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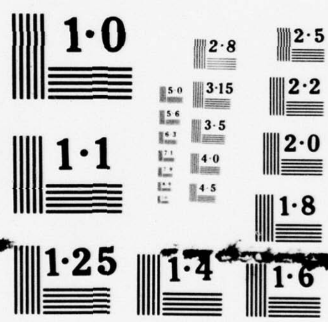

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MEMORANDUM REPORT ARBRL-MR-02835

TRANSLATION AND IMPINGEMENT OF FURNITURE DEBRIS IN A MODEL APARTMENT HOUSE SHELTER

George A. Coulter

May 1978

AD No.
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US ARMY ARMAMENT RESEARCH AND DEVELOPMENT COMMAND
BALLISTIC RESEARCH LABORATORY
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Blast Loading	Object Translation
Blast Shelter	Translation Velocities
Debris	

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

Experimental results are presented from the air blast loading of a 1/30th scale model of a five-story apartment house shelter. Pressure-time histories of wall loading and interior room pressures are shown for several locations. High speed photographs document the motion of room objects under the influence of shock wave induced internal flows. Calculations of model object translational and rotational velocities are given with the application to a full size apartment house shelter.

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SUMMARY

I. INTRODUCTION

The work reported here is a part of a study funded by the Defense Civil Preparedness Agency under Project Order No. DCPA 01-76-C-0287, Work Unit 1123C, entitled "Blast Loading in Existing Structures."

An experiment is described in which shock waves enter a model apartment house shelter to cause a resulting motion of furniture debris. The motion caused by these shock induced internal flows is shown by means of high speed photography.

II. EXPERIMENT

A 1/30th scale model of an apartment house shelter was exposed inside the Ballistic Research Laboratory's 2.4 metre diameter shock tube. Pressure transducers were placed on the exterior walls of the model and inside the model apartment rooms to record the pressure-time histories at those several locations.

High speed cameras were used to record the motion of the model furniture in two selected apartments. Motion was recorded for flows from input shock waves of 7.8, 13.9, and 23.7 kPa overpressure.

III. RESULTS AND CONCLUSIONS

Pressure-time histories were obtained at exterior wall locations on the front, end, back, and top of the model. These, along with interior apartment pressure-time traces, are presented in the body of this report.

Translational velocities were found to vary approximately as the input shock overpressure. A comparison of measured interior translational velocities for furniture type debris is made with calculated shock wave induced free field object velocities.

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LIST OF TABLES

I. INTRODUCTION

The Defense Civil Preparedness Agency has sponsored the present work at the Ballistic Research Laboratory[1] under Project Order No. DCPA 01-76-C-0287, Work Unit 1123C entitled "Blast Loading in Existing Shelter Structures." The purpose of the present work is to determine what kind of a missile hazard room furniture may represent when under the induced flow loading from blast waves entering an apartment house shelter.

The approach taken in the work was to model a five-story apartment house shelter with an approximate size scale of 1/30th. Furniture was constructed to the same scale and with densities corresponding to the densities of various full size objects of furniture. The model apartment house top floor was filled with the scaled furniture and then exposed to shock waves in the BRL 2.4 metre (8 ft) shock tube.

II. EXPERIMENT

A 1/30th scale model of a five-story apartment shelter was constructed of 0.8 cm thick plywood and 0.6 cm thick transparent plastic (one end and roof) as shown in Figure 1. The model was constructed as a non-responding model except for the interior room walls in each apartment, which were allowed to be moved during the flows. All window spaces were left open; no attempt was made to model the glass of the real windows. Figure 2 shows the critical model dimensions and locations of the pressure transducers used. Figures 3 - 5 show model mounting and floor plan details. Figures 6 - 8 show sketches of the scaled furniture used in the top floor apartments. Furniture labeling code and weights are given for reference in Appendix A, Table A-I. See work listed in Reference 1 for translation of model dummies.

Pressure transducers, PCB Model 113A28, were located on the outside walls (No. 1 - 6) and in the model as shown in Figures 2 and 4. Position 6 (hidden in the sketch) was located on the back wall of the model and corresponds to Position 2 on the front wall. The two input positions were instrumented with Endevco transducers Model 8510-5. All transducer outputs were recorded by a Model 7600 Honeywell FM tape machine. Records were sorted, filtered at 160 Hz, to remove mechanical vibration from the records, and displayed by means of a paper oscillograph.

Two camera stations were located at the shock tube test section. One was overhead focused on Apartment G and the other was at a position to view Apartment D on the right end of the model. Both cameras were set to run at about 2500 pps.

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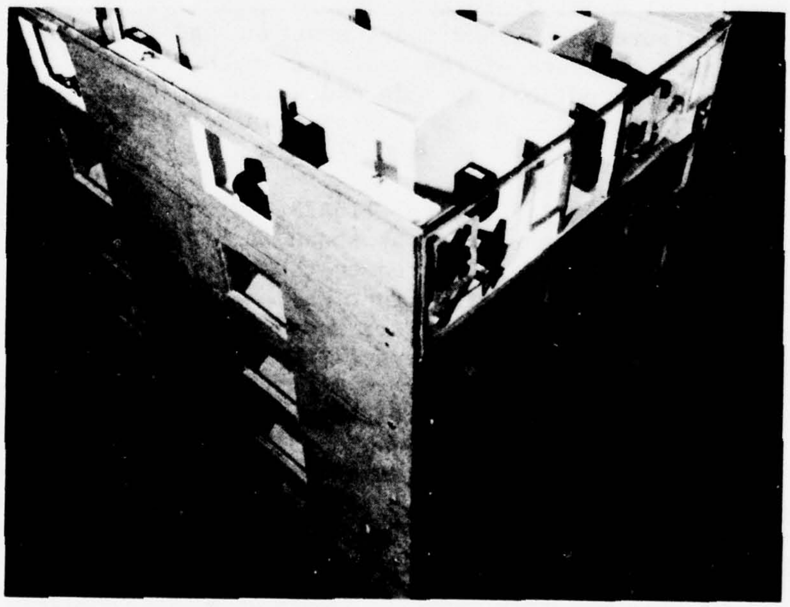
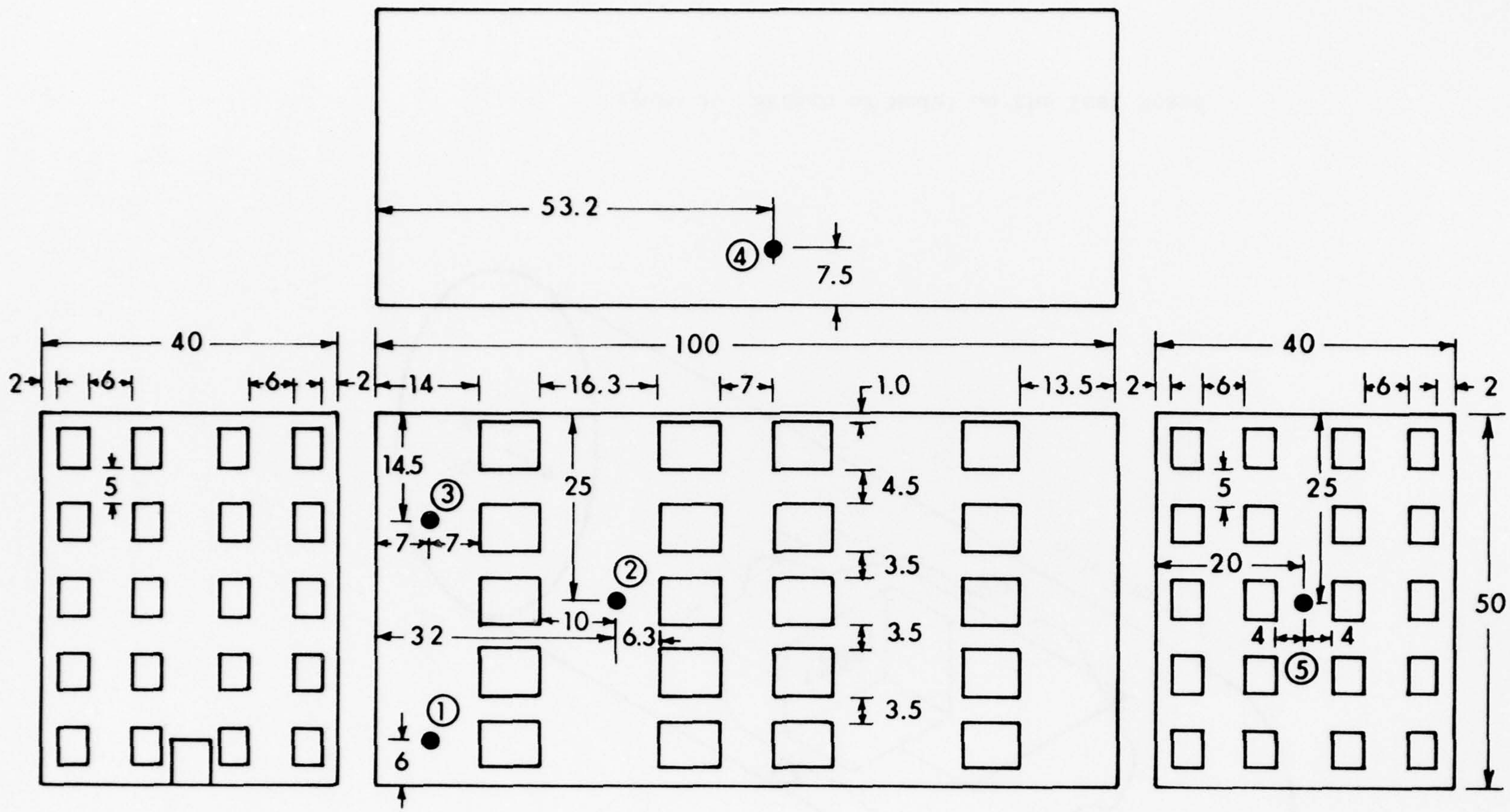
[1] *George A. Coulter, "Blast Loading on Model Dummies in Two-Room Shelters," Ballistic Research Laboratories Memorandum Report No. 2674, September 1976, AD A031522.*

(A) Front View



(B) Corner View

Figure 1. Apartment Shelter Model Mounted in the 2.4 Metre Shock Tube



NOTES–
FRONT WINDOWS - 6.25 × 8 cm
END WINDOWS - 4 × 5 cm
DOOR - 6 × 6.5 cm
● = GAGE POSITIONS - OUTSIDE
DIMENSIONS IN CENTIMETRES

Figure 2. Sketch of 1/30th Scale Model Apartment House Shelter

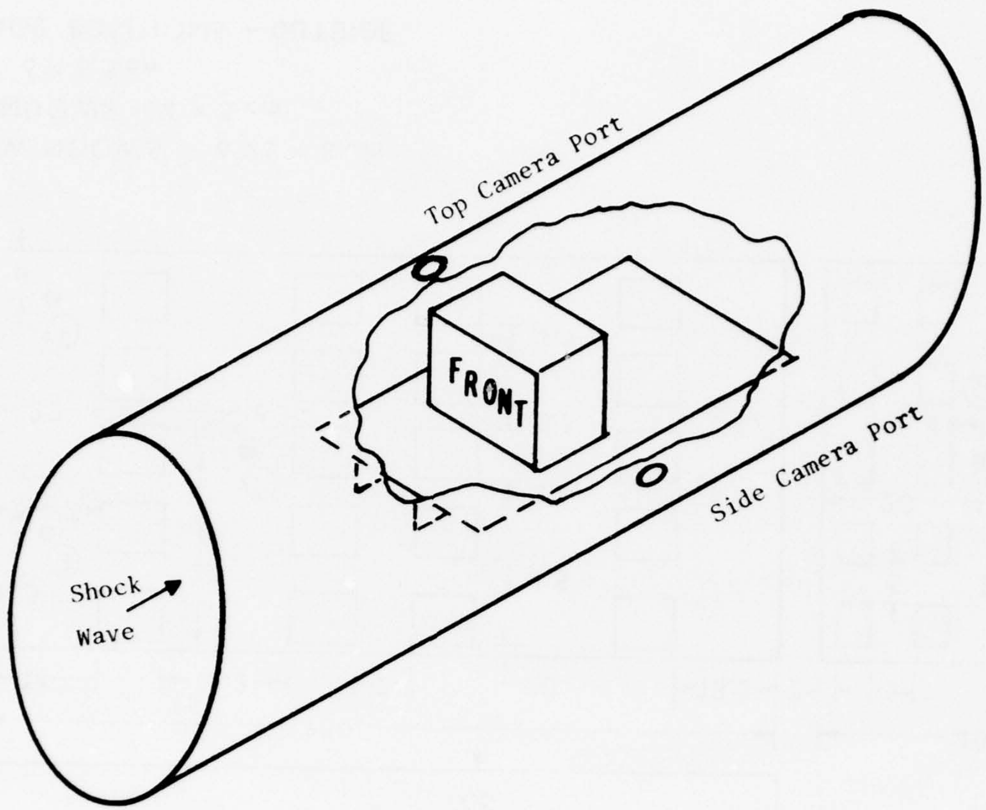
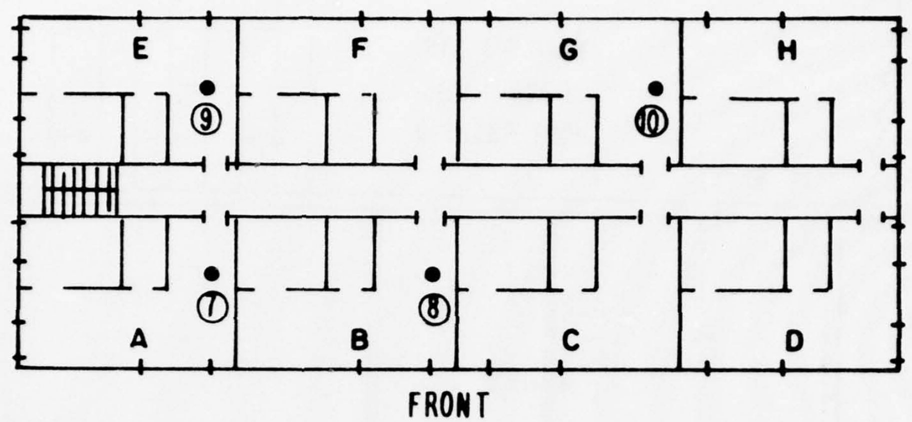
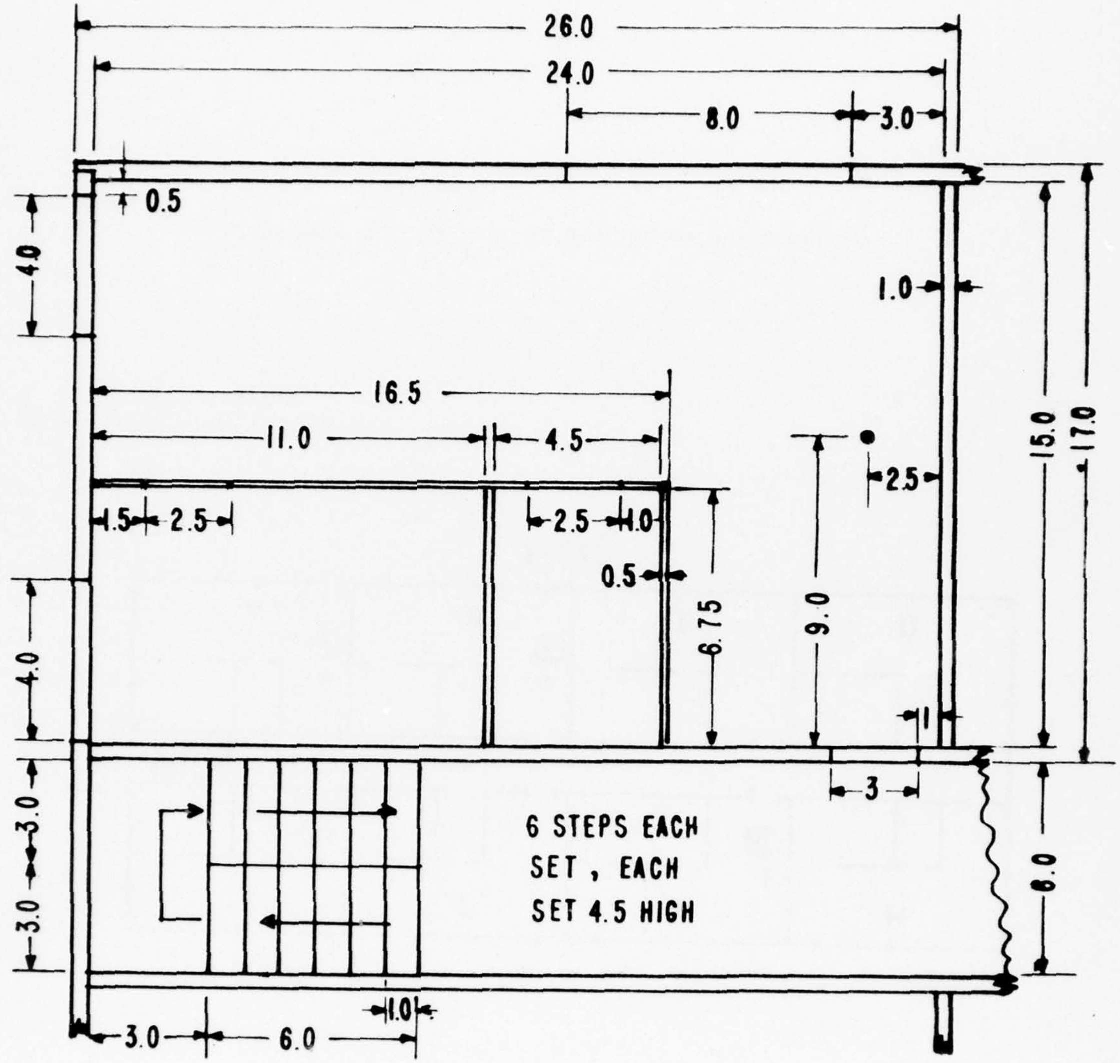


Figure 3. Sketch of Model on the Test Stand



NOTE: GAGE POSITIONS ARE ON THE FLOOR.

