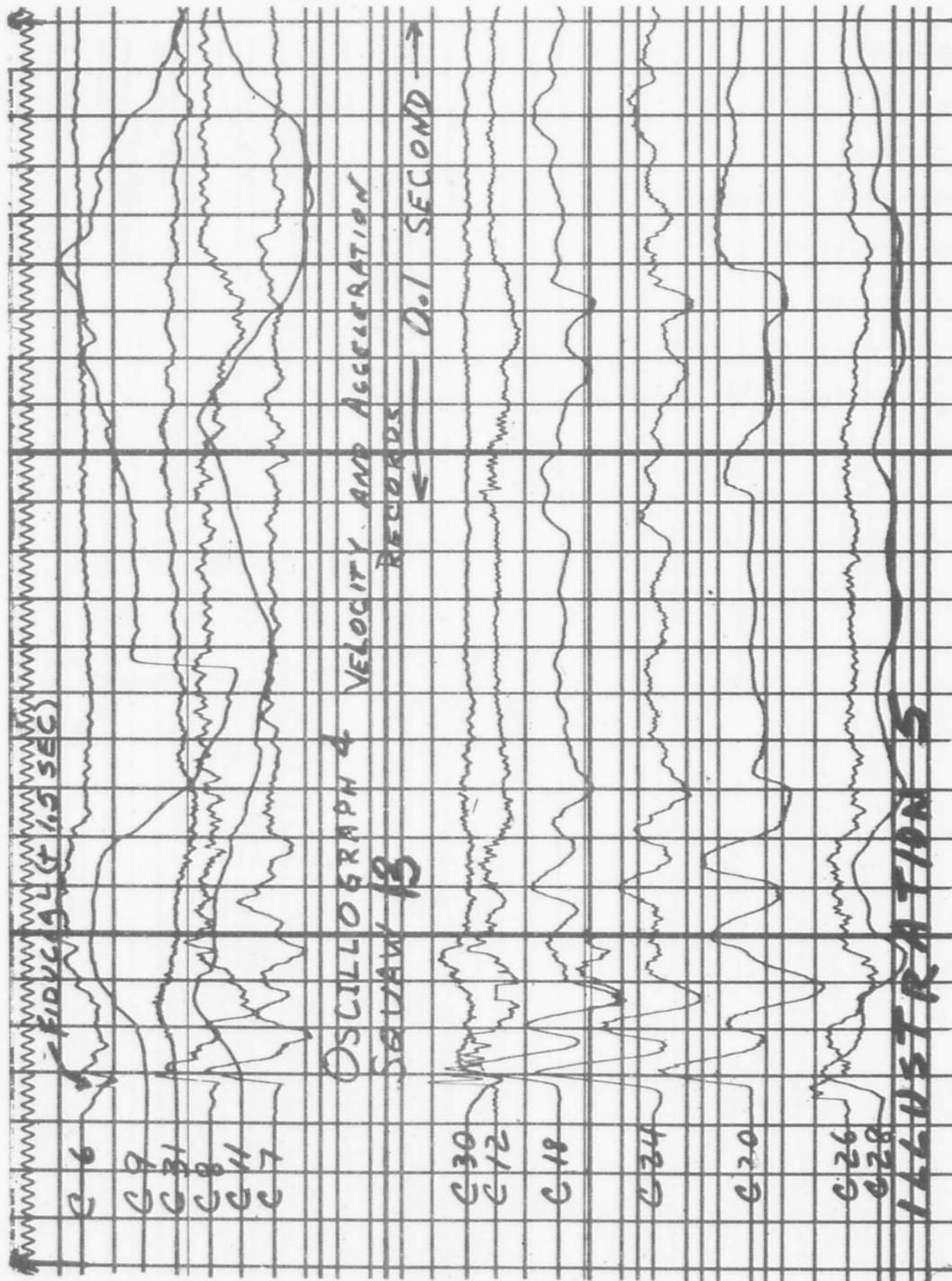


TABLE 3 - SHOCK MOTIONS AND SHOCK DURATIONS, SQUAW TARGETS

Position	Position Description	SQUAW-12			SQUAW-13			SQUAW-29		
		Peak Velocity Feet Per Second	Average Acceleration G's	Duration of Velocity Pulse Milsec	Peak Velocity Feet Per Second	Average Acceleration G's	Duration of Velocity Pulse Milsec	Peak Velocity Feet Per Second	Average Acceleration G's	Duration of Velocity Pulse Milsec
A-1	Trim tank axial, Fr 2	15.0	90	7	11.80	28	25	-0.9	-9	7
A-2	Trim tank vert, Fr 2	*			*			*		
B-1	Hull stiffener radial, Fr 21				7.25	110	6	-3.7	19	13
	1200 o'clock									
B-2	Hull stiffener radial, Fr 21				-12.00	-125	7	-2.4	15	17
	1030 o'clock									
B-3	Center of bulkhead axial	14.1	150	7	7.8	15	27	0.6	2	13
	Fr 26.5									
B-4	Center of bulkhead vertical				-5.00	-50	8	3.0	13	72
	Fr 26.5									
B-5	Port side of bulkhead axial				6.2	12	**			
	Fr 26.5						16			
C-1	Hull stiffener radial Fr 28						7			
	1200 o'clock									
C-2	Hull stiffener radial Fr 28				-10.5	-110	7			
	1030 o'clock									
C-3	Hull stiffener radial Fr 32				6.5	50	8			
	1200 o'clock									
C-4	Hull stiffener radial Fr 32				-11.6	-90	7			
	1030 o'clock									
C-5	Hull stiffener radial Fr 32	19.2	300	44				1.9	20	7
	0900 o'clock									
C-6	Port engine foundation axial	9.2	90	5	11.0	50	8	-0.7	-8	4
	Fr 29.5									

Position	SQUAW-12			SQUAW-13			SQUAW-29		
	Peak Velocity Feet Per Second	Average Acceleration G's	Duration of Velocity Pulse Milsec	Peak Velocity Feet Per Second	Average Acceleration G's	Duration of Velocity Pulse Milsec	Peak Velocity Feet Per Second	Average Acceleration G's	Duration of Velocity Pulse Milsec
C-7							1.2	20	4
C-8				8.3	80	6	3.3	15	26
C-9				6.2	130	9	1.2	0.4	160
C-10				4.3	4	65	0.3	0.2	80
C-11				3.9	7	53	2.1	1.9	77
C-12				8.2	170	13	3.2	14	27
C-13							-0.8	-4	11
C-14							-1.1	-3	19
C-15				10.3	22	**	3.5	22	55
C-16						33	1.4	6	9
C-17				-13.8	-31	21	-2.8	-10	16
C-18				5.6	19	20	3.6	14	28
C-19				10.7	17	70	1.2	6	11
C-20				12.2	19	60	3.8	19	23
C-21							0.2	0.2	85
C-22							2.1	0.9	77

TABLE 3 - (Continued)

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Position	Position Description	SQUAW-12			SQUAW-13			SQUAW-29		
		Peak Velocity Feet Per Second	Average Acceleration G's	Duration of Velocity Pulse Milsec	Peak Velocity Feet Per Second	Average Acceleration G's	Duration of Velocity Pulse Milsec	Peak Velocity Feet Per Second	Average Acceleration G's	Duration of Velocity Pulse Milsec
C-23	Stbd generator athwartship Fr 32.5	-9.7	-30	20			1.4	7	14	
C-24	Stbd generator vertical Fr 31.5	3.3	4	>30**	9.4	100	2.8	12	22	
C-25	Port motor foundation axial Fr 34.5	7.9	120	18			-0.4	2	18	
C-26	Stbd motor foundation vertical Fr 35	11.9	18	>55**	4.5	140	2.9	7	36	
C-27	Stbd motor axial Fr 35.5									
C-28	Stbd motor vertical Fr 35.5	7.4	11	>33**	4.7	24	0.4	7	6	
D-1	Trim tank axial Fr 51				*		3.0	12	36	
D-3	Trim tank vertical Fr 51	2.9	40	1	*		*			

\* Meters not located here on SQUAWS 13 and 29.

\*\* Complete record not obtained, channel failed at this time.

Blank spaces indicate that no record was obtained.

TABLE 3 - (Continued)

TABLE 4 PEAK ACCELERATIONS AND SHOCK DURATIONS - SQUAW TARGETS

Position	Position Description	SQUAW-12		SQUAW-13		SQUAW-29	
		Peak Acceleration G's	Duration of Pulse Milli-second	Peak Acceleration G's	Duration of Pulse Milli-second	Peak Acceleration G's	Duration of Pulse Milli-second
C-29	Center of bulkhead axial Fr 28			-60	6	-9.7	2
C-30	Stbd engine axial Fr 31			-81	9	-12	7
C-31	Port engine axial Fr 31	19	20	17	30	6.5	
D-2	Trim tank axial Fr 51					-81	1

TABLE 5 - SHOCK MOTIONS AND SHOCK DURATIONS, YFNB TARGETS

Position	Position Description	YFNB-12			YFNB-13			YFNB-29		
		Peak Velocity Feet Per Second	Average Acceleration G's	Duration of Pulse Milliseconds	Peak Velocity Feet Per Second	Average Acceleration G's	Duration of Pulse Milliseconds	Peak Velocity Feet Per Second	Average Acceleration G's	Duration of Pulse Milliseconds
1	Inner bottom on centerline vertical Fr 7	4.8	19	>31	2.0	3	40	0.93	7.3	85
2	Inner bottom port side vertical Fr 17	6.1	24	>22	3.2	7	40	1.2	12.5	45
3	Inner bottom on centerline vertical Fr 17	6.9	24	>19	3.3	9	>37	1.4	7.5	46
4	Transverse bulkhead axial Fr 17	0.7	22	1	0.4	12	2	0.25	4.0	8
5	Longitudinal bulkhead athwartship Fr 18	-1.1	-11	4	-0.4	-3	5	0.18	0.6	13
6	Main deck on centerline vertical Fr 17	6.9	23	>19	2.8	9	51	1.33	5.2	50
7	Upperdeck on centerline vertical Fr 17	7.5	33	>15	3.5	5	>30	2.25	2.9	50
8	Inner bottom on centerline vertical Fr 23	6.8	30	>15	3.7	19	49	1.12	7.0	40
9	Transverse bulkhead axial Fr 23	-0.7	-7	5	0.3	3	4	0.14	4.3	2
10	Main deck on centerline vertical Fr 23	6.8	21	>17	3.2	20	>37	1.37	4.2	45
11	TMB Instrument Trailer vertical Fr 22	4.7	2	>63	2.0	1	>132	0.56	0.4	125

NOTE: The sign ">" indicates that the meter "bottomed" at this time.

