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Finite Element Crash Models of Motor Vehicles

Research and Development
Turner-Fairbank Highway Research Center
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McLean, Virginia 22101-2296

FOREWORD

This report documents a study to develop a finite element model of a Honda Civic automobile for frontal crash simulation. The model development process and simulation response verification process is documented.

Two Honda Civic automobiles were used to measure the relevant dimensions and inertial properties. The surface profiles, dimensions, and mass of vehicle components (such as engine and suspension parts) and sheet metal parts were measured and weighed by disassembling a Honda Civic automobile.

The measured properties were used to develop an INGRID mesh generation model of the vehicle. This model was used to create a DYNA3D finite element simulation model. The response of the finite element model was verified by performing a 30 mi/h, (48 km/h) offset pole, frontal impact simulation.

Lyle Saxton
Director, Office of Safety and Traffic
Operations Research and Development

NOTICE

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16. Abstract

This report describes the results of vehicle measurements, finite element modeling, and response verification of a Honda Civic Automobile. The objective of this program of work was to create an impact finite element model of the vehicle. The model was developed for frontal impact with a sign or pole type highway structure.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yards	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
NOTE: Volumes greater than 1000 l shall be shown in m^3.				
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5(F-32)/9 or (F-32)/1.8	Celcius temperature	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.71	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact)		
°C	Celcius temperature	1.8C + 32	Fahrenheit temperature	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

* SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.

(Revised September 1993)

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INTRODUCTION

This report documents the results of vehicle measurements, finite element modeling, and response verification of a Honda Civic automobile. The objective of this program of work was to create an impact finite element model of the vehicle. The model was developed for a frontal impact with a sign or pole type highway structure. The response of the model was verified by performing an impact analysis with an offset rigid pole.

Global properties of the vehicle were measured with an Inertial Property Measurement Device (IPMD). Structural surfaces were scanned using a large digitizing machine (Tarus). The digitized surface data were used to create a finite element model of the vehicle using the INGRID[(1)] mesh generator. DYNA3D[(2)] was used for crash simulation (INGRID and DYNA3D are the names of the software, for which no acronyms exist).

VEHICLE ACQUISITION AND MEASUREMENT

VEHICLE ACQUISITION

Two Honda Civic two door hatchbacks were purchased from owners as used vehicles. Attempts to acquire "junk yard" vehicles proved to be a fruitless venture. One of the vehicles was a 1982 model. The other was a 1983 model and was structurally similar to the 1982 car. The vehicles were in running condition with a minimum of rust. The 1983 vehicle was used to determine global properties, and is shown in figure 1 and figure 2. The 1982 vehicle was disassembled to determine surface geometries.

GLOBAL PROPERTIES MEASUREMENT

The requirement for this task were to obtain:

- Total Mass of the Vehicle
- Gross Vehicle Moments of Inertia
- Gross Vehicle Center of Gravity (C.G.) Location

Data from global.vehicle measurements performed at the Transportation Research Center of Ohio (TRC) using the IPMD. The results from these measurements are given in tables 1, 2, and 3. Table 1 lists the information gathered to determine the height of the center of gravity (C.G.) of the vehicle. Table 2 lists the information gathered to determine vehicle inertial properties using the original units of measurement. Table 3 summarize individual wheel loads, C.G. location in the horizontal plane, wheel base, and track dimensions. Photos of the test facilities used to develop this data can be seen in the background in figure 1 and figure 2.

Figure 1. Vehicle at test facility, front three-quarter view

Figure 2. Vehicle at test facility, side view

Table 1. Center of gravity measurement data.

IPMD MEASURED DATA Version 2.05
Vehicle # and Run # 526 Date: 08-21-1992 Time:13:48:45
Vehicle Type: HATCHB Fuel: FULL
LOAD: CURB
Weight (kg): 880.9 Wheelbase (m): 2.23 Roof Height (m): 1.34
Ramp Distance (m): 1.13 UltraSonic Offset (m) : 0.45

IPMD Calibration Check (no vehicle)

APPLIED Weight (kg)	Schaevitz Output (deg.)	System C.G.Pivot (m)
+0	0.11	0.00
+45.5	5.17	.8345
+91.0	-10.37	.8346
+0	0.10	0.00
-45.5	5.41	.8312
-91.0	10.59	.8341
+0	0.11	0.00

platform C.G. Pivot (m):
Platform C.G. is -0.002667 m from Cal Value

C.G. Height:

Applied Weight (kg)	Schaevitz Output (deg.)	Longitudinal Movement (m)	Individual C.G. Values (m)
+0	-0.14	0.000	0.00
+45.5	-3.79	-0.0000254	.515112
+91.0	-7.42	-0.0001524	.515366
+0	-0.17	-0.0002032	0.00
-45.5	3.52	-0.0001016	.518922
-91.0	7.21	-0.0001524	.525272
+0	-0.11	-0.0001270	0.00

Average calculated C.G. Height (m): .518668

Table 2. Vehicle inertia measurement data.

Vehicle # and Run # 526 Date:08-21-1992 Time : 13:48:46
Vehicle Type : HATCHB Fuel: FULL
Load: CURB
Weight (kg) :880.9 Wheelbase (m): 2.23 Roof Height (m): 1.34
Ramp Distance (m): 1.12 UltraSonic Offset (m): 0.45

Pitch Inertia:

Run #	Period(s)	Platform Motion Amplitude (deg.)	Relative Motion Amplitude (m)	Individual Pitch Calc.
1	3.185	10.85	0.0037592	1127.24
2	3.185	10.68	0.0037084	1127.38
3	3.185	10.84	0.0038100	1126.83

Average Pitch Inertia (kg m^2): 1127.10

Roll Inertia:

Run #	Period (s)	Platform Motion Amplitude (deg.)	Relative Motion Amplitude (m)	Individual Roll Calc.
1	2.255	10.36	0.001651	248.15
2	2.260	10.52	0.001676	253.03
3	2.260	10.32	0.001651	253.03

Average Roll Inertia (kg m^2): 251.4

Yaw Inertia:

Run #	Period(s)	Platform Motion Amplitude (deg.)	Relative Motion Amplitude (m)	Individual Yaw Calc.
1	1.800	8.71	0.002794	1221.75
2	1.800	8.72	0.002794	1221.62
3	1.800	8.55	0.002794	1221.62

Average Yaw Inertia (kg m^2) : 1221.62

Table 3. Gross vehicle data.

L/F=283.6 (kg) R/F=271.3 (kg) R/R=162.7 (kg) L/R=163.2 (kg)

TOTAL FRONT=554.9 (kg) TOTAL REAR= 325.9 (kg)

LONGITUDINAL C.G.= 0.8269 m FROM FRONT AXLE CENTER LINE

lateral C.G.= -0.009954 m FROM CENTERLINE (LEFT)

wheel base=2.2352 m WHEEL TRACK 1.32715 m AVG.

GEOMETRY MEASUREMENT

The entire vehicle as well as individual component surfaces were scanned via a large coordinate measuring machine (Tarus) as illustrated in figures 3 and 4. This system records each scanned point in x,y, and z coordinates with respect to x, y, and z reference planes.

A gross total vehicle scan was conducted to develop the vehicle profile and to tie all outer surfaces to the reference x, y, and z planes. All major components (i.e., engine, suspension, seats, etc.) were scanned to locate their positions with respect to the reference planes and the external surfaces of the vehicle. Therefore all components were located with respect to the reference planes.

Figure 5 shows a photo of the stylus being used to measure points on the bumper. Figures 6 to 21 are photographs of various components and sub-regions of the vehicle structure.

PART THICKNESSES

A parts list was developed prior to obtaining measurements of the vehicle structure. Part numbers were assigned to all measured components. Table 4 shows these part numbers and the corresponding part thicknesses.

Table 4. Part thickness.

No.	Name/description	Thickness(in)	Thickness (mm)
1A	Hood outer	0.023	0.58
1B	Hood inner	0.024	0.61
2	Engine cradle assembly		
2A	E/C - basic member	0.093	2.36
2B	E/C - bracket - front	0.075	1.91
2C	E/C - bracket - rear	0.080	2.03
2D	E/C bottom plate - front	0.065	1.65
2E	E/C bottom plate - rear	0.063	1.60
3A	Fender - outer (2)	0.024	0.61
3B	Fender - inner (2)	0.032	0.81
4	Cowl/plenum assembly		
4A	C/P - top plate	0.024	0.61
4B	C/P - bottom plate	0.028	0.71
4C	C/P - side plates (2)	0.049	1.24
4D	C/P - back plate - center	0.034	0.86
4E	C/P - back plate - sides (2)	0.049	1.24
4F	C/P - back plate - driver's side	0.034	0.86
5	Hinge pillar assembly (2)		
5A	Hp - outer	0.024	0.61
5B	Hp - inner	0.046	1.17
5C	Hp - interior reinforcement	0.041	1.04
5D	Hp - lower hinge reinforcement		
6	A pillar assembly (2)		
6A	AP - outer	0.024	0.61
6B	AP - inner	0.039	0.99
6C	AP - interior reinforcement	0.041	1.04
7	Frame rail assembly (2)		
7A	FR - outer	0.032	0.81
7B	FR - inner	0.058	1.47
7C	FR - interior reinforcement	0.048	1.22
7D	FR - inner rear	0.058	1.37
8	Headlamp mounting plate	0.030	0.76
9	Bumper		
9A	Bumper - front plate	0.054	1.37
9B	Bumper - back plate	0.041	1.04

Table 4. Part thickness (continued).

10	Firewall	0.035	0.89
11	Firewall bulge	0.044	1.12
12	Shock tower (2)	0.065	1.65
13	Floor pan		
13A	Floor pan - partial	0.047	1.19
13B	Floor pan - inner	0.047	1.19
14	Suspension arm (2)	0.125	3.18
15	Sway bar support bracket (SBSBR)- right		
15A	SBSBR - upper plate	0.049	1.24
15B	SBSBR - lower plate	0.057	1.45
16	Sway bar support bracket - left	0.126	3.20
17	Engine mount - front	0.049	1.24
18	Engine mount - rear	0.055	1.40
19	Engine mount - left		
19A	EML - upper	0.056	1.42
19B	EML - lower	0.063	1.60
20	Bumper brackets (2)	0.076	1.93
21	Frame rail to floorpan brackets (2)	0.044	1.12
22	Front crossmember		
22A	FC Front plate	0.040	1.02
22B	FC Rear plate	0.049	1.24
23	Steering rack brackets (2)	0.065	1.65

14	Suspension arm (2)	0.125	3.18
15	Sway bar support bracket (SBSBR)- right		
15A	SBSBR - upper plate	0.049	1.24
15B	SBSBR - lower plate	0.057	1.45
16	Sway bar support bracket - left	0.126	3.20
17	Engine mount - front	0.049	1.24
18	Engine mount - rear	0.055	1.40
19	Engine mount - left		
19A	EML - upper	0.056	1.42
19B	EML - lower	0.063	1.60
20	Bumper brackets (2)	0.076	1.93
21	Frame rail to floorpan brackets (2)	0.044	1.12
22	Front crossmember		
22A	FC Front plate	0.040	1.02
22B	FC Rear plate	0.049	1.24
23	Steering rack brackets (2)	0.065	1.65

Figure 3. Tarus digitizing machine, front view

Figure 4. Tarus digitizing machine, side view

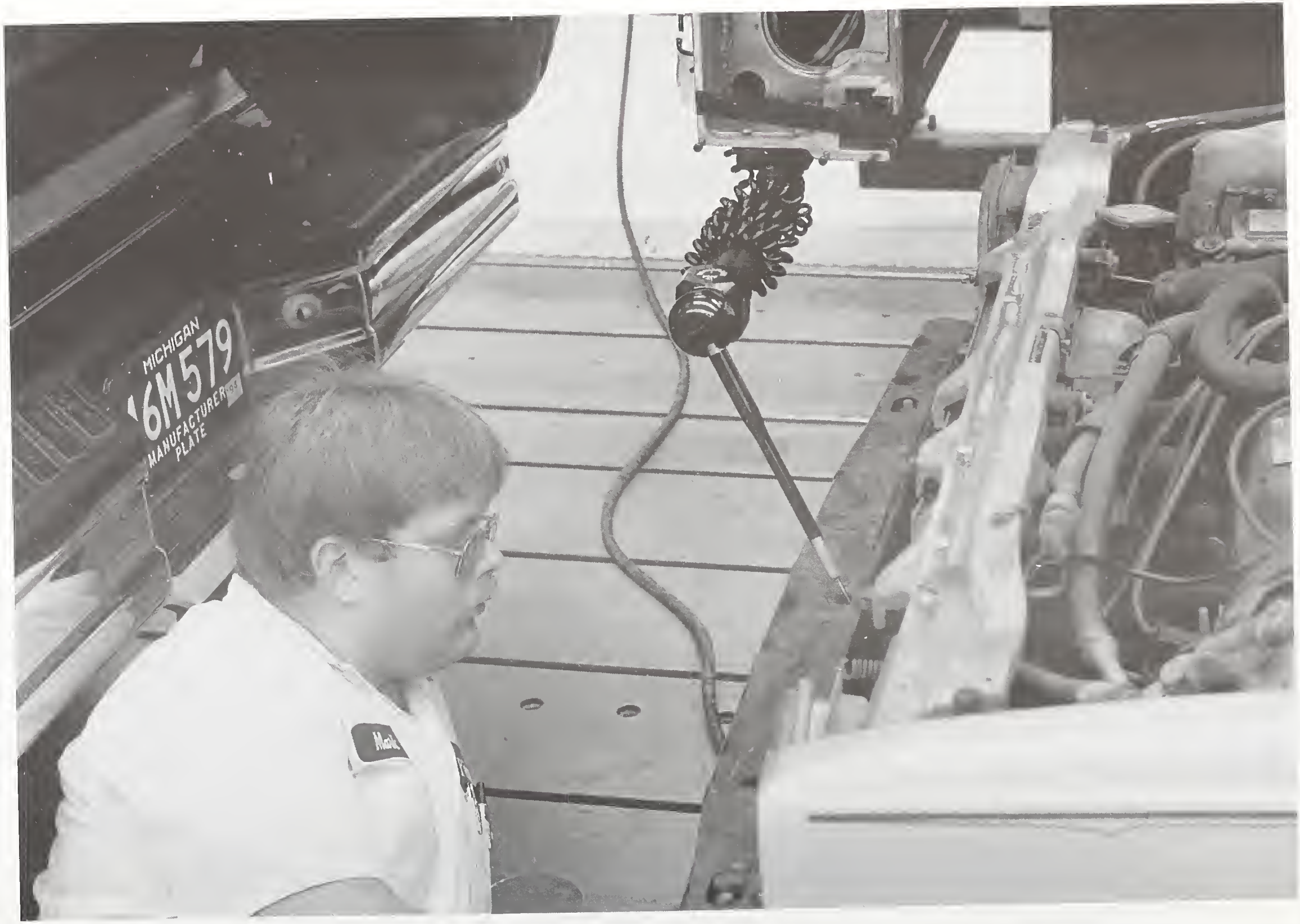


Figure 5. Measuring stylus on bumper.

COMPONENT PROPERTIES MEASUREMENT

The mass and C.G. data of vehicle components were measured separately from the development of the gross vehicle data. The methodology for developing this data is as follows. This parts were weighed on a specially constructed weighing platform which consisted of a 1.2-by-1.5 m (48-by-60 in) wooden deck supported by three bolts, each resting on a scale. The bolts additionally provided adjustment so that the platform could be leveled.

The centers of gravity of various components were first determined with respect to a rigid system inscribed on the weighing platform. These coordinates were then transferred to a coordinate system on the vehicle. Several reference points on each component, previously located with respected to the vehicle, were located with respect to the platform grid. This procedure allowed transformation of the platform C.G. coordinates to vehicle local coordinates.

Scales with a capacities of 90 kg (200 lb) that weighed to an accuracy of +/- 0.01 kg (0.02 lb) were rented for the purpose. The scales were calibrated by the renting company's technicians prior to use. The platform was placed on the scale and leveled. The scales were set to zero pounds with the platform in place, making it unnecessary to subtract tare weights from the readings.

Each component was placed on the platform in a convenient location with respect to the grid system. Scale readings were recorded, and locations of preselected locating points were measured. Two dimensions of the C.G. of the component were computed using conventional static equations for equilibrium. The components was then rotated 90 degrees and the procedure repeated. The step yielded the third dimension of the C.G.

The engine, transmission, clutch, differential and air conditioning compressor, which were weighted as a unit, required special techniques because it was not possible to rotate the assembly exactly 90 degrees. Therefore, three points on the assembly, which had been located when the entire vehicle was digitized, were located with respect to the weighing platform, and two dimensions of the C.G. were determined as previously explained. The assembly was then rotated approximately 90 degree, and the procedure repeated.

A computer solid modeling design software (Aries) was used to rotate and translate the planes defined by the three points and the axes defined by the two dimensional coordinates of the C.G. until the axes intersected. the location of the C.G. was then translated to the vehicle coordinate system. Figure 22 show the scales and platform arrangement to measure component mass and C.G . Figures 23 and 24 show components being measured. The following is a list of measured inertial properties of the vehicle and major components. The origin and orientation of the local vehicle coordinate system is defined for each group of parts.

Data set-1 Summary of Gross Vehicle Properties

Individual Wheel Loads (kg)

Left Front = 284	Right Front = 271	Total front = 555
Left rear = 163	Right rear = 163	Total rear = 326
		Total = 881

C.G. Location (m)

Longitudinal = 0.827 from front axle centerline
Lateral = 0.010 from centerline (left)
Vertical = 0.518 above floor

Inertias ($kg.m^2$)

Pitch = 1126
Roll = 251
Yaw = 1221

Other data

Wheelbase = 2.235 m
Wheel track = 1.378 m, average
Roof height = 1.344 m

Data set-2 **Engine, Steering Column, Instrument panel, Suspension Assembly**

C.G. location coordinate system:

Vehicle direction	0 Line	Positive Direction
Lateral (x)	Centerline of body	Left
Height (y)	Floor(Torus bed plate)	Up
Fore-aft (z)	Shock tower centerline	Vehicle Front

Component/Assy	Weight(kg)	X	Y	Z
Steering Column	6.2	.307	.757	-.699
Instrument panel	12.5	.034	.744	-.527
Engine Assembly	173.2	.029	.393	.149
Suspension Assembly	21.1	.443	.457	.6

Engine assembly includes engine, transmission, clutch, differential, A/C compressor, and part of axle shafts. Suspension assembly includes spring,strut,brake,U-joint,shock absorber, and suspension arm.

Data set 3 **Bumper complete with fascia, lights, and mounting brackets**

Mass = 13.15 kg
C.G. location coordinate system : forwardmost-central-lowermost point on bumper

x (rear of vehicle +) = .113 m
y (right of vehicle +) = .004 m
z (upward +) = .065 m

Data set 4 **Radiator, empty, with fan, shroud, and hoses**

Mass = 7.00 kg
C.G. location coordinate system : forwardmost-rightmost-lowermost point on radiator
x (rear of vehicle +) = .066 m
y (right of vehicle +) = -.272 m
z (upward +) = .144 m

Data set 5 **Hood with hinges**

Mass = 10.59 kg
C.G. location coordinate system : .508 m rearward from forwardmost edge, on top surface of hood centerline

x (rear of vehicle +)	= -.101 m
y (right of vehicle +)	= .004 m
z (upward +)	= -.028 m

Data set 6 **Battery**

Mass = 10.52 kg
C.G. location coordinate system : bottom right rear corner

x (long side)	= .194 m
y (short side)	= .108 m
z (up)	= .102 m

Data set 7 **Brake booster and master cylinder**

Mass = 3.22 kg
C.G. location coordinate system : center of mounting hole on firewall

x (forwards along cylinder axis)	= .0624 m
y	= 0.
z (upwards along firewall)	= -.002 m

Data set 8 **Steering Column**

Mass = 6.20 kg
C.G. location coordinate system at center of steering wheel plane

x (downwards along column axis)	= .180 m
y (right hand side +)	= .002 m
z (upward +)	= .002 m

Data set 9 **Instrument panel**

Mass = 12.5 kg
C.G. location coordinate system : 3 points on top surface of I.P. reference axis line perpendicular to reference plane through reference point on I.P.

x = .034 left of reference axis
y = .153 above reference axis
z = .189 below reference plane

Data set 10 **Door, seats, and wheel**

Front door	= 23.6 kg
Front seat	= 12.5 kg each
Rear seat back	= 3.8 kg
Rear cushion	= 9.4 kg
wheel + tire	= 13.2 kg each

WELDS AND FASTENERS

The following information was gathered during vehicle disassembly.