Figure 4. Sketch of Top Floor Apartments



NOTES -
① DIMENSIONS IN CENTIMETERS
② HEIGHT 9cm

Figure 5. Details of Apartment E, Including Hallways and Stairs

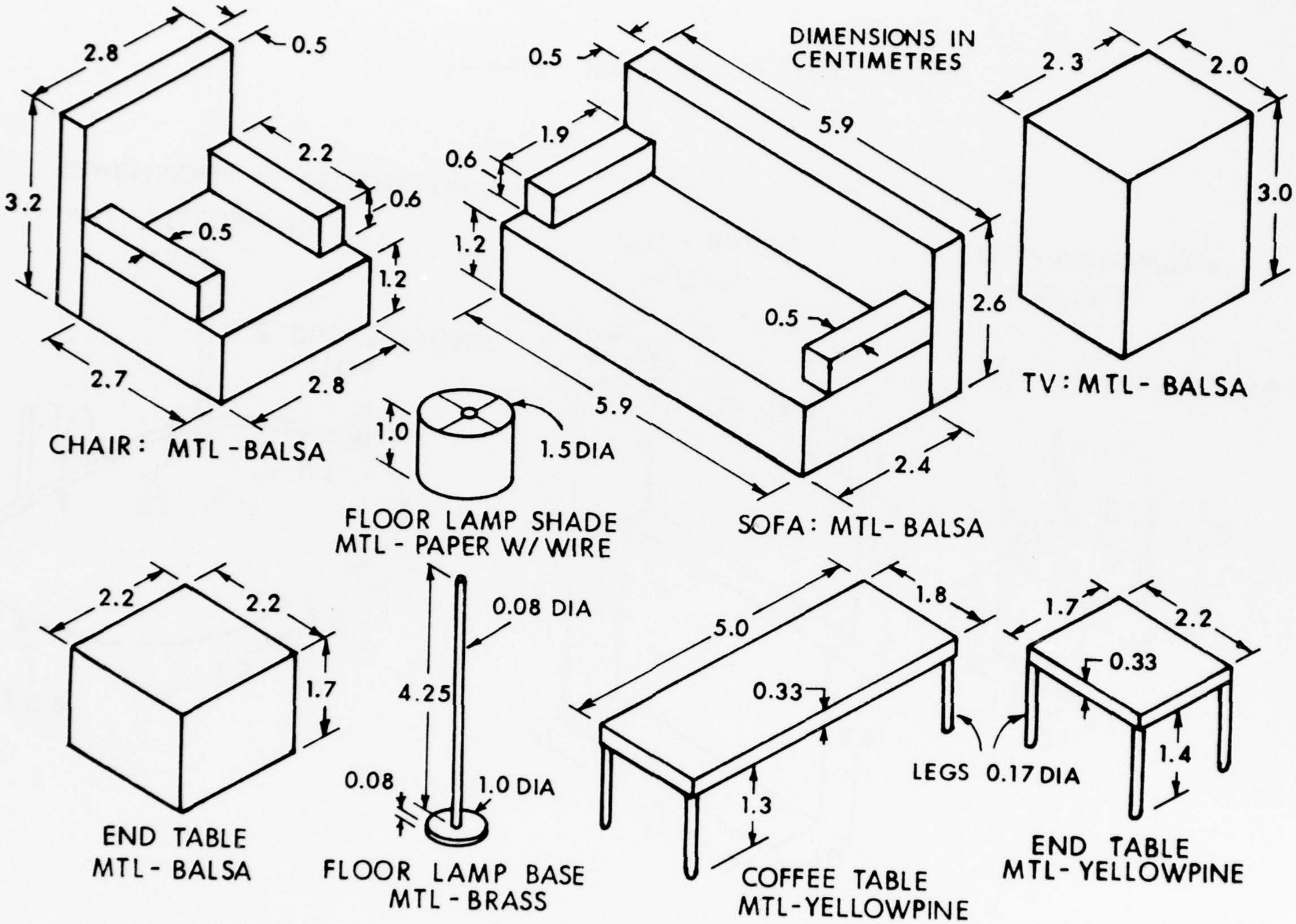


Figure 6. Living Room Furniture

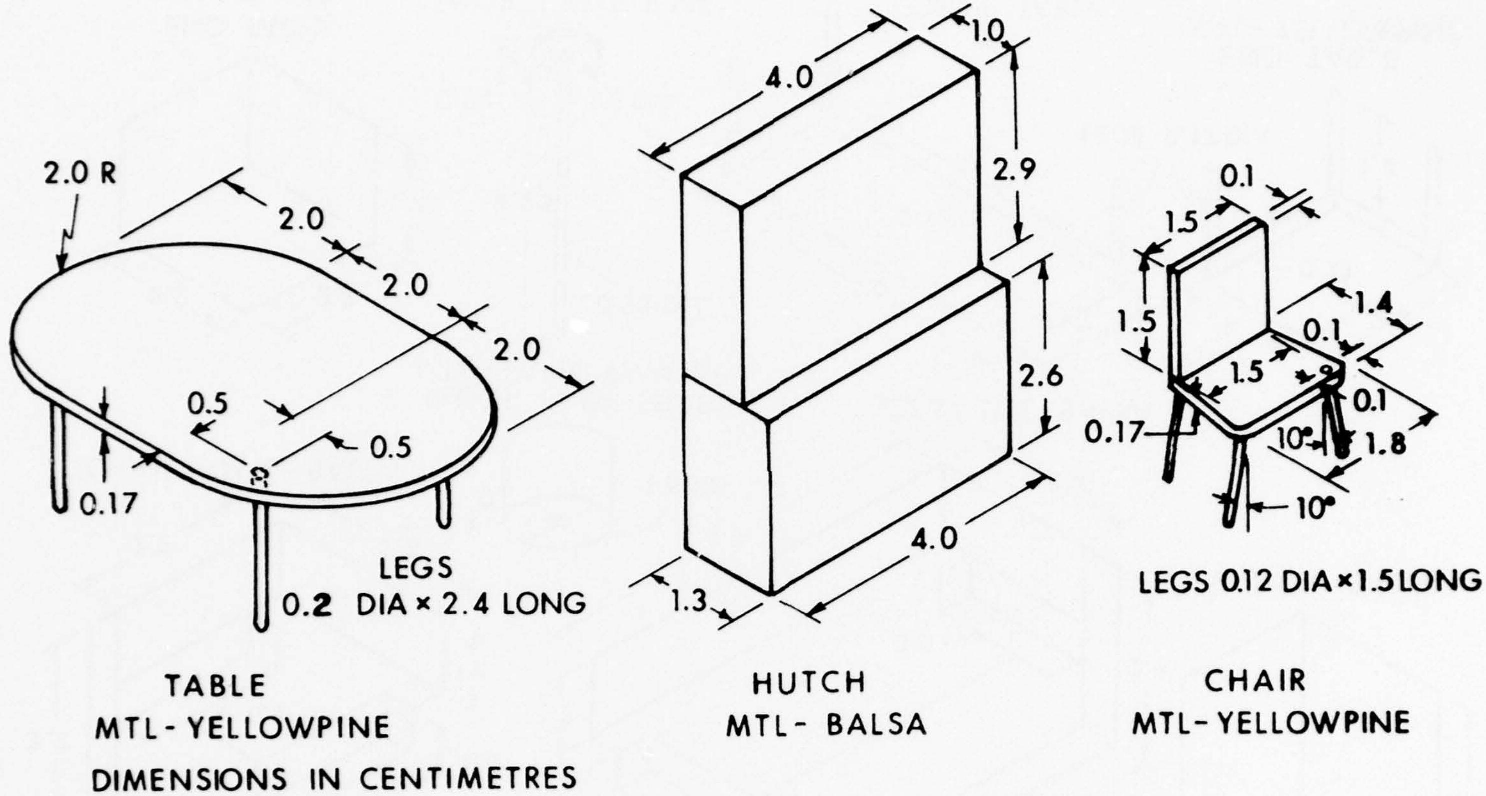


Figure 7. Dining Room Furniture

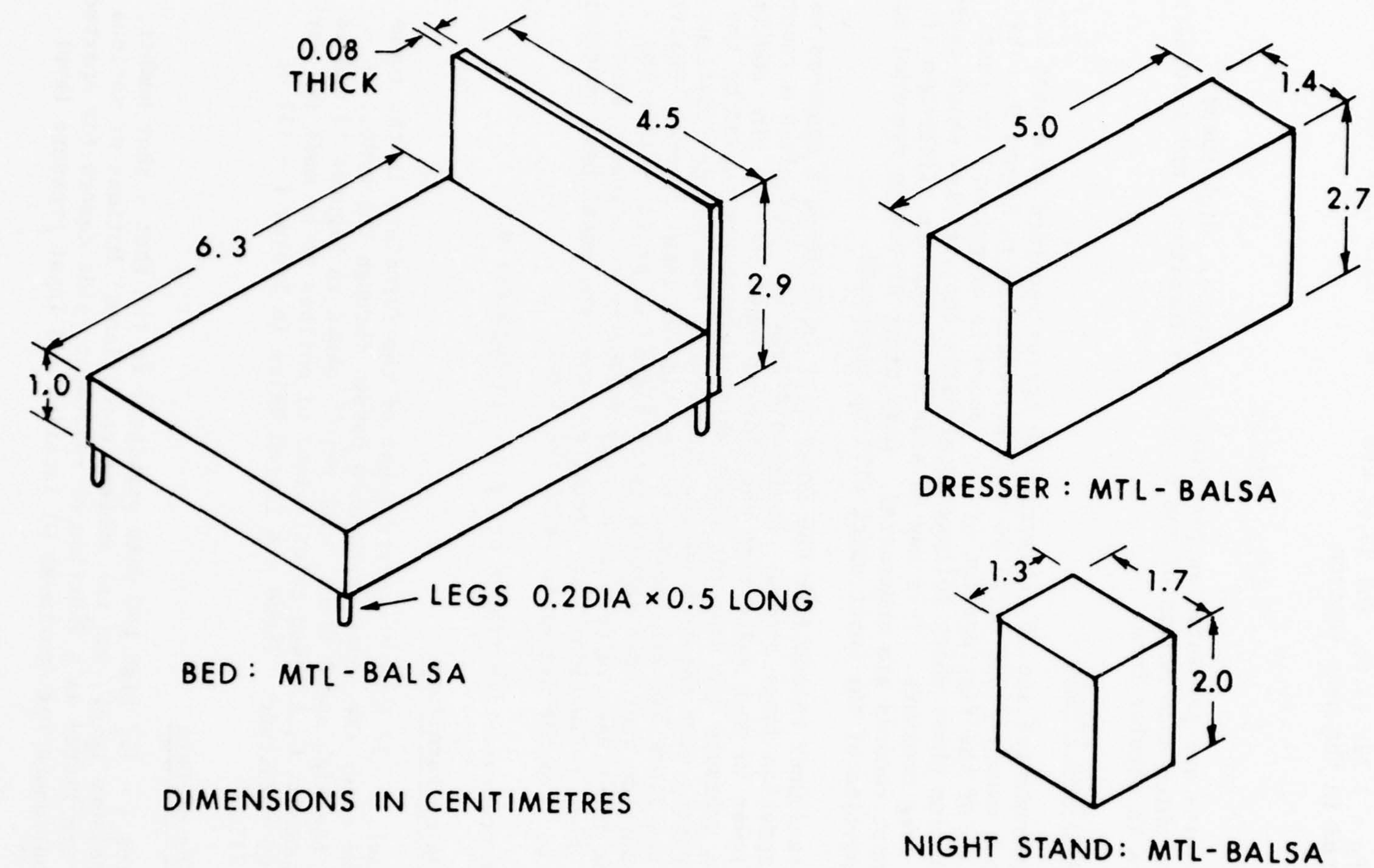


Figure 8. Bedroom Furniture

Three shots were fired in the shock tube at side-on overpressure levels of P_S = 7.79, 13.86, and 23.65 kPa. The results from these shots are presented in the next section.

III. RESULTS

The results are presented as pressure-time traces, high speed photographs which show motion of the objects of furniture, and a summary of the data in tabular form.

A. Pressure-Time Traces

A representative set of pressure-time traces recorded from Shot 8-77-1, for an input overpressure of 13.86 kPa, is presented in Figure 9. The first 130 ms of the flat portion of the record is of primary interest. The rarefaction phase which follows accelerates the air flow which causes increased drag pressure. This may be seen as a pressure difference if the two input records are subtracted. Only times of motion recorded during the flat portion of the input shock will be discussed.

The transducer record from the front wall in Position 3 compares well to the stagnation input record. Position 4 from the roof gives a record somewhat lower in peak value than the side-on input record. In addition, there is a pressure dip near the front which is probably caused by the vortex crossing over the transducer. The traces from inside Positions 7 - 10 on the floor are all similar to the side-on input record. Position 6 on the outside rear wall shows a trace higher in pressure than the stagnation input wave value with a decay following to a lower value. Multiple shock reflections from around and over the model have probably combined to give the higher value at the front.

Other pressure-time traces are given in Appendix B.

B. Motion of Furniture

Figures 10 - 12 show the arrangement of the furniture in the rooms before and after the shock waves have passed through the model. A study of the high speed films, with prints shown in Figures 13 and 14 and in Appendix C, allowed calculations of motions to be made for various objects of furniture. These are listed below in Tables I - III of Section IIIC.

C. Tables of Data

Tables I - III list the data pertinent to the shot - shot number, input pressure level, and the ambient conditions. Motions of various objects are listed as a function of apartment (side camera for Apartment D and top camera for Apartment G) location and input pressure level.