TABLE 6. ARRIVAL TIMES \* OF DIRECT SHOCK WAVE AND SUBSEQUENT SHOCK AND BUBBLE PULSES AT SELECTED GAGE POSITIONS ON EACH SQUAW AND YFNB TARGET

Target	Gage Position	Time of Arrival of Pulse, Seconds*					
		Direct	2nd	3rd	4th	5th	6th
SQUAW-12	D-3	1.052	#	#	#	#	#
	C-5	1.056	#	#	#	#	#
	C-15	1.057	#	#	#	#	#
SQUAW-13	D-2	1.462	4.29	5.57	6.12	6.77	8.88
	B-1	1.475					
	C-3	1.471					
SQUAW-29	D-2	2.036	6.36	11.97			
	B-1	2.049					
	C-26	2.043					
YFNB-12	8	1.121	3.91	6.12			
	1	1.159					
YFNB-13	8	1.592	6.19				
	1	1.633					
YFNB-29	8	2.186	6.41				
	1	2.228					

- \* Time from detonation of charge, corrected for error in fiducial "zero time" signal
- # Recording channels failed after initial shock wave

may be determined from the elapsed time between the arrival of the direct shock wave pulse at different positions on a target. From the difference in times between the arrivals of the direct shock wave and bubble pulses, the periods of the bubble may be estimated.

Velocities and accelerations produced by the various pulses following the direct shock wave appear on all oscillograms except those produced by velocity meters and accelerometers on SQUAW 12. On this target intelligible records from all pickups terminated by 0.5 seconds after the arrival of the shock wave.

## 5.2 Autographic Measurements with Mechanical Instruments

Autographic measurements were made with 34 shock spectrum recorders on each SQUAW and 10 on each YFNB target. Four clusters of mechanical displacement gages recorded maximum deflections of the resiliently mounted engine on each SQUAW.

Complete recordings were obtained from all autographic instruments on the YFNBS and on the SQUAW 29. Inasmuch as SQUAWS 12 and 13 were not recovered after the test, instruments and data on these targets were lost.

### 5.2.1 Shock Spectra Data

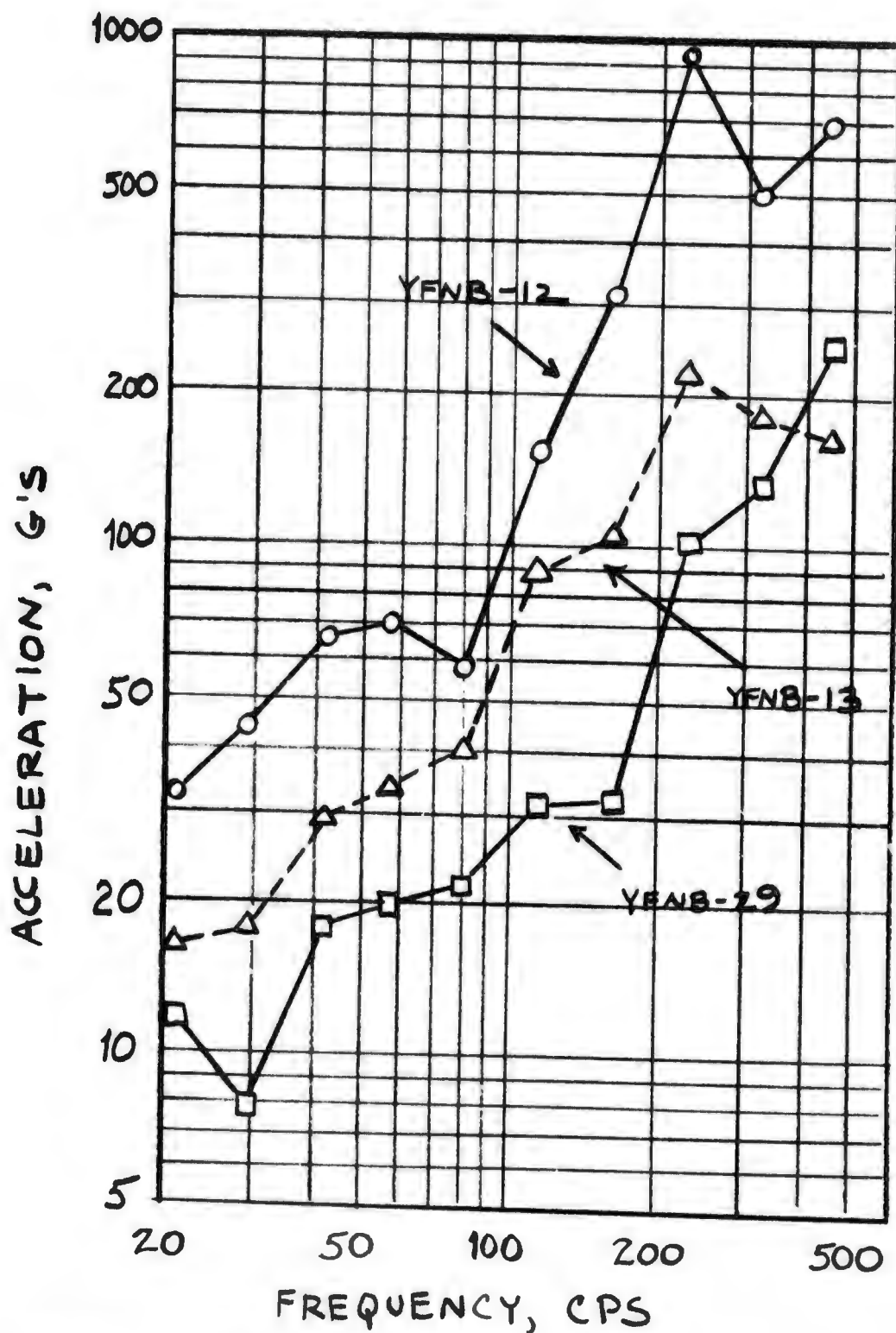
Since the predominant motions on both the YFNBS and on the SQUAW 29 were vertical, only spectra from meters arranged to record the response to this component are reproduced here. The spectra for three midship positions, one above another, in the YFNBS are shown in Illustrations 6, 7, and 8. Additional spectra for the position at the stern near the bottom of the vessel are shown in Illustration 9. In all cases, spectra for the same position in all three YFNBS are shown in each illustration.

Typical spectra from positions in the SQUAW 29, which was also at the surface, are shown in Illustrations 10 and 11. Illustration 10 shows the spectrum at the center of the midship bulkhead and Illustration 11 shows the spectrum at the starboard motor foundation.

These will be discussed and compared briefly with data from shipboard tests in which conventional weapons were used.

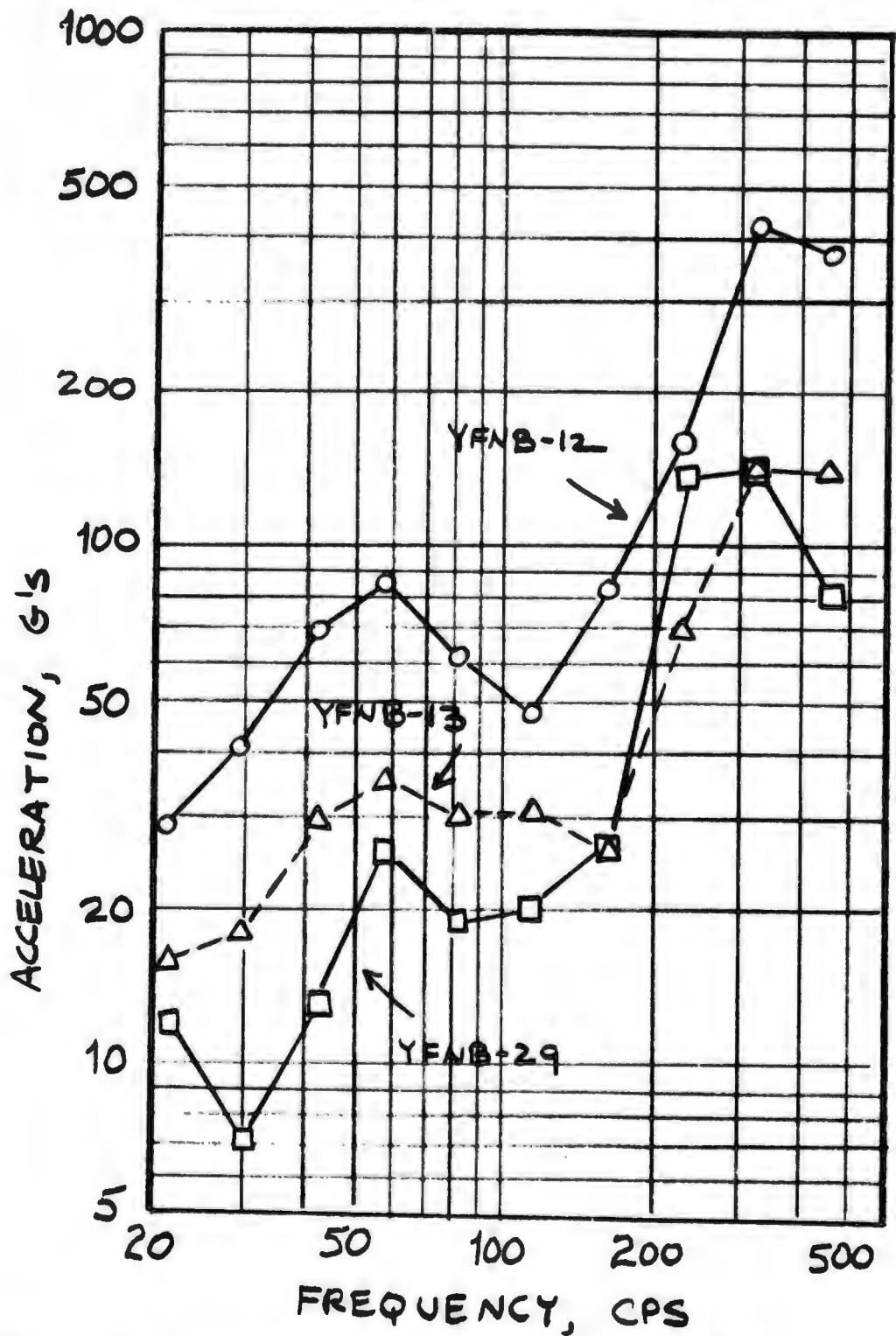
### 5.2.2 Displacement Data

The peak relative displacement data recovered from SQUAW 29 are tabulated in Table 7. These show the maximum excursion at the four corners of the resiliently mounted simulated engine-generator.