Location Components Joined	Name	Type	Spacing (in/mm)
Hood			
1A - 1B	Inner to hood outer	adhesive	All contact surfaces
Engine Cradle Assembly			
2A - 2B	Basic member to front bracket	spot	1.3/32
2A - 2C	Basic member to rear bracket	spot	1.0/25
2A - 2D	Basic member to bottom plate	spot	1.3/32
Fender - outer			
3A - 7A	Fender outer to frame rail outer	bolts	9.0/229
Plenum Assembly			
4A - 4B	Top plate to bottom plate	spot	1.90/48
4A - 4C	Top plate to side plates	spot	2.70/69
4A - 4D	Top plate to back plate - center	spot	2.70/69
4A - 4E	Top plate to back plate - sides	spot	2.70/69
4B - 4C	Bottom plate to side plates	spot	5 welds
4B - 4D & E	Bottom plate to side & back plates	spot	2.70/69
4D - 4E	Back plate-center to back plate sides	spot	2.70/69
Hinge Pillar Assembly			
5A - 5B - 5C	Outer to inner to inner reinforcement	spot	1.30/34
5B - 13	Outer to floor pan (wheel well)	spot	1.2/30
5A - 5C	Outer to reinforcement	spot	1.5/38
A Pillar			
6A - 6B - 6C	Outer to inner to reinforcement	spot	2.5/64

Location Components Joined	Name	Type	Spacing (in/mm)
Frame rail Assembly			
7B - 7A	Outer to inner	spot	1.30/32
7A - 10	Outer to firewall	spot	1.60/41
7B - 10	Inner to firewall	spot	1.40/36
7A - 8	Outer to headlamp mntg plt	spot	1.80/44
7B - 21	Inner to bracket, framerail to floorpan	spot	2.50/64
7A - 19	Framerail - outer to eng. mount - left	spot	1.00/25
7B - 19	Framerail - inner to eng mount - left	spot	1.30/32
Bumper			
9A - 9B	Front plate to back plate	spot	1.30/32
Firewall Bulge Area			
10 - 11	Firewall to firewall bulge	spot	1.30/32
10 - 18	Firewall to engine mount - rear	spot	1.00/24
10 - 11 - 23	Firewall bulge to ste.rack brkts.	spot	1.00/25
Shock Tower			
12 - 3B	Shock tower to fender inner	spot	7 at top adhesive on sides
Floor pan			
13A - 13B	Floor pan partial to floor pan inner	spot	1.50/38
13A - 21	Partial to brkts, framerail to floorpan	spot	1.00/25
Swaybar Support Bracket - right			
15A - 15B	Upper plate to lower plate	spot	1.50/38
15A - 7B	Upper plate to framerail inner	spot	1.50/38
15B - 22B	Lower plate to frt.crossmember rear	spot	1.30/32
15A - 22B	Upper plate to frt.crossmember rear	spot	1.00/25
Swaybar Support Bracket - left			
16 - 22B	Bracket to frt.crossmbr rear plate	12 mm bolts (2)	
16 - 7B	Bracket to frame rail inner	12 mm bolt (1)	

Location Components Joined	Name	Type	Spacing (in/mm)
Front eng. mnt.			
17 - 22B	Mount to frt. crossmember front plate	spot	0.90/22
Bumper			
20 - 8	Bumper brkts to headlamp mnt.plate	bolts (2)	
20 - 7B	Bumper brackets to framerail inner	bolts (2)	
Front Crossmember			
22A - 22B	Front plate to rear plate	spot	2.00/51
22B - 7A	Rear plate to framerail outer	spot	1.30/34
22B - 7B	Rear plate to framerail inner	spot	1.00/25

The following dimensions of major suspension components were measured. These measurements were used to define beam element properties.

Suspension Diameters (m)

Rack & pinion	= .0287
Sway bar	= .018
Axle shaft	= .0252
Susp. strut	= .0440
Tie rods	= .012 (hex section)

Figure 6. Inner fender.

Figure 7. Front bumper.

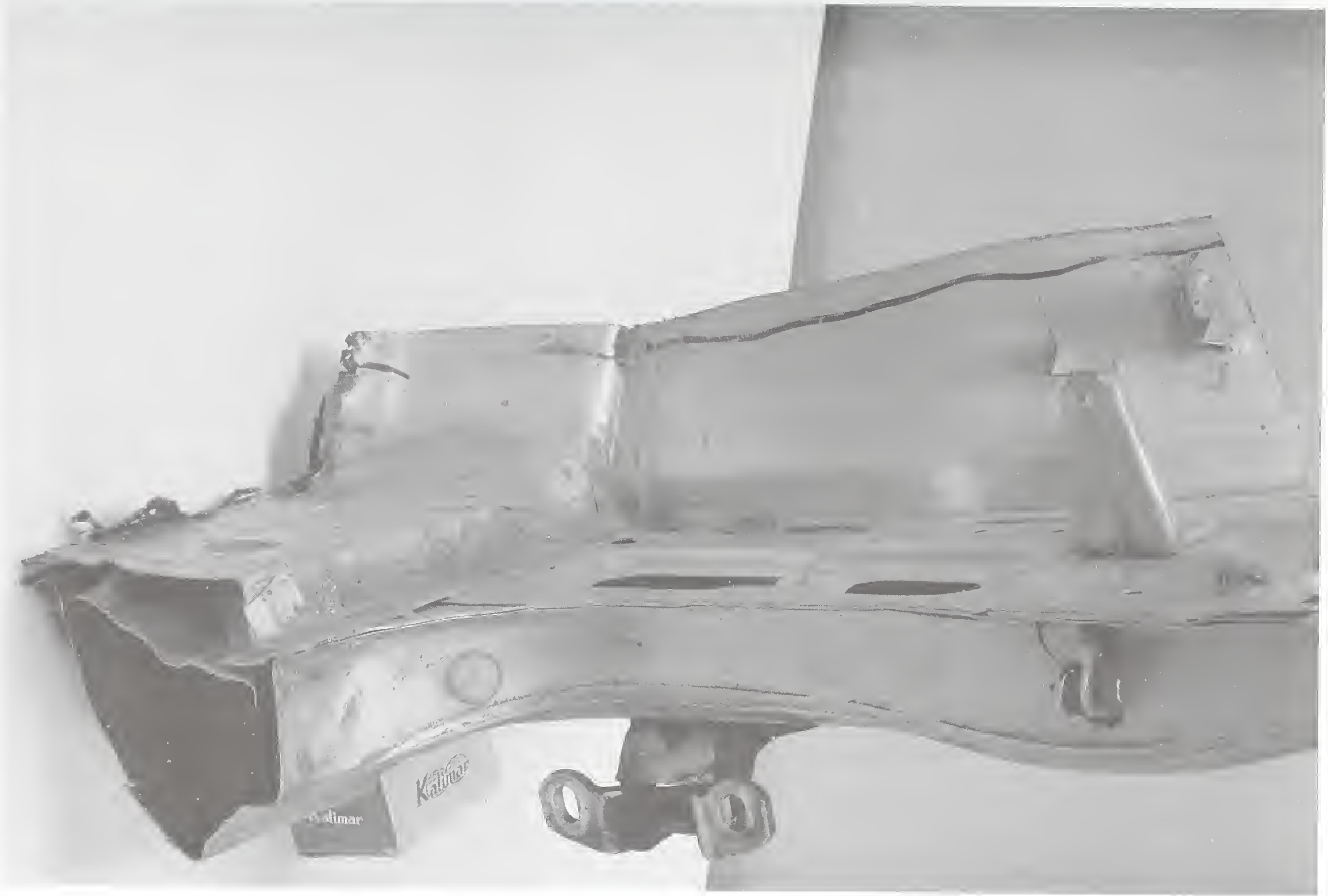


Figure 8. Hinge pillar and rocker.

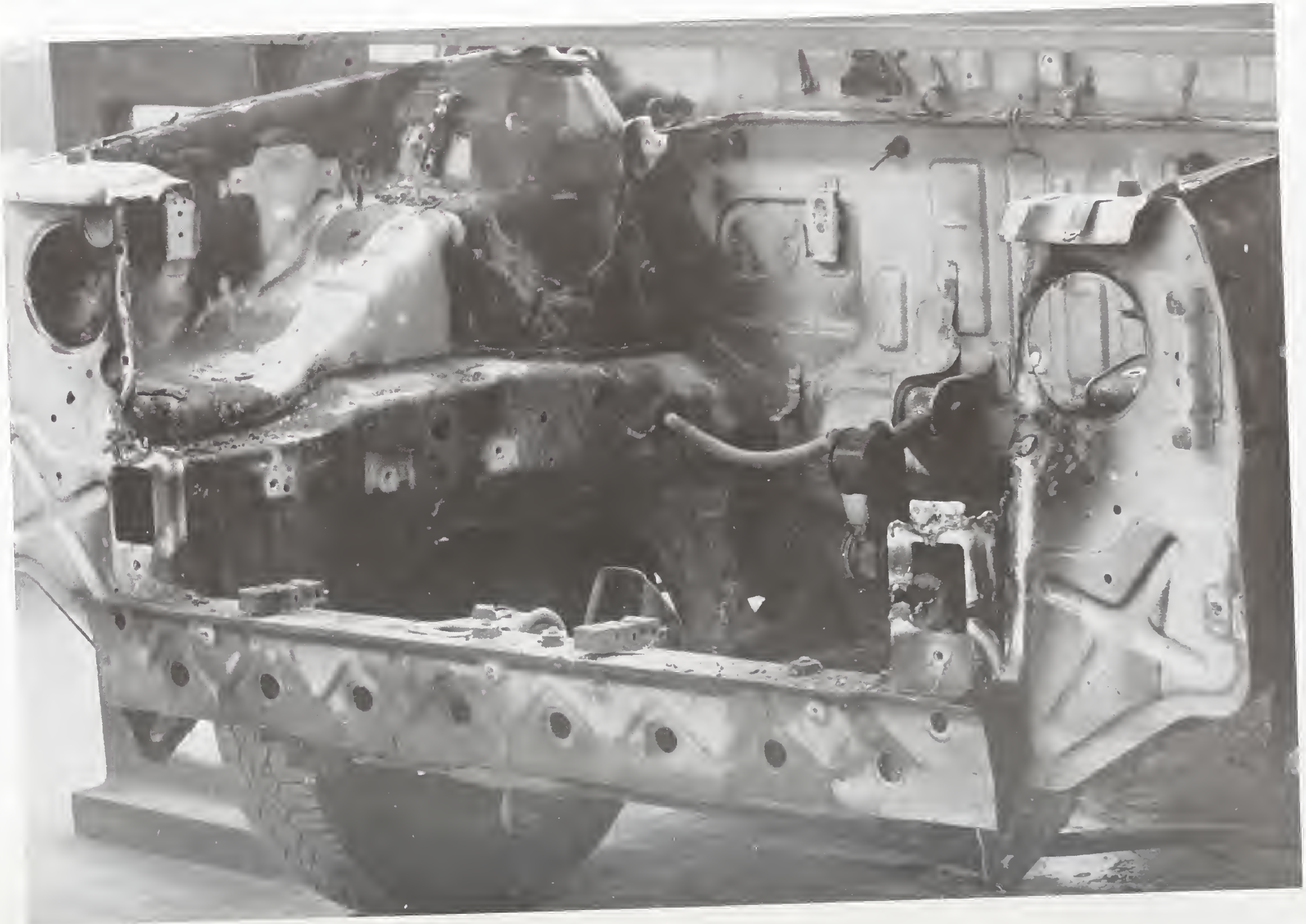


Figure 9. Front sheet metal, fender, front cross member.

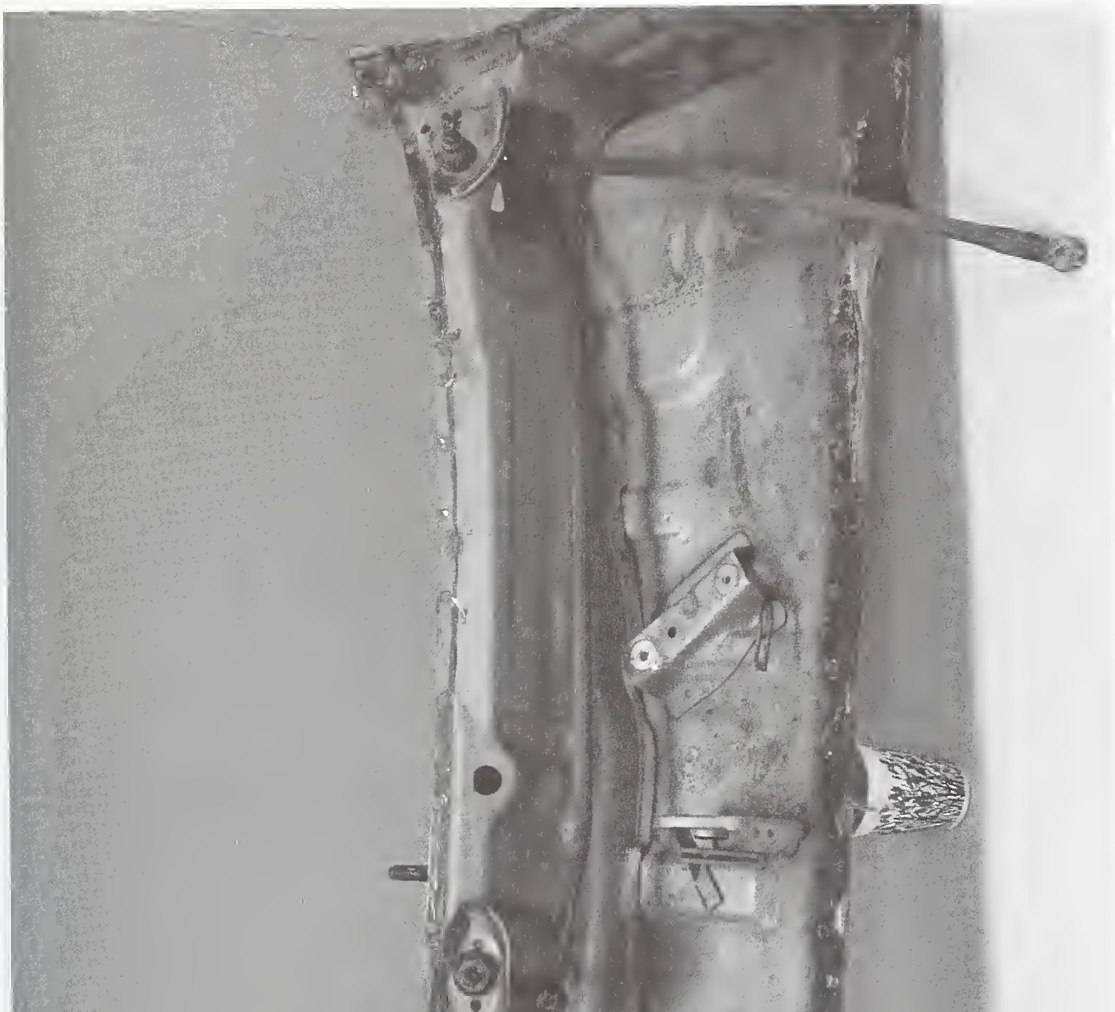


Figure 10. Cowl.

Figure 11. Right front frame, inner fender, fire wall.

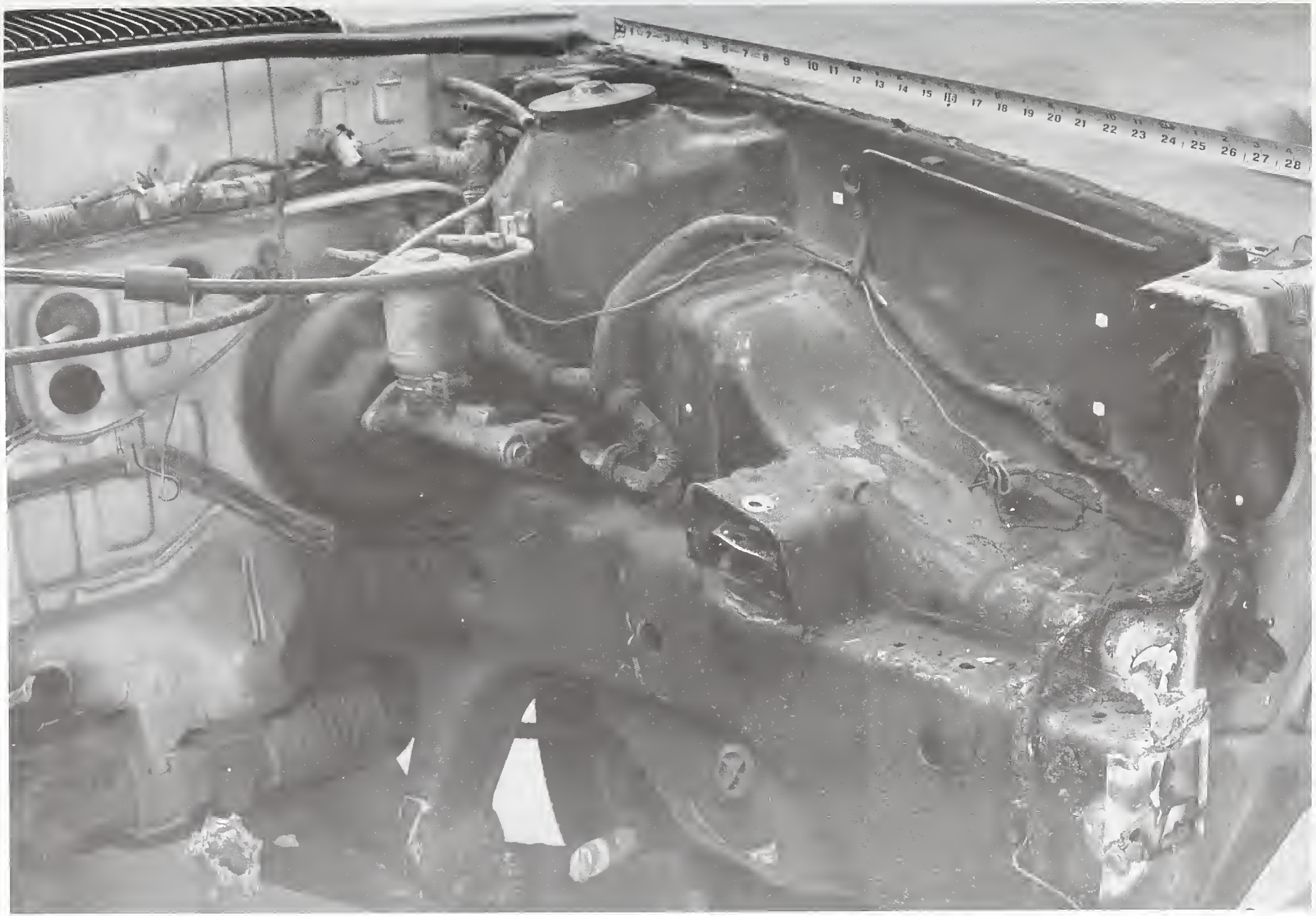


Figure 12. Left front frame, inner fender, fire wall .

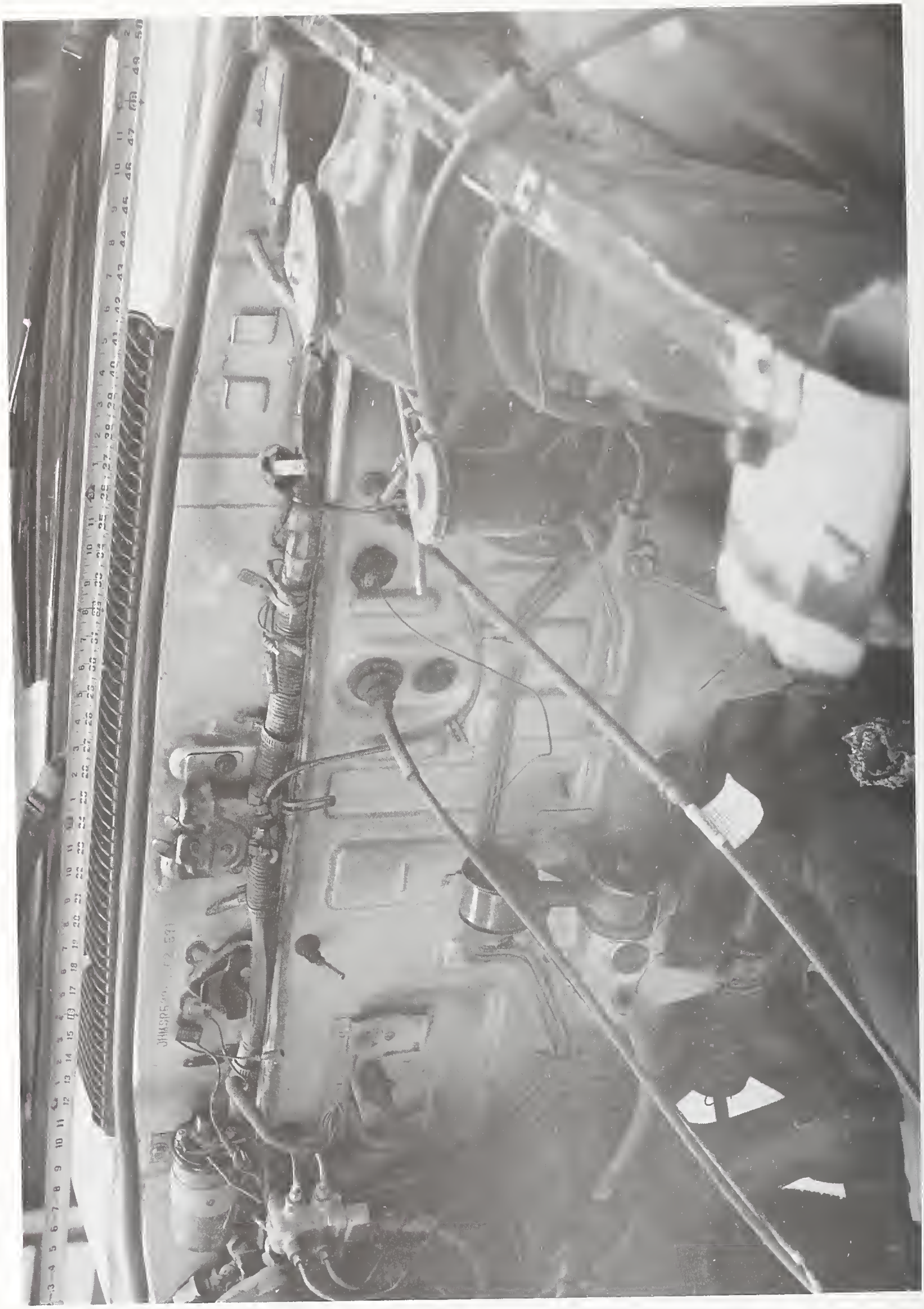


Figure 13. Fire wall.

