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Shock Tube Tests Of Model Communal Shelters

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DEPARTMENT OF THE ARMY PROJECT No. 503-04-002
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BALLISTIC RESEARCH LABORATORIES

ABERDEEN PROVING GROUND, MARYLAND

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B A L L I S T I C R E S E A R C H L A B O R A T O R I E S

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ABSTRACT

Shock tube tests on a 1/24 scale model air raid shelter are described giving the pressure-time history of several areas in the seating chamber as the shelter model is subjected to a long duration shock wave. Some minor changes in the construction of the shelter entrance-way are suggested which effect significant reduction in pressures in the seating chamber.

INTRODUCTION

On formal request by the Atomic Energy Commission, Division of Biology and Medicine, Civil Defense Liaison Branch, the Ballistic Research Laboratories conducted a series of tests on a scale model of a communal shelter in the 24-inch shock tube. The purpose of this testing was to determine the best possible shelter entrance configuration to accomplish maximum pressure diminution of over-pressures within the shelter structure proper. Also, the results of this test with small scale models were to be checked with those obtained on prototype shelters at the Nevada Proving Ground in the Spring of 1953.

The criteria for good shelter design are not well defined. Presumably the shelter itself must be rugged enough to withstand high blast pressures, must be so designed that people can enter rapidly from ground level and then be reasonably well protected from air blast damage. To reduce costs, to allow persons to enter rapidly, and to prevent exclusion of others before the shelter was filled, it was decided to try to eliminate heavy, blast-resistant doors and to depend upon reduction of the peak over-pressure in the blast wave in the chamber and possibly reshaping of the wave for protection of personnel. The first consideration thus arises from the theory that a classical shock wave may be more damaging physiologically than a slow pressure build up.

The manner in which the initial wave enters the seating chamber is therefore important. The initial wave may be a shock, followed by a slow build-up to a pressure equal to that on the outside, or the wave that first enters may not be a shock but only a slow rise in pressure. In either case the same maximum pressure may be reached in about the same time, which may amount to some large fraction of a second. Whether this difference between a discontinuity and a continuous rapid rise time is significant as far as the human body is concerned has not been determined.

Secondly, it is reasonable to assume that, if pressure is applied to a chamber through a hole, the inside pressure will at some time equal the outside pressure; the larger the entrance hole, the quicker this final value will be reached. If the pressure on the outside of a chamber is not a constant but decreasing with time, then the larger the entrance hole, the higher the pressure, since the rate of pressure change in the chamber will be greater. Ideally the shelter should have a very large seating chamber and a very small entrance. And, third, reflections should be avoided wherever possible.

EXPERIMENTAL PROCEDURE

The model shelter was constructed of 1/4 inch steel. Otherwise, a scale of 1/2 inch to the foot was maintained. The vestibules leading into the seating chamber were made so that the volumes could be varied. This allowed considerable variation in the test and aided in identifying

reflected waves.

The model was instrumented with 1/2 inch piezo-electric gauges mounted flush with the inside walls at locations as shown in Figure 1. The shelter was mounted in the side of the shock tube so that the ramp received the shock without reflections; that is, the inside wall of the tube represented ground level (See Fig. 2)

In considering the validity of the test conditions, it is obvious that the blast wave in the shock tube as well as the shelter model dimensions must be scaled to the full scale phenomena.

For wave shape similarity, consider first the duration of the shock wave as compared to linear dimensions of the structure. With a nuclear blast wave over a prototype shelter, the outside pressure may have decayed to 85% of peak value in the time required for the shock front to reach the farthest corner of the shelter. For a small HE explosion the outside pressure in comparable time would be zero. So the first requirement of model work is to scale the shock wave, that is, choose a model size, such that when the shock has traversed a given dimension, the pressure at this time is the same in the model as in the prototype.

Secondly, the general shape of the scaled wave over the model and the shock wave in the field should be similar. Figure 3 shows in generalized form the pressure decay in the BRL shock tube wave at peak pressures between 12 and 20 psi as compared to the Friedlander equation for the decay in an air shock.[1] The differences are readily apparent in the initial portion of the wave.

The positive phase of a shock wave varies with distance, i.e., the duration becomes longer as the peak pressure decreases. Thus, there is an optimum pressure for a given experiment at which the shock tube should operate and this is established by the linear scale factor and the bomb size. Ideally the shock tube might operate at a peak pressure of 18 psi. with a positive phase of 60 msec. The blast wave from a 20 K.T. nuclear explosion is about 600 msec. long in the 18 psi region. The durations differ here by a factor of 10. If the prototype were 10 times larger than the model in linear dimension then the same occurrence would appear at about the same relative positions. If the scale factor is 24 to 1 the wave will traverse a given dimension of the model in a shorter time and the outside pressure will be higher.