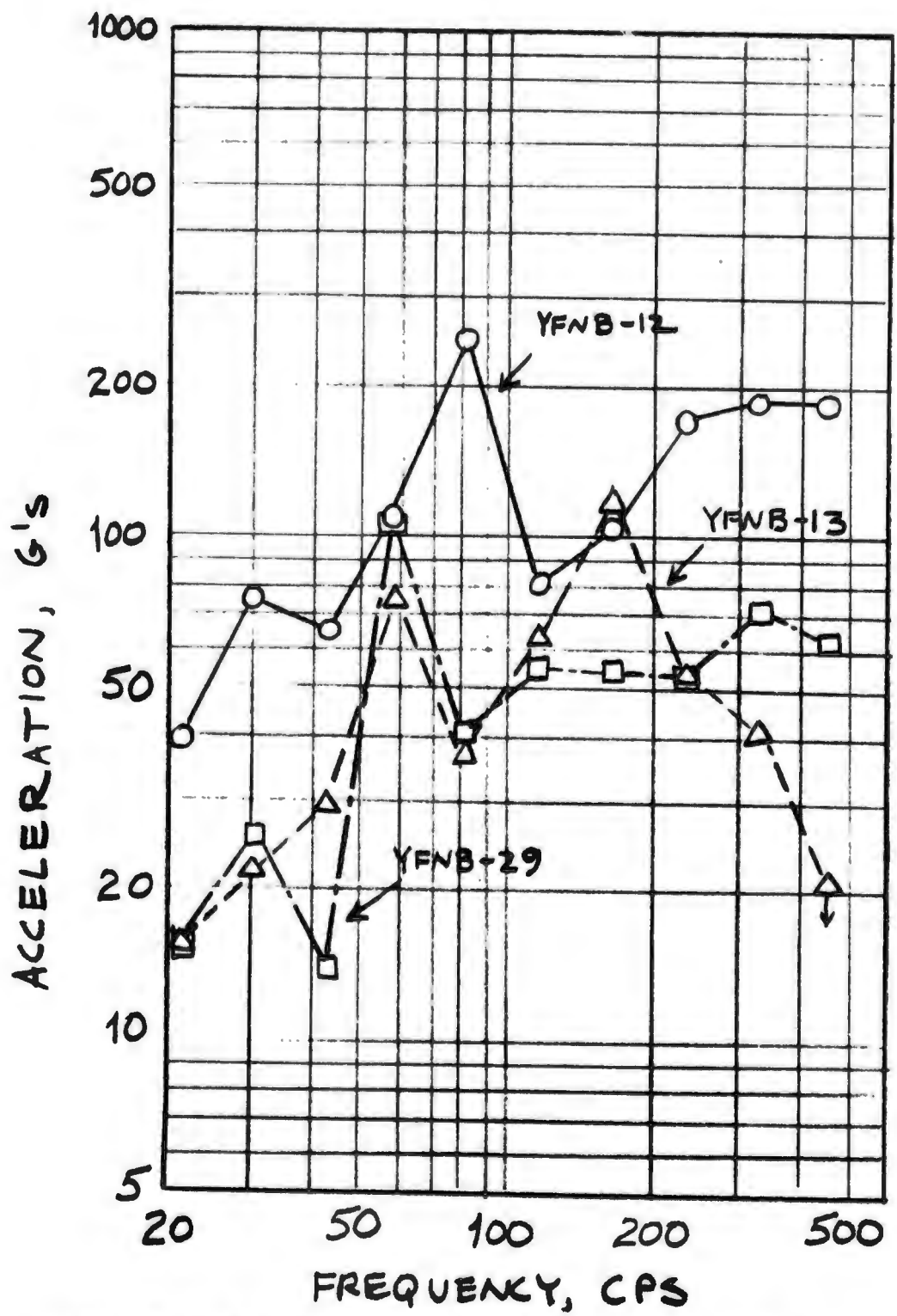


ILL. 6. SHOCK SPECTRA, ALL YFNB TARGETS. POSITION 3, VERTICAL ON KEEL, AMIDSHIPS

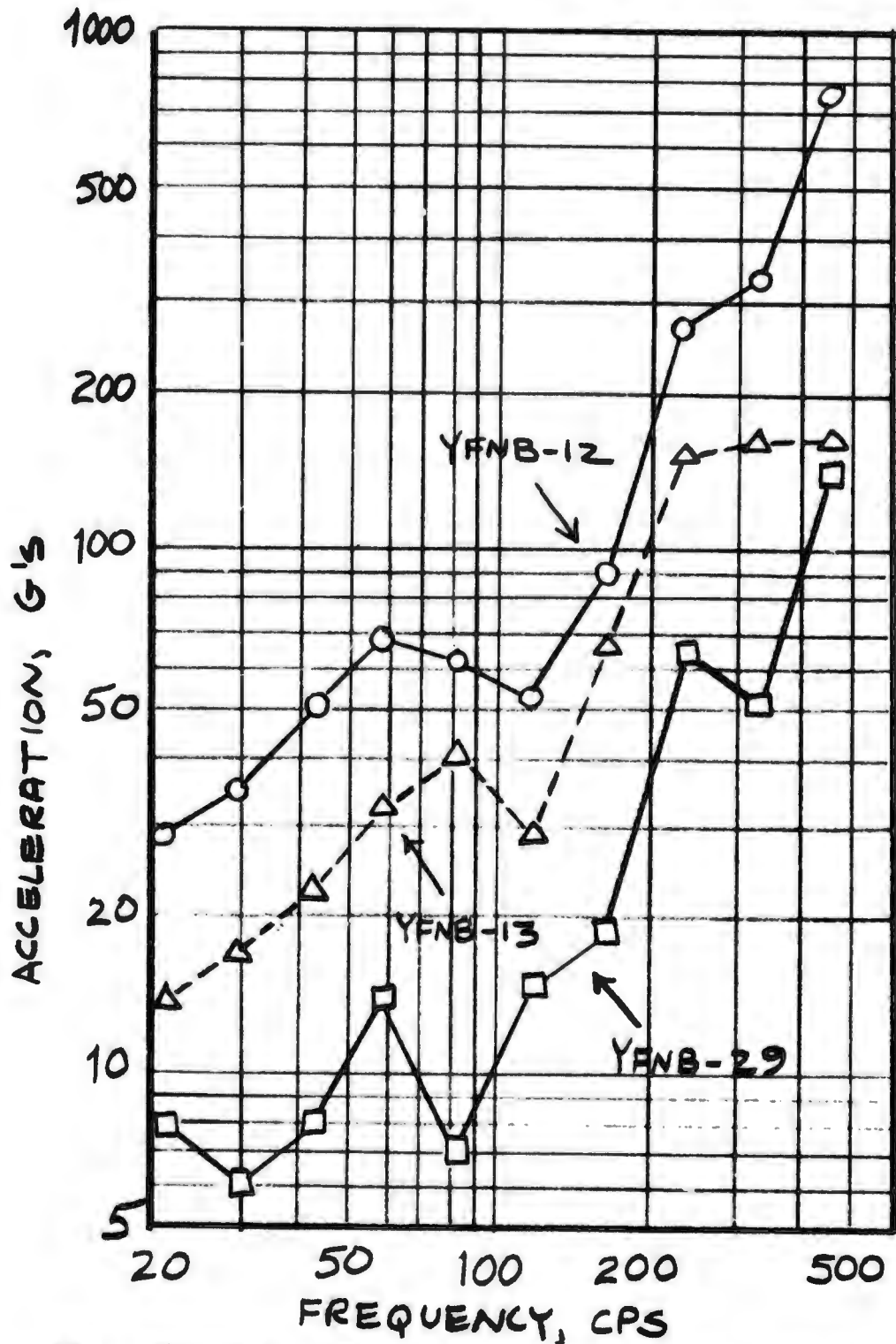
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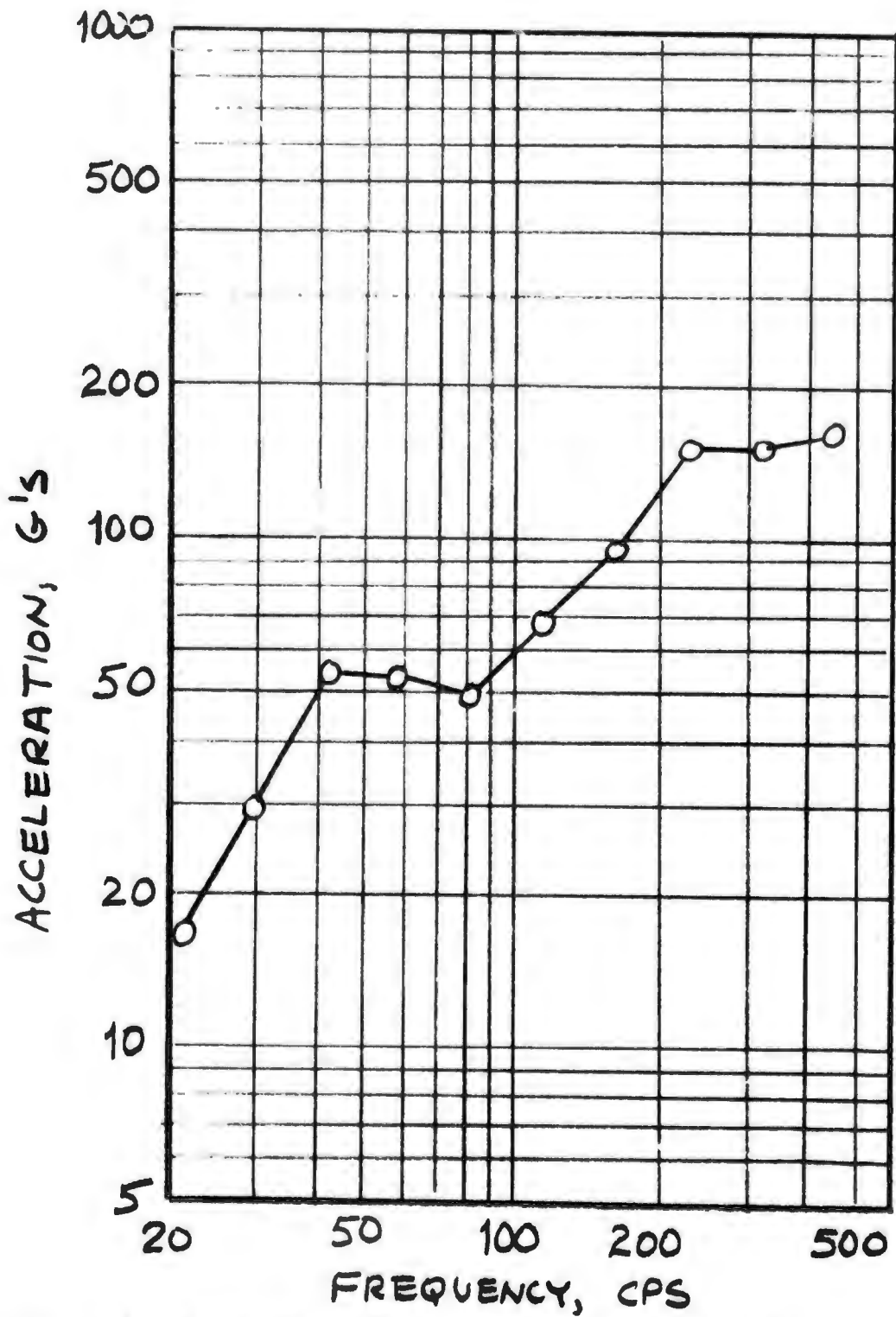
ILL. 7. SHOCK SPECTRA, ALL YFNB TARGETS. POSITION 6, VERTICAL ON MAIN DECK AMIDSHIPS