Figure 14. Engine cradle .

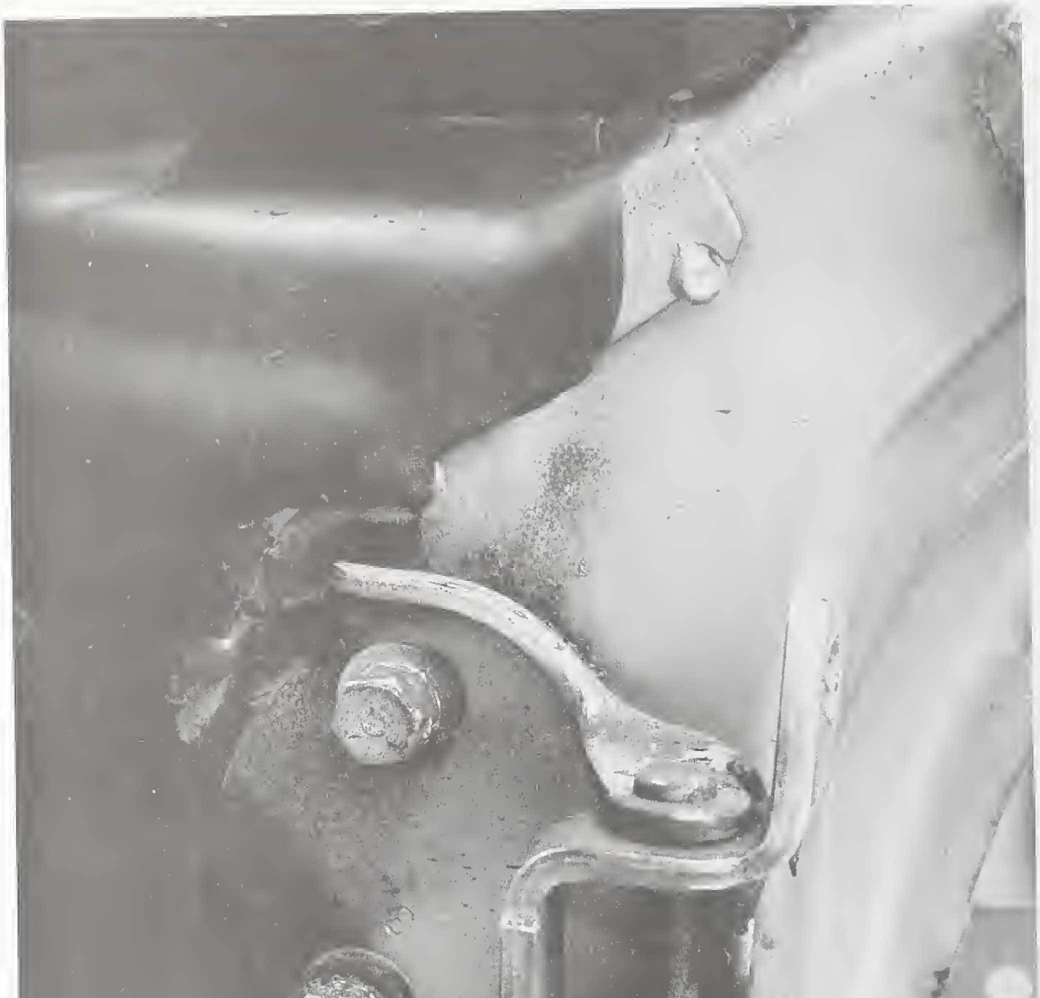


Figure 15. Top of front suspension mount.

Figure 16. Firewall, floor pan, hinge pillar, cowl .

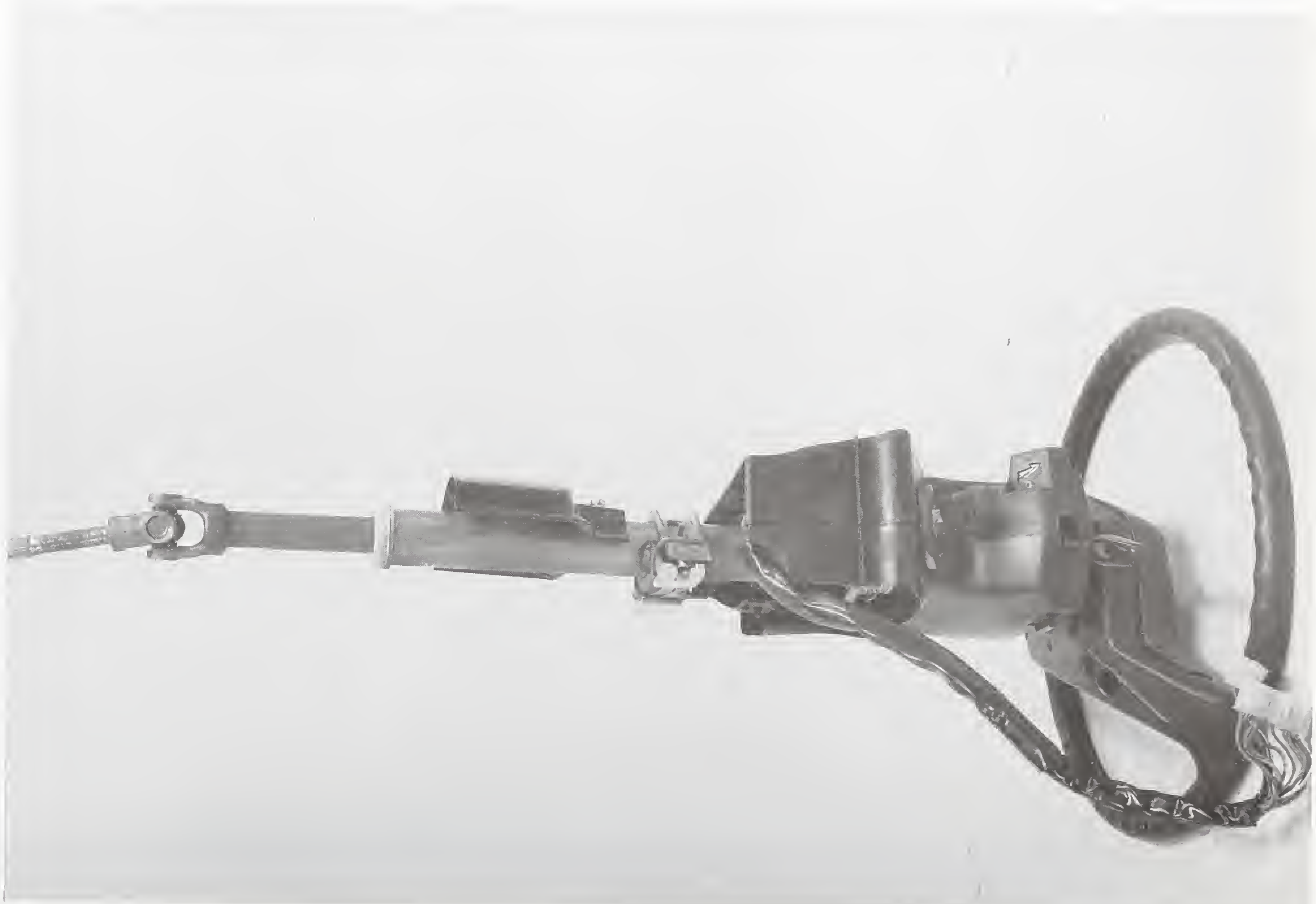


Figure 17. Steering column .

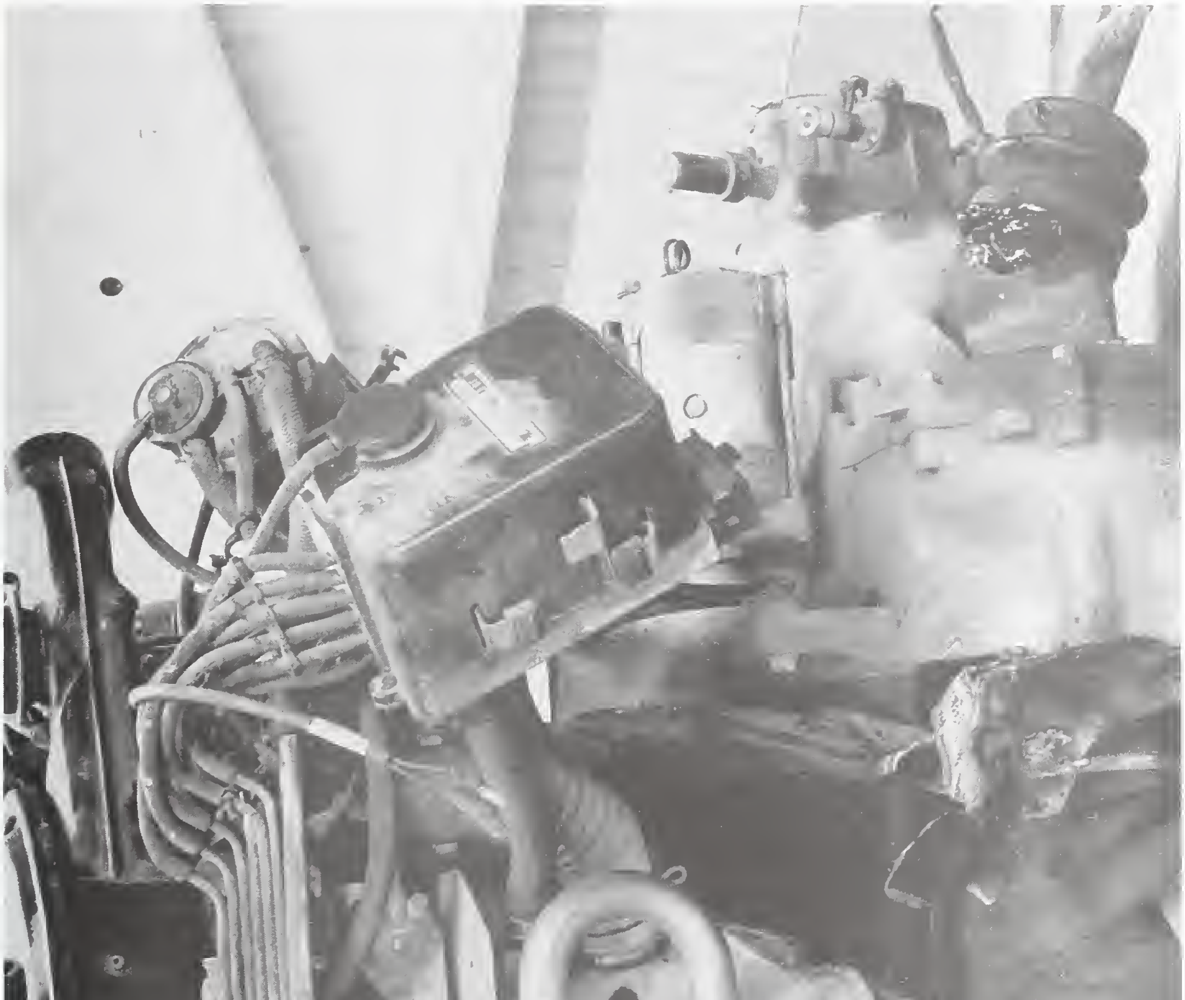


Figure 18. Engine and transaxle .

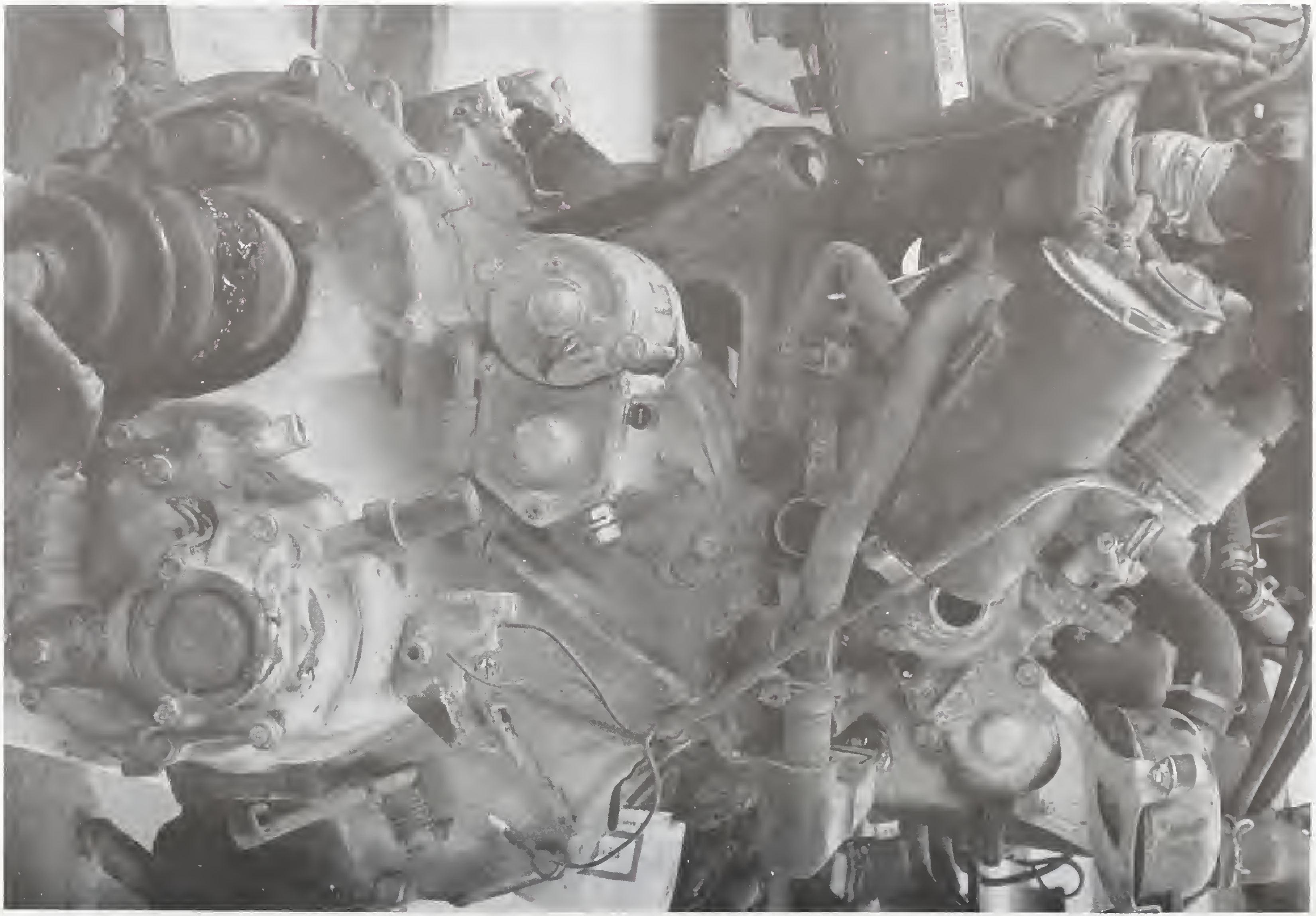


Figure 19. Engine front view

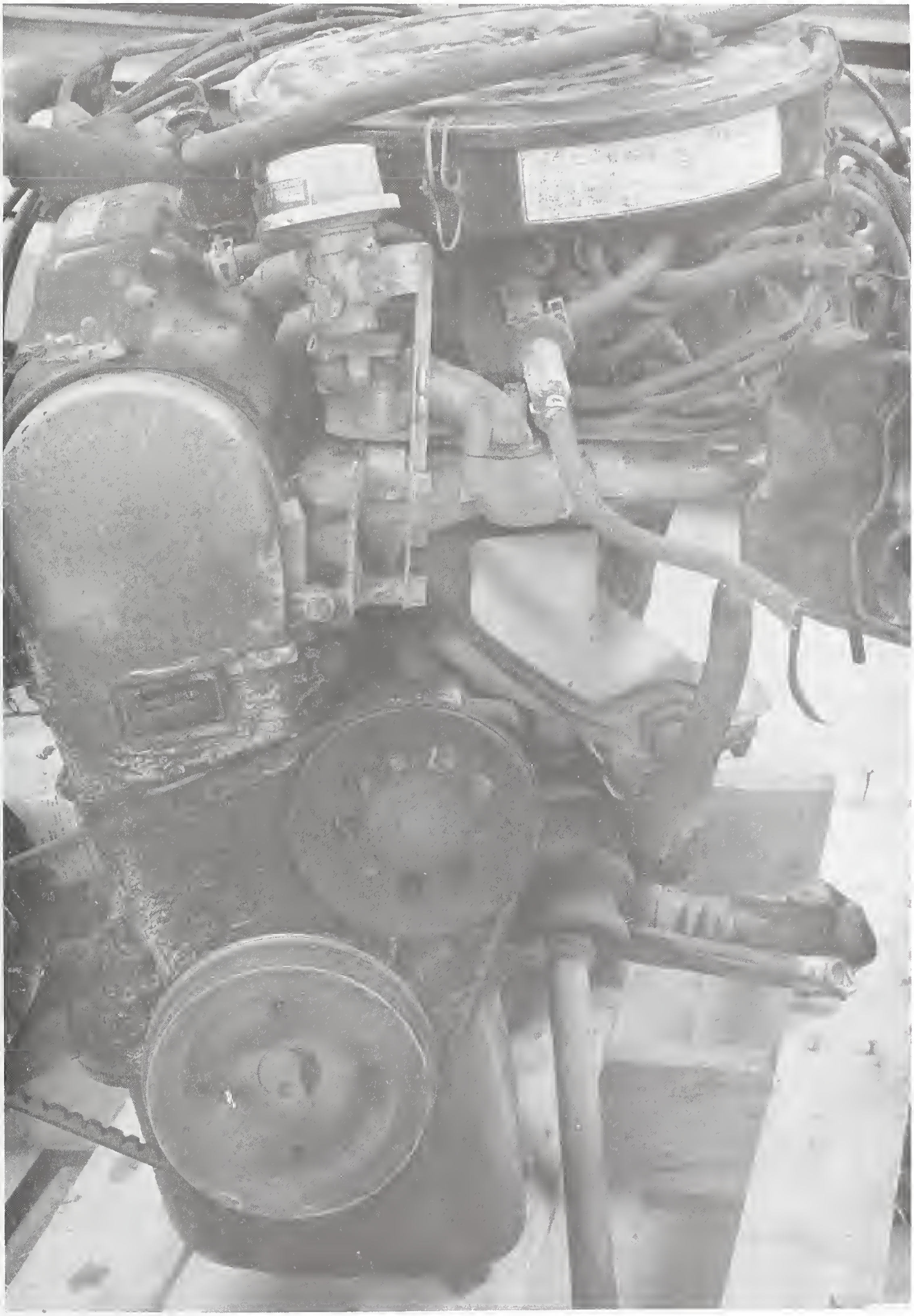


Figure 20. Engine rear view

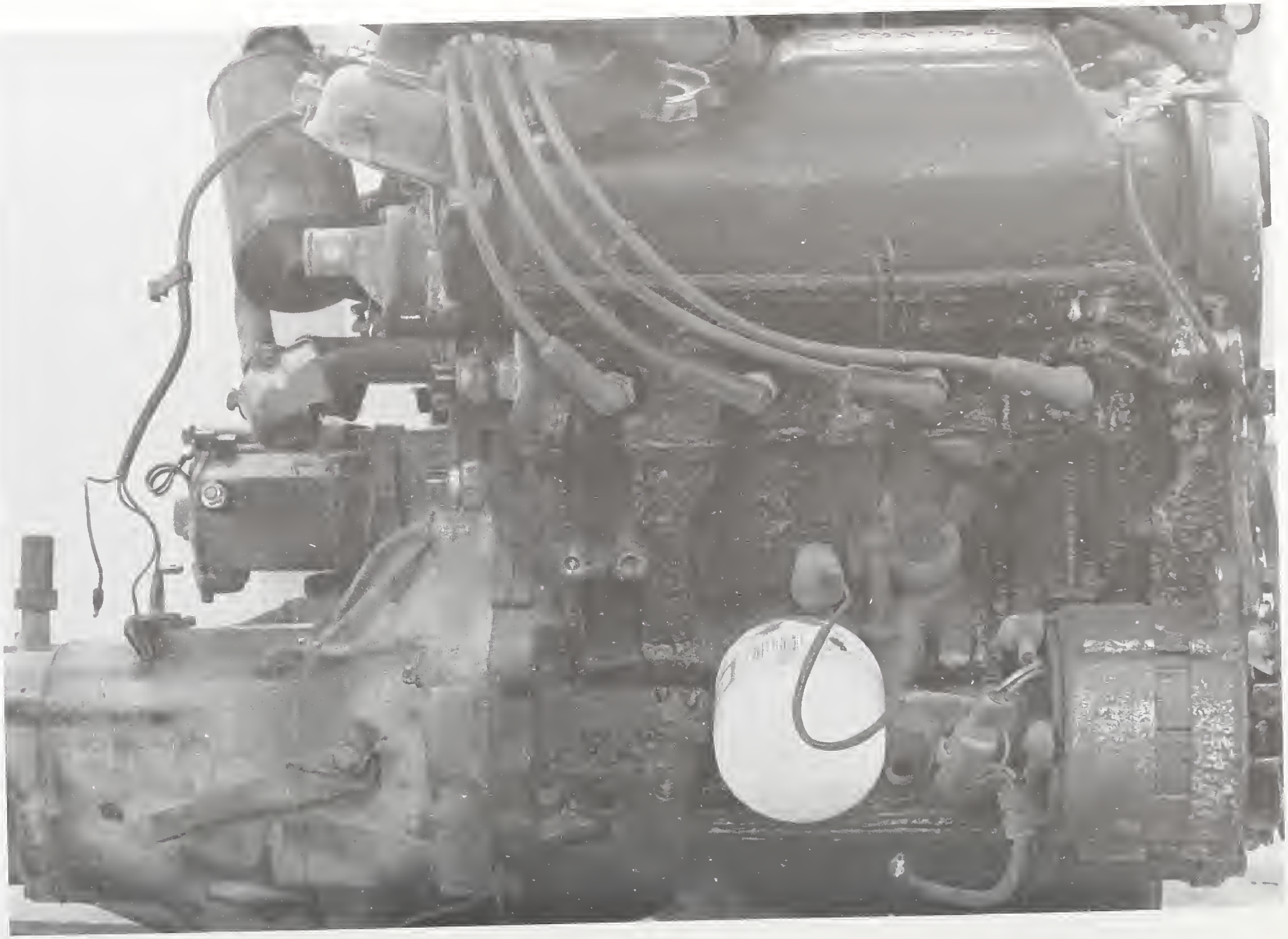


Figure 21. Engine side view.