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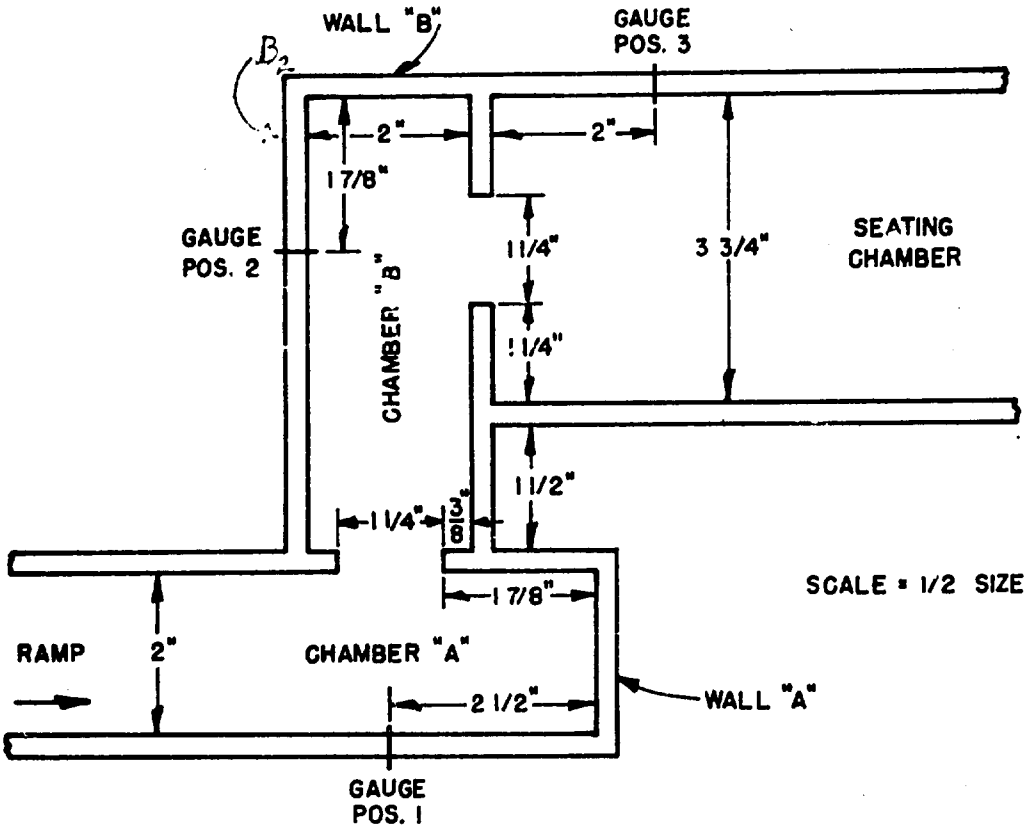
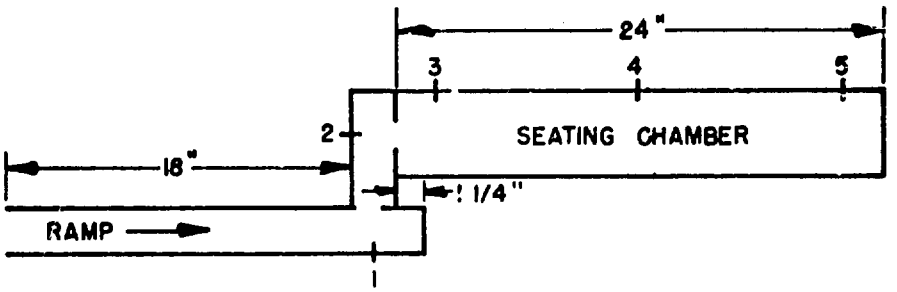
1. Effects of Atomic Weapons, Los Alamos Scientific Laboratory, 1950 p. 124

FIG. 1

LOCATION OF PIEZOELECTRIC GAUGES IN MODEL AIR RAID SHELTER





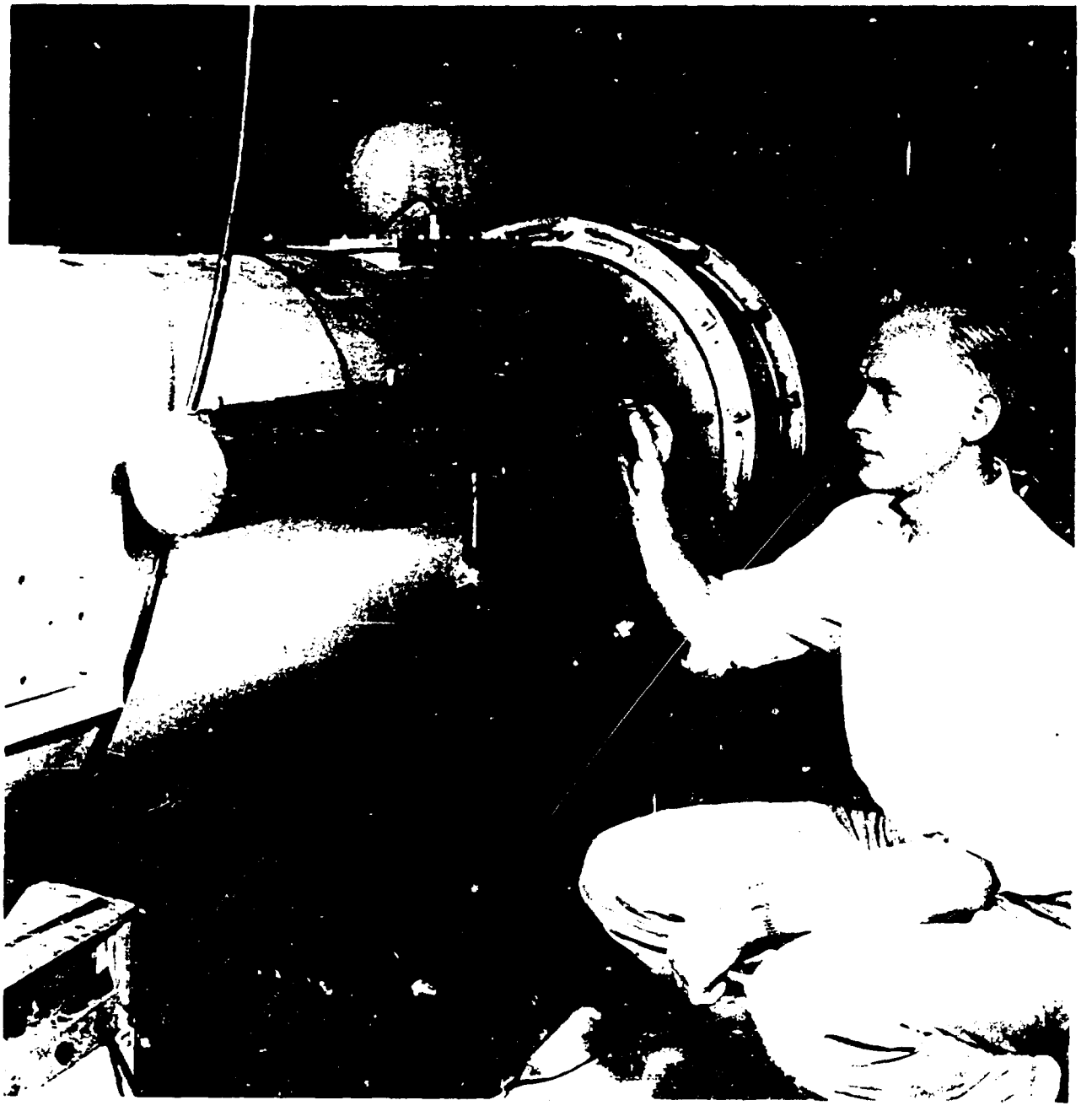


FIGURE 2. Shock Tube Facility - Test of Instrumented Model Air Raid Shelter.