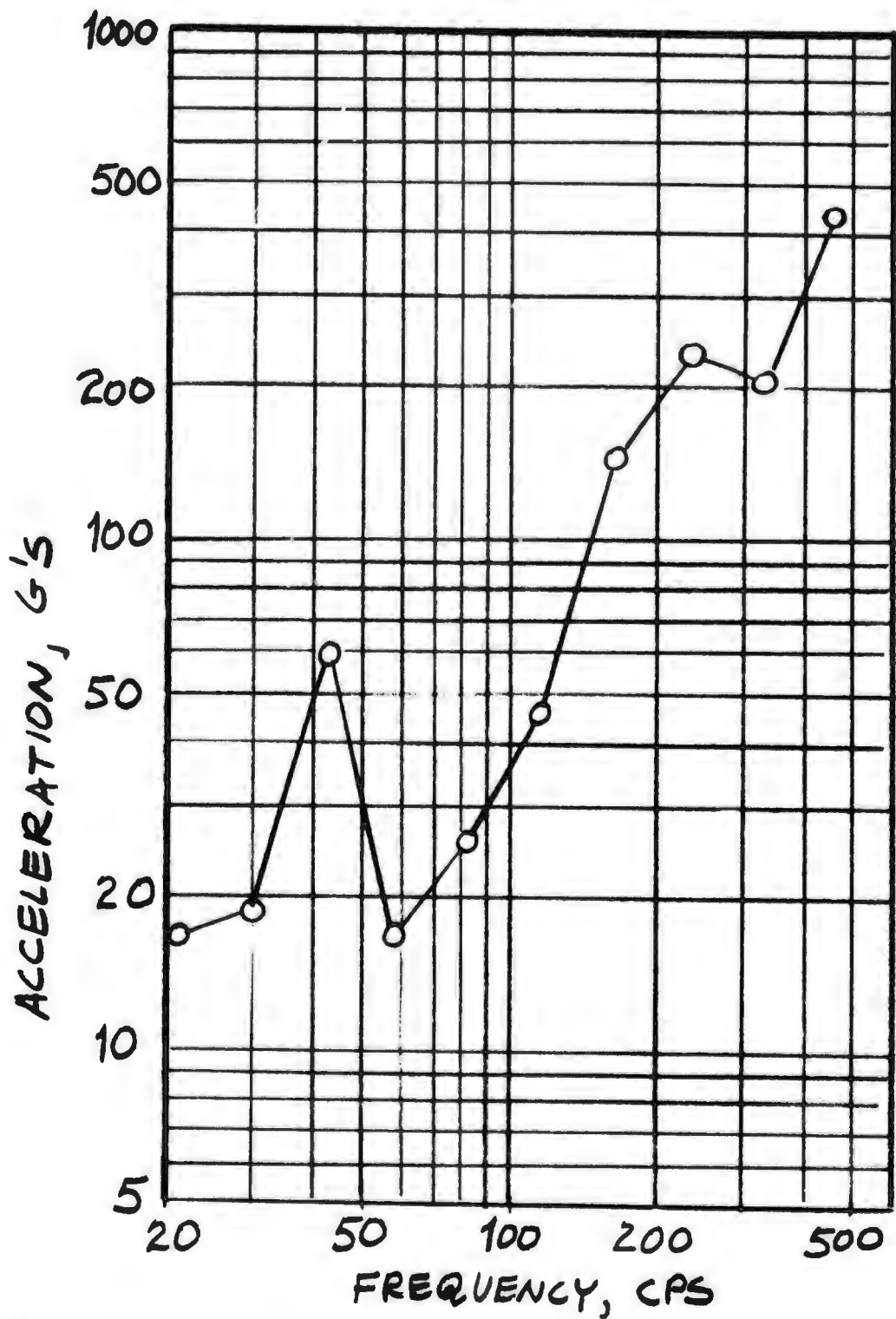
ILL. 8. SHOCK SPECTRA, ALL YFNB TARGETS. POSITION 7, VERTICAL ON TOP DECK AMID-SHIPS



ILL. 9. SHOCK SPECTRA, ALL YFNB TARGETS. POSITION 8, VERTICAL ON KEEL, AFT.



ILL. 10. SHOCK SPECTRUM, SQUAW 29.  
 POSITION B4, VERTICAL ON MIDSHIP  
 BULKHEAD



ILL. 11. SHOCK SPECTRUM, SQUAW 29.  
 POSITION C26, VERTICAL ON STARBOARD  
 MOTOR FOUNDATION.

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TABLE 7. DISPLACEMENT MEASUREMENTS OF RESILIENTLY-MOUNTED  
ENGINE-GENERATOR ON SQUAW-29

Position	Gage Location	Gage Deflection, Inches*					
		Up	Down	Fwd	Aft	Port	Stbd
C-32	Forward Outboard	.650	.375	.075	.100	.400	.350
C-33	Forward Inboard	.650	.325	.100	.075	.400	.325
C-34	Aft Outboard	.625	.425	.075	.075	.225	.275
C-35	Aft Inboard	.675	.350	.075	.100	.225	.225

\* Deflection of weight relative to foundation

## 6 ANALYSIS AND DISCUSSION

In the previous section, the test results were presented without interpretation. In this section the data are discussed and interpreted in order to present a picture of the overall and the local response. The test results are compared with data from tests using conventional explosives. The position and bearing of each target is calculated. The effect of pulses which appeared after the direct shock wave is discussed. In view of the interim nature of this report, the above will be only briefly covered.

### 6.1 Position and Bearing of the Targets

The distance from the charge to each target, and the bearing of each target relative to the direction of propagation are of importance in a consideration of the effect of the shock wave on the target. Values for both quantities were determined for each of the six targets. These are listed in Table 8. In order to make this tabulation more complete, values for the pitch angle and depth of each of the SQUAW targets are also included. The latter values are from measurements made by Project 3.6<sup>3</sup>.

#### 6.1.1 Calculation of Target Distance from Bomb

From the transit time of the shock wave from the bomb to a target and its velocity of propagation, the corresponding distance may be calculated. The velocity of propagation of a shock wave through water is a function of its pressure.

In determining the slant distances it was assumed that the shock wave traversed the first 2000 feet in 383 milliseconds, and that its velocity of propagation thereafter was 4850 feet per second.<sup>2</sup> In determining horizontal stand off distances for the target, it was assumed that the depth of the bomb was 2000 feet and that the depths of the SQUAWS were as given in the interim report for Project 3.6<sup>3</sup>.

The accuracy of the fiducial time reference is  $\pm 5$  milliseconds<sup>2</sup>. The time measurements made on these oscillograms are correct to  $\pm 1$  milliseconds. Consequently the total error may be as large as  $\pm 6$  milliseconds. This corresponds to an accuracy of  $\pm 30$  feet in the tabulated target distances.

#### 6.1.2 Calculation of Target Bearing

It was intended that each SQUAW and YFNB target have its longitudinal axis horizontal, and be contained in the same vertical plane as was the bomb.

The actual test geometry is given in Table 8.

The angle made by the longitudinal axis of each target with the

TABLE 8. TEST GEOMETRY OF EACH SQUAW AND YFNB TARGET AT  
"ZERO TIME"

Target	Slant Distance to Stern	Horizontal Distance to Stern	Bearing <sup>1</sup>	Pitch, Angle <sup>4</sup>	Depth to Center of Midships Bulkhead	Roll Angle <sup>4</sup>
	Feet	Feet	Degrees	Degrees	Feet	Degrees
SQUAW-12	5240	4960	60 <sup>2</sup>	35	290	--
SQUAW-13	7230	7030	0 <sup>3</sup>	-3	265	1
SQUAW-29	10,020	9800	0 <sup>3</sup>	-2	0	4'
YFNB-12	5530	5200	25 <sup>2</sup>	--	--	--
YFNB-13	7810	7600	0 <sup>3</sup>	--	--	--
YFNB-29	10,700	10,600	0 <sup>3</sup>	--	--	--

- 1 Angle between longitudinal axis of ship and direction of propagation of shock wave
- 2 Stern and port side toward bomb
- 3 Stern toward bomb
- 4 Data from ITR 1078. Bow up is positive angle; roll to starboard is positive angle

direction of propagation of the initial shock wave was determined from the differences in its time of arrival at two or more gage positions. From the longitudinal distance between two gage positions, the time for the shock wave to traverse this distance at sonic velocity, 4850 feet per second, was calculated. The desired angle is that angle whose cosine is the ratio of the measured difference-time to the calculated-time. The accuracy of the bearing angles given in Table 8 is estimated to be  $\pm 15^\circ$ .

The results show that SQUAW 12 was actually rotated  $60^\circ$  from the direction of propagation of the shock wave and YFNB 12 was rotated  $25^\circ$ . From the direction of the shock motion at a hull frame and on engine-generator positions on SQUAW 12, it appears that the port side of this target was toward the charge. Motion pictures taken during the test show that the port side of YFNB 12 was toward the bomb.

## 6.2 Discussion of Shock Motion at Hull Locations

### 6.2.1 SQUAW 12

Because of cable failure only one velocity meter record, C-5, on a hull stiffener ring was obtained. This meter measured the radial velocity of Frame 32 in the engine compartment. It was attached at the 9 o'clock position, i.e. on the port side in the plane of the horizontal axis, Illustration 1D. This meter recorded the highest velocity, 19.2 feet per second, measured at any position during this test. This motion was in the inward direction, i.e. toward the axis of the vessel. The time to reach peak velocity was 2 milliseconds, the average acceleration over this time was 300 g. The velocity meter "bottomed" after a displacement of  $2\frac{1}{2}$  inches, 24 milliseconds after the arrival of the shock wave. After one correction for "bottoming" it was found that the initial pulse had a duration of approximately 40 milliseconds. Integration of the record to this time gave a displacement of the frame of about 4 inches. Inasmuch as this deflection equals 4 times the shell plate thickness, severe plastic deformation, and possible failure must have resulted. About 0.38 seconds after the arrival of the shock wave this channel suddenly ceased to record any motion. The termination may have been due to flooding of the compartment with salt water. Although some instruments continued to give small indications up to 15 seconds after "Zero Time", no meters gave intelligible records after 0.5 seconds. From the records, it appears that flooding of the compartment occurred in less than 0.5 seconds.

### 6.2.2 SQUAW 13

The maximum velocity measured on SQUAW 13 was 12 feet per second; this occurred at position B-2, a radial meter oriented at 10:30 o'clock, at Frame 21, in the battery compartment, Illustration 13. Two additional similarly oriented meters were installed on other frames.

These were: C-2 on Frame 28 and C-4 on Frame 32, both in the engine compartment. The peak velocities recorded by these meters were 10.5 feet per second and 11.5 feet per second, respectively. All three meters indicated the predominate motion to be in an outward direction, i.e. away from the ship's axis. Velocity meters B-1 on Frame 21 and C-3 on Frame 32 were mounted vertically on the overhead at the 12:00 o'clock position. These showed the primary motion to be inward, i.e. toward the axis. All four velocity meters mounted vertically on the bottom of the vessel showed the motion to be predominantly upwards, i.e. toward the axis. Because of cable failures, no records were obtained at the 9:00 o'clock positions. All of the records from these meters showed a rise time to peak velocity of 1 to 3 milliseconds and an average acceleration over the rise time of 100 to 170 gs. The duration of the velocity pulse was about 13 milliseconds and the peak displacements were 0.5 to 0.8 inch.

From these measurements, and measurements made by Project 3.1, the mode of deformation of the hull may be determined.

It was apparent from the oscillograph records, which began four seconds before the arrival of the direct shock wave and continued for approximately 27 seconds, that little or no flooding of any compartment occurred. This conclusion was verified by instrument cable checks performed in the instrument trailer on the day after the test.