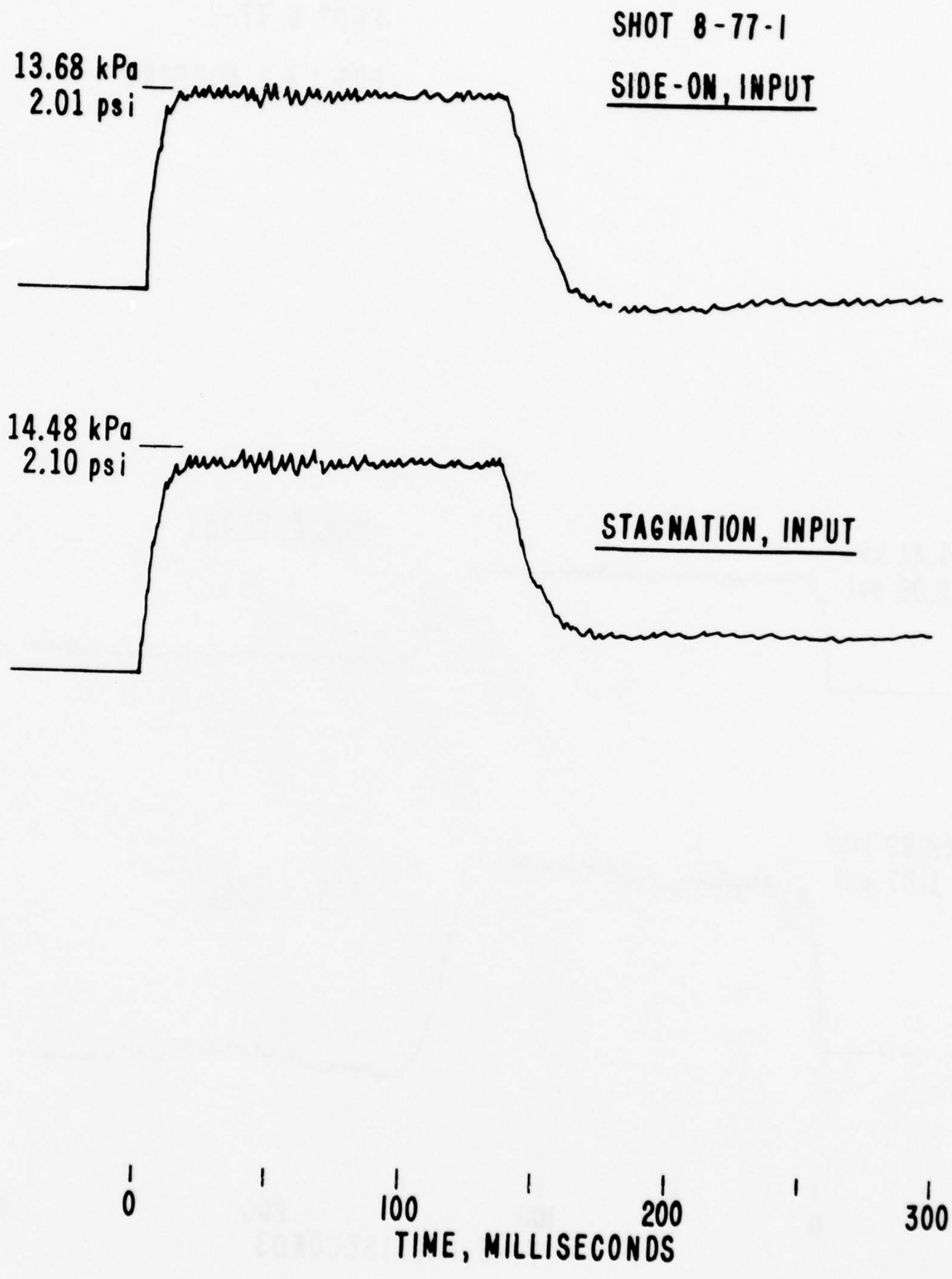


Figure 9. Pressure-Time Traces for Shot 8-77-1

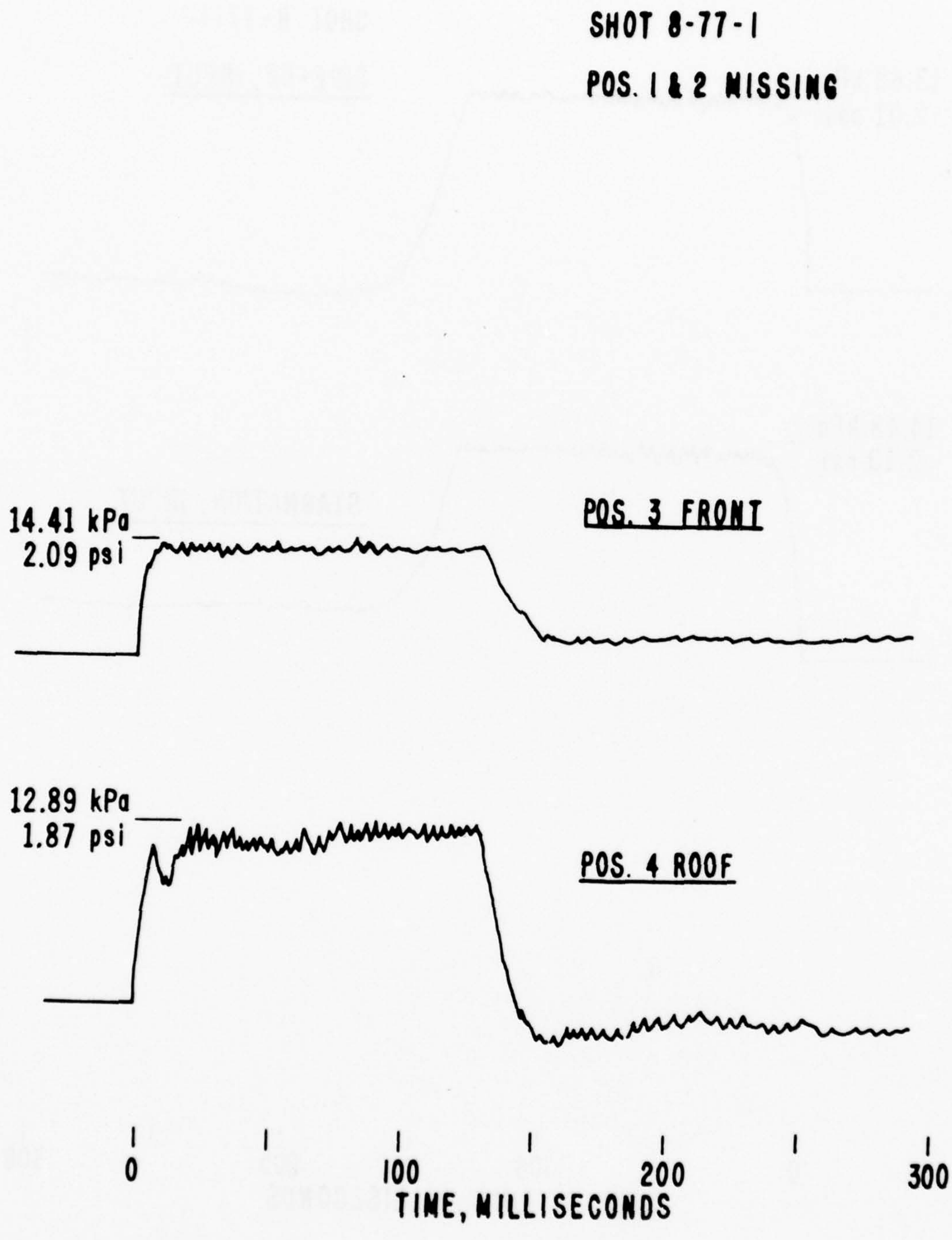


Figure 9. Pressure-Time Traces for Shot 8-77-1 (Continued)

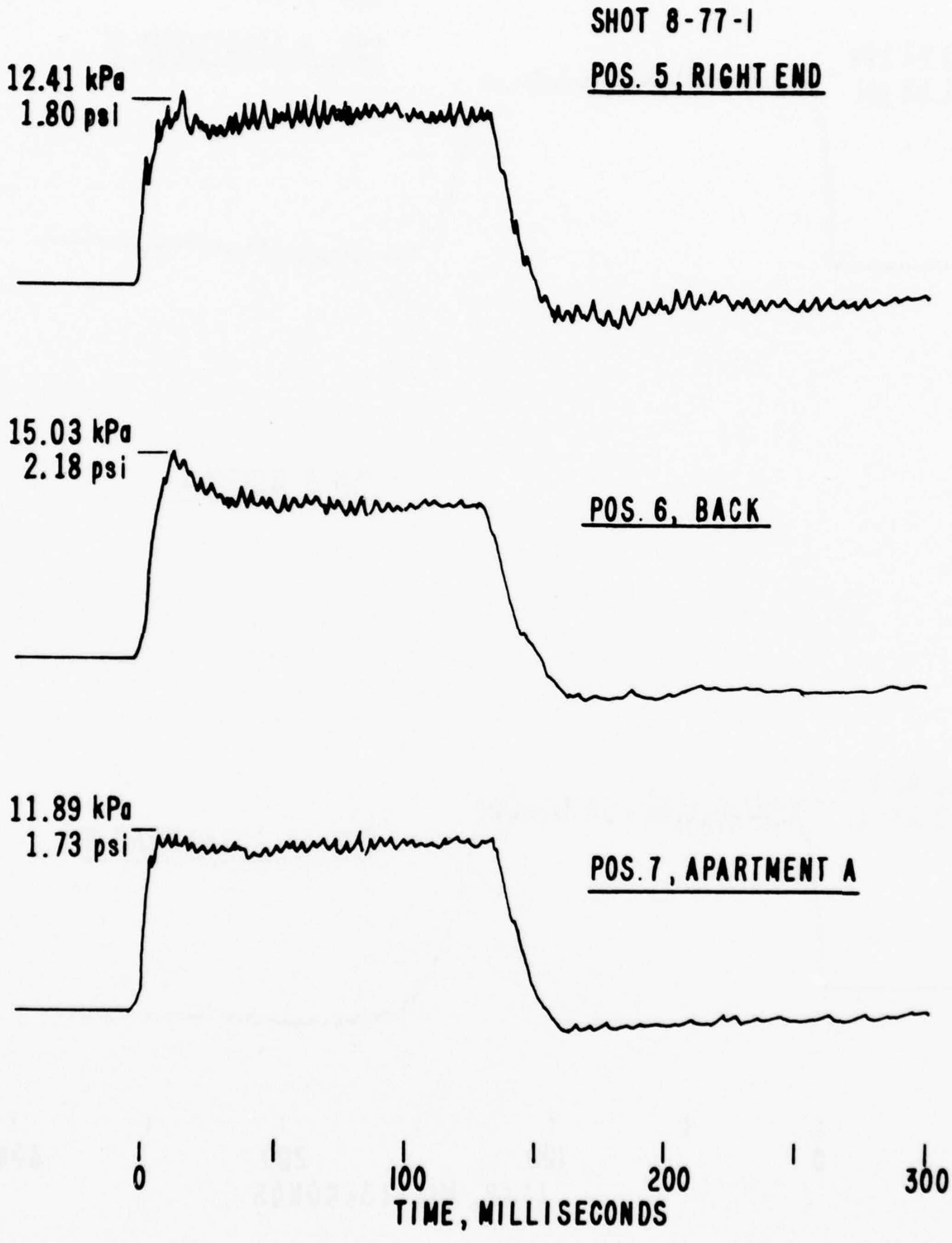


Figure 9. Pressure-Time Traces for Shot 8-77-1 (Continued)

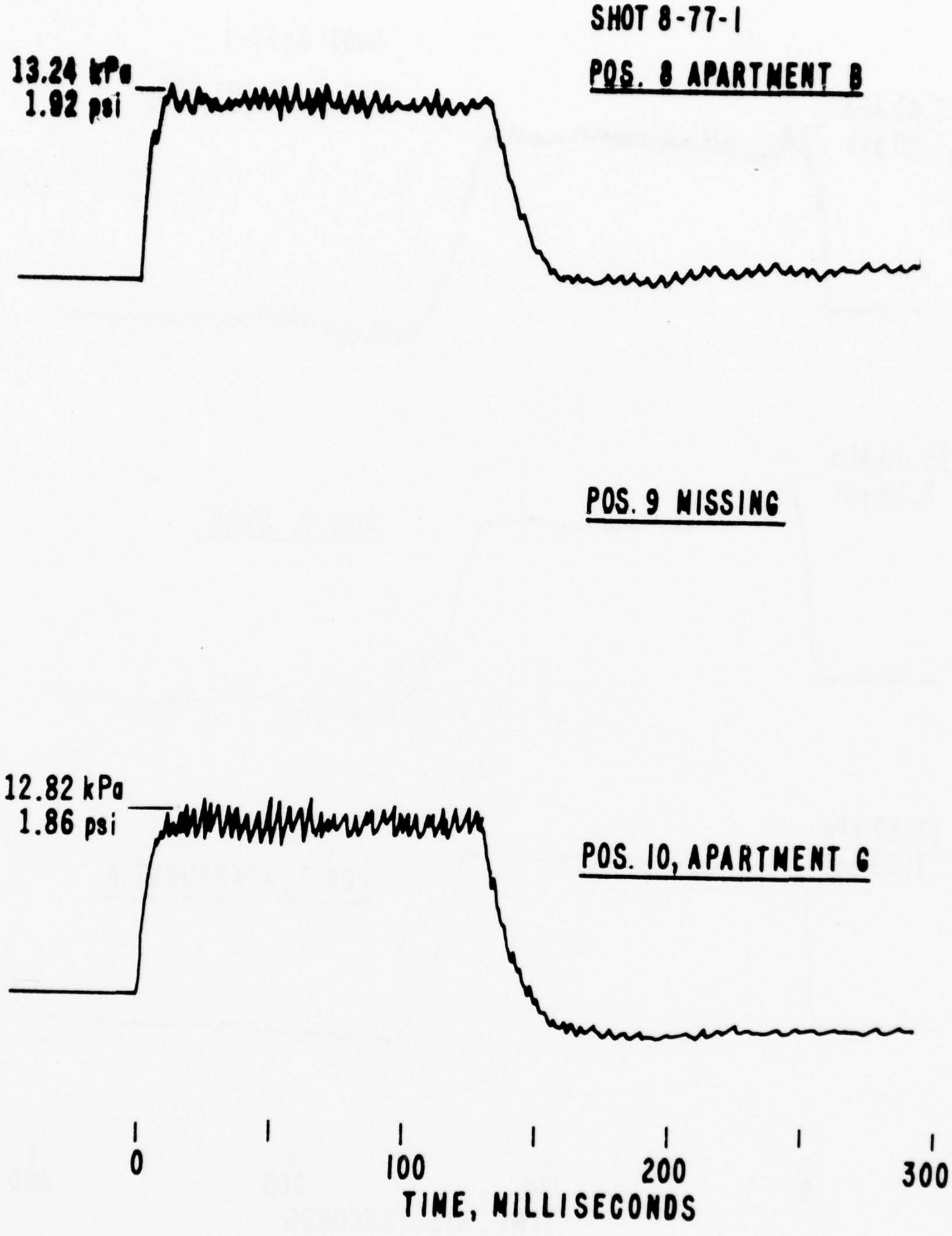
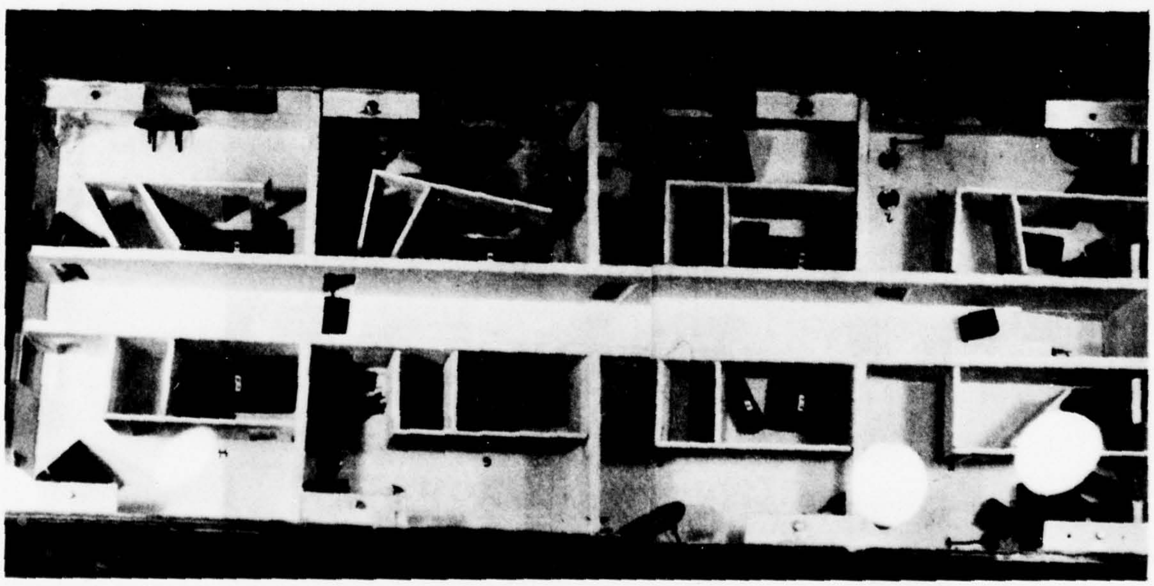


Figure 9. Pressure-Time Traces for Shot 8-77-1 (Continued)