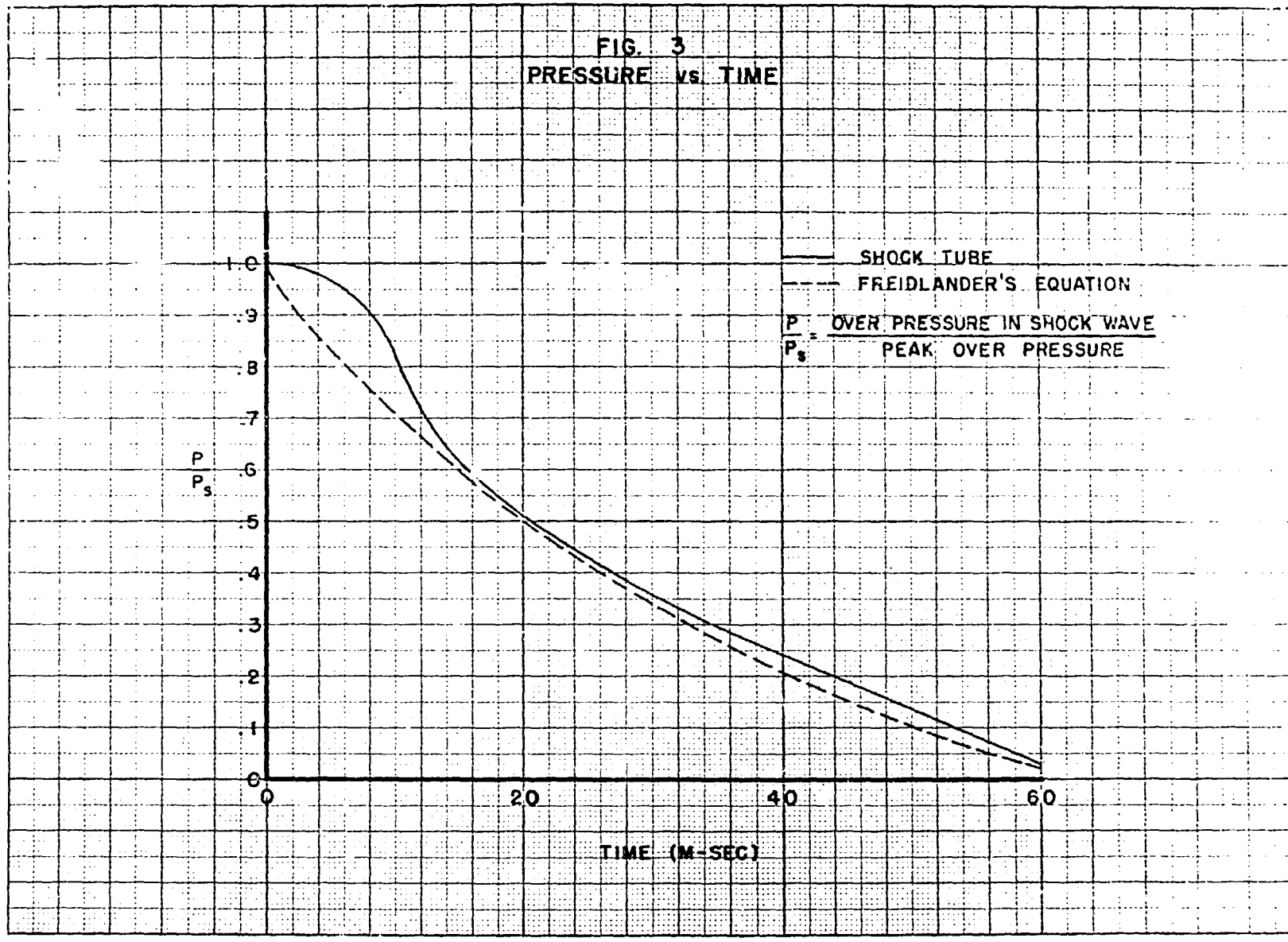


FIG. 3
PRESSURE vs. TIME
SHOCK TUBE
FREIDLANDER'S EQUATION
P/Ps = OVER PRESSURE IN SHOCK WAVE / PEAK OVER PRESSURE
P/Ps
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
0
0
20
40
60
TIME (M-SEC)

The difference in pressure at the entrance at the completion of filling for models constructed with these two scale factors would be difficult to determine without the respective pressure profiles, but a rough value would be about 4 psi. for an 18 psi. wave.

The pressure at the entrance-way at any time can be considered the effective head. The pressure that will be reached in the chamber when pressure equilibrium is established in the structure, is the outside pressure or pressure at this entrance at some time after incidence of the blast wave.

The duration of the wave in the tube is about 60 msec. (Fig. 3). The shock wave that enters the model shelter is reflected from the far end of the seating chamber and appears again at the entrance in about 5 msec. In 5 msec. the pressure in the outside wave is only slightly less than incident pressure.

In the prototype the reflection of this wave should appear in about 150 msec., the pressure in the outside wave is then about 70% of the incident. The model and prototype conditions are thus qualitatively similar but differ due to improper scaling. Figures 4 and 5 show the pressure-time history at positions 1 and 2. The initial pressure on position 1 opposite the first doorway is incident pressure. There is an immediate decay of this wave caused by the doorway opposite the gauge. Part of this wave continues straight and reflects from wall A. The other part of the wave enters chamber B. When this wave enters the doorway between A and B it is expanded and thus the pressure first recorded on pos. 2 inside the vestibule will be less than that first recorded on pos. 1. The reduction in shock strength between pos. 1 and 2, will depend upon the cross-sectional area change between orifice and chamber and perhaps a little upon the distance from the orifice to the measuring point. This cross-sectional area change on the model amounted to 1.8 and the pressure measurement was made about 3 1/2 inches from the orifice. The reduction in shock strength between positions 1 and 2 was from 20 to 9 psi. or about 55%. Wall B_2 was then moved 2 inches so the area change was twice as great. The reduction in shock strength in this case was from 20 to 6 psi., or about 70%. An increase in cross-sectional area will thus decrease the shock pressure. The increase in volume accompanying this area increase was not enough to increase the filling time appreciably and hence the final maximum pressure was not reduced.