### 6.3 Shock Motion of Resiliently Mounted and Bolted Engine-Generator and Motor and Their Foundations

The simulated port engine-generator was resiliently mounted on all three SQUAWS. The center and starboard simulated engine-generators and the port and starboard simulated motors were bolted to foundations.

In order to evaluate the effectiveness of each type of mounting in attenuating the shock motion transmitted to the masses, the peak velocity, time of rise to peak velocity, average acceleration to peak velocity, duration of the velocity pulse, and the displacement at both foundation and equipment locations were measured and tabulated in Table 9. Because of cable failures complete data was not obtained on all units. However, sufficient data were available to permit some evaluations on all SQUAWS.

#### 6.3.1 SQUAW 12

The vertical velocity of the starboard engine-generator and starboard motor foundations were measured by velocity meters C-15 and C-26. The records, Illustration 3, are similar to each other. They show an initial velocity pulse which lasts about 10 to 15 milliseconds, and a peak of about 4 feet per second. Following this period, the velocity gradually increased until at 40 milliseconds it had reached a

TABLE 9 - SHOCK MOTIONS ON EQUIPMENT AND EQUIPMENT FOUNDATIONS

POSITION	PEAK VELOCITY FT/SEC	TIME OF RISE TO PEAK VELOCITY MILLISECONDS	AVERAGE ACCELE- RATION G's	DURATION MILLISECONDS	DISPLACEMENT INCHES
<u>SQUAW 12 VERTICAL AND ATHWARTSHIPS MOTIONS</u>					
FOUNDATIONS OF EQUIPMENT RESILIENTLY MOUNTED	10 to 12	15 to 20	20	>35	>1
EQUIPMENT BOLTED	9 to 12	20	20	>60	5 to 6
EQUIPMENT	7 to 14	10 to 25	10 to 30	20 to >33	2 to >2
<u>SQUAW 13 AXIAL, VERTICAL, AND ATHWARTSHIPS MOTIONS</u>					
FOUNDATIONS OF EQUIPMENT RESILIENTLY- MOUNTED	6 to 11	1 to 6	50 to 170	6 to 13	0.4 to >0.6
EQUIPMENT BOLTED	4	16 to 30	4 to 7	30 to 65	2
EQUIPMENT	5 to 9	3 to 7	25 to 100	7 to 23	0.3 to 0.5
<u>SQUAW 29 VERTICAL MOTIONS</u>					
FOUNDATIONS OF EQUIPMENT RESILIENTLY- MOUNTED	3	5 to 12	7 to 22	26 to >55	0.4 to 0.6
EQUIPMENT BOLTED	2	34 to 35	1 to 2	77	1.3
EQUIPMENT	3 to 4	6 to 8	12 to 19	22 to 36	0.3 to 0.4

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peak of about 10 feet per second, see Illustration 3.

The corresponding displacement at this time was approximately 2.5 inches. At this time the records from both meters suddenly terminated. The increase in velocity after 10 to 15 milliseconds may be due to plastic yielding of the hull structure.

On the resiliently mounted engine-generator, data in Table 9 shows that the shock motion transmitted to the equipment was about the same as that produced on the foundation, although the displacement of the equipment was greater. The shock motion transmitted to the bolted equipment was about the same as that measured on the foundation.

#### 6.3.2 SQUAW 13

On the resiliently mounted engine-generator on SQUAW 13 data given in Table 9 shows that the shock velocity and average acceleration were greatly attenuated compared to that on the foundation. The displacement and duration of the motion were correspondingly increased. On the bolted equipment much less attenuation was evident.

#### 6.4 Comparison of Shock Motion From Conventional and Atomic Weapons

In order to compare the character and magnitude of the shock motion produced in submerged vessels undergoing near lethal attack from conventional and from atomic weapons, data from SQUAW 13 were compared in a preliminary way with data obtained during tests on the USS ULUA (SS-428) by the Taylor Model Basin. The following primary differences are apparent:

1. The magnitude of the velocity produced was considerably greater with the conventional charge. Hull frame velocities greater than 50 feet per second did not produce hull failure during the SS-428 tests, while velocities of 19 feet per second were recorded on SQUAW 12 which flooded and 12 feet per second on the SQUAW 13, which did not flood.
2. The duration of the initial velocity pulse was considerably greater for the atomic weapon.

An underwater atomic weapon produces pressure waves of long duration compared with those produced by any conventional weapons. The peak pressure necessary to produce near lethal attack or collapse of the hull of a deeply submerged submarine is considerably less with the atomic weapon; the velocities measured on the hull were also lower.

This topic will be considered at greater length in the final report. In order to obtain data which will be directly comparable, it is suggested that instrumented tests with conventional weapons be conducted on the undamaged target, the SQUAW 29.

## 6.5 Rigid Body Motion of Squaws

The qualitative features of the rigid body motion of the submerged SQUAWS can be determined. When the shock wave from a bomb fired astern strikes the vessel, the SQUAW will be accelerated forward. It will continue to be accelerated forward until the shock front envelops the bow and the pressure on the bow balances the pressure on the stern. The SQUAW is then moving forward with a slowly decreasing velocity. Its velocity is approximately the particle velocity in the water if the SQUAW is neutrally buoyant and rigid.

The subsequent arrival of a pressure-release wave (cut-off) reflected from the water surface cancels the pressure at the stern. The SQUAW decelerates until the pressure-release wave reaches the bow. The dash line curves in Illustrations 12 and 13 show the motion of SQUAWS 12 and 13 as calculated from this simple theory and from the test geometry, Table 8.

In computing the motion, it was assumed that the pressure wave decayed with a time constant of 40 milliseconds, and that the cut-off wave was the mirror image of the pressure wave. Since SQUAW 12 was oriented with its axis at  $60^\circ$  to the direction of propagation of the shock front, the period of acceleration and deceleration should correspond to the projected length of 60 feet normal to the shock front. The maximum axial velocity should be only about half of the particle velocity in the water.

Records of axial velocity were obtained from four meters mounted on SQUAW 12 and from four meters on SQUAW 13. A record was obtained from the meter at position B-3, on the center bulkhead, at Frame 26 $\frac{1}{2}$ , on both SQUAW 12 and SQUAW 13. Tracings of the velocity records are shown as solid lines on Illustrations 12 and 13.

The velocity meter record reproduced in these Illustrations shows the total motion at this location, i.e. the rigid body and the local motion. In Illustration 12, the higher frequency mode of motion was faired through. An estimate of the actual rigid body motion remains. The calculated peak velocity is in reasonable agreement with the estimate. The faired curve falls off more rapidly than does the calculated curve.

A displacement of about three inches of both SQUAW 12 and 13 is indicated by the calculations. However, the displacements, obtained by integrating the actual velocity records at position B-3, are only 1.0 inches for SQUAW 12 and 1.6 inches for SQUAW 13. This low value of displacement is characteristic of all records of axial motion on SQUAWS 12 and 13 and is believed to be real. An illustration of the accuracy of these records is shown in Illustration 14. In this Illustration, the integrated record from the accelerometer, at pos.C-29, as well as the record from a velocity meter, B-3, which was mounted

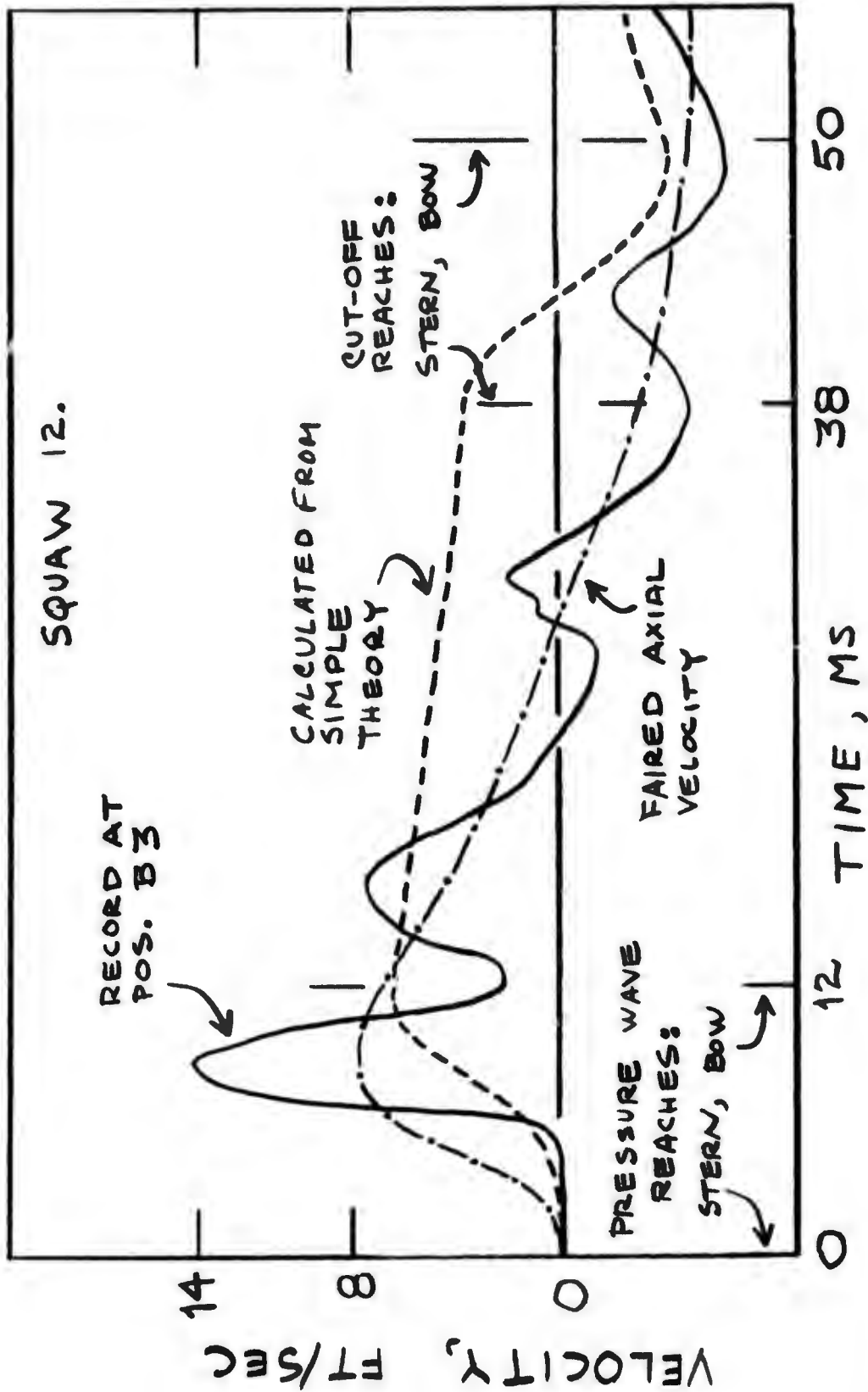


Illustration 12 - Comparison of Calculated and Measured Rigid Body Motion, SQUAW-12