Figure 22. Platform arrangement to measure mass.

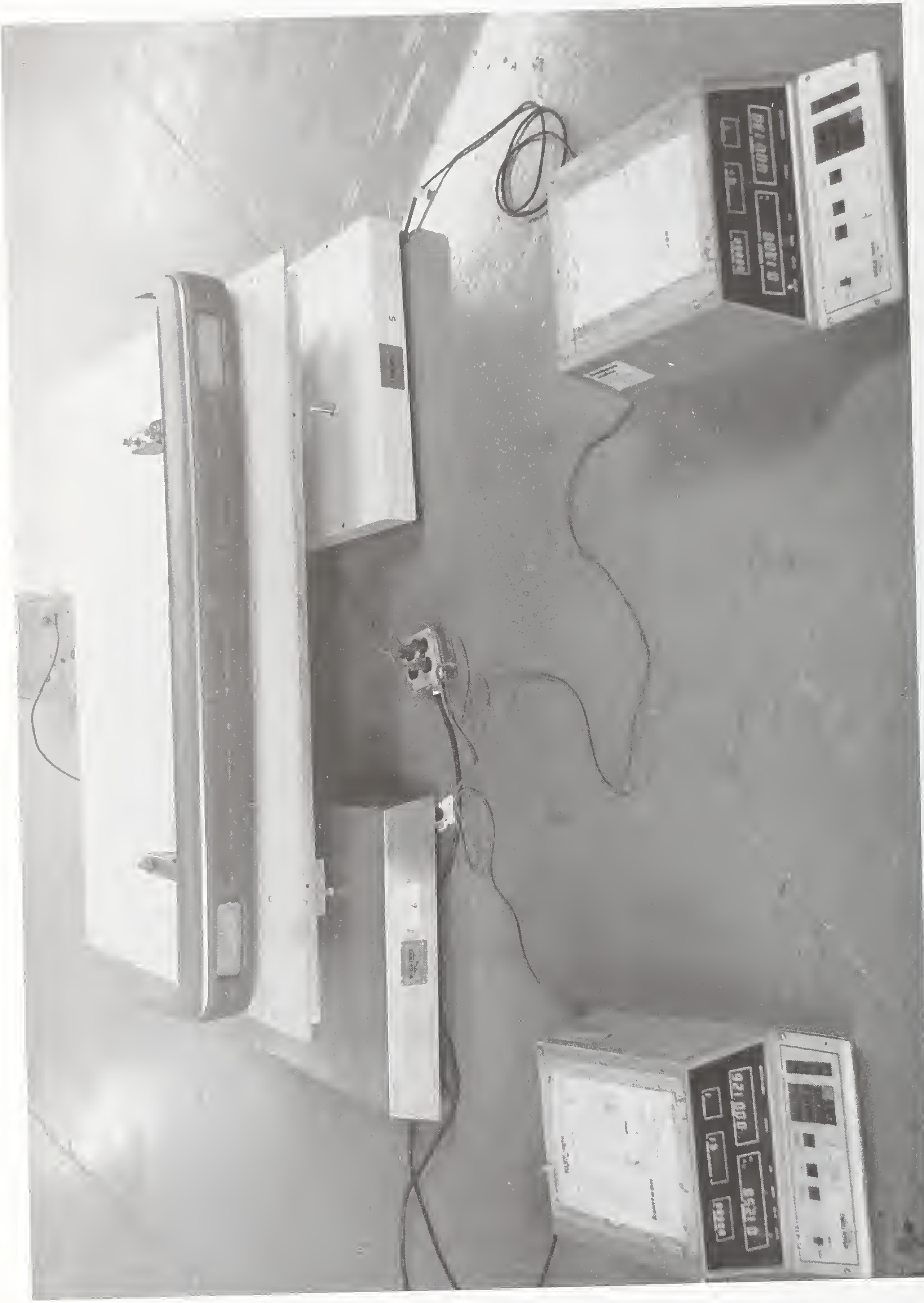


Figure 23. Bumper on weighing scale.

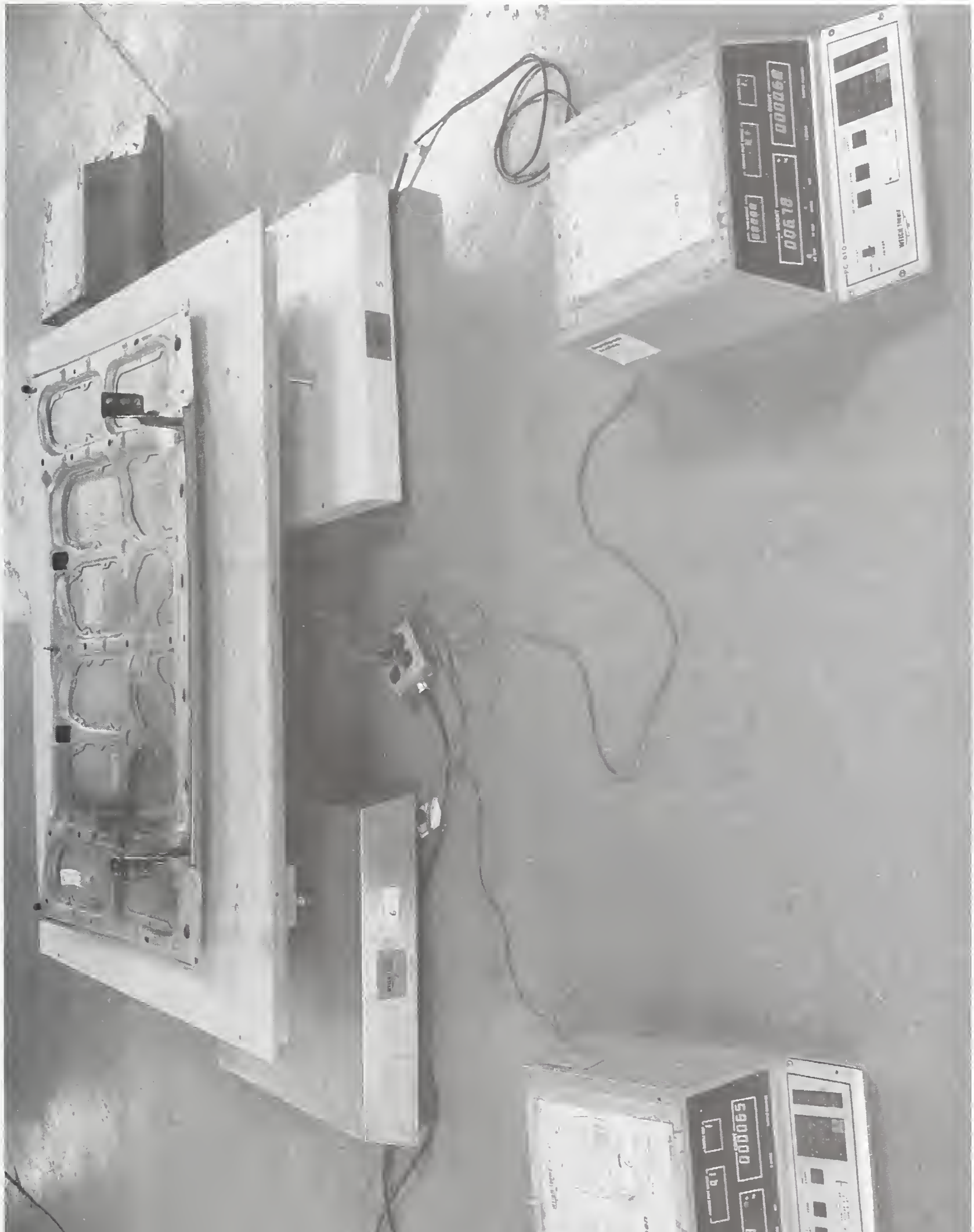


Figure 24. Hood on weighing scale.

FINITE ELEMENT IMPACT MODELING AND VERIFICATION

MODEL BUILDING METHODOLOGY

The finite element model of the Honda Civic hatchback was developed as a tool to evaluate the crash performance of highway sign posts and barriers. Frontal impact of vehicles with these structures is of interest. Therefore the front half of the car was modeled as a deformable finite element structure. The rear half was modeled as a rigid body. Mesh generation was performed in INGRID. Finite element analysis was performed using the DYNA3D non-linear structural dynamics code. The following system of consistent units was used in the finite element model.

Length	:	millimeters
Mass	:	Metric tonnes (1000 kg)
Time	:	Seconds
Force	:	Newtons
Stress	:	N/mm^2 (Mega Pascals)
Density	:	$Tonne/mm^3$

The finite element model of the car was created as follows. The major components of the vehicle were digitized using the Tarus digitizing machine. The vehicle was gradually disassembled as external parts were digitized first and then removed in order to reach internal parts. The geometries of regions inaccessible to the Tarus machine, and simple parts such as suspension bars, were manually measured. The surfaces formed by the digitized points were defined by line data contours in International Graphics Emulation Standard (IGES) format. The IGES data for each digitized part was converted to a PATRAN data base. PATRAN is the name of the software for which no acronym exists. The parts were visualized in PATRAN. This process allowed visual inspection of the part geometry so that a suitable INGRID model of the part could be synthesized. A brief description of the mesh generation procedure used in INGRID is discussed in the next section. More detailed information is available in the cited reference 1.

INGRID MESH GENERATION

The vehicle parts are defined sequentially in the INGRID input data file. Each definition contains required INGRID commands to recreate the finite element mesh of that particular part. Appropriate parts are joined to each other using the "standard part tolerance" (stp) command to equivalence nodes (which was the only tolerancing command effective in the INGRID 1992a version). A tolerance of 10 mm was used. Mesh refinement of adjoining part edges were carefully adjusted so that when the parts are toleranced together, the structural effects of bolts and welds are appropriately modeled. The bolt and weld information gathered during vehicle disassembly was evaluated to determine the nodal tolerancing requirements and spacing between parts. The INGRID input file also contains data cards that define the thickness, density, and material properties of each part. The INGRID input file is executed to create a DYNA3D input data file. Some simple but crucial modifications have to be made in this DYNA3D input file. These modifications cannot be defined or are improperly defined in INGRID and are specified in detail in a section that follows.

Each sheet metal part that was meshed was visualized as an assemblage of planar and/or curved four sided regions. The vertices of the regions were defined using the measured data points. Beam and truss elements were used to model engine tiebars, suspension, steering, and driveline components. Figure 25 shows a perspective view of the finite element car model. Figure 26 shows the vehicle with the hood removed.

INGRID PARTS LISTS

The following parts were defined in the INGRID input data file and are listed in the order in which they are numbered:

(01) wheel house

(02) shock tower

(03) upper rail

(04) inner frame rail 2 (rounded portion)

(05) inner frame rails 2 (added channel part)

(06) firewall

(07) cradle

(08) cradle forward bracket

(09) cradle rear bracket

(10) cowl

(11) floor pan (part 1)

(12) floor pan (part 2)

(13) framerail to floorpan

(14) hinge outer

(15) hinge pillar (square plate reinforcement)

(16) h-pillar inner

(17) lower cross bar

(18) upper tie bar

(19) head lamp panel

(20) firewall bulge

(21) firewall engine mount

(22) front framerail engine mount

(23) left framerail engine mount

(24) left swaybar bracket

(25) right lower swaybar bracket

(26) right upper swaybar bracket

(27) radiator

(28) engine

(29) ea-unit

(30) outer bumper

(31) inner bumper

(32) battery

(33) fender

(34) windshield

(35) steel tire

(36) rubber tire

(37) beam: front stub axle carrier

(38) beam: windshield top edge header

(39) beam: front suspension lower arms

(40) beam: engine drive shafts

(41) beam: swaybar

(42) rear profile

(43) beam: engine tie bar beams

(44) beam: engine tie bar trusses

(45) beam: steering linkage

(46) cradle to floorpan joiner

(47) rail reinforcement

(48) B-pillar beam

(49) cowl2, edge reinforcement

(50) cowl3, windshield wiper motor bracket

(51) hood latch bracket

(52) beam: rear axle

(53) hood

(54) beam: front shock absorber

(55) mass box (for point masses)

(56) modesty panel

(57) door beam

(58) brake booster

(59) brake master cylinder

(60) fan-1

(61) fan-2

(62) a/c freon tube

(63) beam: freon cylinder attachment tubes

(64) stone guard

(65) dummies

(66) pole

INERTIAL PROPERTIES OF THE MODEL

The finite elements account for approximately 50 percent of the unladen vehicle mass because only the front half of the vehicle is modeled in detail. Therefore discrete masses are defined in the INGRID model so that the DYNA3D vehicle model has correct mass, C.G., and principal moments of inertia. The method of calculating these discrete masses is described below.

Target Mass and Inertia

Mass of vehicle without dummies ("test mass without dummies" in test report (3))

M = .794 Tonne

C.G. Location from test report[3]
Origin = center of front axle line

xcg = 866 mm

ycg = -30 mm

zcg = 261 mm

Moments of Inertia (From TRC measurements - sprung and unsprung mass)

Ixx (Roll) = 2.514×10^5 Tonne.mm^2

Iyy (Pitch)= 11.271×10^5 "

Izz (Yaw) = 12.216×10^5 "

Model mass and inertia without point masses

M = .470 Tonnes

xcg = 270 mm

ycg = -32 "

zcg = 186 "

Ixx = 1.113×10^5 Tonne.mm^2

Iyy = $4.185 \mathrm{x} 0^5$ "

Izz = 4.83×10^5 "

Calculated point mass and inertia to reach targets

M = .324 Tonnes

xcg = 1731 mm

ycg = -26 "

zcg = 369 "

The calculated point mass is divided into eight equal parts and placed at the vertices of a hexagonal lattice, whose centroid is located at the point mass C.G.. This mass lattice provides the required increase in the three principal moments of inertia. The half dimensions of this lattice are as follows:

1/2*dx = 867 mm

1/2*dy = 512 "

1/2*dz = 388 "

The eight mass lattice is attached to the rigid body defined for the rear part of the vehicle. The mass, C.G., and the three principal moments of inertia of the model were then verified to be equal to the respective target values.

Dummy masses

The C.G. for two dummies were positioned at the following visually estimated locations.

Dummy position in car coordinates

x = 1200 mm

y = 310 mm passenger, -310 mm driver

z = 200 mm

The following dummy masses were used.

Driver = 76 kg (.076 Tonne)

Passenger = 1 kg (.001 Tonne) due to unrestrained dummy.

The mass properties of the final model includes the effect of the pole. The pole was not included in any of the previous mass property calculations discussed above.

CRASH TEST OVERVIEW

The finite element model was evaluated by comparing its response with results from a 8.88 m/s^2 (20 mi/h) pole impact crash test of a Honda Civic hatchback. A .2032 m (8 in) diameter rigid pole was offset .1778 m (7 in) to the right side (starboard) of the vehicle centerline. However the actual impact location was later found to be .1143 m (4.5 inches) starboard. The test procedure and results are discussed in detail in the cited reference.[3] The two major response parameters that were considered in assessing the performance of the finite element model were pole impact force and pole intrusion into the vehicle. Pole impact force was measured with two load cells at the pole attachment locations. Vehicle intrusion had been determined by film analysis.[(3)]

DYNA3D MODEL SETUP

The 8.88 m/s^2 (20 mi/h) pole impact was simulated using the Honda Civic finite element model. Eleven slide surfaces were defined. These interfaces were chosen based on prior experience in structural crash analysis, as well as on several preliminary simulations. These simulations were performed to evaluate deformation patterns and resulting contact between parts.

The DYNA3D slide interfaces defined in the model are listed below. The interface type is given within parentheses.

Interface 1 (type-4) Bumper bracket self contact.
Interface 2 (type-4) Radiator front and back surface self contact
Interface 3 (type-4) Upper tie bar + hood contact
Interface 4 (type-4) Bumper + radiator front surface
Interface 5 (type-4) Radiator back surface + fans + engine + a/c freon tube
Interface 6 (type-4) Lower cross bar + cradle front arm + cradle + engine
Interface 7 (type-4) Hood + cowl
Interface 8 (type-3) Pole + car (lower cross bar, radiator, bumper, upper tie bar, hood, swaybar, swaybar brackets, cradle front edge)
Interface 9 (type-4) Stone guard + cradle
Interface 10 (type-4) Brake master cylinder + engine
Interface 11 (type-4) Modesty panel + lower cross bar

Sliding interfaces are defined in INGRID by identifying the required region within a part. Each surface is tagged as either a master surface or a slave surface. For a type-4 interface INGRID defines four noded contact segments on all elements within a selected region. The vehicle to pole contact was defined as a type-3 interface. Master segments were defined on the pole and slave segments were defined on the vehicle. Planar stonewalls can be defined in INGRID version 1992a. Nodes for stonewall interaction are defined by surface or volume regions. The ground surface was defined as a stonewall interacting with nodes on the tires.

SIMULATION RESULTS

Preliminary model simulations were performed using the single precision version of DYNA3D. Many iterations were performed to ascertain realistic model response. Based on these results several revisions were implemented. The final validation simulations were performed on a Cray YMP8, using a double precision version of DYNA3D. It had been determined that the single precision version that had been made available (version 3.3.1) could accumulate round off errors in large models that could lead to sudden termination of the simulation. The results are shown in figures 27 to 55. These figures show the deformation of the vehicle during the impact.

The slide surface force of the vehicle to pole interaction had been determined to be incorrectly calculated. However the pole force was indirectly estimated using two different methods. In the first method, the deceleration of the undeformed rear part of the vehicle was multiplied by the total mass to calculate the force acting on the vehicle. The deceleration of a node on the floorpan was chosen for this purpose because the floorpan does not deform during the impact. This deceleration is shown in figure 47. Figure 48 shows this curve after the "smooth" option is used in TAURUS (TAURUS is the name of the software, for which no acronyms exists). The second method of estimating the pole force was to use the rigid body acceleration in the x-direction made available from Taurus' "gtim 7" command, multiplied by the vehicle mass. This deceleration is shown in figure 49, and smoothed in figure 50. Figure 51 shows the fore-aft (x-direction) displacement of node 2696 on the floorpan, which is representative of the pole intrusion into the vehicle.

COMPARISON WITH TEST DATA

Figure 52 shows the pole impact force as measured by load cells during the crash test. The two estimates of the pole force based on the accelerations of figures 48 and 50 are shown compared with the test data in figure 53. Figure 54 shows the vehicle intrusion which had been determined by film analysis. Figure 55 shows the x-displacement of node 2696 on the floorpan compared with the pole intrusion determined from film analysis of the test. Figures 56 and 57 show photographs of the Honda Civic after the pole impact test.

The simulation results show deformation patterns similar to those seen in the high speed films of the actual crash test. The agreement between simulation and test is especially noteworthy for the following parts. These are parts where the post impact shape is clearly seen in the films, or described in the crash test report.[3] The deformation patterns apply to a pole impact at .1143 m (4.5 in) to starboard.