BACK

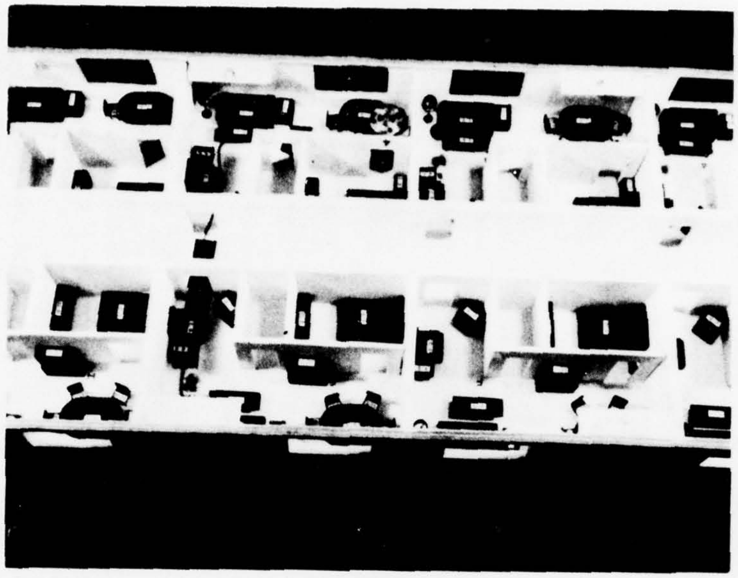
(A) Pre-Shot



BACK

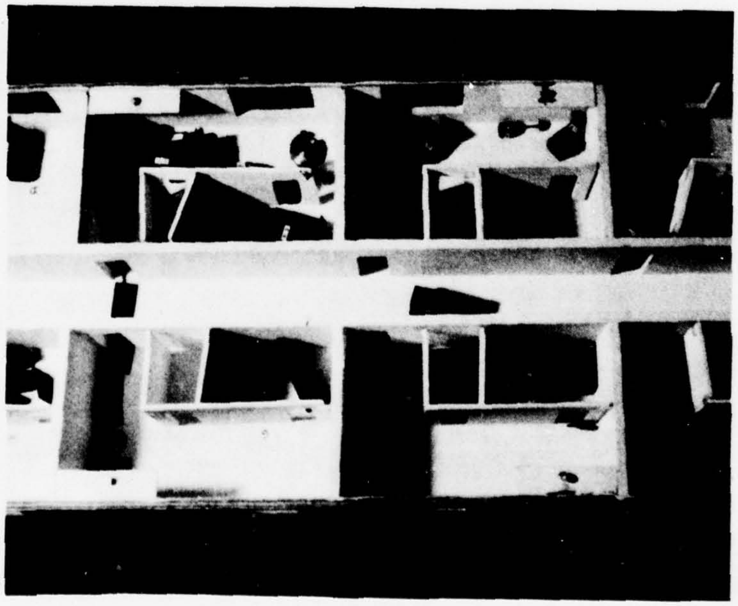
(B) Post-Shot

Figure 10. Furniture Arrangement - Shot 8-77-2, P_S = 7.79 kPa



BACK

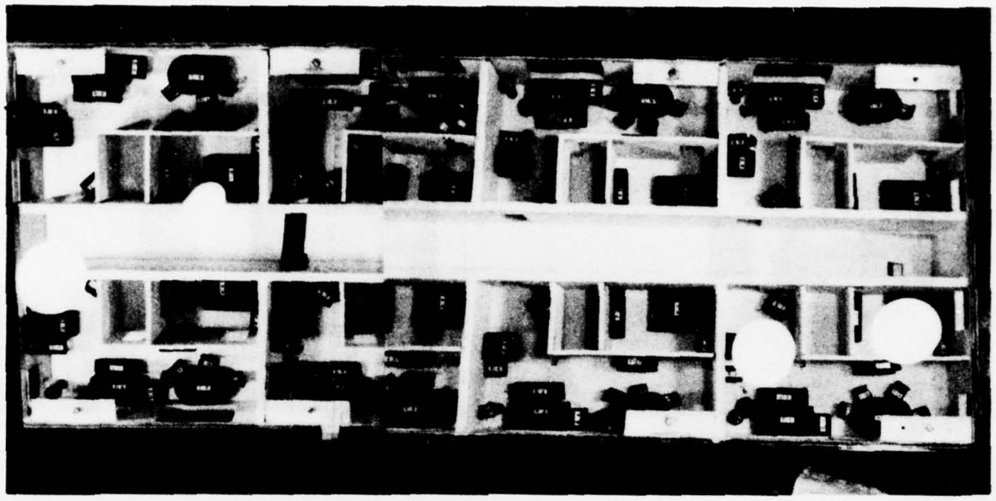
(A) Pre-Shot



BACK

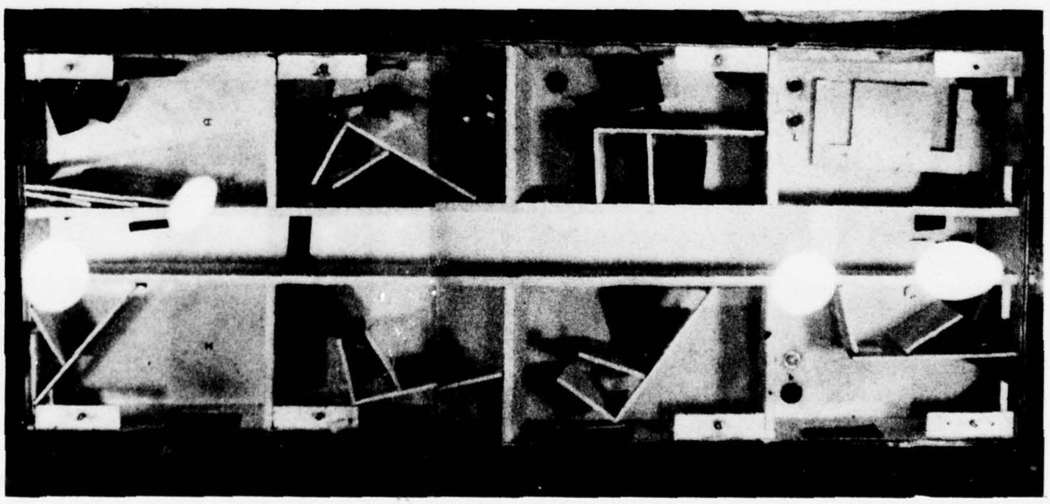
(B) Post-Shot

Figure 11. Furniture Arrangement - Shot 8-77-1, P_S = 13.86 kPa



BACK

(A) Pre-Shot



BACK

(B) Post-Shot

Figure 12. Furniture Arrangement - Shot 8-77-3, P_S = 23.65 kPa

SHOT 8-77-1

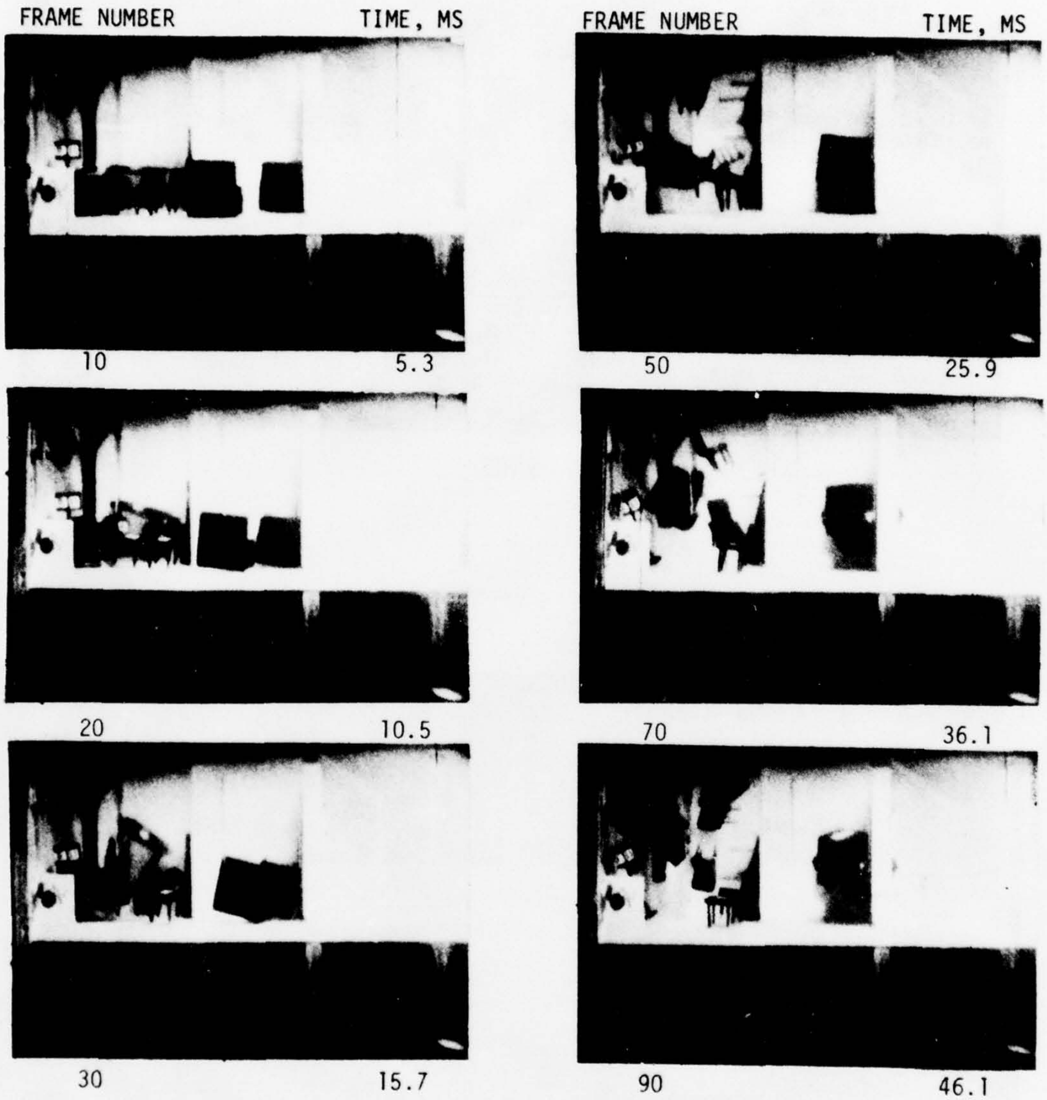


Figure 13. Apartment D for Input Pressure of 13.86 kPa

SHOT 8-77-1

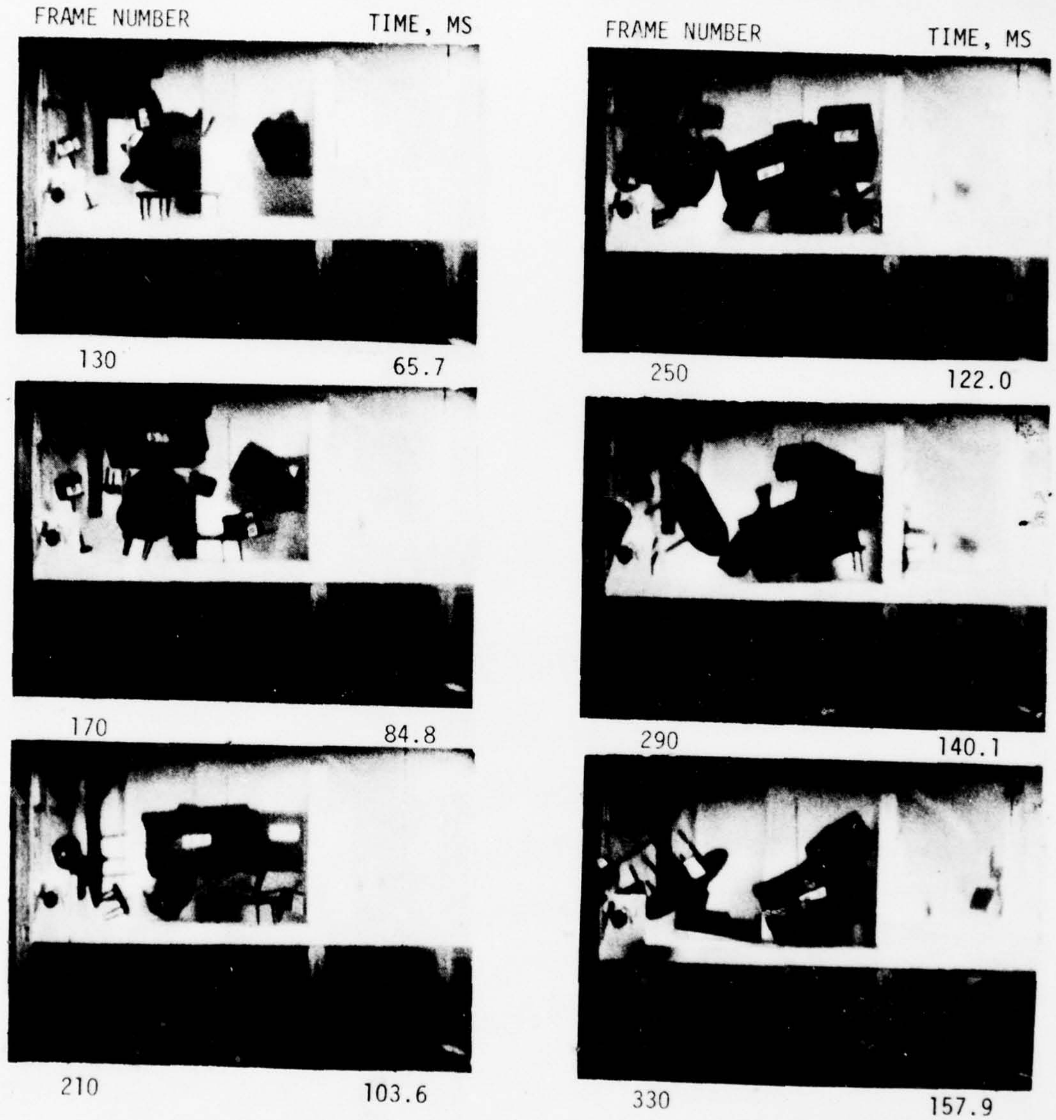


Figure 13. Apartment D for Input Pressure of 13.86 kPa (Continued)

Figure 14. Apartment G for Input Pressure of 13.86 kPa

SHOT 8-77-1

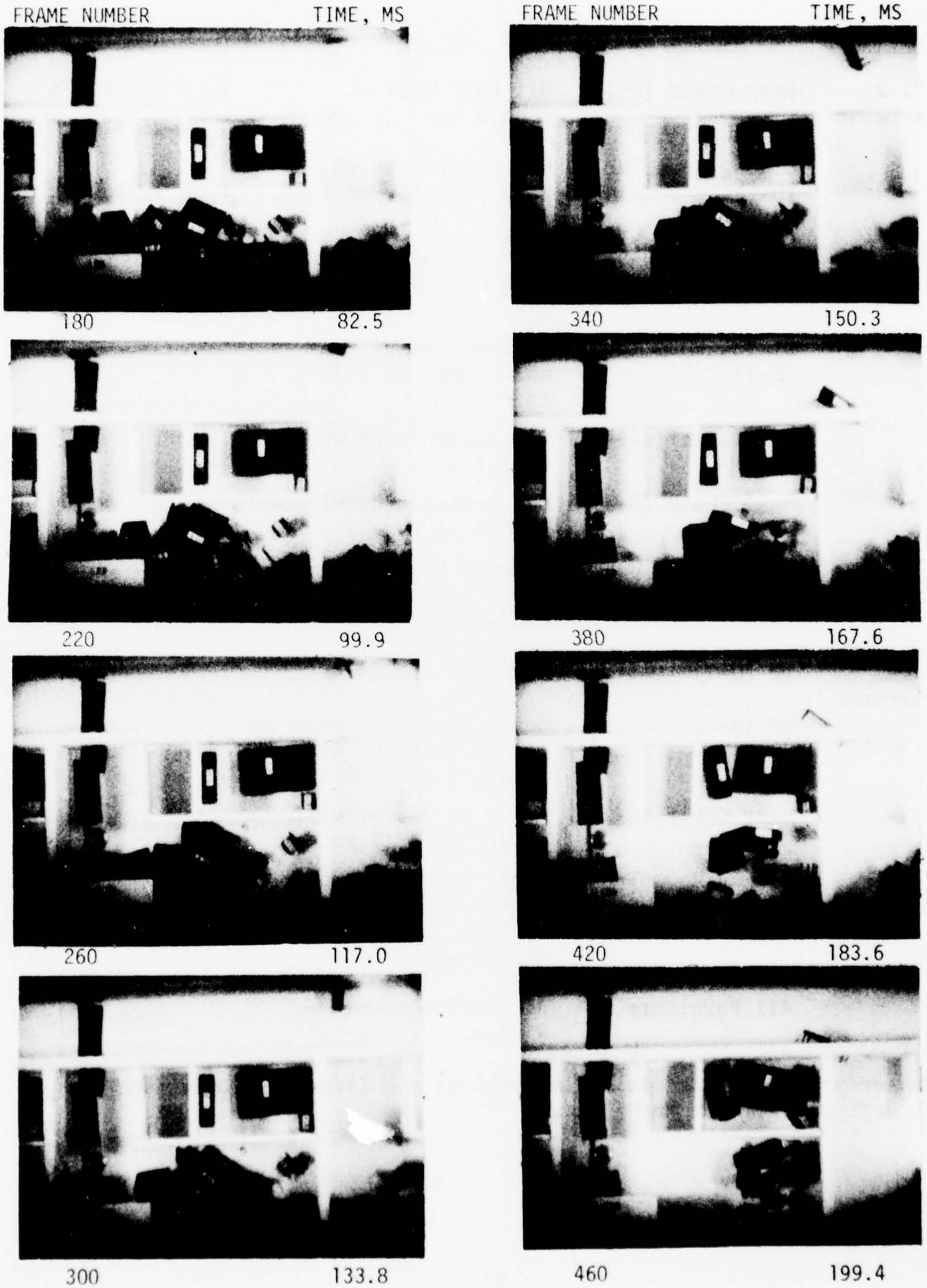


Figure 14. Apartment G for Input Pressure of 13.86 kPa (Continued)

Table I. Data for Input Pressure of 7.79 kPa

Shot Number	Object	Motion	Remarks*
8-77-2 Apartment D	Easy Chair (D-2)	Hit hall wall at 42.6 ms.	P_1 = 101.5 kPa T_1 = 25.6°C
	Dining Room Table (D-1)	Hit ceiling at 46.9 ms with velocity of 1.5 m/s.	P_S = 7.79 kPa
	End Table (D-9)	Hit ceiling at 91 ms with velocity of 0.79 m/s.	
	Dining Room Table (D-1)	Rotated toward rear about edge at 173 rad/sec.	
	End Table (D-9)	Hit second side window at 163 ms.	
	Easy Chair (D-2)	Out second side window at 224 ms.	
	Dining Room Chair	Rotated toward rear about length at 264 rad/sec.	
8-77-2 Apartment G	TV (G-7)	Moved by 4.3 ms.	
	TV (G-7)	Moved to end of wall corner at 42 ms with velocity of 0.96 m/s.	
	Easy Chair (G-2)	Moved to end of wall corner by 42.1 ms.	
	Dining Room Table (G-1)	Began to exit through first side window at 44.2 ms; completes exit at 119 ms.	
	All Furniture	All motion toward window.	

**Subscript (1) is used to define ambient conditions and subscript (S) to define the shock front value.*

Table II. Data for Input Pressure of 13.86 kPa

Shot Number	Object	Motion	Remarks
8-77-1 Apartment D	Easy Chair (D-2)	Moved to end of hall wall by 23.9 ms.	P_1 = 102.3 kPa
	Dining Room Table (D-1)	Hit ceiling at 24.9 ms with velocity of 2.8 m/s.	T_1 = 12.8°C
	Dining Room Chair	Hit ceiling at 32.5 ms with velocity of 2.1 m/s.	P_S = 13.86 kPa
	Easy Chair (D-2)	Out first side window by 159 ms.	
	Dining Room Chair	Out second side window by 129 ms.	
	Dining Room Chair	Rotated clockwise about seat axis at 315-360 rad/s.	
	All furniture	General motion towards side windows.	
8-77-1 Apartment G	TV (G-7)	Moved in about 5 ms. Average velocity at end of 38.2 ms is 1.9 m/s.	
	Easy Chair (G-2)	Moved to end of wall corner by 16.7 ms.	
	End Table (G-6)	Moved to back wall by 42.3 ms.	
	Dining Room Table (G-1)	Out large window by 116 ms.	
	Bedroom Furniture	Mostly stayed in room.	
	All other Furniture	General motion towards windows.	

Table III. Data for Input Pressure of 23.65 kPa

Shot Number	Object	Motion	Remarks
8-77-3 Apartment D	Easy Chair (D-2)	Hits hall wall at 26.3 ms.	P_1 = 102 kPa
	Dining Room Table (D-1	Hit ceiling at 9.7 ms with velocity of 7.2 m/s.	T_1 = 30.6°C
	Dining Room Chair	Hit ceiling at 20.8 ms with velocity Of 3.3 m/s.	P_S = 23.65 kPa
	Sofa (D-3)	Hit ceiling at 41.9 ms with velocity of 1.9 m/s.	
	End Table (D-6)	Rotated toward rear at 283 rad/s.	
	TV (D-7)	Out second side window at 48 ms.	
	Dining Room Chair	Rotated at 63 rad/s.	
	Other Furniture	Jammed at first side window.	
8-77-3 Apartment G	TV (G-7)	Moved by 4.9 ms.	
	TV (G-7)	Moved to end of wall corner at 42.5 ms with velocity of 1.7 m/s.	
	TV (C-7)	Came from Apt C at 31.7 ms.	
	Dining Room Table (G-1)	Out window at 95 ms.	
	Easy Chair (G-2)	At back wall at 25.6 ms.	
	TV (G-7)	Rotates to front of room at 63 rad/s.	
	All Furniture	In motion by 11.1 ms. General motion towards window.	

Three different types of motion can be seen in the test. Some objects (TV set) loaded by the interior floor were translated across the floor of rooms. Other furniture (table) was lifted up to hit the room ceiling. In some cases (dining room chairs), a rotation occurred with the translation. The translation velocity of the TV set was found to vary from about 1 m/s for the low input pressure to about 2 m/s at the higher input pressures. Vertical velocity to ceiling for the table varied between 1.5 m/s to 7.2 m/s. Rotational velocities varied between 60 - 360 rad/s for dining room chairs and end tables.

Arrival times to each the various room positions or window openings are also listed in Tables I - III.