About 0.3 msec. after the incident wave passed pos. 1, its reflection from Wall A was noticed. The magnitude of this reflection was recorded as about 45 psi., and will depend upon the distance from the gauge to the wall and also the orifice opening between chambers A and B. If there was no opening and the gauge was near the reflecting wall, full reflected pressure of about 60 psi. would be observed from this 18 psi. incident wave. If there was no wall (A) there would be no reflection and the pressure at this point would drop to some value below incident pressure. The pressure at this position was observed to be

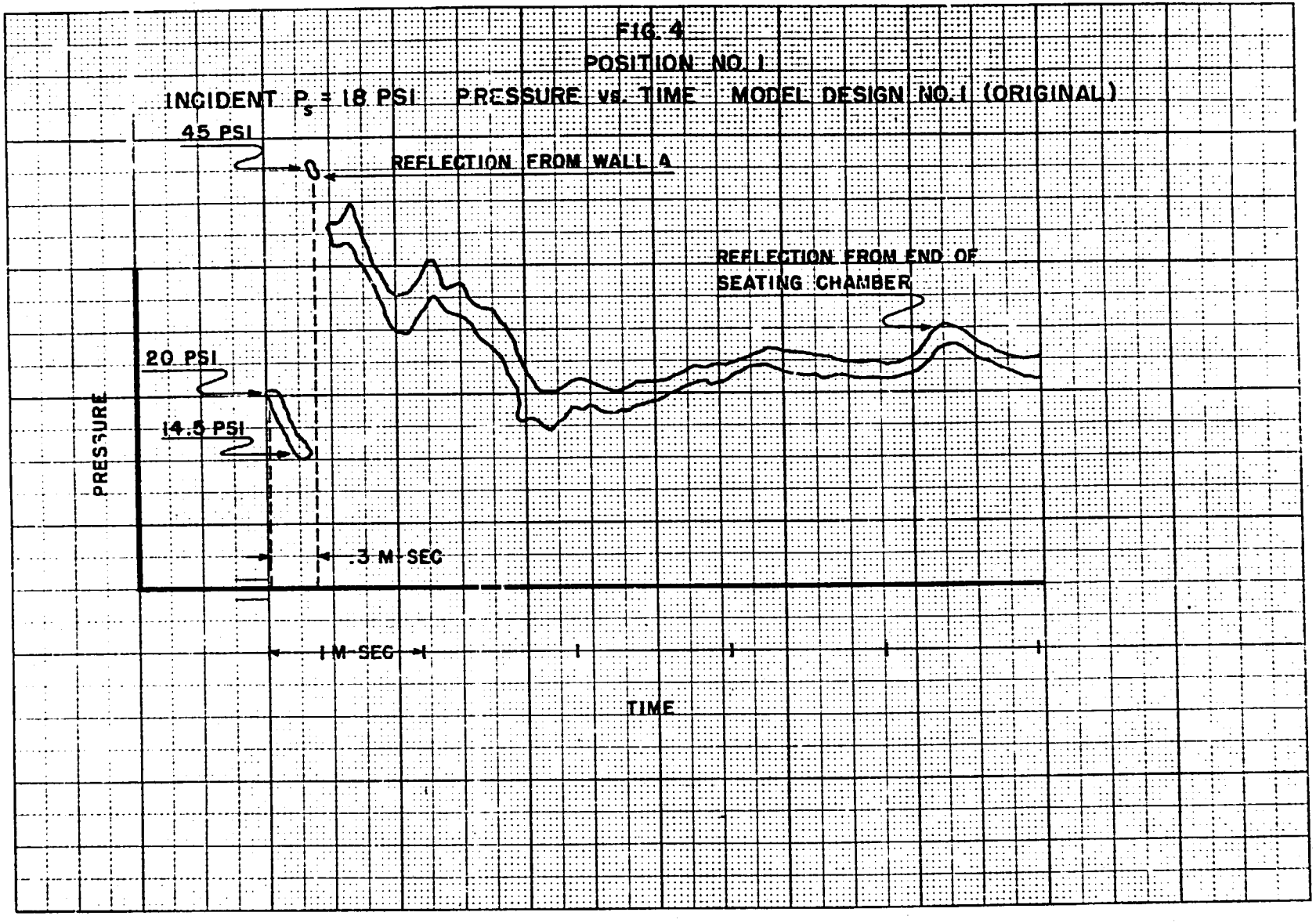


FIG. 4
POSITION NO. 1
INCIDENT P_s = 18 PSI PRESSURE vs. TIME MODEL DESIGN NO. 1 (ORIGINAL)
45 PSI
REFLECTION FROM WALL A
REFLECTION FROM END OF SEATING CHAMBER
20 PSI
14.5 PSI
PRESSURE
.3 M-SEC
1 M-SEC
TIME