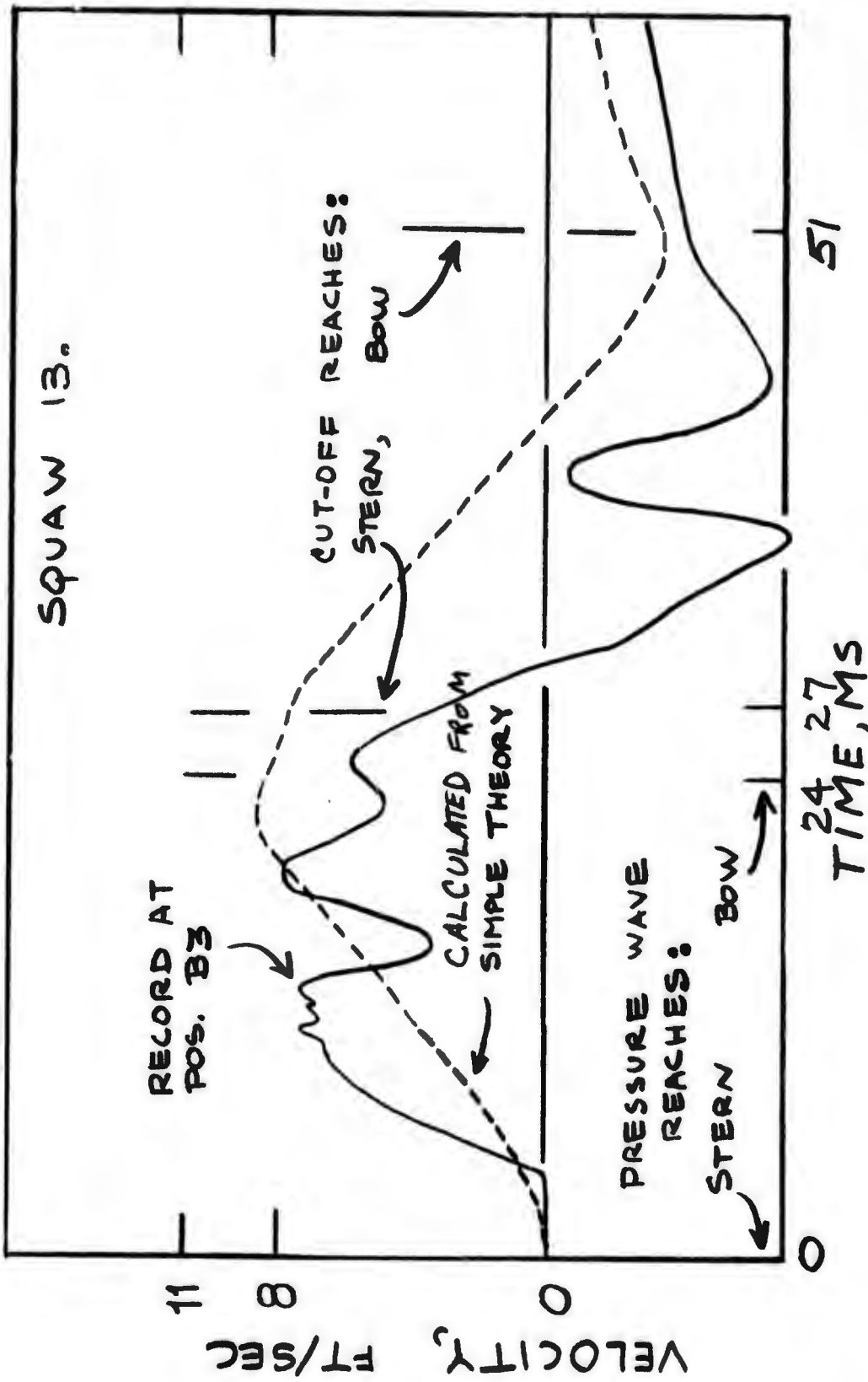


Illustration 13 - Comparison of Calculated and Measured Rigid Body Motion, SQUAW-13

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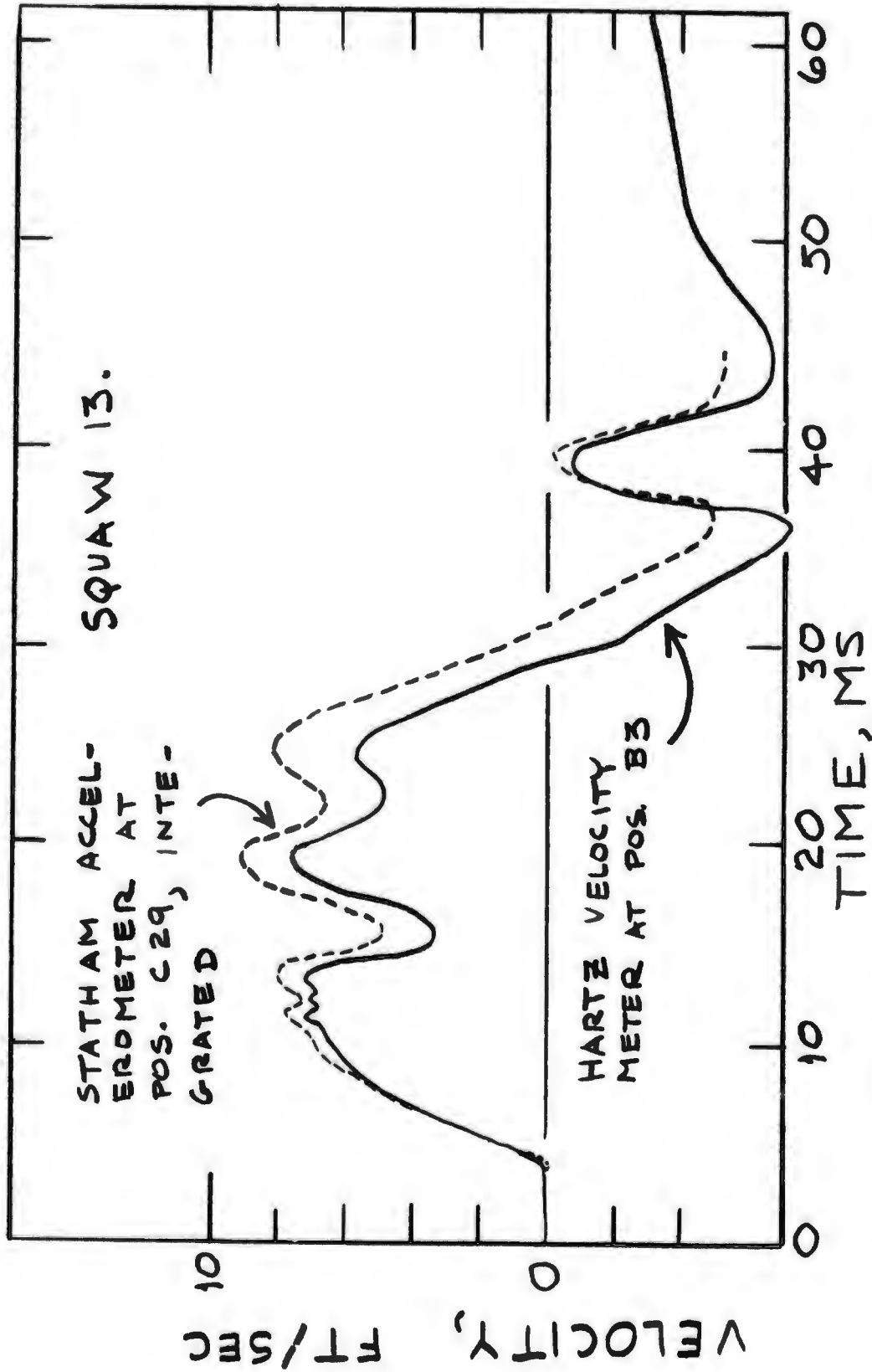


Illustration 14 - Comparison of Axial Velocity Meter and Integrated Accelerometer Records, Midship Bulkhead, SQUAW-13

base-to-base with the accelerometer on the opposite side of the mid-ship bulkhead, are shown. The integrated accelerometer record shows good agreement with the velocity meter record.

Double integration of the accelerometer record C-29 gives a peak displacement of 2 inches occurring 30 milliseconds after the arrival of the direct shock wave.

## 6.6 Shock Motions of Surface Targets

### 6.6.1 Character, Magnitude, and Damage

It was originally intended that the YFNB instrument ships be the only large surface vessels in the test array. However, in the final set up the SQUAW 29 also remained on the surface. Eleven velocity meters and ten shock spectrum recorders were installed on each YFNB, and 35 velocity meters and 34 shock spectrum recorders were installed on the SQUAW 29. The portion of the oscillograph records obtained on the YFNB 12 which show the first 200 milliseconds after the arrival of the direct shock wave are reproduced in Illustration 4. The oscillograms from the YFNBs 13 and 29, and SQUAW 29 which are not reproduced in this report were similar to those shown in the above illustration. Peak velocities and other data read from all oscillograms are given in Tables 3, 4, and 5.

As a result of the test some equipment was damaged on the YFNB 12. This included failure of the hold down bolts on a panel board of a 75 KW diesel alternator, fracture of the main casting on the deck winch at the bow, breakage of light bulbs and the disarrangement of insecurely fastened items. The shock motion produced on the YFNBs was not of sufficient intensity to produce serious damage.

### 6.6.2 Variation of Shock Motion Produced by the Direct Shock Wave with Distance from the Charge

All the records from the vertical meters on each YFNB show essentially the same type of motion, except that the individual meter records are shifted in time in accordance with the arrival of the shock at each position, see Illustration 4. The initial motion produced by the direct shock wave was roughly a step velocity. For example, in the YFNB 12 the magnitude for the various positions ranged from 6 to 7 feet per second, the time of rise ranged from 6 to 10 milliseconds and the duration, after correction for meter bottoming, was in excess of 50 to 80 milliseconds. Accelerations averaged over the rise time ranged from 25 to 30 gs. Displacements obtained by integration of the records ranged from 3 to 4 inches.

An explanation for the surprisingly long durations of the velocity pulse is not available. Further consideration of it will be given in the final report.

It is of interest to determine how velocities produced on the target ships varied with distance. The variations can be of value in making predictions of damage radii and in ascertaining whether the velocity of selected structures depended on the peak pressure or on the impulse in the shock wave.

The velocity changes due to both the direct and the reflected shock wave may be used to determine velocity vs distance relationships. The peak vertical velocities produced by the direct shock wave at three velocity meter positions on the bottom of the YFNB's are plotted logarithmically as a function of horizontal standoff distance in Illustration 15. It is seen that the experimental points for each gage position fall closely on a straight line. The lines for the various gages are almost parallel and each has a slope of about -2.3, i.e.,

$$V = kd^{-2.3}$$

Where  $v$  is the change in velocity,  
 $d$  is the horizontal distance to the device, and  
 $k$  is a constant.