(1) Bumper (film): The region of impact caves in, pivoting about the two bracket attachments. The outer ends are turned forward due to the pivoting action.

(2) Hood (film): The hood buckles and bends upwards in the region immediately behind the pole, and tapers off toward the sides.

(3) Wheels (film): The orientation of the front wheels does not change appreciably.

(4) Cradle (report): The cradle, which connects the lower cross bar in front and the floorpan, bends downwards due to compressive loading.

(5) Radiator fans (report): Parts of the fan shroud get crushed between the engine and the perimeter.

(6) Driveshafts (report): The driveshafts (front wheel drive "half shafts") had been pulled out from the engine/transaxle. The amount of force needed for such a dislocation is unknown. It was deemed that this was not a significant aspect of the overall crash dynamics. Therefore the driveshafts were modeled simply as beam elements defined between nodes on the engine/transaxle and the wheels.

CONCLUSION

The overall performance of the model was considered satisfactory, and the comparison with test data was considered within acceptable limits for a modeling program of this nature. The results of this project have illustrated the feasibility of the vehicle data gathering methods that were employed, and the use of INGRID mesh generation and DYNA3D analysis to perform finite element vehicle crash simulation. The results have also shown that response details are captured in sufficient detail to be useful in optimal design of roadside safety structures.

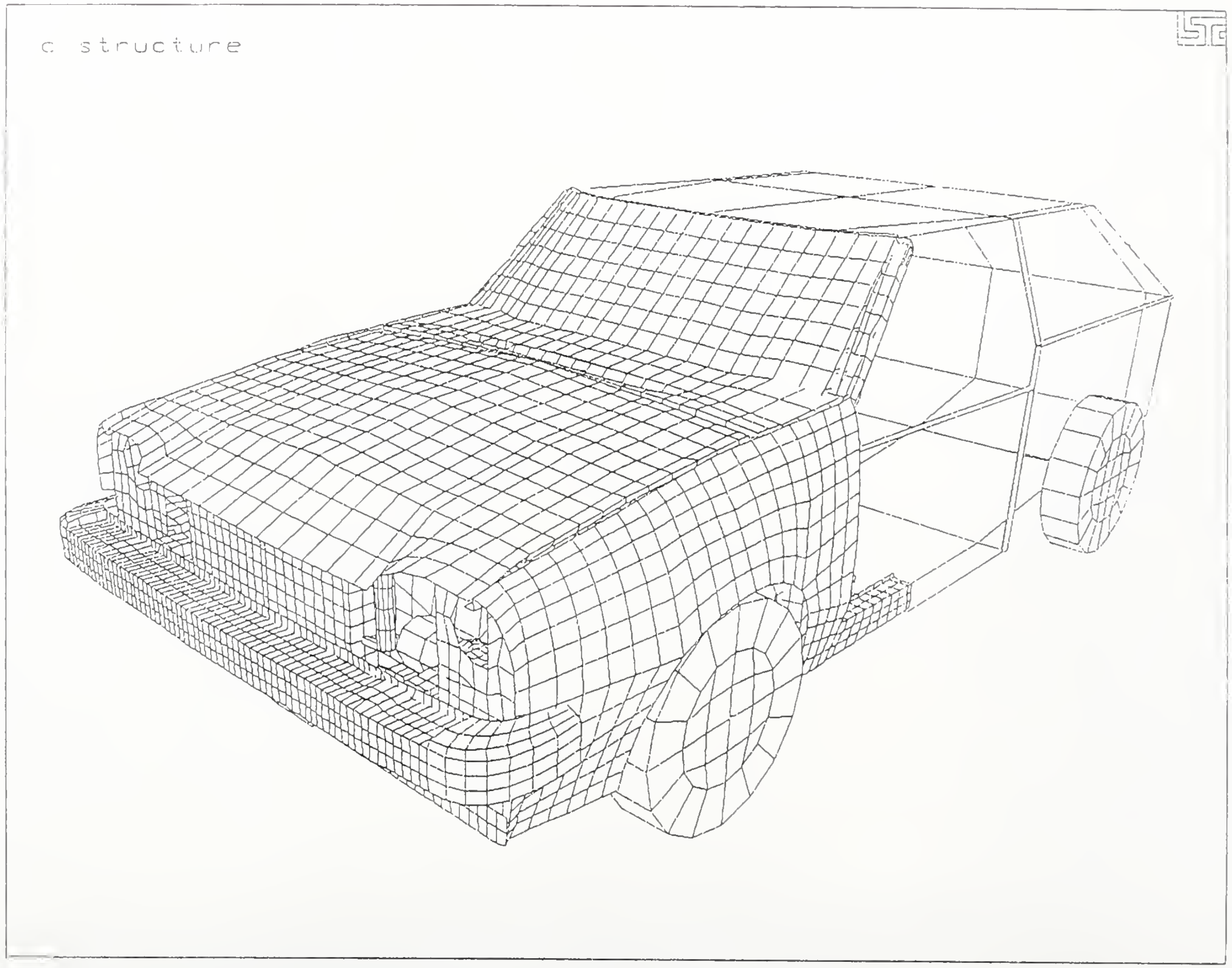


Figure 25. INGRID finite element model of vehicle.

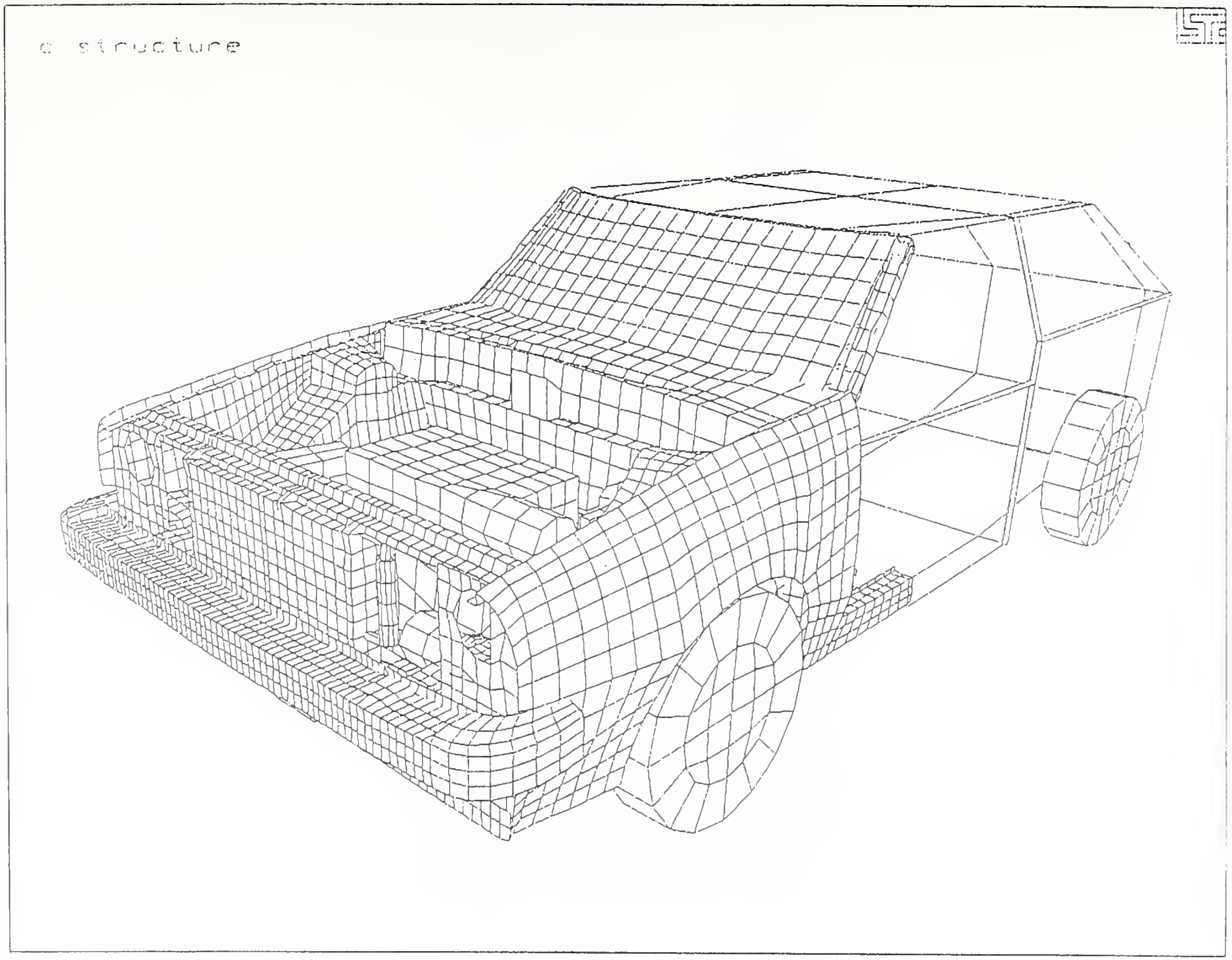


Figure 26. INGRID finite element model of vehicle, hood removed.

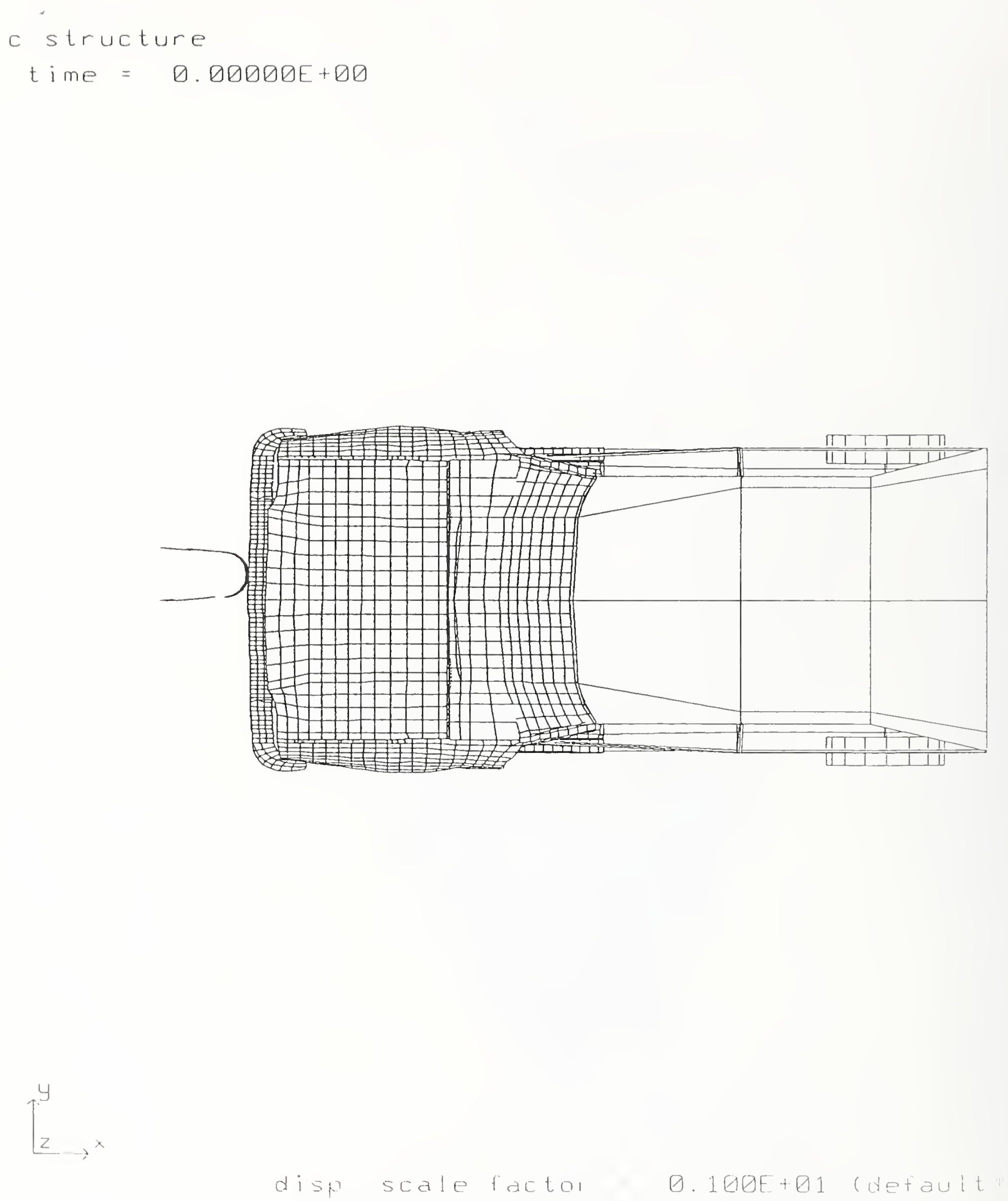
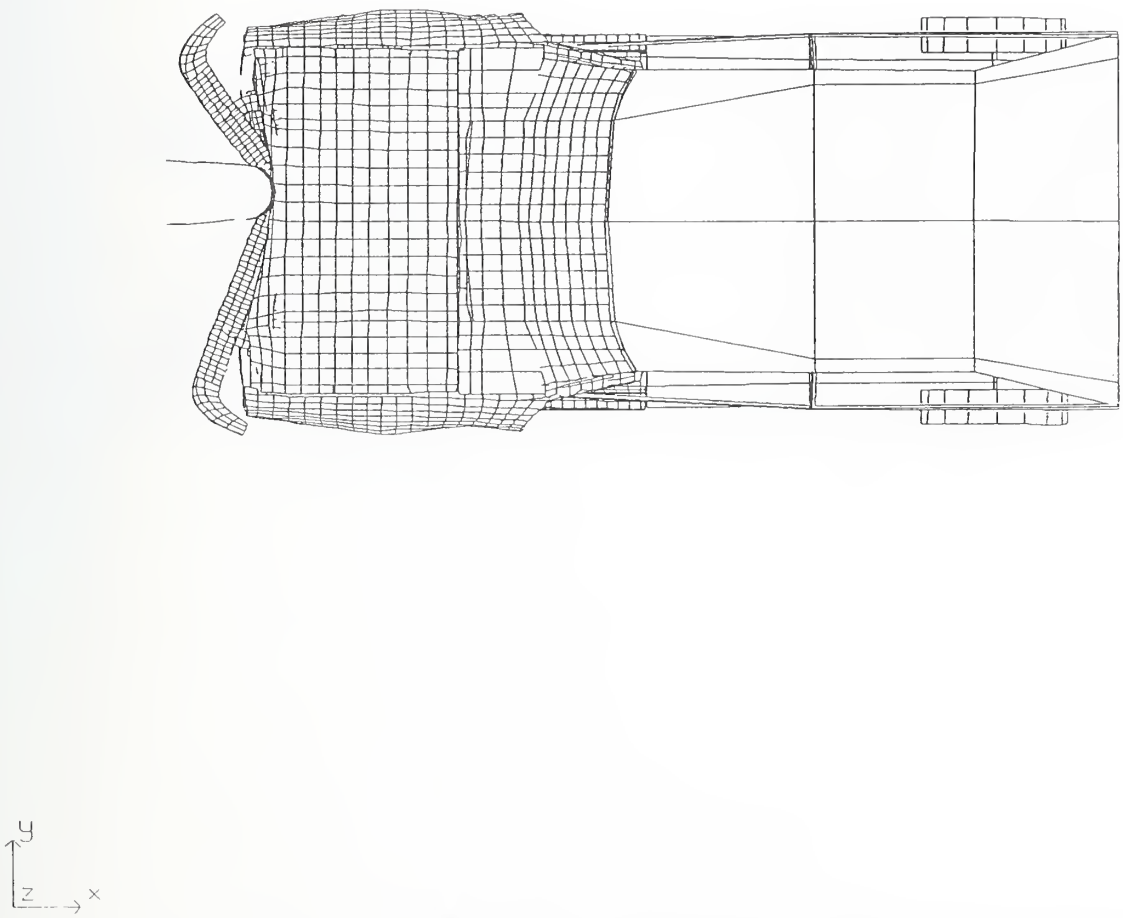


Figure 27. Top view 0 ms.

c structure
time = 0.30000E-01



disp. scale factor 0.100E+01 (default)

Figure 28. Top view 30 ms

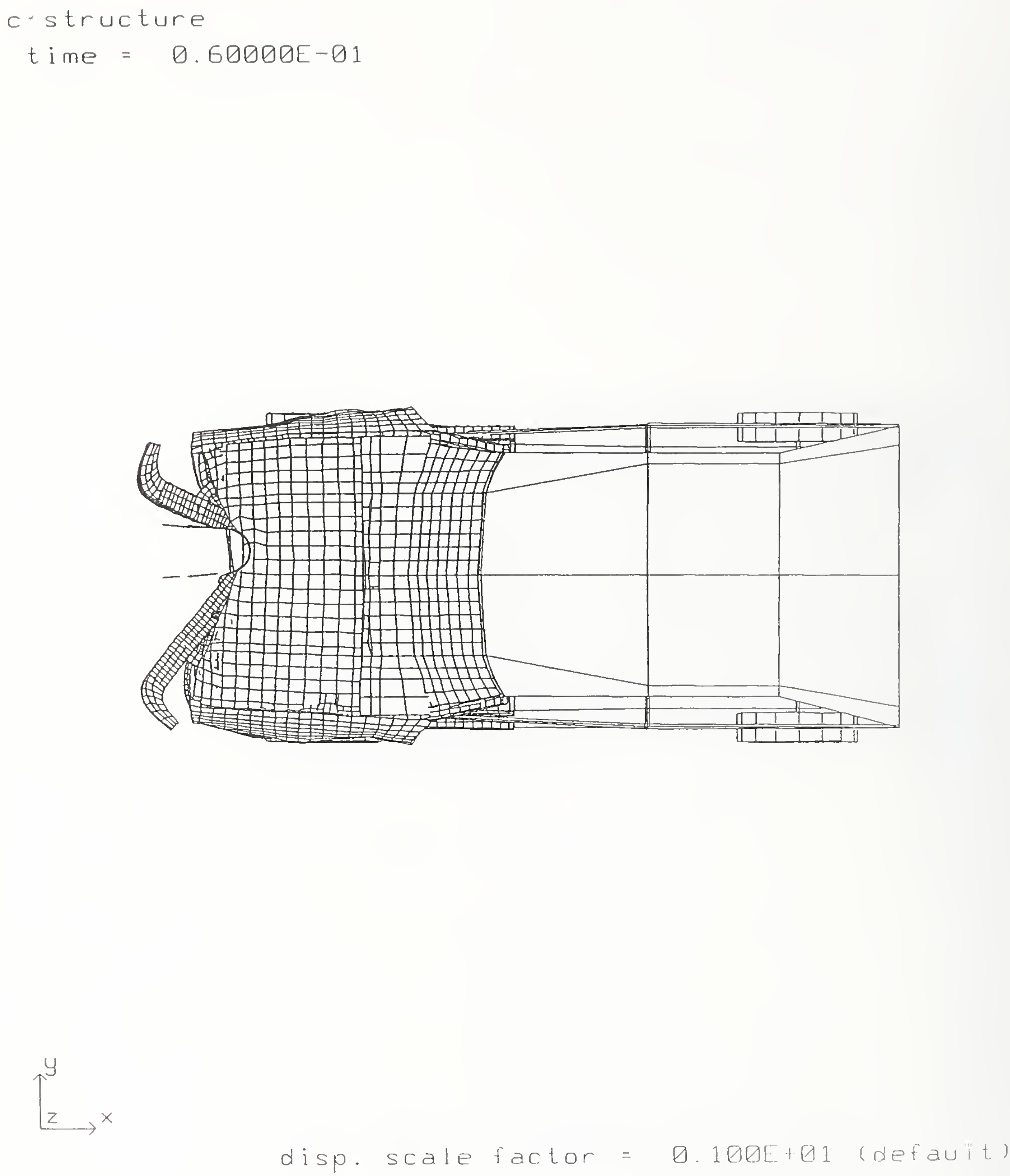


Figure 29. Top view 60 ms.