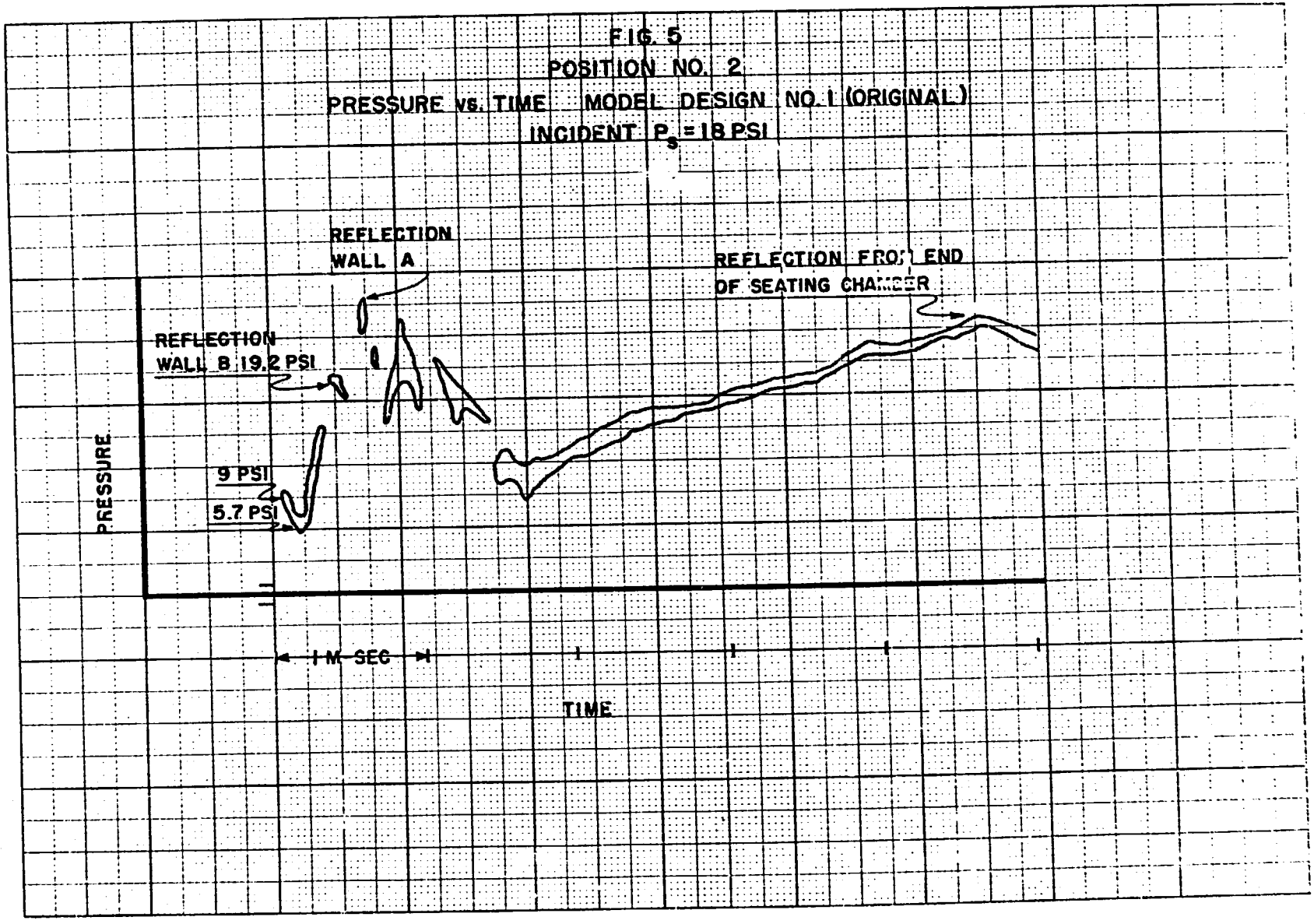


FIG. 5
POSITION NO. 2
PRESSURE vs. TIME MODEL DESIGN NO. 1 (ORIGINAL)
INCIDENT P_s = 18 PSI
REFLECTION WALL A
REFLECTION FROM END OF SEATING CHAMBER
REFLECTION WALL B 19.2 PSI
9 PSI
5.7 PSI
PRESSURE
1 M-SEC
TIME

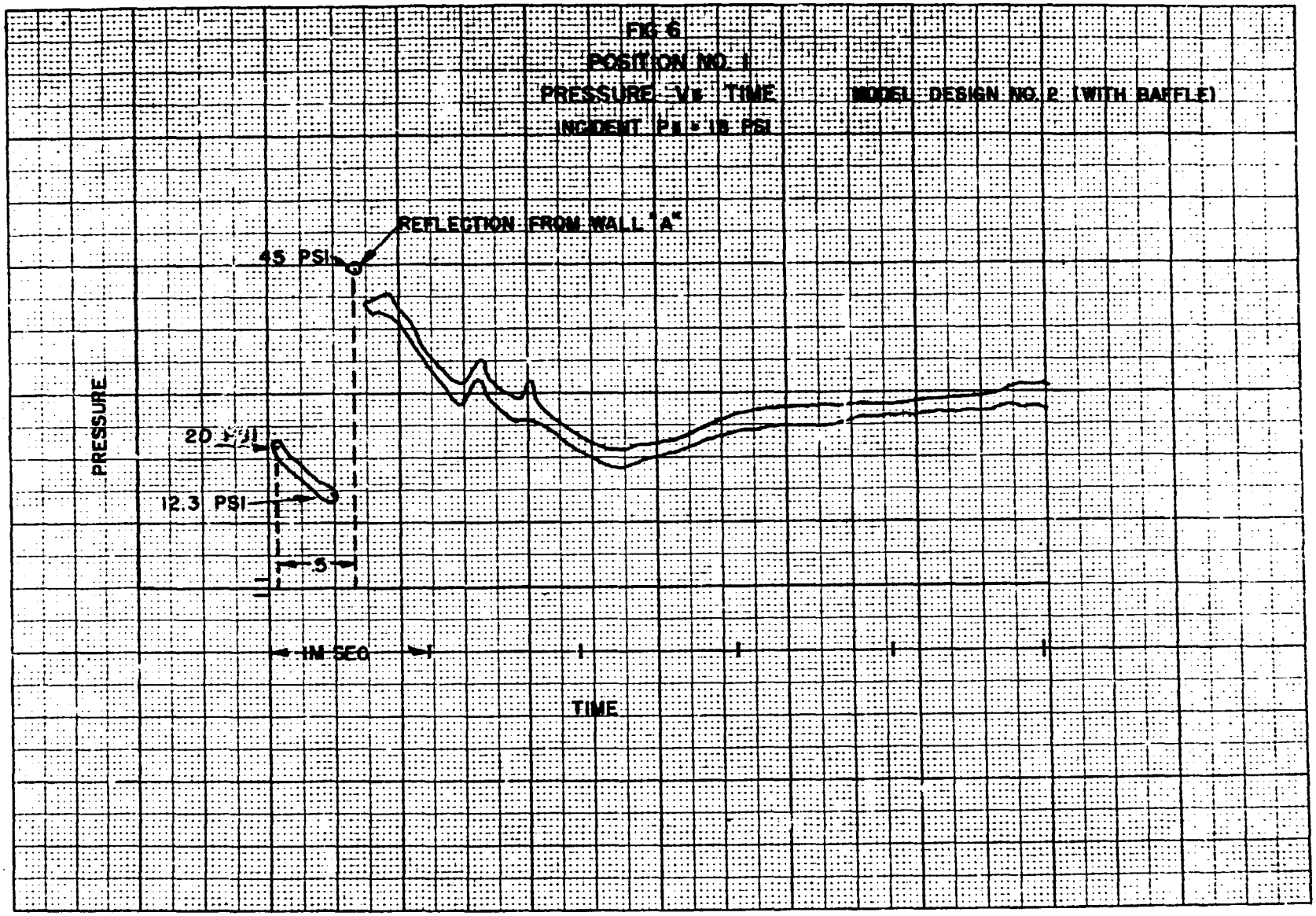


FIG 6
POSITION NO. 1
PRESSURE Vs TIME
MODEL DESIGN NO. 2 (WITH BAFFLE)
INCIDENT P.S. = 18 PSI
REFLECTION FROM WALL "A"
45 PSI
20 PSI
12.3 PSI
5
1M SEC
PRESSURE
TIME