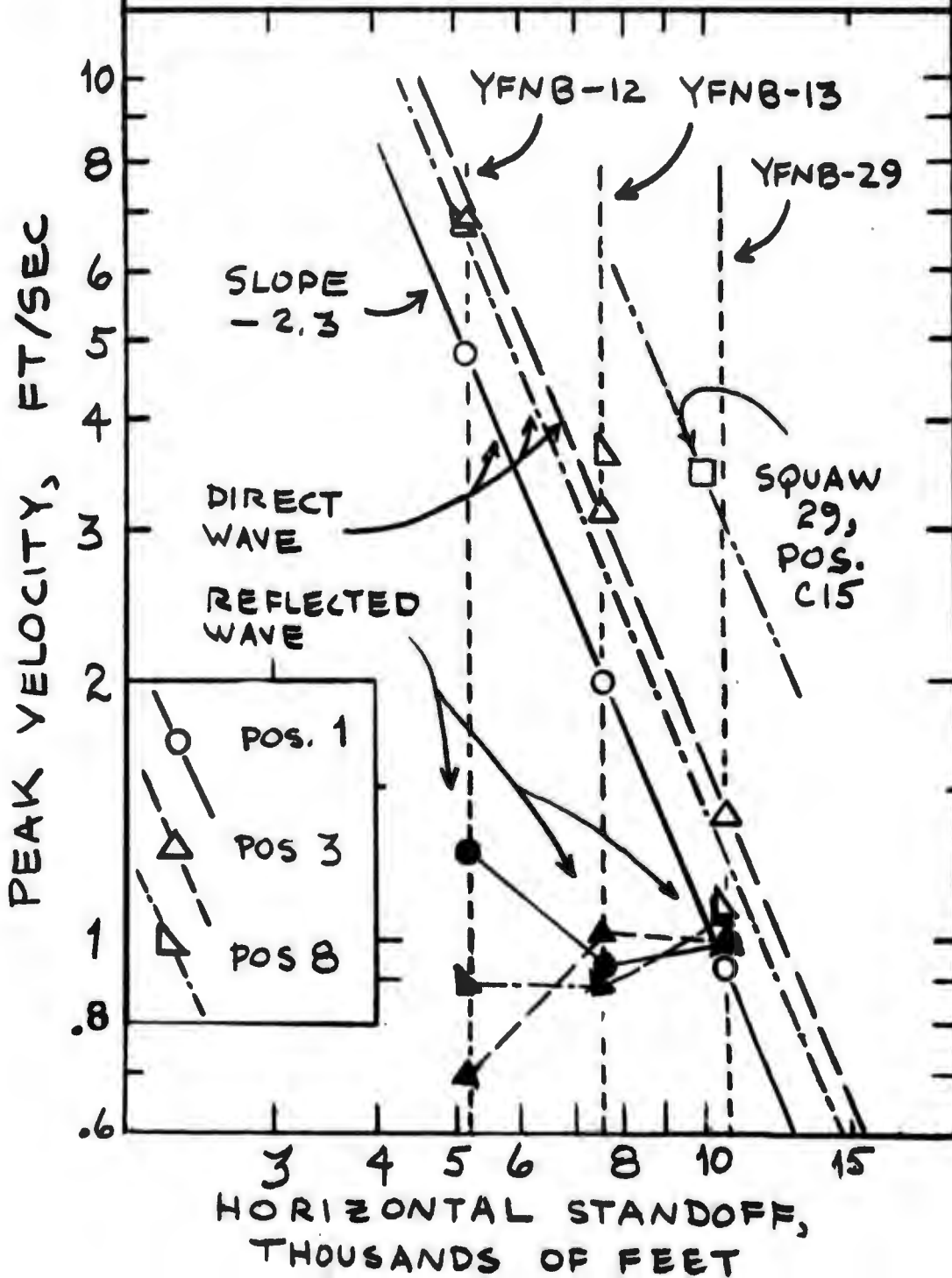
At any position both the pressure and the cut off time vary approximately inversely with horizontal distance from the charge. The impulse should therefore be inversely proportional to the square of the distance. Since the vertical component of the impulse is a linear function of the angle of incidence of the shock wave, the vertical velocity would be expected to vary to a negative power between 2 and 3. The actual slope as shown on Illustration 15 is -2.3. It is noteworthy that in Operation Crossroad, Shot Baker, an underwater atomic bomb test at shallow depth, the slope of such a curve was found to be about the same, although the velocities measured during Operation Crossroads were less<sup>4</sup>.

The maximum vertical velocity measured on the bottom of the YFNB 29 was 1.4 feet per second. A vertical velocity of 3.3 feet per second was measured on the SQUAW 29, on the starboard engine generator foundation. This velocity was larger than that measured on YFNB 29, which was at approximately the same distance; the greater velocity is probably due to the greater draft of the SQUAW. The maximum velocity measured on the bottom of the SQUAW 29 is indicated in Illustration 15. The slope of the line drawn through this point is -2.3, the same as that for the YFNB's.

#### 6.6.3 Shock Velocity Produced by Shock Wave Reflected from Ocean Floor

It was noted by observers on vessels at large distances (about 5 miles) from the bomb that the shock motion produced by a later shock wave felt considerably more intense than that produced by the direct shock wave. Concern was expressed over possible damage which might be produced by such a pulse. The time of arrival of this later pulse

ILL. 15 - VARIATION OF PEAK VELOCITY WITH DISTANCE, SURFACE TARGETS



coincided with the calculated arrival time of a pulse reflected from the ocean floor. Instrumental data were available showing the magnitude of the shock velocity produced by this reflected wave on the target vessels. The data from the same three meters were again plotted as a function of standoff distance. The resulting curves appear at the bottom of Illustration 15. The curves show that there is apparently no systematic variation of peak velocity over the range where the measurements were made. It was concluded that over the range of distances plotted, the peak velocity does not vary appreciably with distance. The large scatter for the data on the YFNB 12, at 5,200 feet, is due primarily to the error in reading low velocities on the oscillograms.

If the path traversed by the shock wave reflected from the ocean floor is calculated, it is observed that it is about the same for all three targets, about 30,000 feet. The time to cut off and the incident angle are also about the same at all three targets. The velocity produced on all three targets by the reflected wave should be, as observed, about the same.

In Illustration 16 the calculated impulse per foot of draft from the direct and from the wave reflected from the ocean bottom are plotted.

Impulse was calculated from the formula:

$$I = p T_c \left( \frac{1 + \sin \theta}{2} \right)$$

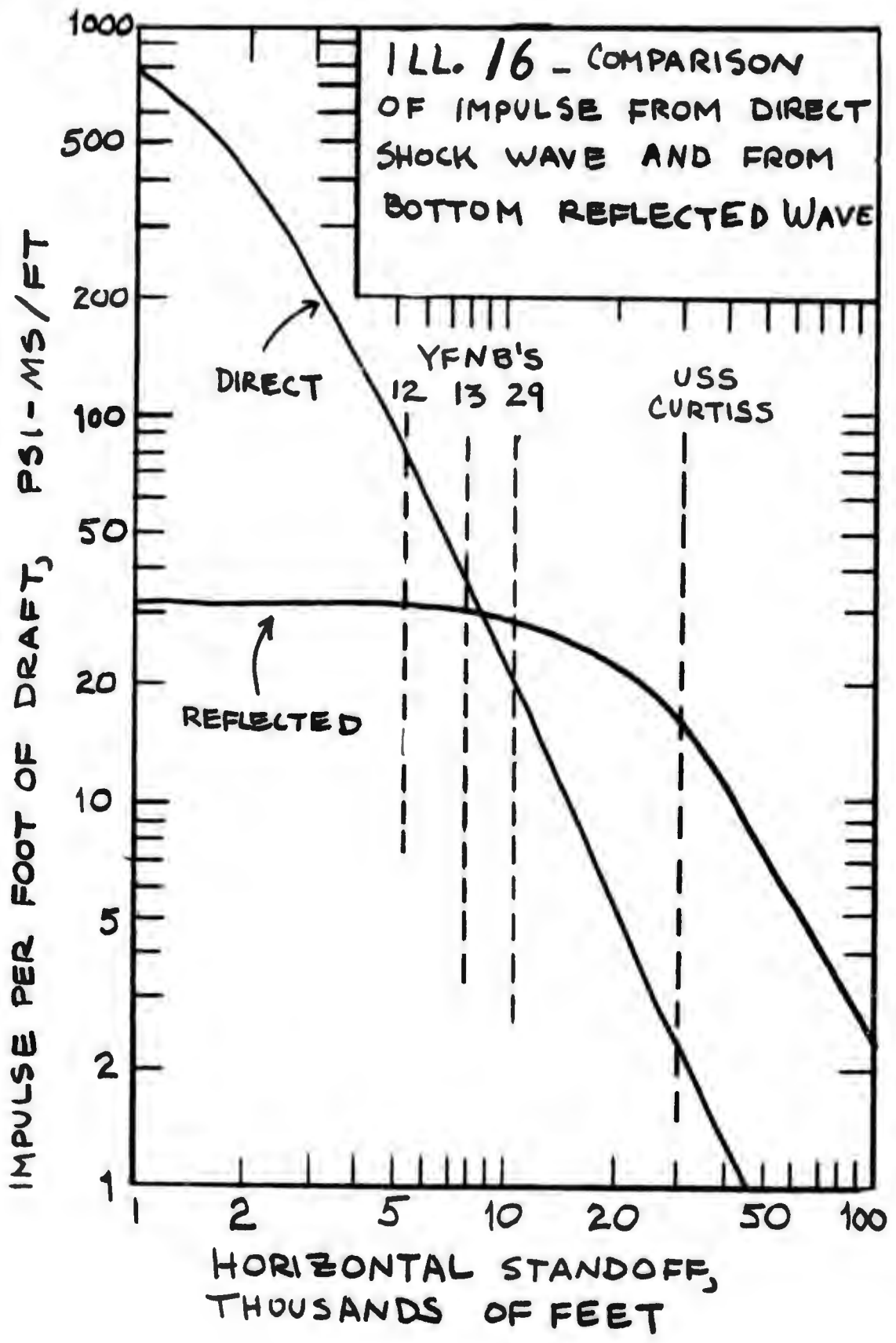
where  $p$  is the shock wave pressure in psi,  $T_c$  is the cutoff time in milliseconds and  $\theta$  is the angle of incidence. In the calculation it was assumed that  $p$  varied inversely with the distance and was reduced by a factor of 2 upon reflection from the ocean floor.

The plot shows that at large distance the impulse from the reflected wave would be considerably greater than that from the direct wave. Furthermore, a vessel with a large draft at the position of the CURTISS, 5 miles from the charge, may receive a greater impulse from the reflected pulse than a vessel with a shallow draft, e. g. the YFNB 29, would receive at its position, 10,000 feet from the charge. However, it is to be noted that in the case of the YFNB 29 the velocities produced were of low magnitude and were not damaging.

It should be noted that the pressure on the YFNBS from the reflected pulse is a function of the depth of the ocean. Had the depth been somewhat less, the shock motion produced by the reflected pulse would have been greater.

#### 6.6.4 Axial and Athwartship Motions

On the YFNBS and SQUAW 29 the axial and athwartship motions were



of small magnitude compared to the vertical motions. They consisted of oscillations at high frequency which are probably associated with the motions of local structures.

The largest axial or athwartship velocity produced on the YFNB's by the initial shock wave was 1.1 feet per second. The corresponding durations were not over 4 milliseconds.