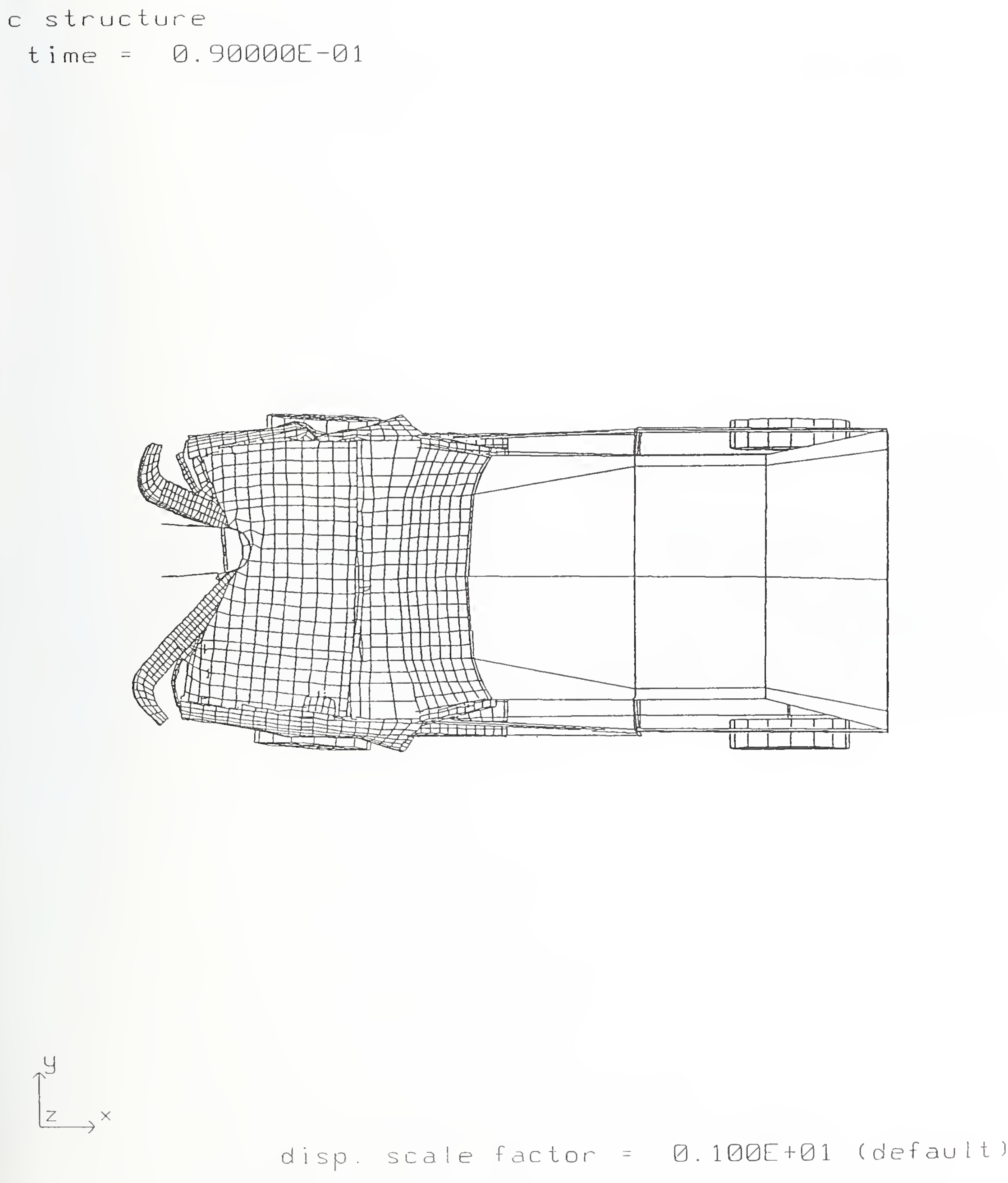


Figure 30. Top view 90 ms.

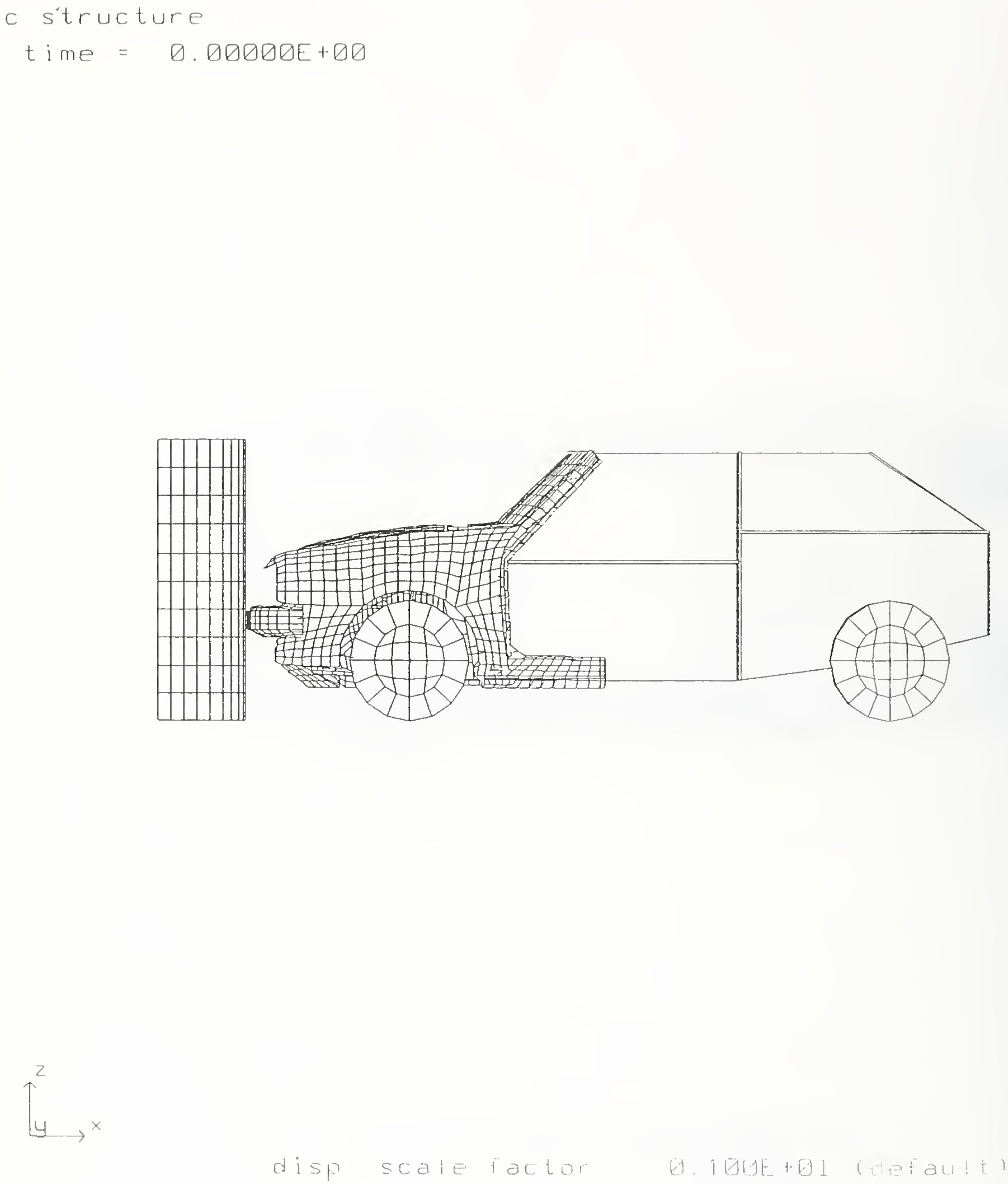


Figure 31. Side view 0 ms.

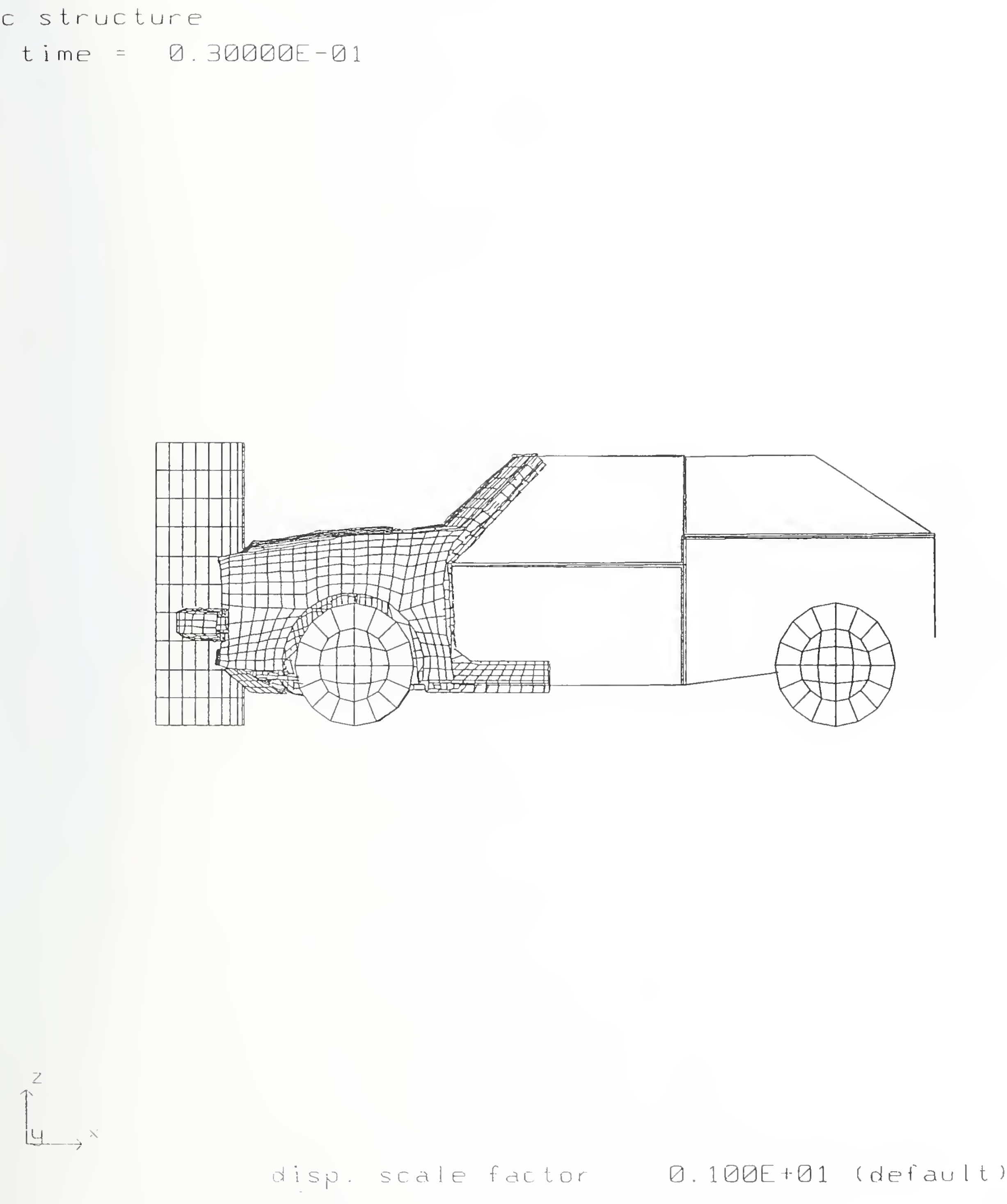


Figure 32. Side view 30 ms.

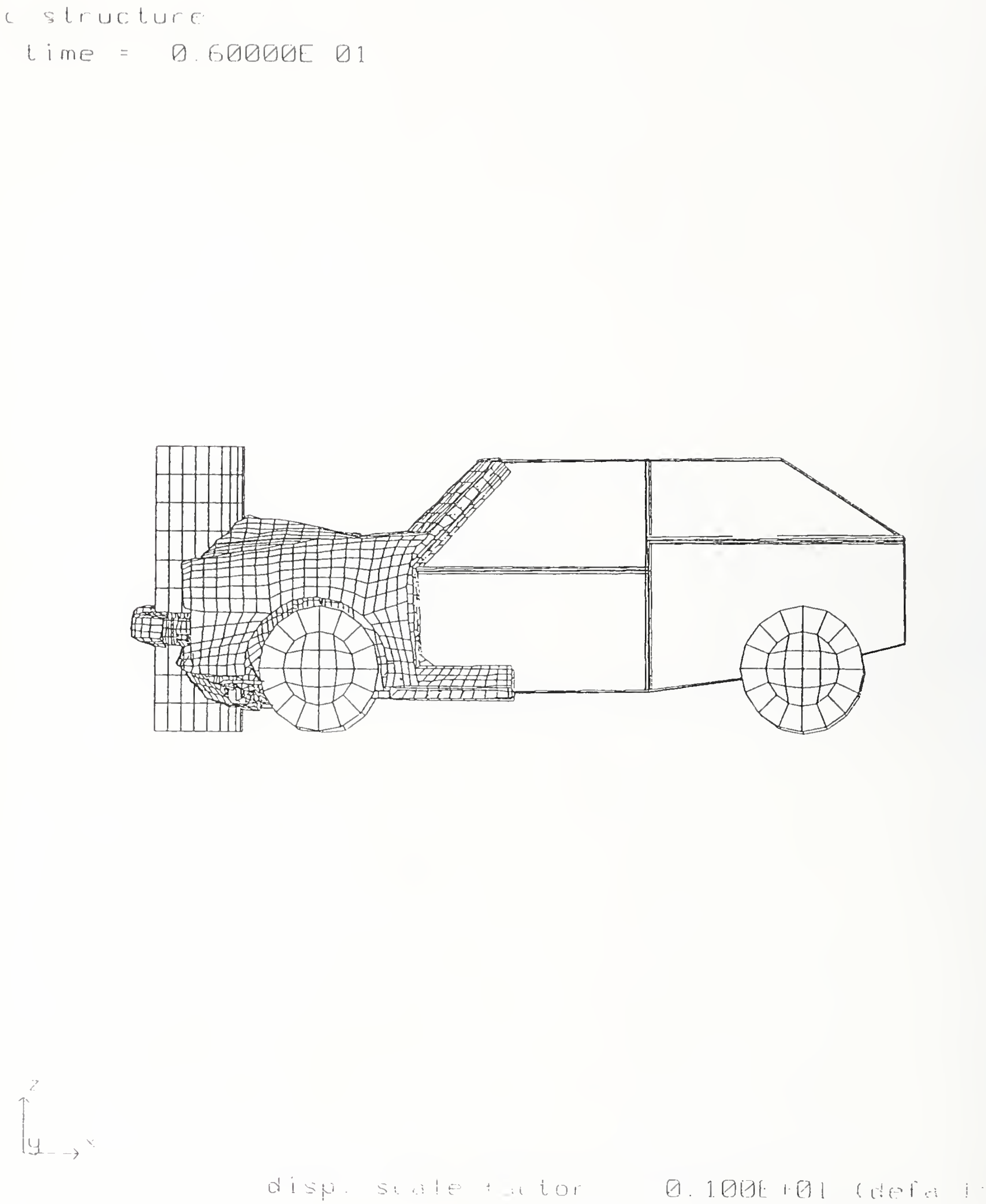


Figure 33. Side view 60 ms

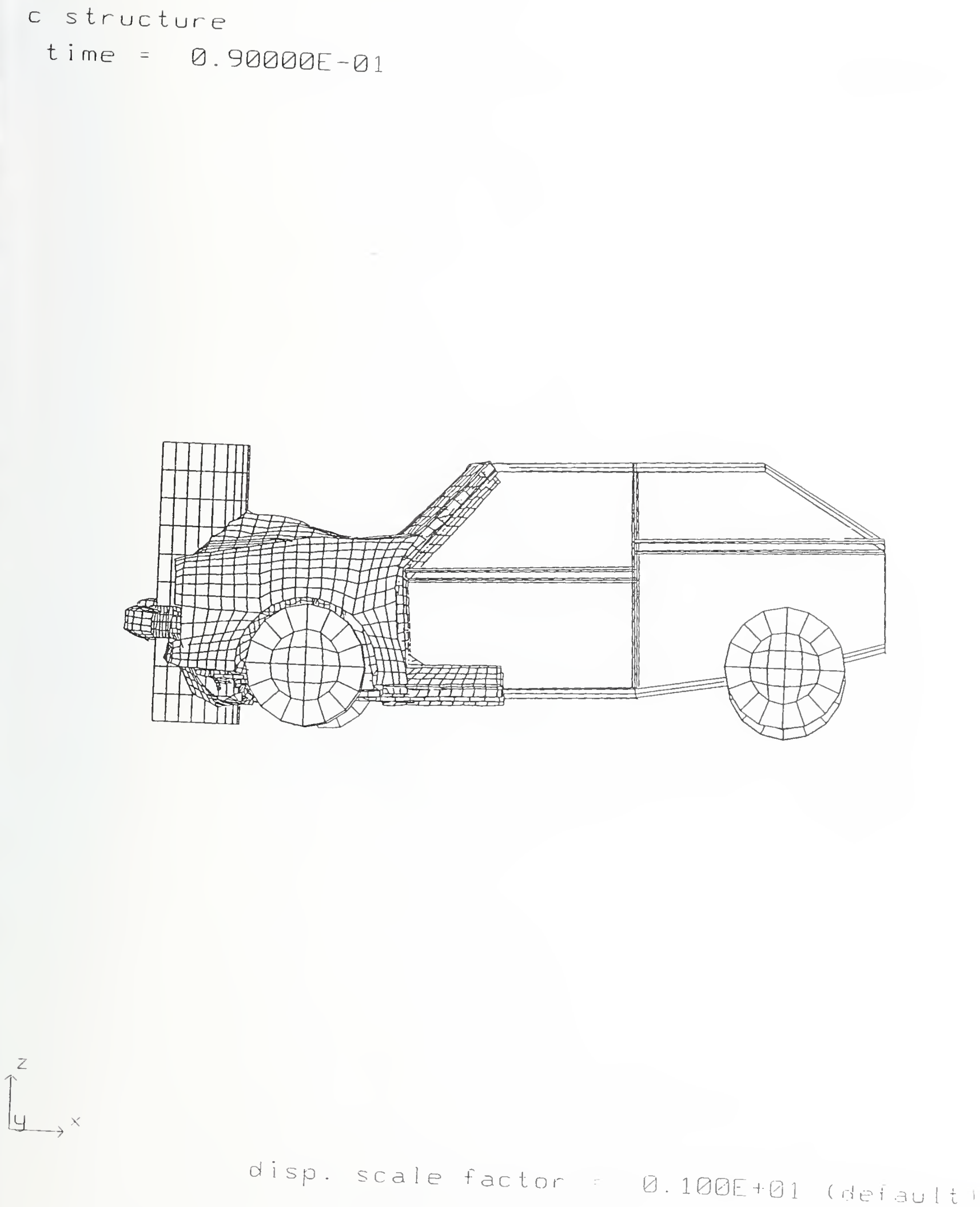


Figure 34. Side view 90 ms.

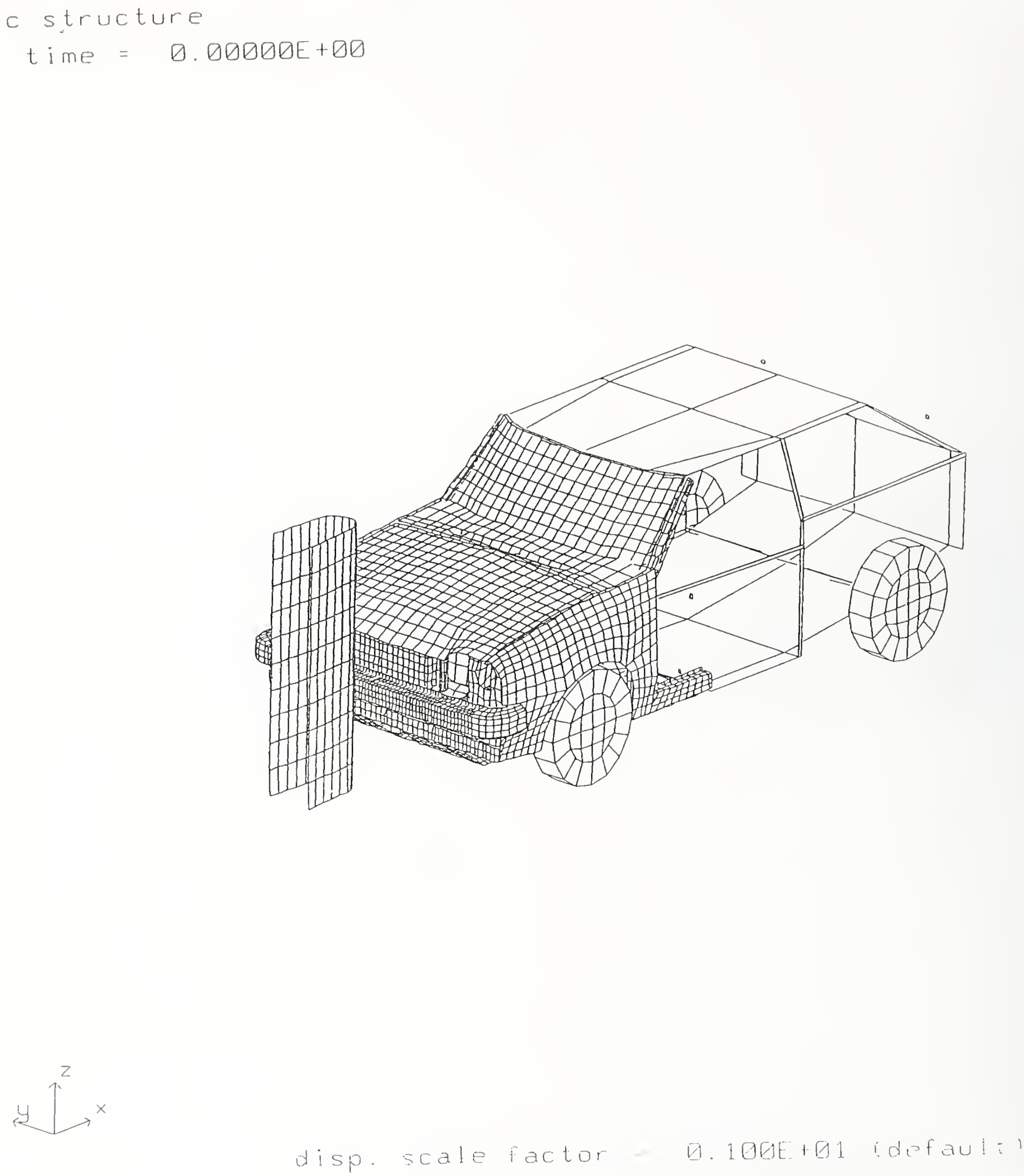


Figure 35. Oblique view 0 ms.