IV. ANALYSIS

It would be of help, from a shelter standpoint, to show what kind of decrease in translation velocity the apartment house shelter brings about compared to free field conditions. To show this, a comparison may be made by calculating a set of predicted translation velocities of objects (assuming free field conditions for the shock wave) and comparing these values to the experimentally observed velocities.

To do this, an object with a rectangular front (the scaled model TV set) will be used for the comparison. The force, F, to translate the box, neglecting friction, may be written as Equation 1. The drag pressure ($1/2\ \rho_2 V^2$) is a function of the air density, ρ_2, and relative velocity, $V = \mu_2 - v_o$, where μ_2 is the air flow velocity behind the shock wave and v_o is the object's translational velocity as a function of time.

$$F = ma = -m \frac{dV}{dt} = 1/2\ C_D A\ \rho_2\ V^2, \tag{1}$$

where C_D is the coefficient of drag (neglecting friction), A is the frontal area of the objective with a mass, m, μ_2, is the air density of the shock wave, and V_o, is the relative velocity. Rewriting Equation 1 in the form of Equation 2, where $K = \frac{C_D A\ \rho_2}{2m}$;

$$-\int_{\mu_2}^{V} \frac{dV}{V^2} = K \int_{o}^{t} dt. \tag{2}$$

Then integrating over the given limits and rearranging of terms results in Equation 3 from which the object's translational velocity may be calculated:

$$v_o = \mu_2 \left(1 - \frac{1}{1 + \mu_2 Kt}\right). \tag{3}$$

Some representative values of translational velocities have been calculated for a scaled model TV set over the input pressure range 6.8 - 24.1 kPa. Flow parameters μ_2 and ρ_2 were taken from Reference 2. The value for C_D was taken as 1.2 (Reference 3), A = 6.9 cm^2, m = 1.61 g, and t = 0.40 s. The translational velocities calculated for these values are listed in Table IV.

Table IV. Calculations for Free Field Translational Velocities

Input Pressure		Translational Velocity	
kPa	psi	m/s	ft/s
6.8	1.0	2.82	9.2
10.3	1.5	5.80	19.0
13.7	2.0	9.49	31.1
17.2	2.5	13.6	44.6
20.6	3.0	18.3	60.0
24.1	3.5	23.0	75.4

After taking into account the fact that the calculations give translational velocity after the time, t, and the measurements listed in the data in Tables I - III are average velocities comparable to values of $v_o/2$ instead of v_o, the apartment house model results show values of translational velocity perhaps 0.7 of the calculated free-field values for the lowest pressure to about 0.15 for the highest pressure shown.

V. SUMMARY AND CONCLUSIONS

This section summarizes the experiment with the results obtained and discusses the application to the full size shelter.

A. Summary of the Experimental Results

A 1/30th scale model of a five story apartment house shelter was exposed in the BRL 2.4 metre shock tube to shock waves of 7.79, 13.86, and 23.65 kPa overpressure levels. Exposure to the shock waves caused

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[2] *Joseph F. Melichar, "The Propagation of Blast Waves into Chambers," Ballistic Research Laboratories Memorandum Report No. 1920, March 1968, AD 672476.*

[3] *S. F. Hoerner, "Fluid-Dynamic Drag," 148 Busteed Drive, Midland Park, New Jersey 07432, published by author, 1965.*

internal air flows sufficient to set in motion the model furniture within the apartment rooms. In some instances, objects were even blown out of the apartment windows.

Average horizontal translational velocities (TV set) across the room were found to be in the 1 - 2 m/s range. Vertical motion (Dining Room Table) with average velocities of 1.5 - 7.2 m/s were measured to the ceiling. This vertical motion was sometimes accompanied as well by rotational velocities.

A mass movement of objects toward the apartment windows was observed generally for all objects. The bedrooms of the apartments seemed to be an exception and contained after the shots the majority of the furniture there before the shots. Least motion of all occurred in the bedroom as expected because of the small entrance and the more complicated path the blast wave had to follow.

B. Translation Predictions for Full Size Objects

The model data obtained may be used to predict the translational velocity of full size objects of furniture for the apartment house shelter by use of Equation 3. The linear dimensions of the model objects are multiplied by the scale factor of 30 as are the measured translation times. Table V lists the predicted impact velocities (twice average values from experiment) and times for a few objects of furniture.

Values of rotational velocities for full size objects listed in Table V were obtained in the following way. The rotational forces on the full size objects were assumed to act for a time equal to the model time multiplied by the scale factor of 30. Since (according to the references listed in the footnote to Table V) the rotational velocities vary according to $1/(\text{scale factor})^2$, the increased time accounts for only one value of scale factor. The experimental values of rotational velocities for the model are divided by the scale factor of 30 in order to give the predicted values of rotational velocity for the full size objects as listed in Tables V.

ACKNOWLEDGMENTS

The author wishes to thank Messrs. Robert Peterson, Kenneth Holbrook, and Rodney Abrahams for the experimental work performed at the BRL 2.4 metre shock tube.

Table V. Predictions for Full Size Objects - Apartments A and G Combined

Input Pressure kPa	Objects	Impact Time s	Impact Velocity* m/s	Weight kg	Rotational Velocity rad/s
7.8	Dining Room Chair	-	-	12.15	8.8
	End Table	2.73	Ceiling 1.6	45.1	-
	Dining Room Table	1.40	Ceiling 3.0	70.2	5.8
	TV Set	1.26	End of Wall 1.9	45.4	-
13.9	Dining Room Chair	0.97	Ceiling 4.2	12.15	10.5-12
	Dining Room Table	0.74	Ceiling 5.6	70.2	-
	TV Set	1.14	End of Wall 3.8	45.4	-
23.7	Dining Room Chair	-	-	12.15	2.1
	Dining Room Table	0.29	Ceiling 14.4	70.2	-
	End Table	-	-	45.1	9.4
	TV Set	1.27	End of Wall 3.4	45.4	-

*A description of scaling may be found in Suffield Technical Paper No. 132, "The Use of Models in the Study of the Blast Effects of Simulated Nuclear Weapons," by G.H.S. Jones, 25 April 1958 and Explosions in Air, W. E. Baker, University of Texas Press, Austin, Texas, 1973.

APPENDIX A

TABLES FOR FURNITURE PARAMETERS

Table A-1. Code for Model Furniture

Item	Weight, g	Item	Weight, g	Item	Weight, g
Dining Room Table		Easy Chair		Sofa	
A-1	2.58	A-2	3.25	A-3	4.50
B-1	2.36	B-2	3.24	B-3	4.52
C-1	2.52	C-2	2.98	C-3	4.45
D-1	2.61	D-2	3.17	D-3	4.37
E-1	2.21	E-2	2.95	E-3	4.76
F-1	2.44	F-2	3.01	F-3	5.06
G-1	2.64	G-2	3.17	G-3	4.89
H-1	2.66	H-2	2.98	H-3	4.37
Bed		Coffee Table		End Table	
A-4	5.83	A-5	1.97	A-6	0.83
B-4	5.75	B-5	1.66	B-6	0.82
C-4	5.77	C-5	1.67	C-6	0.83
D-4	5.86	D-5	1.93	D-6	0.83
E-4	5.83	E-5	1.58	E-6	0.83
F-4	5.80	F-5	1.92	F-6	0.81
G-4	5.98	G-5	1.95	G-6	0.87
H-4	5.88	H-5	1.64	H-6	0.77
TV		Night Stand		Solid End Table	
A-7	1.61	A-8	0.51	A-9	1.60
B-7	1.59	B-8	0.51	B-9	1.65
C-7	1.60	C-8	0.48	C-9	1.60
D-7	1.59	D-8	0.49	D-9	1.67
E-7	1.58	E-8	0.49	E-9	1.67
F-7	1.62	F-8	0.50	F-9	1.60
G-7	1.61	G-8	0.49	G-9	1.62
H-7	1.60	H-8	0.50	H-9	1.64
Dresser		Floor Lamp		Straight Chair	
A-10	2.53	A-11	2.24	A-13	0.50
B-10	2.33	B-11	2.29	B-13	0.47
C-10	2.49	C-11	2.28	C-13	0.46
D-10	2.57	D-11	2.32	D-13	0.41
E-10	2.63	E-11	2.30	E-13	0.46
F-10	2.82	F-11	2.53	F-13	0.48
G-10	2.49	G-11	2.25	G-13	0.44
H-10	2.43	H-11	2.22	H-13	0.48
Straight Chair		Straight Chair		Straight Chair	
A-14	0.46	A-15	0.43	A-16	0.48
B-14	0.47	B-15	0.45	B-16	0.49
C-14	0.52	C-15	0.43	C-16	0.43
D-14	0.45	D-15	0.49	D-16	0.48
E-14	0.48	E-15	0.46	E-16	0.46
F-14	0.46	F-15	0.46	F-16	0.45
G-14	0.46	G-15	0.45	G-16	0.46
H-14	0.49	H-15	0.47	H-16	0.50

Table A-I. (Cont'd) Code for Model Furniture

Item	Weight, g
Hutch	
A-17	3.56
B-17	3.63
C-17	3.73
D-17	3.48
E-17	3.85
F-17	3.45
G-17	3.69
H-17	3,59

Table A-II. Location of Model Furniture after Shot 8-77-2, P_S = 7.79 kPa

Upstream from Front Wall of Model Apartment		Downstream from Back Wall of Model Apartment	
Item	Distance, m	Item	Distance, m
Dining Room Table		Dining Room Table	
G-1	1.34	B-1	1.55
		H-1	1.54
Easy Chair		Easy Chair	
G-2	3.68	A-2	1.75
H-2	2.66	D-2	11.94
		F-2	5.74
Sofa		Sofa	
B-3	1.62	D-3	6.26
G-3	3.84	F-3	3.90
H-3	5.79		
Coffee Table		Coffee Table	
G-5	8.61	B-5	5.13
		D-5	3.49
		F-5	5.18
End Table		End Table	
A-6	7.25	D-6	5.72
H-6	1.72	E-6	4.00
		F-6	4.22
TV		TV	
G-7	5.82	B-7	7.20
H-7	5.03	C-7	5.60
		D-7	4.96
		F-7	3.20
End Table		Solid End Table	
G-9	4.48	D-9	7.88
		F-9	3.14
		H-9	2.08
Floor Lamp		Straight Chairs	
F-11	6.54	C-13	5.96
		D-14	7.75
		C-15	4.88
		G-16	3.06
		H-16	8.18
Straight Chair			
D-13	2.81		
E-13	3.11		
H-13	4.41		
G-13	5.59		
G-14	0.76		
C-16	4.28		
Hutch			
F-17	9.63		
G-17	9.61		

NOTES: 1. None went out of shock tube.

2. Remainder was inside of model as shown in photographs.

Table A-III. Location of Model Furniture After Shot 8-77-1, P_S = 13.86 kPa

Upstream from From Wall of Model Apartment

Item	Distance, m
Dining Room Table	
C-1	10.18
Easy Chair	
A-2	3.04
F-2	3.06
Sofa	
H-3	7.68
Coffee Table	
A-5	0.88
B-5	2.58
G-5	4.22
H-5	10.84
End Table	
H-6	2.24
TV	
B-7	0.44
E-7	3.74
H-7	15.24
Night Stand	
C-8	7.74
D-8	13.99
E-8	11.54
Solid End Table	
E-9	0.38
H-9	3.41
Dresser	
A-10	10.81
Floor Lamp	
A-11	4.46
E-11 (Shade)	4.62
Straight Chairs	
B-13	1.96
E-13	3.24
E-14	0.94
H-14	2.81
E-15	8.54
G-15	2.36
D-16	7.88
G-16	2.30
Hutch	
G-17	4.18

Downstream from Back Wall of Model Apartment

Item	Distance, m
Dining Room Table	
A-1	33.4
B-1	2.34
F-1	4.98
G-1	3.89
Easy Chair	
C-2	6.52
D-2	45.5
E-2	4.68
G-2	3.86
Sofa	
F-3	5.60
G-3	10.17
Coffee Table	
E-5	9.41
F-5	10.17
End Table	
C-6	5.12
D-6	5.69
E-6	7.32
F-6	8.42
G-6	6.50
TV	
C-7	8.56
F-7	1.64
G-7	5.64
Solid End Table	
G-9	7.60
Floor Lamp	
D-11 (Shade)	40.0
E-11	13.0
F-11	11.5
Straight Chairs	
A-13	37.5
F-13	1.82
H-13	5.32
G-13	43.6
F-14	4.06
G-14	14.5
B-16	1.94
Hutch	
A-17	7.48
B-17	2.45

Table A-IV. Location of Model Furniture After Shot 8-77-3, P_S = 23.65 kPa

Upstream from Front Wall of Model Apartment

Item	Distance, m
Easy Chair	
B-2	14.2
D-2	10.2
H-2	13.4
Sofa	
C-3	8.34
End Table	
F-6	2.10
TV	
A-7	10.1
Night Stand	
A-8	1.63
E-8	3.78
Solid End Table	
B-9	0.22
E-9	0.62
G-9	6.32
Dresser	
H-10	3.72
Floor Lamp	
A-11	2.61
Straight Chair	
B-15	11.51

Downstream from Back Wall of Model Apartment

Item	Distance, m
Dining Room Table	
C-1	1.85
F-1	51.1
H-1	54.0
Easy Chair	
A-2	3.50
C-2	10.8
E-2	61.1
F-2	67.8
G-2	57.6
Sofa	
B-3	13.4
D-3	13.6
E-3	138.6
F-3	76.5
G-3	57.0
H-3	44.8
Bed	
H-4	13.0
Coffee Table	
A-5	51.6
D-5	2.67
E-5	64.6
F-5	132.6
G-5	25.2
H-5	21.6
End Table	
A-6	3.77
C-6	6.27
D-6	64.4
E-6	52.4
G-6	14.9
H-6	61.9
TV	
C-7	8.64
D-7	55.7
E-7	4.78
F-7	76.5
G-7	35.4
H-7	26.9
Night Stand	
F-8	2.23
G-8	1.99
H-8	4.76

Item	Distance, m
Solid End Table	
A-9	3.01
D-9	65.0
F-9	64.4
H-9	54.0
Dresser	
A-10	4.70
F-10	3.22
Floor Lamp	
E-11	10.4
F-11	23.4
G-11	9.72
H-11	9.92
Straight Chair	
A-13	52.1
E-13	36.8
F-13	38.1
G-13	52.1
H-13	56.2
A-14	52.4
D-14	2.54
F-14	50.1
G-14	63.8
H-14	39.6
C-15	7.90
E-15	9.12
G-15	57.3
H-15	56.2
A-16	61.8
C-16	3.90
D-16	6.24
F-16	56.7
G-16	60.5
Hutch	
F-17	37.0
G-17	27.2
H-17	64.5