less than the outside pressure until there was no pressure differential between chambers A and B. The maximum pressure obtained at this doorway would then be incident. The pressure throughout the system could not be more than incident.

Comparing Figures 4 and 6 we see the effect of a dimensional change. Moving the reflecting wall A back 1 1/2 inches changed the arrival time of the reflected wave. In the prototype this wave would arrive in about 7.2 msec. The time shown on the drawing is increased by the linear scale factor. During this interval one should not expect the incident wave to decay more than the 30% shown and hence the reflected over-pressure should be about the same for both the model and the prototype. The reflected wave passes back up the ramp and also into chamber B.

In Figure 5 the rise immediately following the incident shock is the reflection of the incident wave from Wall B. A dimensional change here such as moving wall B should produce the same effect as moving Wall A in chamber A on the time of arrival of the reflected wave. This wave will be met by a reflection from Wall A and cause another rise. It is possible to place the reflecting wall or the gauge at such a distance as to put the two waves directly in phase at the gauge. Changes of this order would account for momentary high pressures in a given shelter area.

After these initial reflections, the pressure at position 1 increases slightly while the structure fills. The pressure approached at this position may be considered a stagnation pressure. This stagnation pressure because of reflection effects will be about 20% greater than the outside pressure. The pressure change due to this effect shown on Figure 4 is slight because the air flowing into the chamber about equals that flowing out, into chamber B. In about 5 msec. a reflection from the end of the seating chamber is noticed on position 1. This signal is also noticed on pos. 2.

The blast wave on entering chamber B expands. The starting pressure for the gas is lower in B than in A. Assuming that mass flow is a function of pressure differential, chamber B will receive air faster than it will discharge into the seating chamber. Hence, there is a slow build-up in the chamber. This build-up does not appreciably affect the pressure on position 1, because this position has an almost infinite supply of air at a very nearly constant pressure for the times involved.

When the reflected wave from the end of the seating chamber arrives at position 2 chamber B is about at its maximum pressure.

On Figure 7 the strength of the shock wave registered by the first gauge in the seating chamber pos. 3 was 5.3 psi. Again, this is a function of the ratio of areas and distance to the measurement point. The region immediately behind the shock is very unstable at this position. Perhaps the measurement was made too close to the doorway. The next two positions (Figure 8) showed this wave to grow from 7 to 8 psi. When the wave reflects we do not see the normal type of shock reflection. Reflected