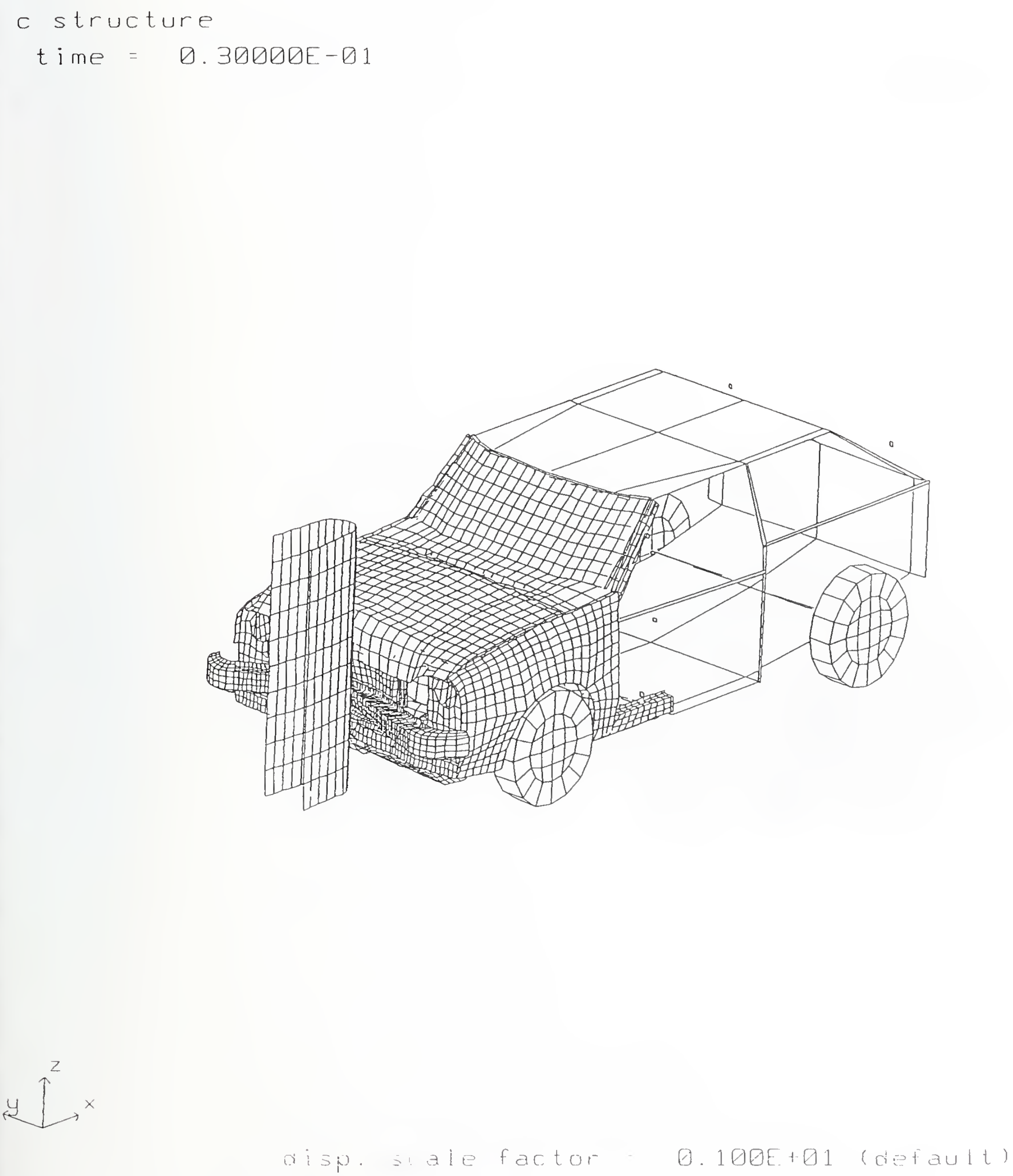


Figure 36. Oblique view 30 ms.

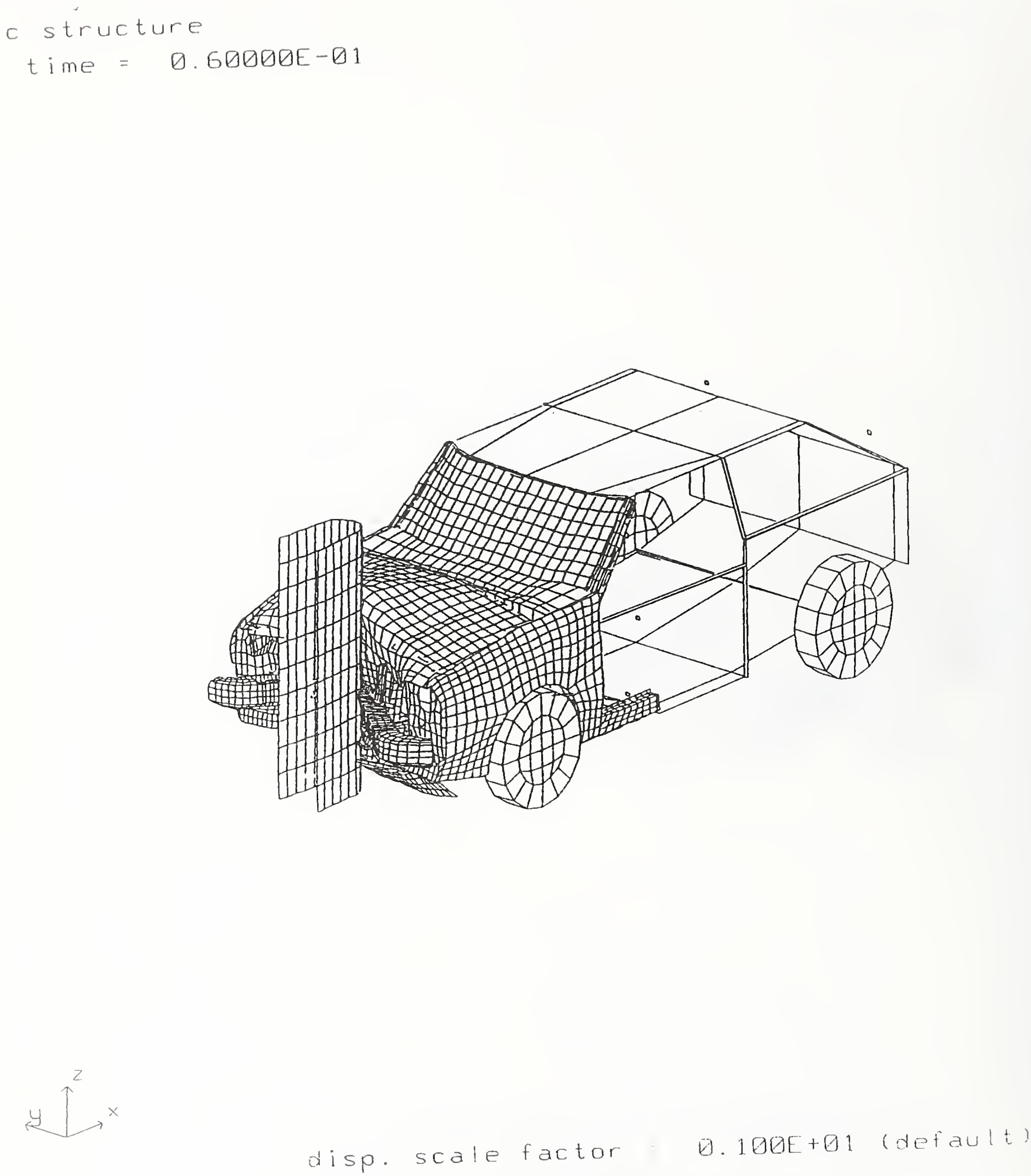


Figure 37. Oblique view 60 ms.

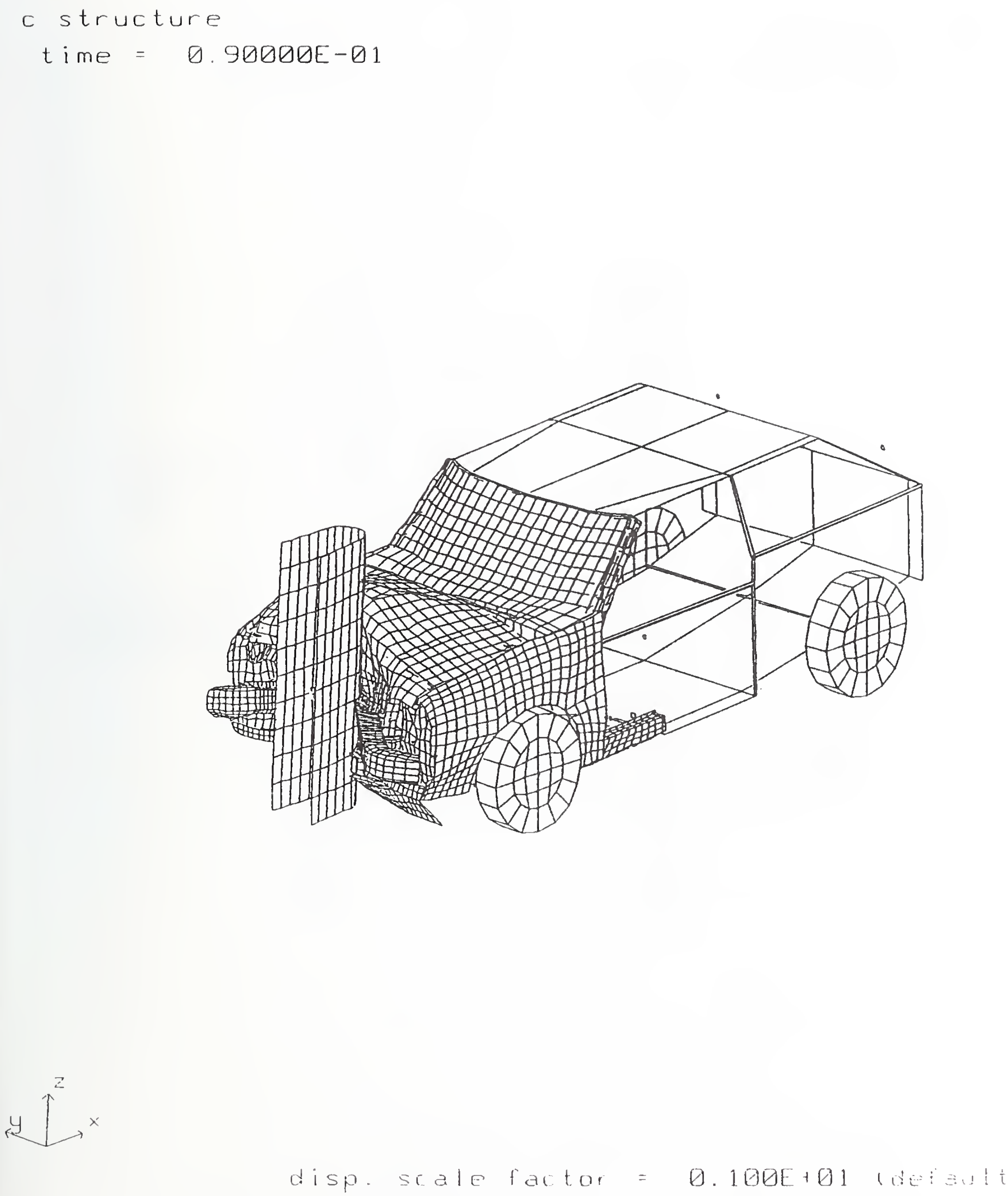


Figure 38. Oblique view 90 ms.

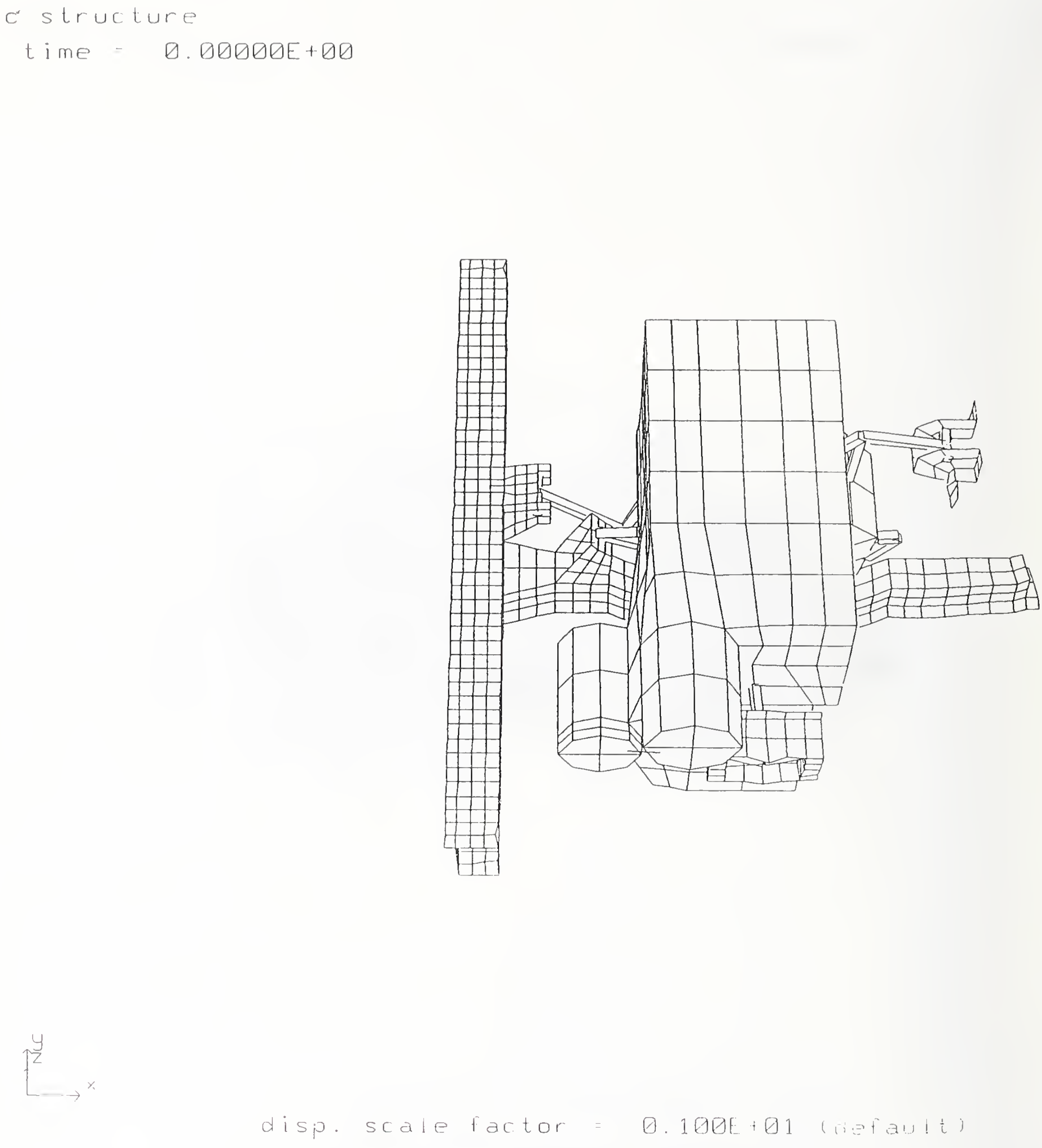


Figure 39. Engine and supports 0 ms.

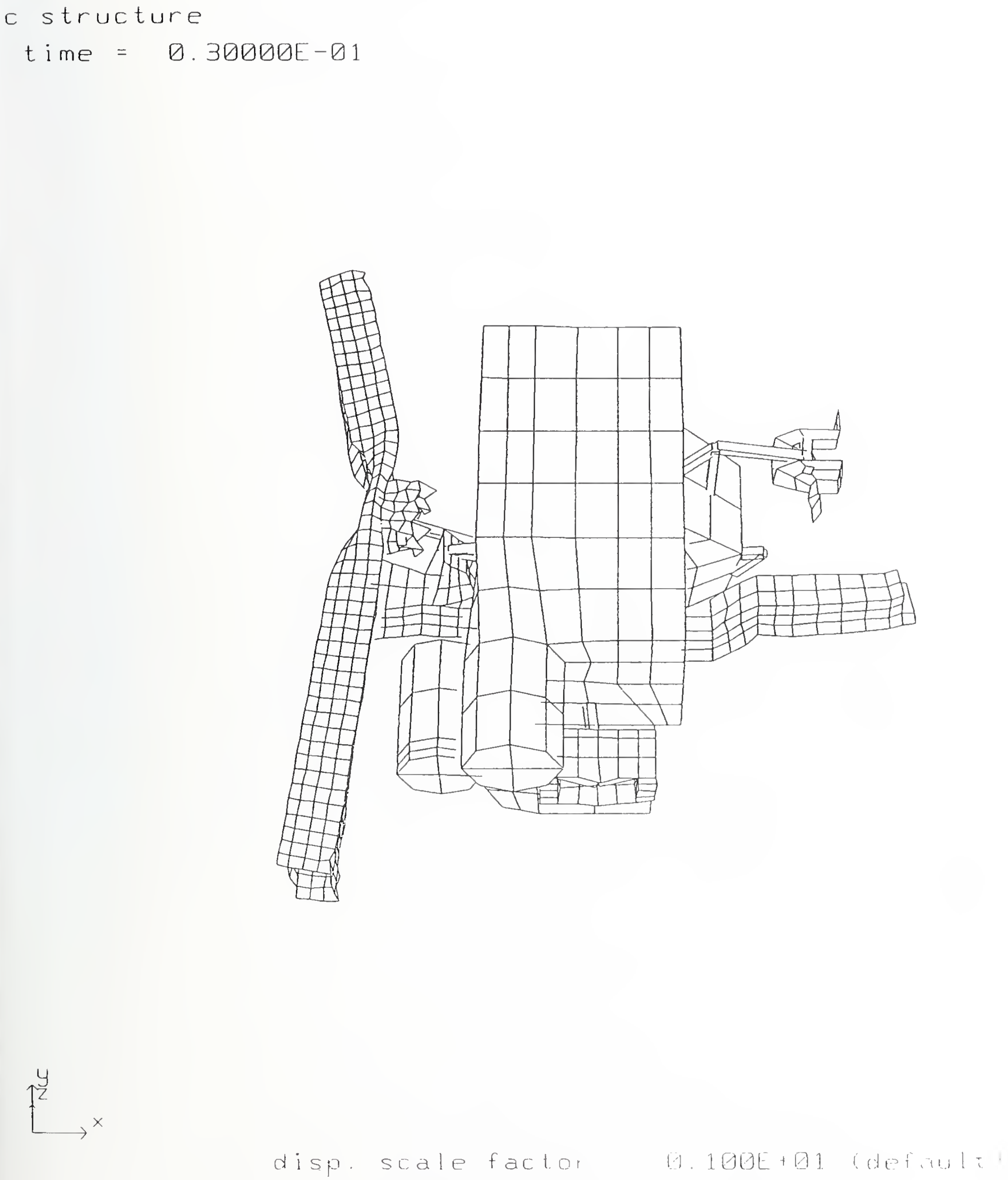


Figure 40. Engine and supports 30 ms.