APPENDIX B

PRESSURE-TIME TRACES

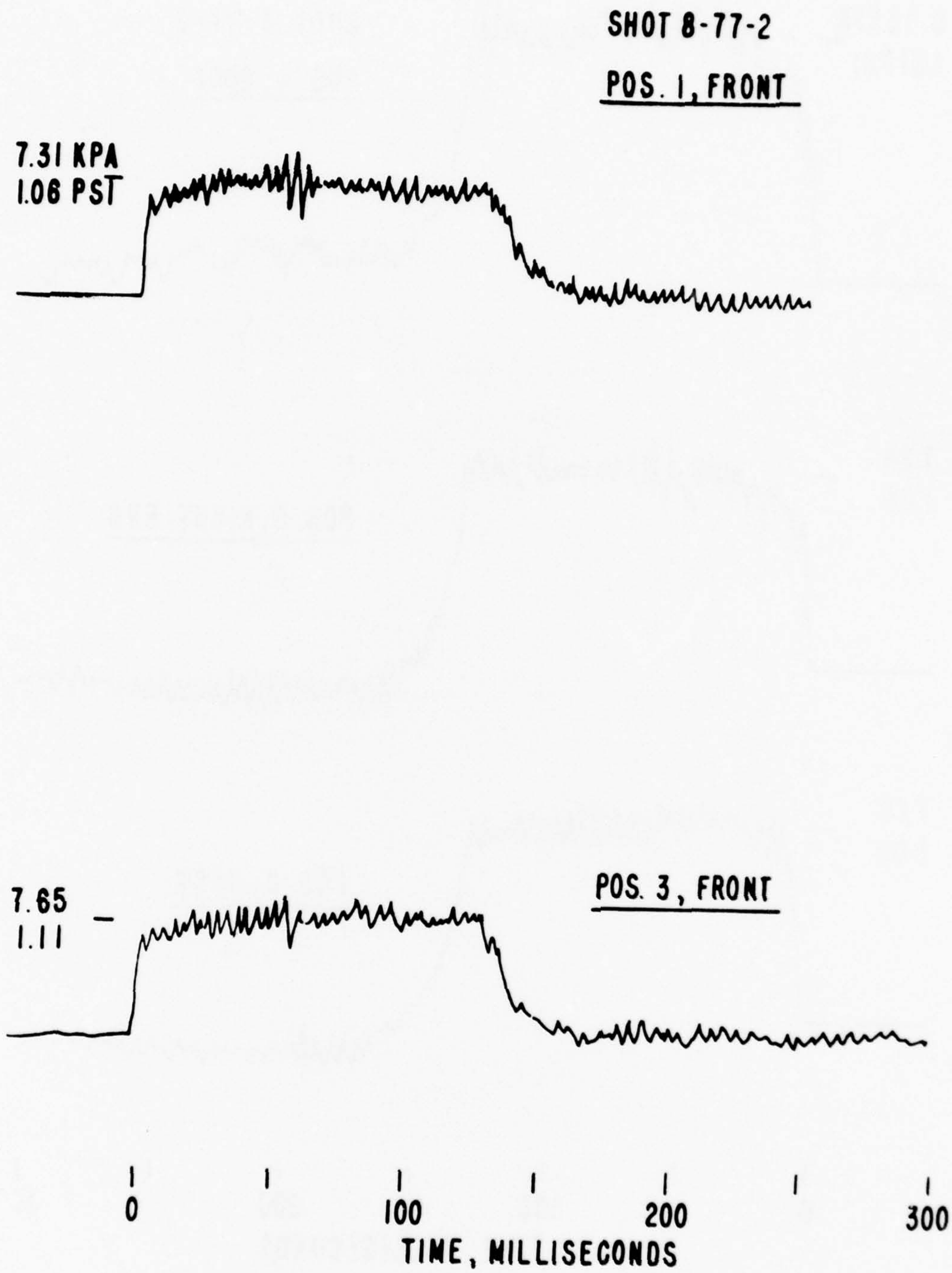


Figure B-1. Pressure-Time Traces for Shot 8-77-2

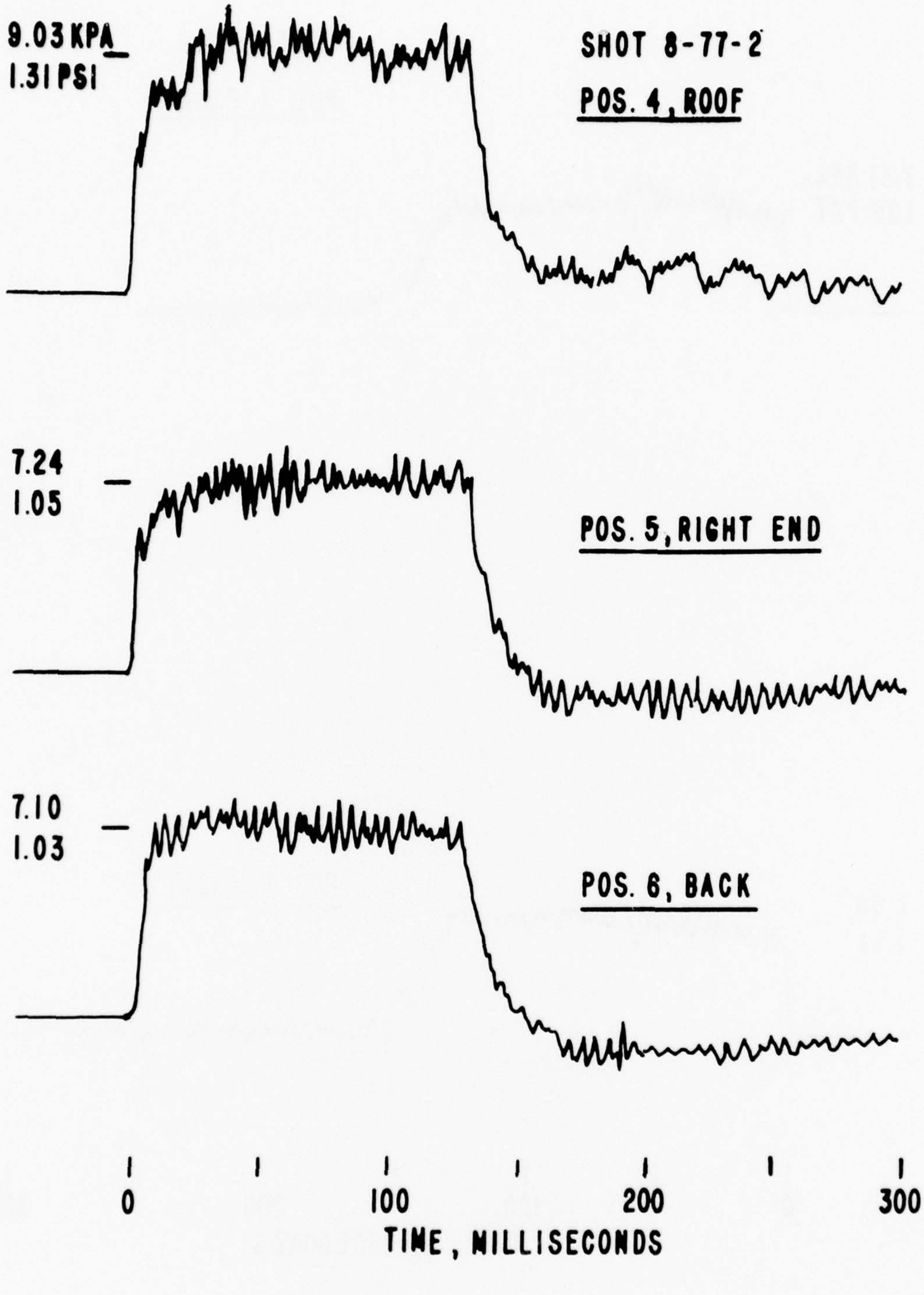


Figure B-1. Pressure-Time Traces for Shot 8-77-2 (Continued)

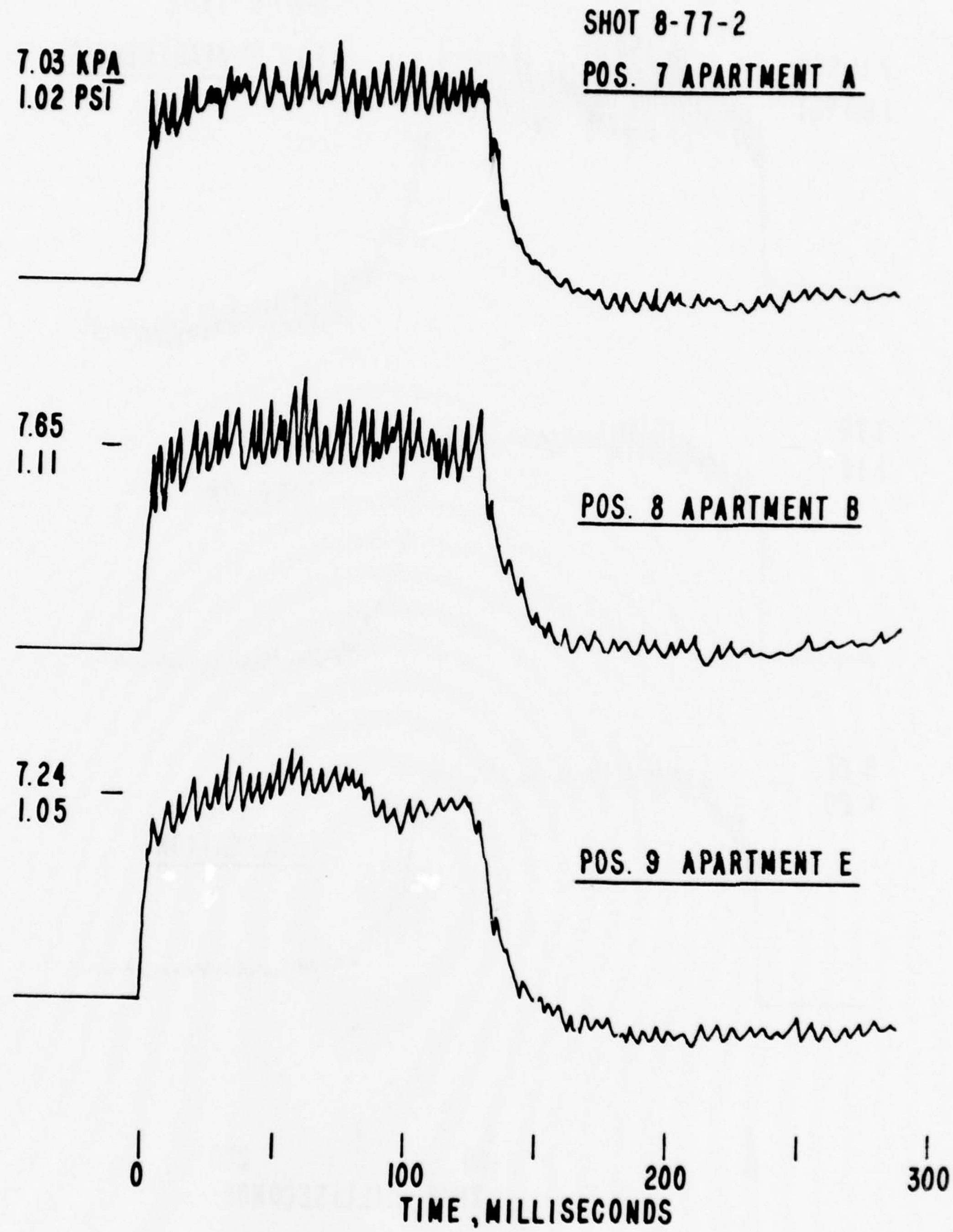


Figure B-1. Pressure-Time Traces for Shot 8-77-2 (Continued)

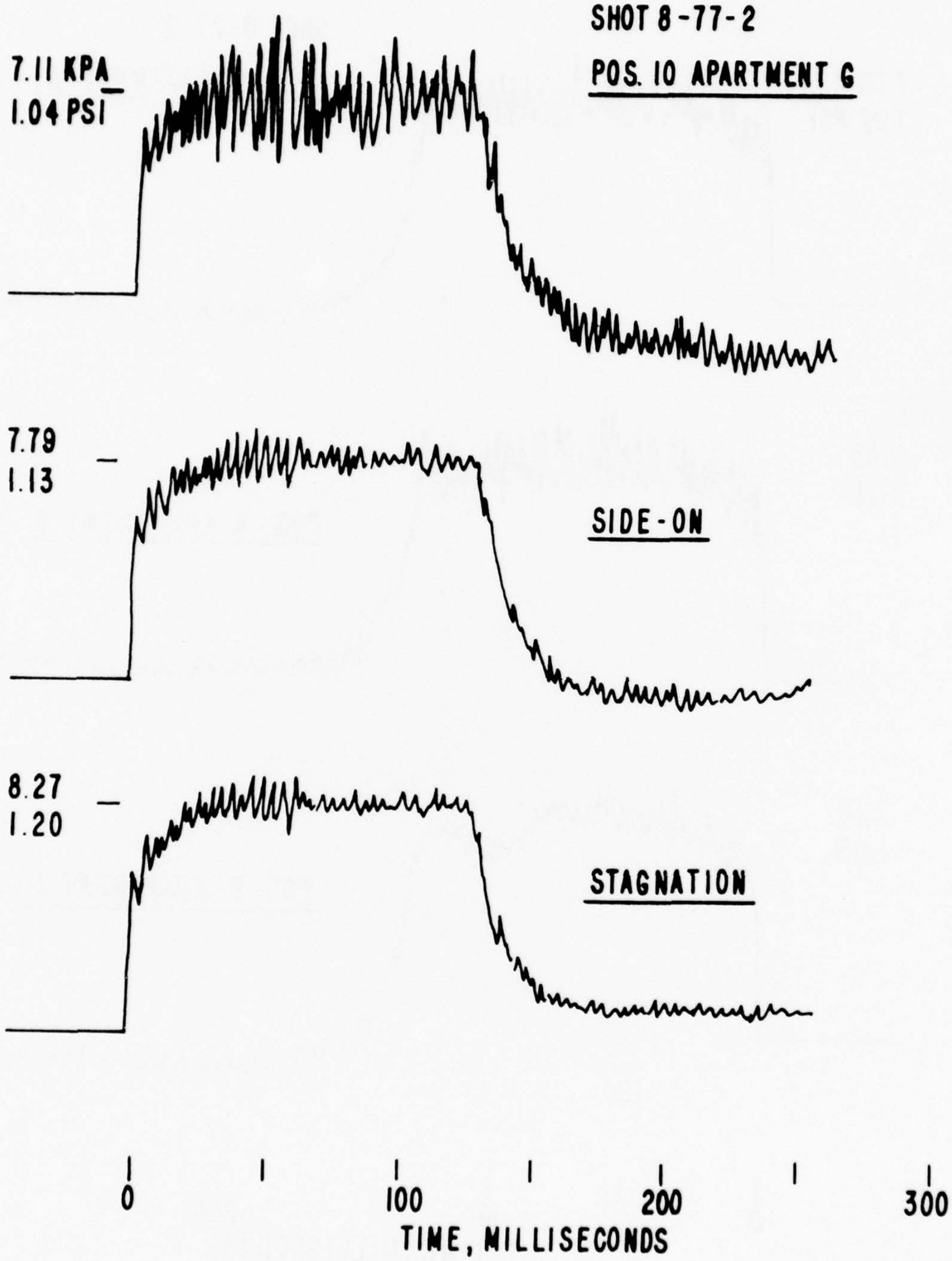


Figure B-1. Pressure-Time Traces for Shot 8-77-2 (Continued)

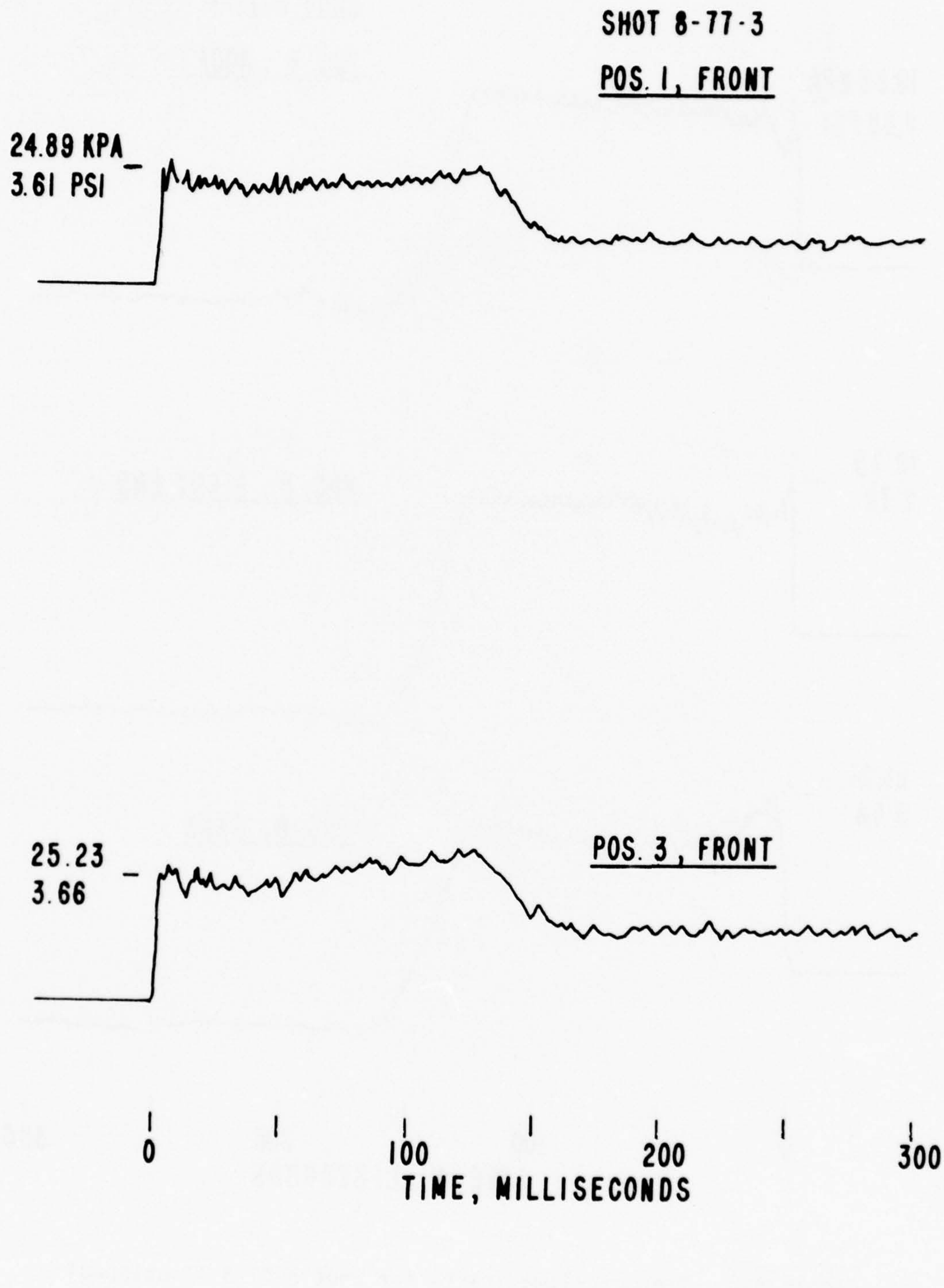


Figure B-2. Pressure-Time Traces for Shot 8-77-3

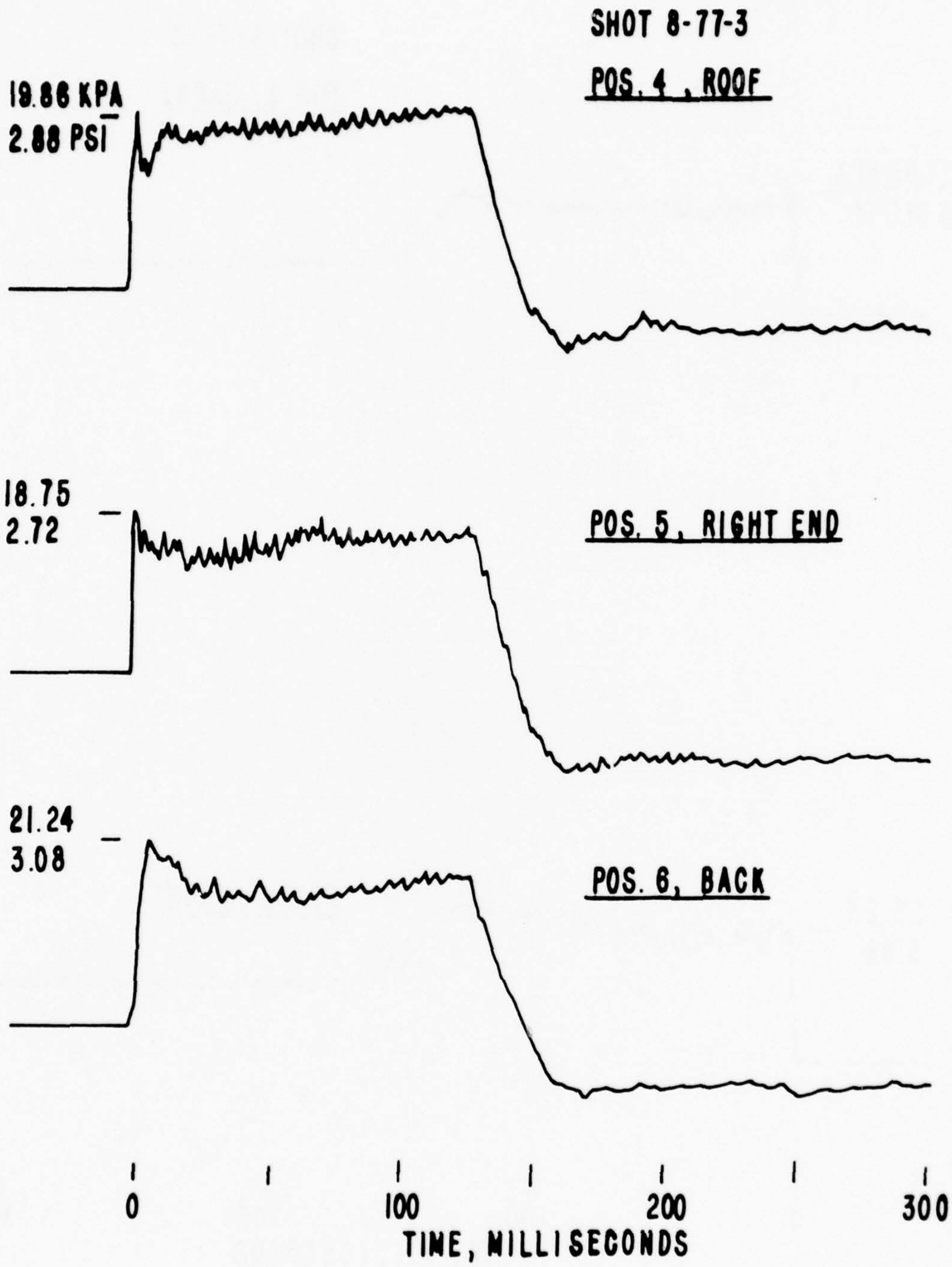


Figure B-2. Pressure-Time Traces for Shot 8-77-3 (Continued)