On the surfaced SQUAW 29, the maximum axial velocity measured was 1.4 feet per second. The maximum athwartship velocity was 1.9 feet per second. This velocity was measured on a hull frame; the duration of the pulse was 7 milliseconds.

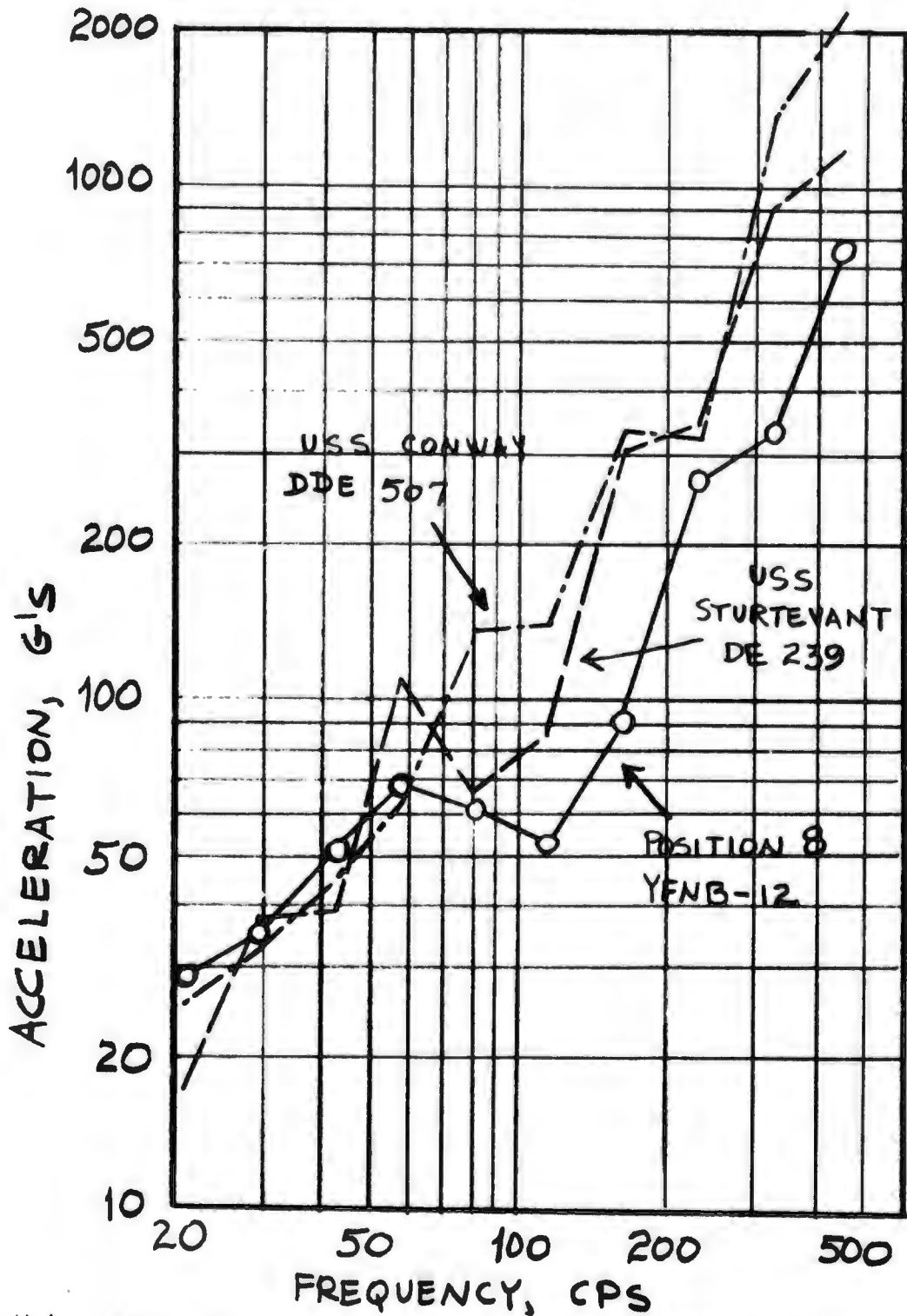
## 6.7 Shock Spectra

Shock spectra from recorders on the YFNB's and SQUAW 29 are shown in Illustrations 6 to 11 inclusive. The spectrum from position 8 on the bottom of the YFNB is plotted on the same graph, Illustration 17, with similar data obtained during depth charge structural firing trials on two destroyers.<sup>5,6</sup> These data were obtained at a position at the bottom deck level near the stern of destroyers dropping MARK-9 depth charges. It is noteworthy that the shape and level of the spectra are similar. Consequently the response of simple mechanical systems on the YFNB 12 and on these destroyers undergoing depth charge attack at small distances should be about the same. Note also that in the destroyer firing trials only minor damage occurs.

Comparison of shock spectra on the YFNB's and the SQUAW 29 shows that the level in the SQUAW is greater than that of the YFNB 29 at the same distance; probably due to the greater draft of the SQUAW.

## 7 CONCLUSIONS

- (a) Good results were obtained with oscillographic equipment in spite of severe weather which produced numerous cable failures.
- (b) Complete shock spectra were obtained from all targets except SQUAWS 12 and 13 which were lost as a result of the test.
- (c) It seems certain that the SQUAW 12 flooded within 0.5 second after the arrival of the direct shock wave, and probably within 0.05 second.
- (d) On the basis of measurements made on the day after the test SQUAW 13 had not flooded by this time.
- (e) The change in velocity produced by the direct shock wave as modified by surface cutoff on the bottoms of surface targets varied as the minus 2.3 power of the distance between the ships and the bomb.



ILL. 17- COMPARISON OF SHOCK SPECTRUM FROM YFNB-12 WITH SPECTRA FROM DEPTH CHARGE STRUCTURAL FIRING TRIALS ON DESTROYERS

It is tentatively concluded that the velocity change was proportional to the incident impulse.

(f) The target ships were subject to a series of excitations caused by the explosion of the bomb; these included a disturbance which was apparently due to a shock wave reflected from the ocean floor as well as shock waves produced by the bubble. On submerged targets as well as on the closer surface targets, the shock motion produced by the direct shock wave was considerably greater than that produced by any subsequent pulse. On the surface targets farthest from the bomb, the shock motions produced by the reflected wave were of about the same velocity as that produced by the direct shock wave. The measured rigid body hull response and equipment shock motions were in reasonable agreement with those predicted.

(g) The maximum velocities produced, at near lethal hull radius, were considerably less and the durations of the initial shock motion were considerably greater for the atomic bomb attack than for attack with conventional weapons.

(h) On the surface targets the motions produced in a horizontal plane were of small magnitude compared to the vertical motions.

(i) Shock spectra obtained on the surface vessels in the present test are similar to those obtained on destroyers undergoing depth-charge structural-firing attack.

## 8 RECOMMENDATIONS

In order to provide a more valid basis for a comparison of the effects of conventional and atomic weapon attack on submarine hulls and equipment, it is recommended that instrumented tests with conventional weapons be conducted on the remaining SQUAW target. Initially, at least, these tests should be conducted at less than damaging radius in order that a maximum of shock measurements may be made.

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- 128 Assistant Chief of Staff, Installations, Headquarters, USAF, Washington 25, D.C. ATTN: AFCEB-E
- 129 Commander, Air Research and Development Command, PO Box 1395, Baltimore, Md. ATTN: RDMW
- 130 Commander, Air Proving Ground Command, Eglin AFB, Fla. ATTN: AG/TMB
- 131-132 Director, Air University Library, Maxwell AFB, Ala.
- 133-140 Commander, Flying Training Air Force, Waco, Tex. ATTN: Director of Observer Training

- 141 Commander, Crew Training Air Force, Randolph Field, Tex. ATTN: 29TB, DCS/O
- 142 Commander, Headquarters, Technical Training Air Force, Gulfport, Miss. ATTN: TAAD
- 143-144 Commandant, Air Force School of Aviation Medicine, Randolph AFB, Tex.
- 145-150 Commander, Wright Air Development Center, Wright-Patterson AFB, Dayton, O. ATTN: WCOSI
- 151-152 Commander, Air Force Cambridge Research Center, 230 Albany Street, Cambridge 39, Mass. ATTN: CRQST-2
- 153-155 Commander, Air Force Special Weapons Center, Kirtland AFB, N. Mex. ATTN: Library
- 156 Commandant, USAF Institute of Technology, Wright-Patterson AFB, Dayton, O. ATTN: Resident College
- 157 Commander, Lowry AFB, Denver, Colo. ATTN: Department of Armament Training
- 158 Commander, 1009th Special Weapons Squadron, Headquarters, USAF, Washington 25, D.C.
- 159-160 The RAND Corporation, 1700 Main Street, Santa Monica, Calif. ATTN: Nuclear Energy Division
- 161 Commander, Second Air Force, Barksdale AFB, Louisiana. ATTN: Operations Anal. Office
- 162 Commander, Eighth Air Force, Westover AFB, Mass. ATTN: Operations Anal. Office
- 163 Commander, Fifteenth Air Force, March AFB, Calif. ATTN: Operations Anal. Office
- 164-170 Technical Information Service, Oak Ridge, Tenn. (Surplus)

OTHER DEPARTMENT OF DEFENSE ACTIVITIES

- 171 Asst. Secretary of Defense, Research and Development, D/D, Washington 25, D.C. ATTN: Tech. Library
- 172 U.S. Documents Officer, Office of the U.S. National Military Representative - SEAFB, APO 55, New York, New York
- 173 Director, Weapons Systems Evaluation Group, OSD, Rm 2E1000, Pentagon, Washington 25, D.C.
- 174 Armed Services Explosives Safety Board, D/D, Building T-7, Gravelly Point, Washington 25, D.C.
- 175 Commandant, Armed Forces Staff College, Norfolk 11, Va. ATTN: Secretary
- 176-181 Commanding General, Field Command, Armed Forces Special Weapons Project, PO Box 5100, Albuquerque, N. Mex.
- 182-183 Commanding General, Field Command, Armed Forces, Special Weapons Project, PO Box 5100, Albuquerque, N. Mex. ATTN: Technical Training Group
- 184-192 Chief, Armed Forces Special Weapons Project, Washington 25, D.C. ATTN: Document Library Branch
- 193-199 Technical Information Service, Oak Ridge, Tenn. (Surplus)

ATOMIC ENERGY COMMISSION ACTIVITIES

- 200-202 U.S. Atomic Energy Commission, Classified Technical Library, 1901 Constitution Ave., Washington 25, D.C. ATTN: Mrs. J. M. O'Leary (For EMA)
- 203-205 Los Alamos Scientific Laboratory, Report Library, PO Box 1663, Los Alamos, N. Mex. ATTN: Helen Redman
- 206-210 Sandia Corporation, Classified Document Division, Sandia Base, Albuquerque, N. Mex. ATTN: Martin Lucero
- 211-213 University of California Radiation Laboratory, PO Box 808, Livermore, Calif. ATTN: Margaret Edlund
- 214 Weapon Data Section, Technical Information Service, Oak Ridge, Tenn.
- 215-260 Technical Information Service, Oak Ridge, Tenn. (Surplus)

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