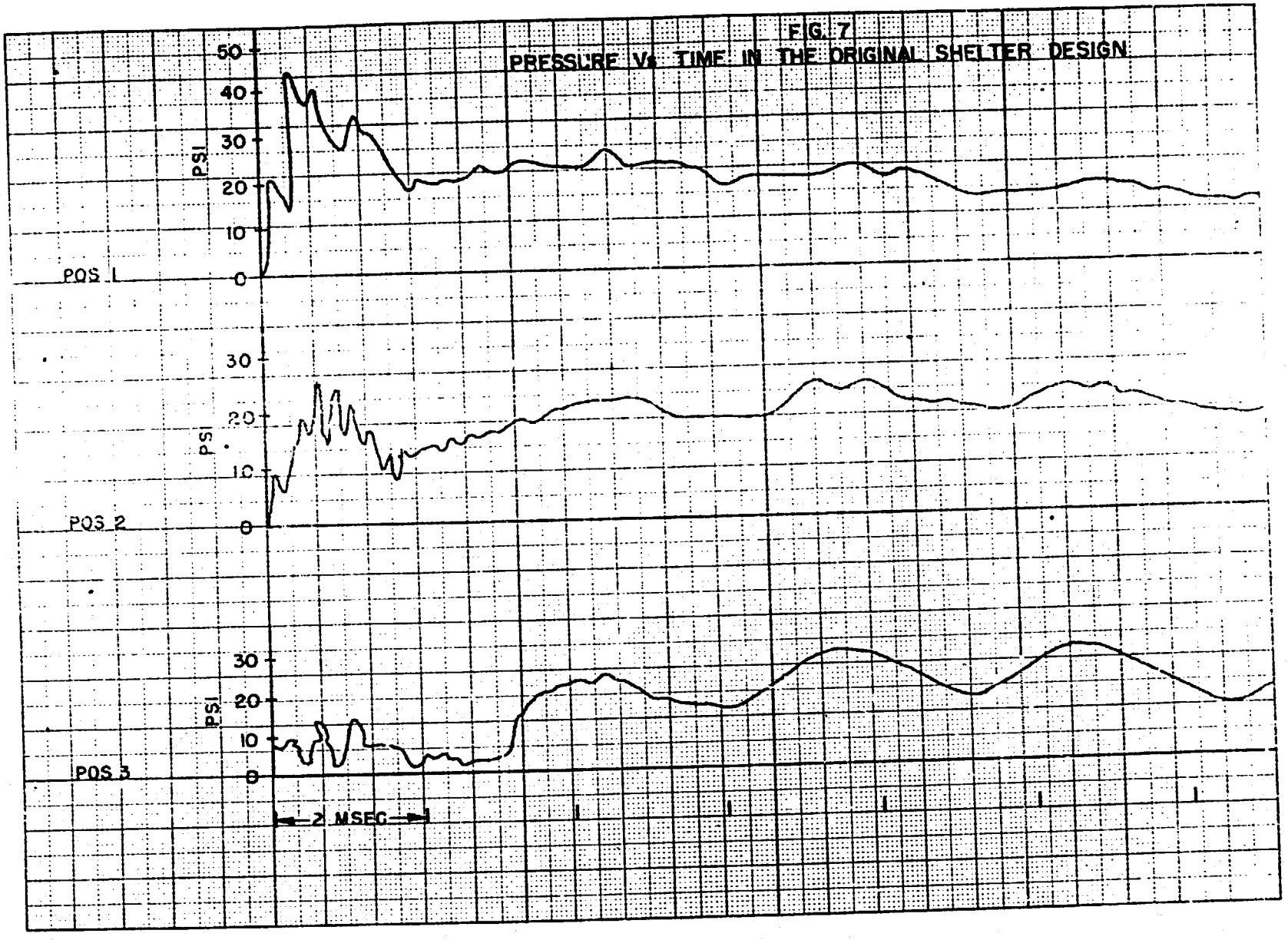


FIG. 7
PRESSURE Vs TIME IN THE ORIGINAL SHELTER DESIGN
50
40
30
20
10
0
PSI
POS 1
30
20
10
0
PSI
POS 2
30
20
10
0
PSI
POS 3
2 MSEC

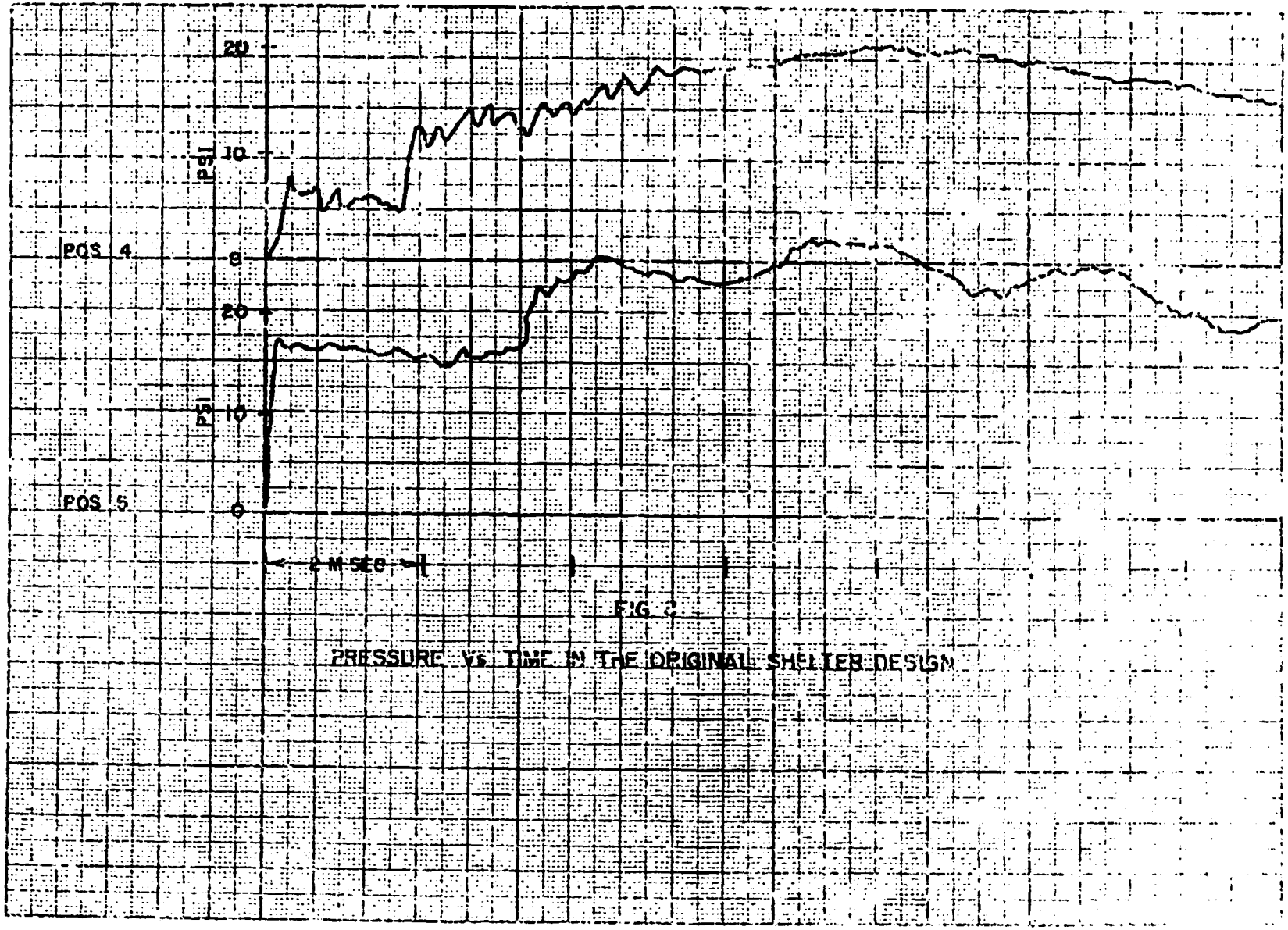


FIG. 2

PRESSURE VS. TIME IN THE ORIGINAL SHELTER DESIGN

pressure from an 8 psi., shock wave is about 24 psi. The magnitude of this reflection is about 16 psi. This lower reflected pressure indicated a deviation of normal reflection phenomena from a classical blast wave. However, reflected pressures recorded are greater than incident shock wave pressures at that time.

If the duration of the blast wave is long enough, the shelter interior will reach an equilibrium pressure equal to stagnation pressures, which is about 20% greater than incident pressure and is such because of mass flow effects.

Figure 9 shows a modification of the shelter entrance design in which a baffle was inserted in an enlarged vestibule of the model. Figure 10 shows the pressure-time curves obtained with this arrangement which may be compared to Figures 7 and 8 for original shelter design without baffle. In the original design a maximum pressure of 27 psi. was noted at pos. 5 and at about the same time the other two positions indicated about 20 psi. With the added baffle design, the rather smooth trace of Figure 10 shows that the wave entering the seating chamber has been deformed. The baffle has arranged the wave such that it distributed itself more evenly in the seating chamber. The baffle has, in effect, slowed up the wave and affected its mode of reflection. The maximum pressure at position 5 was found to be 18 psi. Also, the wave has suffered another expansion through the additional doorway and undergone an additional energy loss, thus reducing the pressure in the chamber. It should also be noted that the baffle has eliminated the discontinuous pressure rise characterized by a classical blast wave.