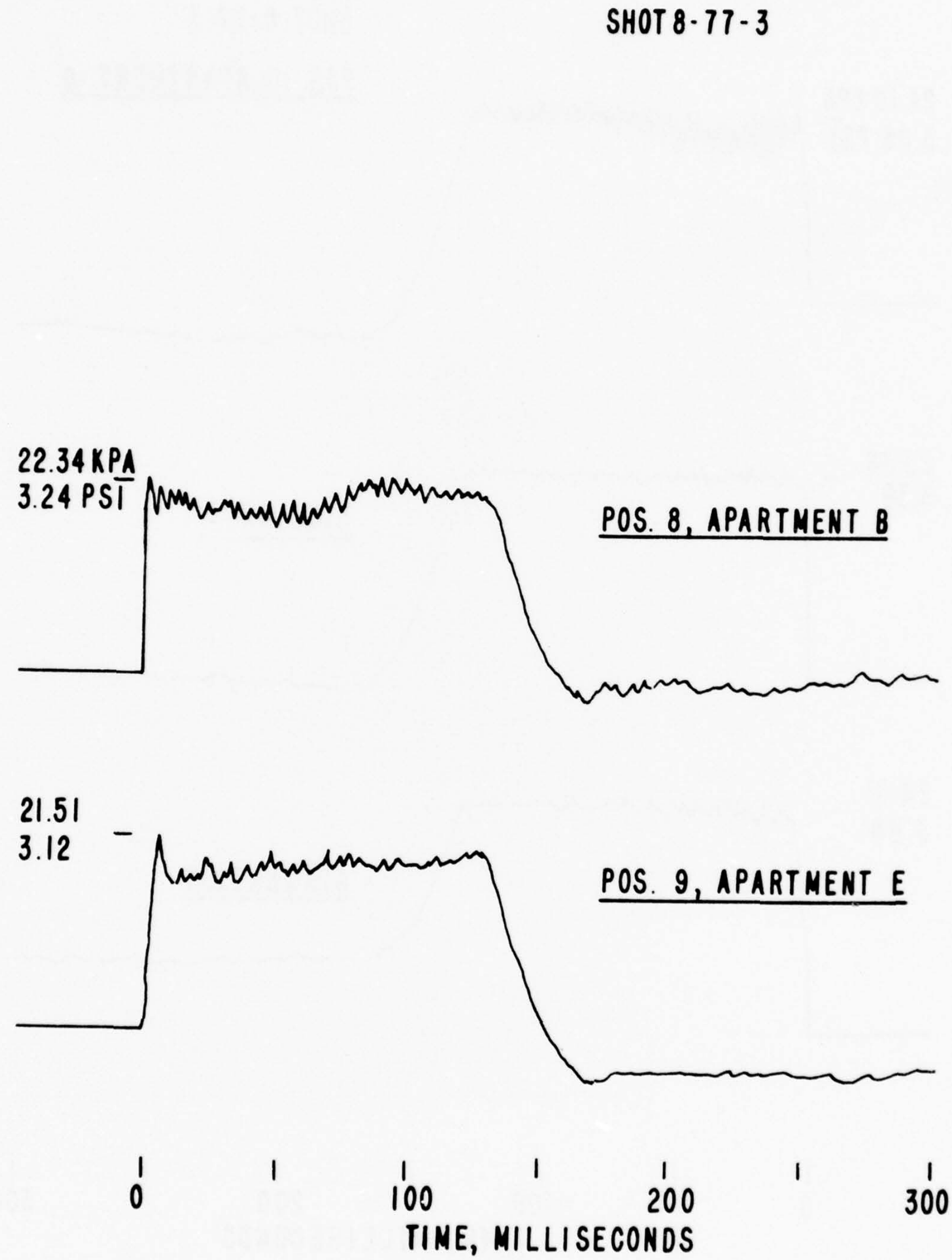


Figure B-2. Pressure-Time Traces for Shot 8-77-3 (Continued)

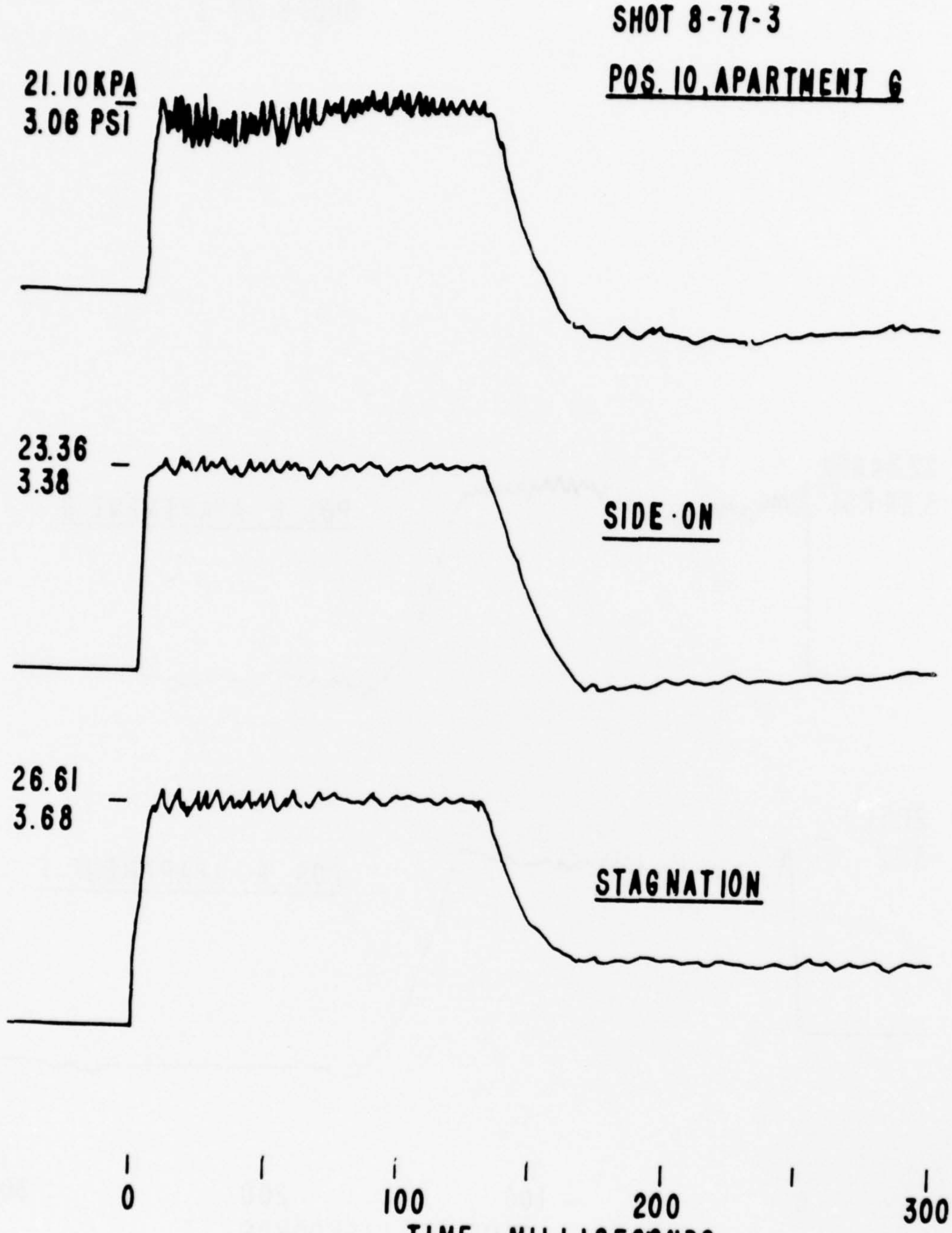


Figure B-2. Pressure-Time Traces for Shot 8-77-3 (Continued)

APPENDIX C

HIGH SPEED PHOTOGRAPHS

SHOT 8-77-2

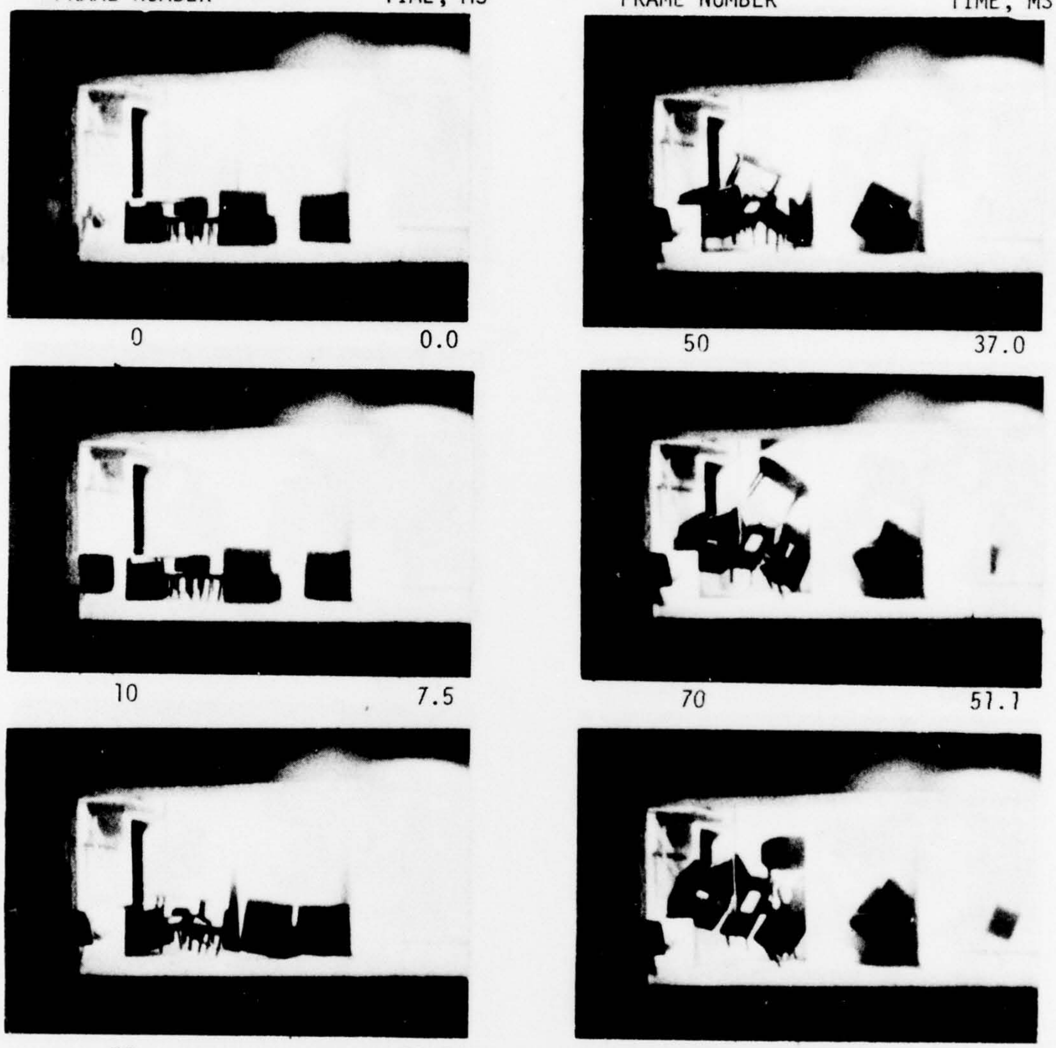


Figure C-1. Apartment D for Input Pressure of 7.79 kPa

SHOT 8-77-2

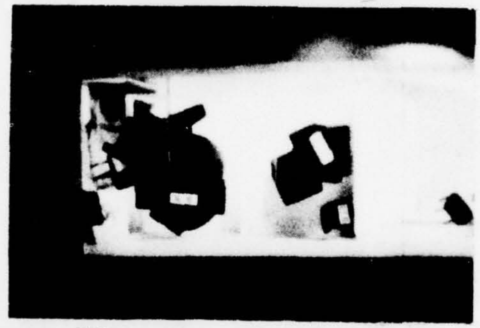
FRAME NUMBER	TIME, MS	FRAME NUMBER	TIME, MS

110 78.5

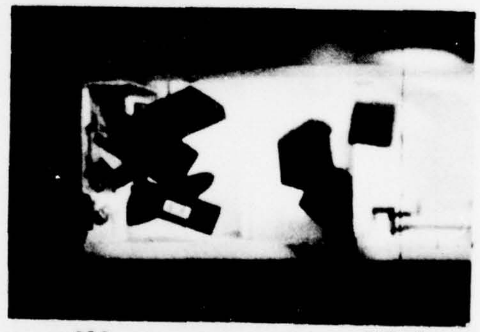
150 104.8

190 130.0

230 154.5



270 178.1



310 201.1

Figure C-1. Apartment D for Input Pressure of 7.79 kPa (Continued)

SHOT 8-77-2

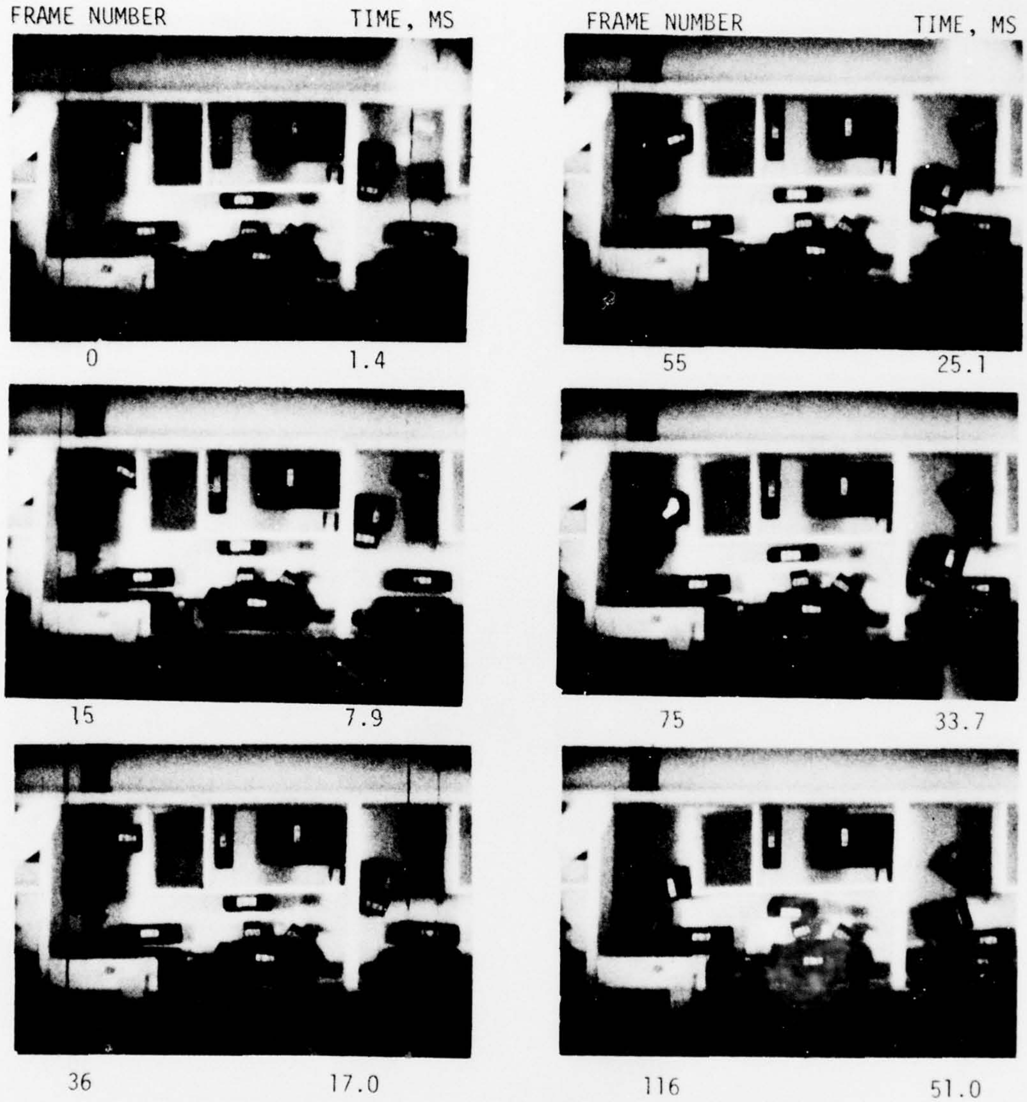


Figure C-2. Apartment G for Input Pressure of 7.79 kPa

SHOT 8-77-2

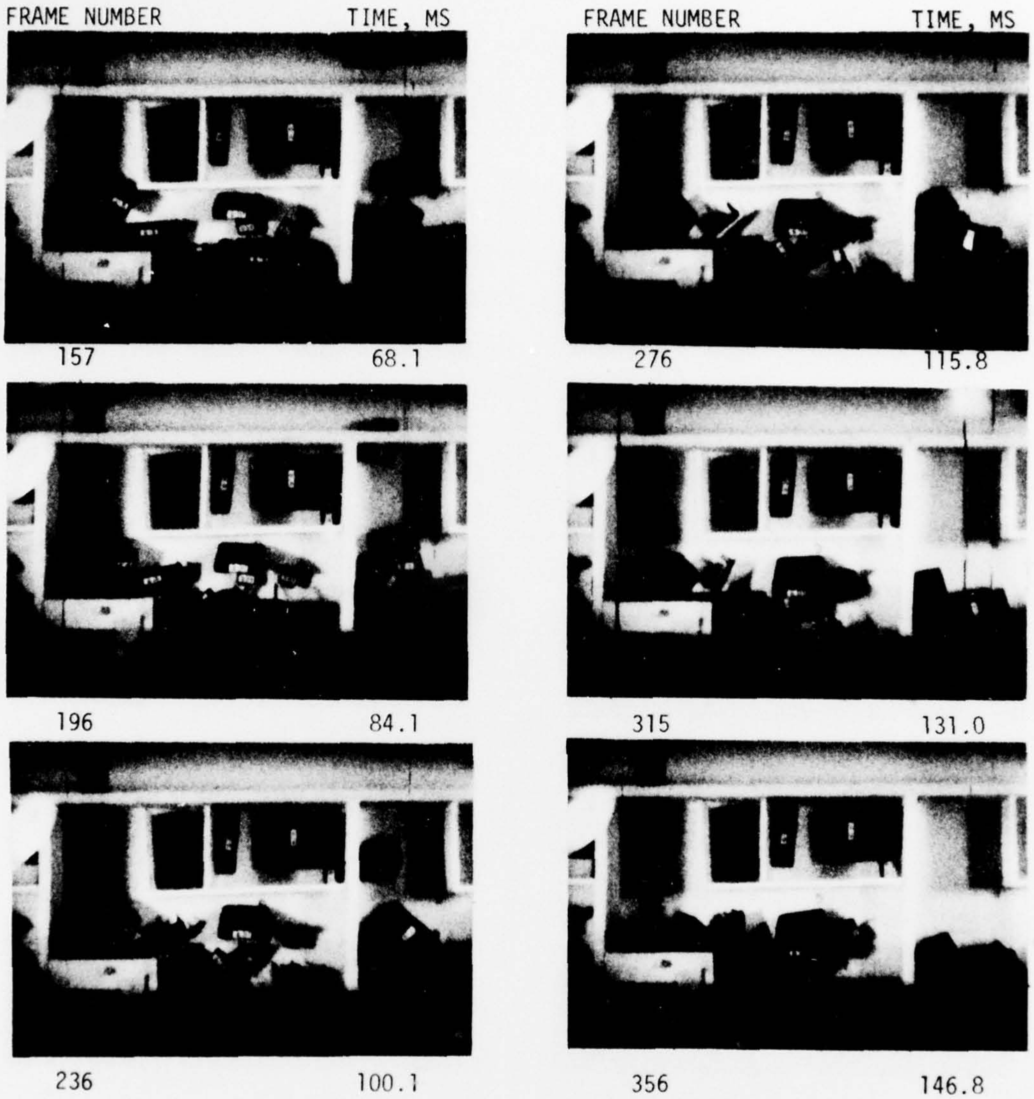


Figure C-2. Apartment G for Input Pressure of 7.79 kPa (Continued)

SHOT 8-77-3

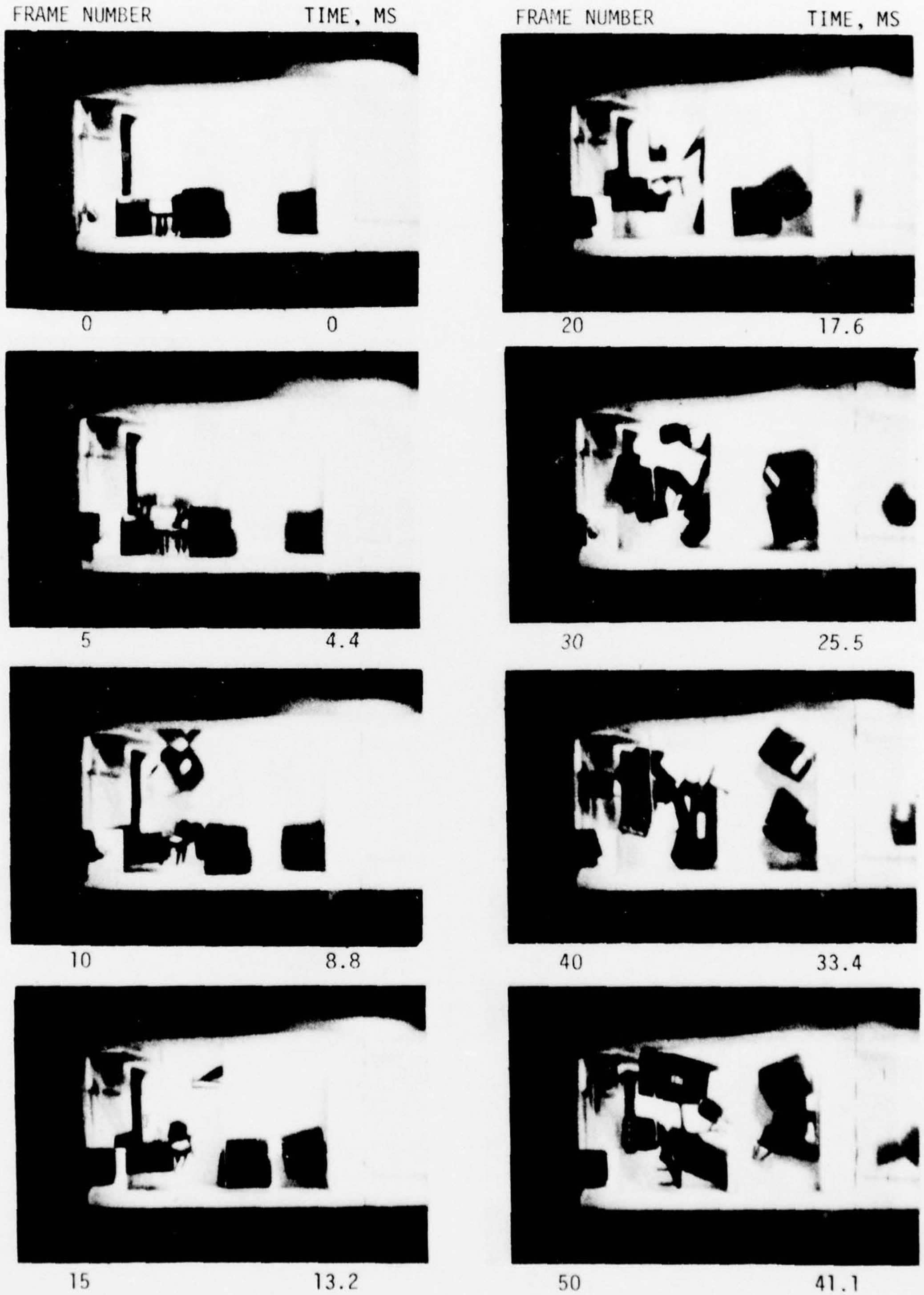
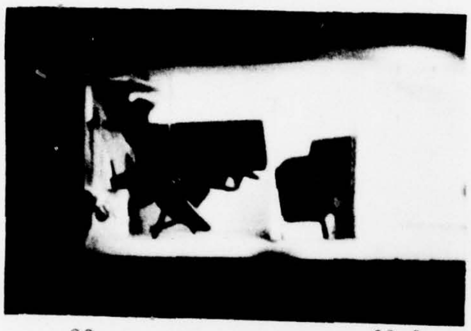


Figure C-3. Apartment D for Input Pressure of 23.65 kPa

SHOT 8-77-3

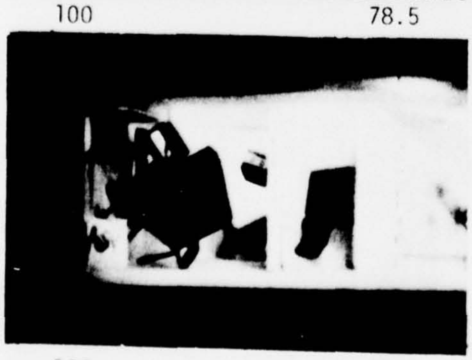
FRAME NUMBER TIME, MS

60 48.8



80 63.8

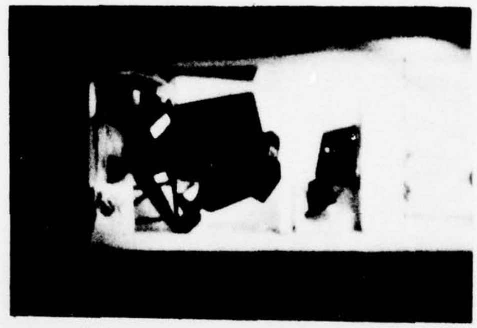
100 78.5



120 92.9

FRAME NUMBER TIME, MS

140 107.2



160 121.1

180 134.8

Figure C-3. Apartment D for Input Pressure of 23.65 kPa (Continued)

SHOT 8-77-3

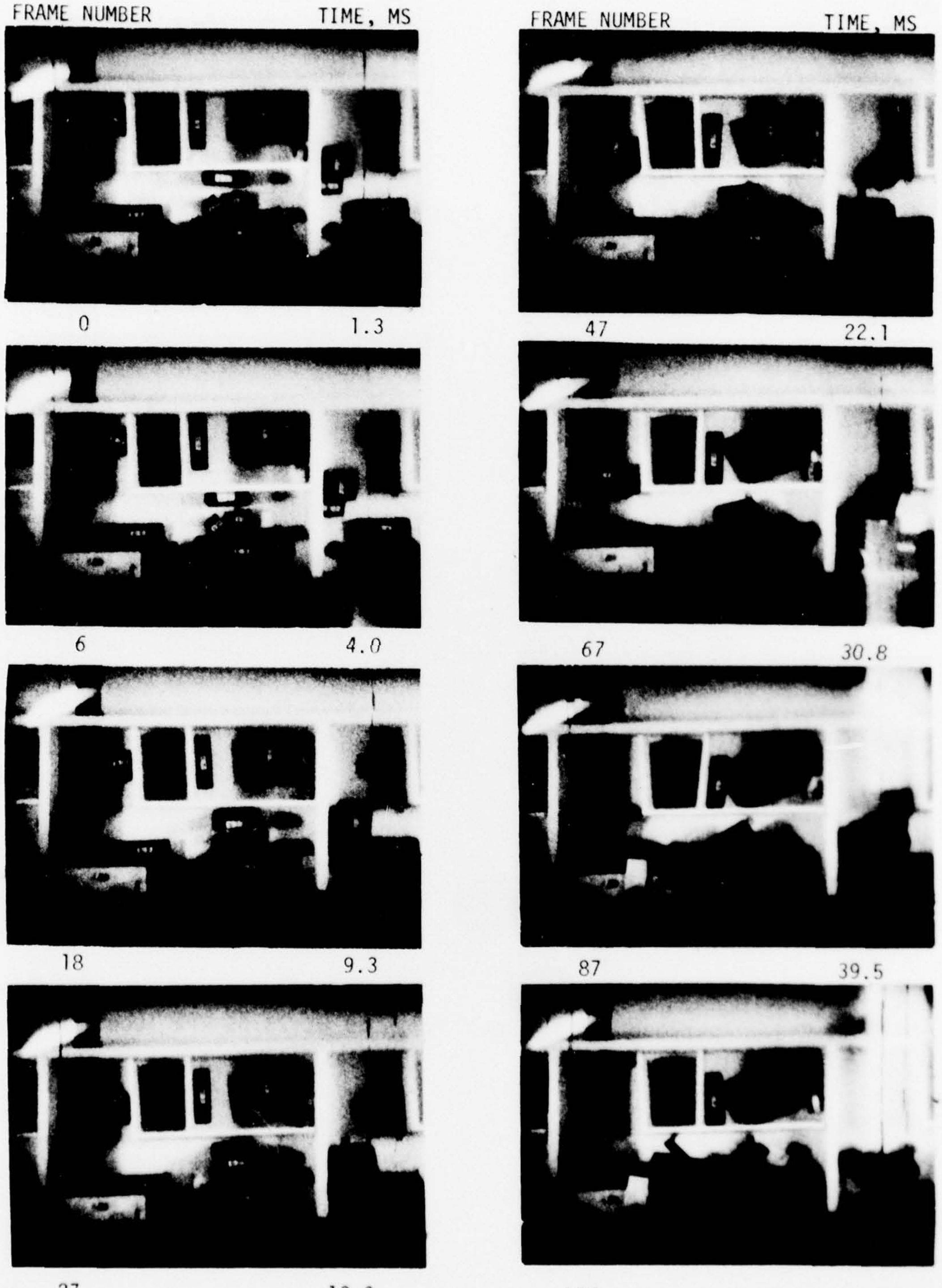


Figure C-4. Apartment G for Input Pressure of 23.65 kPa

SHOT 8-77-3

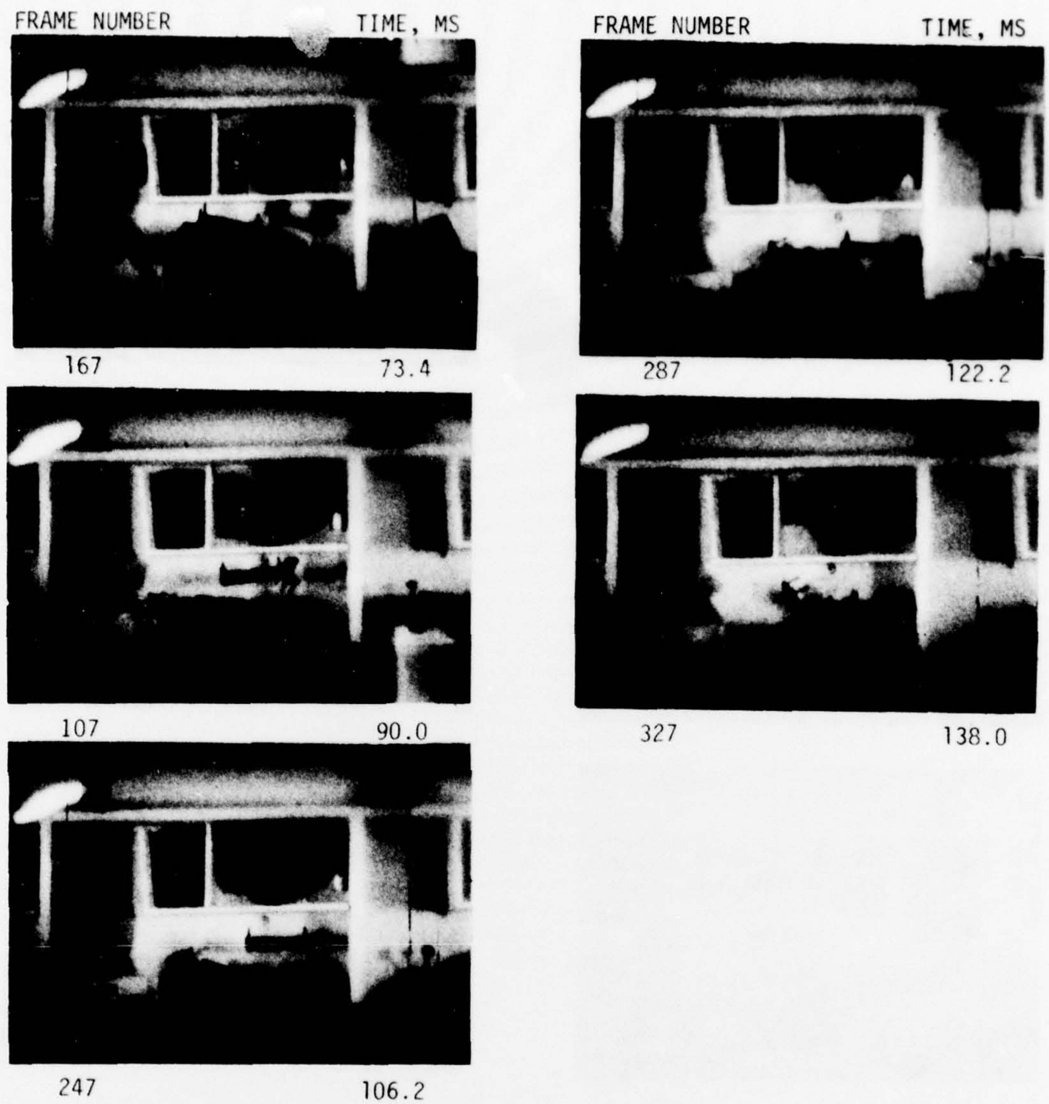


Figure C-4. Apartment G for Input Pressure of 23.65 kPa (Continued)

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1	University of Washington Dept of Civil Engineering ATTN: Prof. W. Miller 307 More Hall Seattle, WA 98105
1	Wiss, Janney, Elstner & Assoc. ATTN: Mr. J. R. Janney 330 Pfinsten Road Northbrook, IL 60062
1	Worcester Polytechnic Inst Dept of Civil Engineering ATTN: Prof. C. Koontz Worcester, MA 01609

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