It was felt that the pressure at position 1 could be made very nearly incident by eliminating Wall A. Another ramp in place of Wall A would provide a free path for shock waves moving along the center line of the ramp from either direction. There would be no reflected pressure occurring within the ramp. It is true that the high pressure developed by a single ramp with an end wall would not be sustained for any length of time but nevertheless this reflection does produce an effect through the entire shelter system. The equilibrium pressure in the system would be less with this double ramp when oriented parallel to the shock flow. The double ramp was recommended with an additional seating chamber so that the resulting increased volume would increase the filling time and hence reduce the pressure. With the double ramp shelter design the entrance door should be held as small in area as possible to obtain maximum benefit.

It is also necessary to consider briefly what might happen if the wave approached in a direction other than that tested in the shock tube.

The least severe conditions exist when the blast wave propagation is along the center line of the ramp. The most severe condition would be a burst directly over the shelter (i.e., blast wave moving normal to ground surface). The entrance-way would immediately feel the high reflected pressure and the interior of the structure would tend to reach a higher equilibrium pressure.

FIG. 9

LOCATION OF PIEZOELECTRIC GAUGES IN MODEL AIR RAID SHELTER MODIFIED

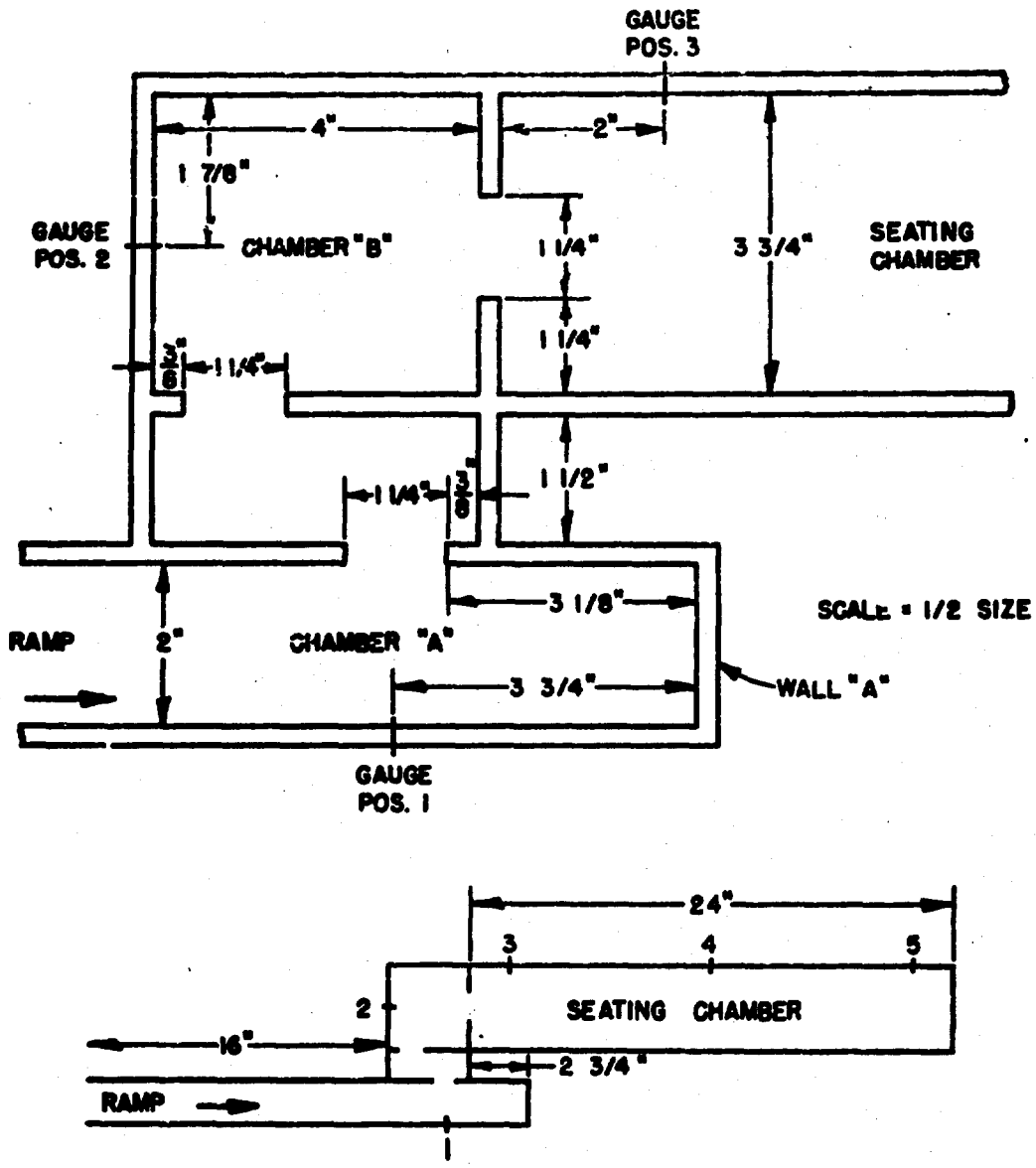


FIG 10
PRESSURE Vs TIME IN THE SHELTER WITH BAFFLE
POS 3
POS 4
POS 5
20
10
0
20
10
0
t = 4 MSec

Shock tube predictions of the pressures in the full scale shelter are based on the use of a blast wave whose shape (P vs t) is somewhat different than that occurring in an actual nuclear burst. Furthermore, due to the absence of thermal and dust effects in the shock tube tests, it is felt that predictions for full scale phenomena may not be quantitatively correct.

However, if the shock tube and field air blast pressure-time curves are similiar, one should expect that a change in a pressure-time curve in the interior of the model produced by a change in model design would produce a similar change in the prototype record if the prototype experienced a similar change in design. Thus, the use of the shock tube for the determination of an optimum design appears to be entirely feasible.

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