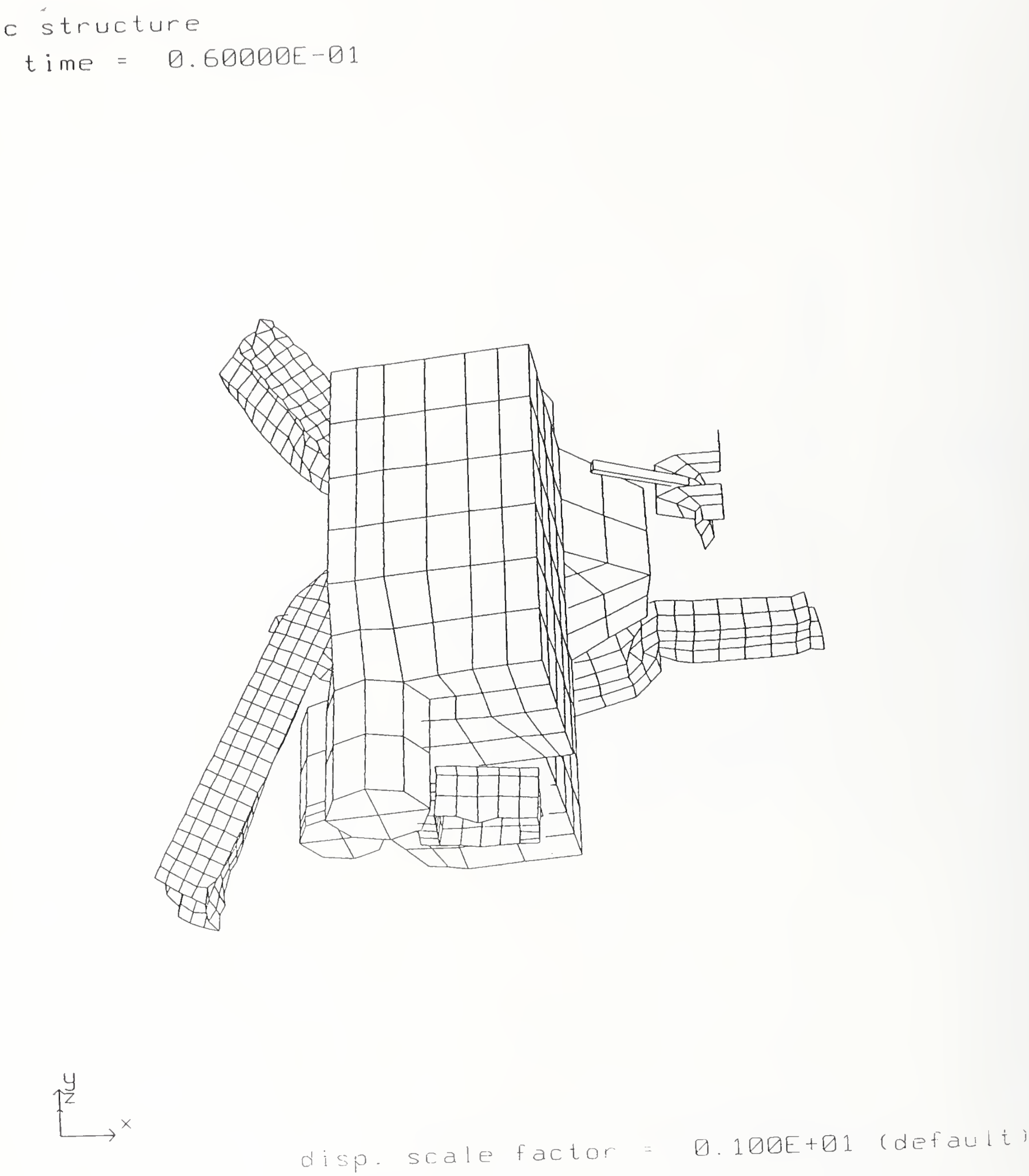


Figure 41. Engine and supports 60 ms.

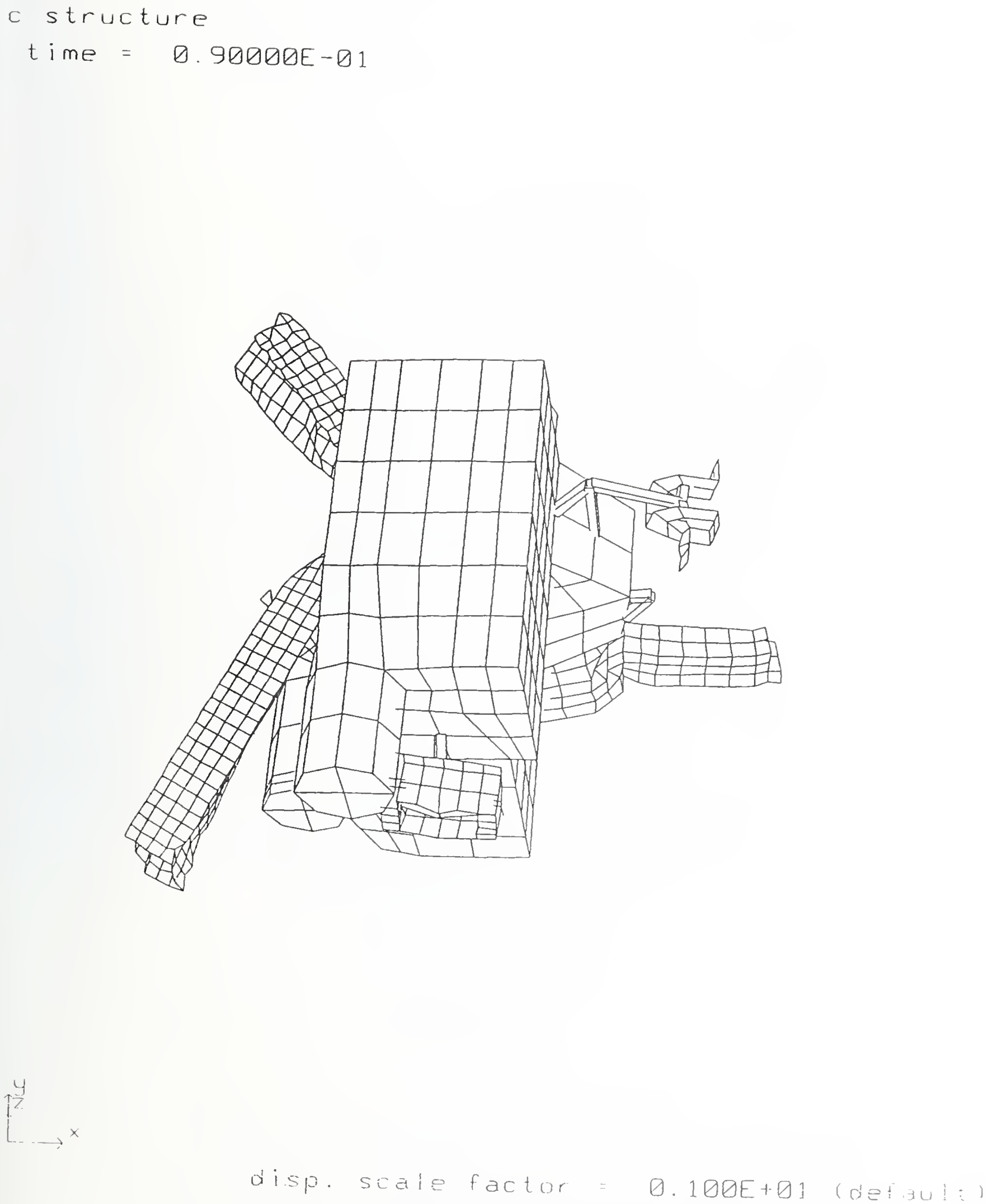


Figure 42. Engine and supports 90 ms

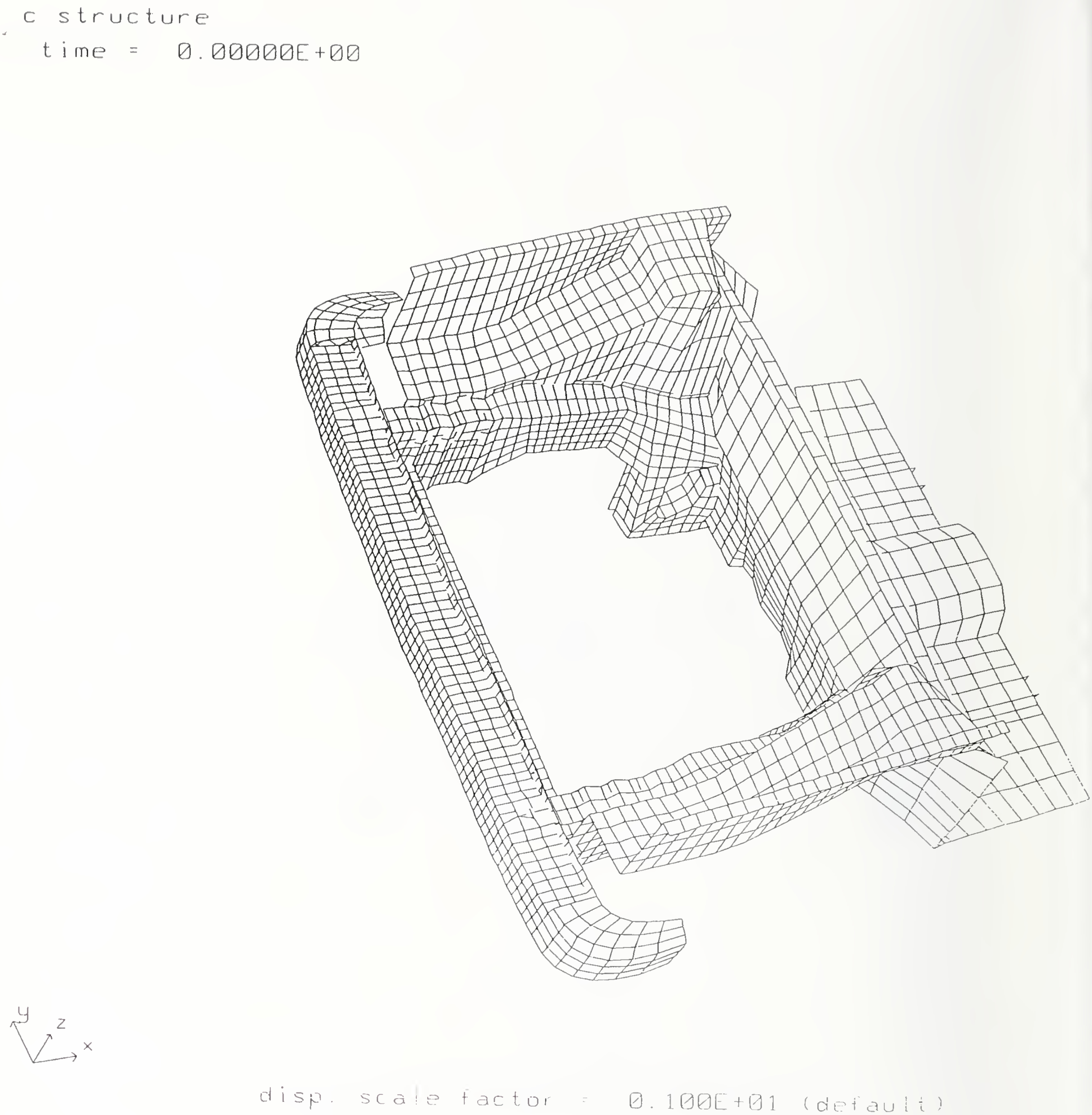


Figure 43. Front structure 0 ms.

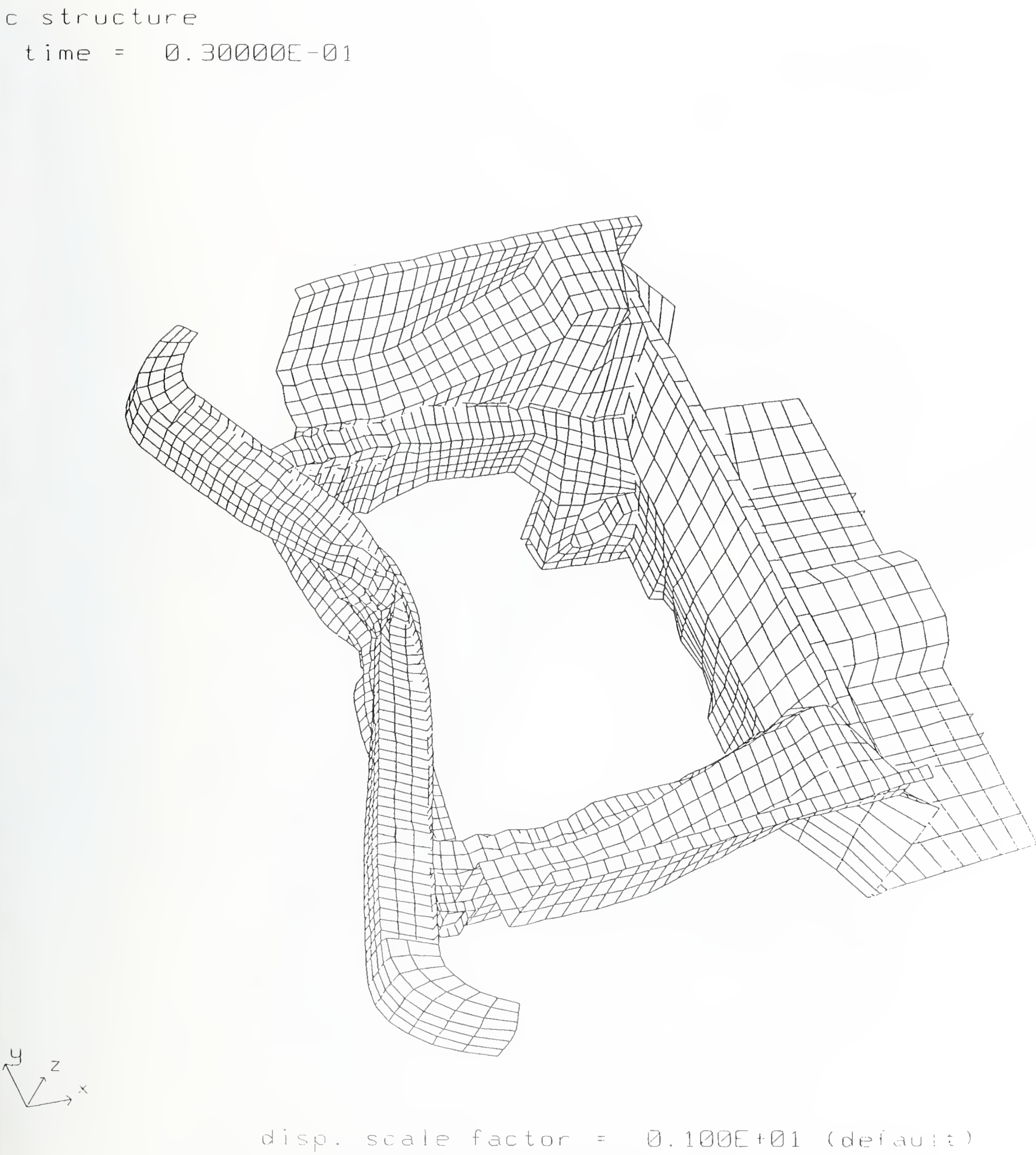


Figure 44. Front structure 30 ms.

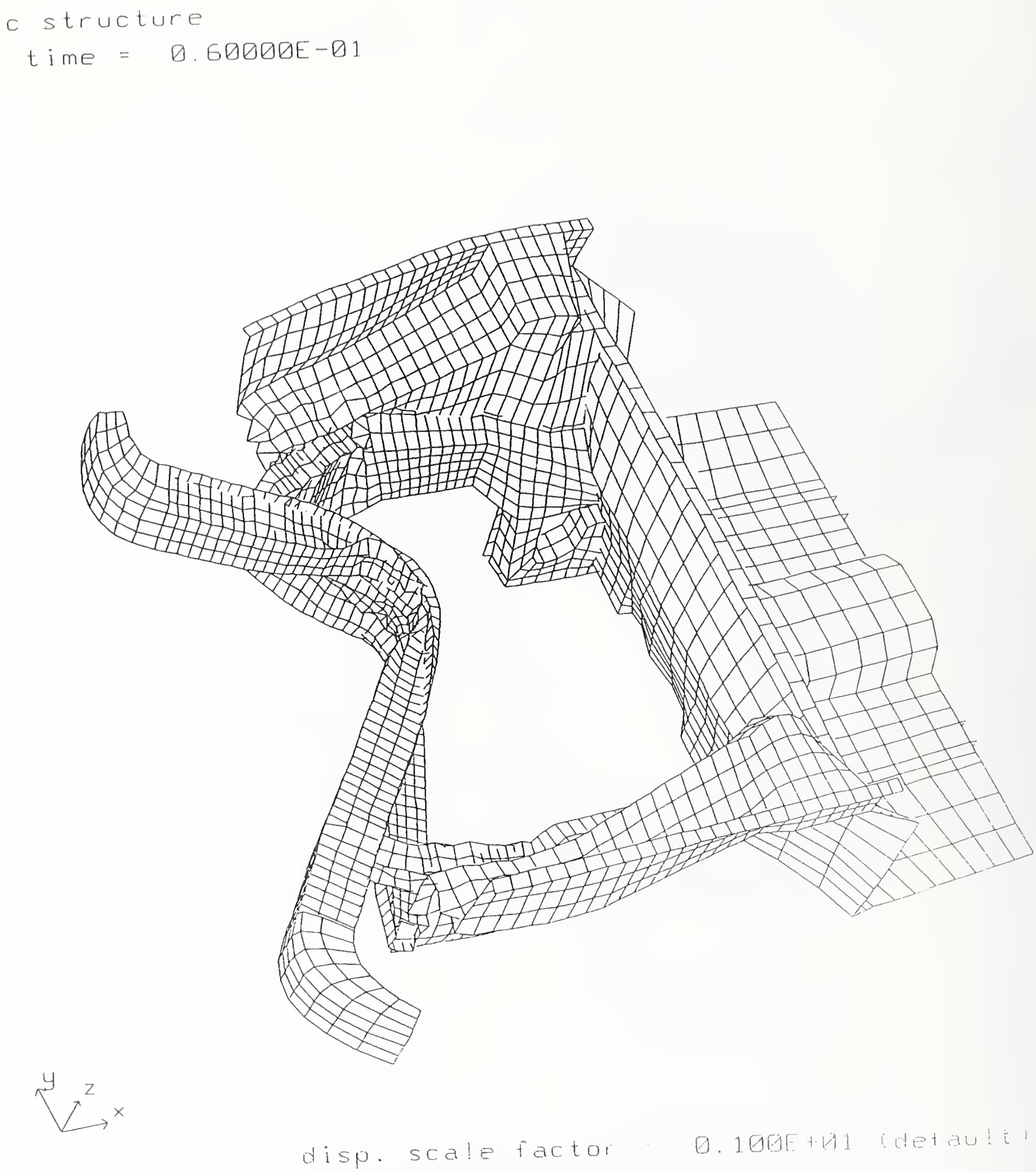


Figure 45. Front structure 60 ms.

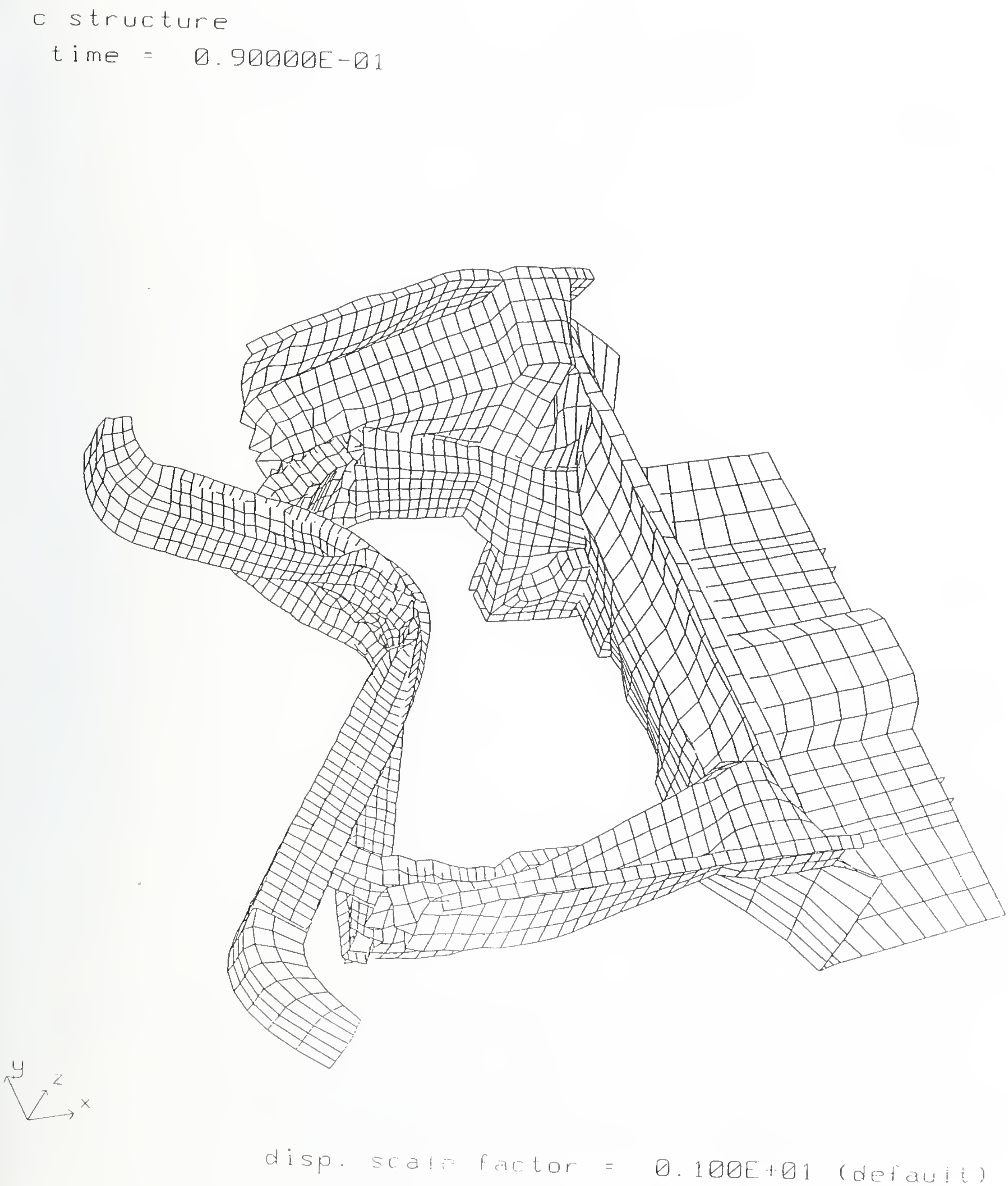


Figure 46. Front structure 90 ms.

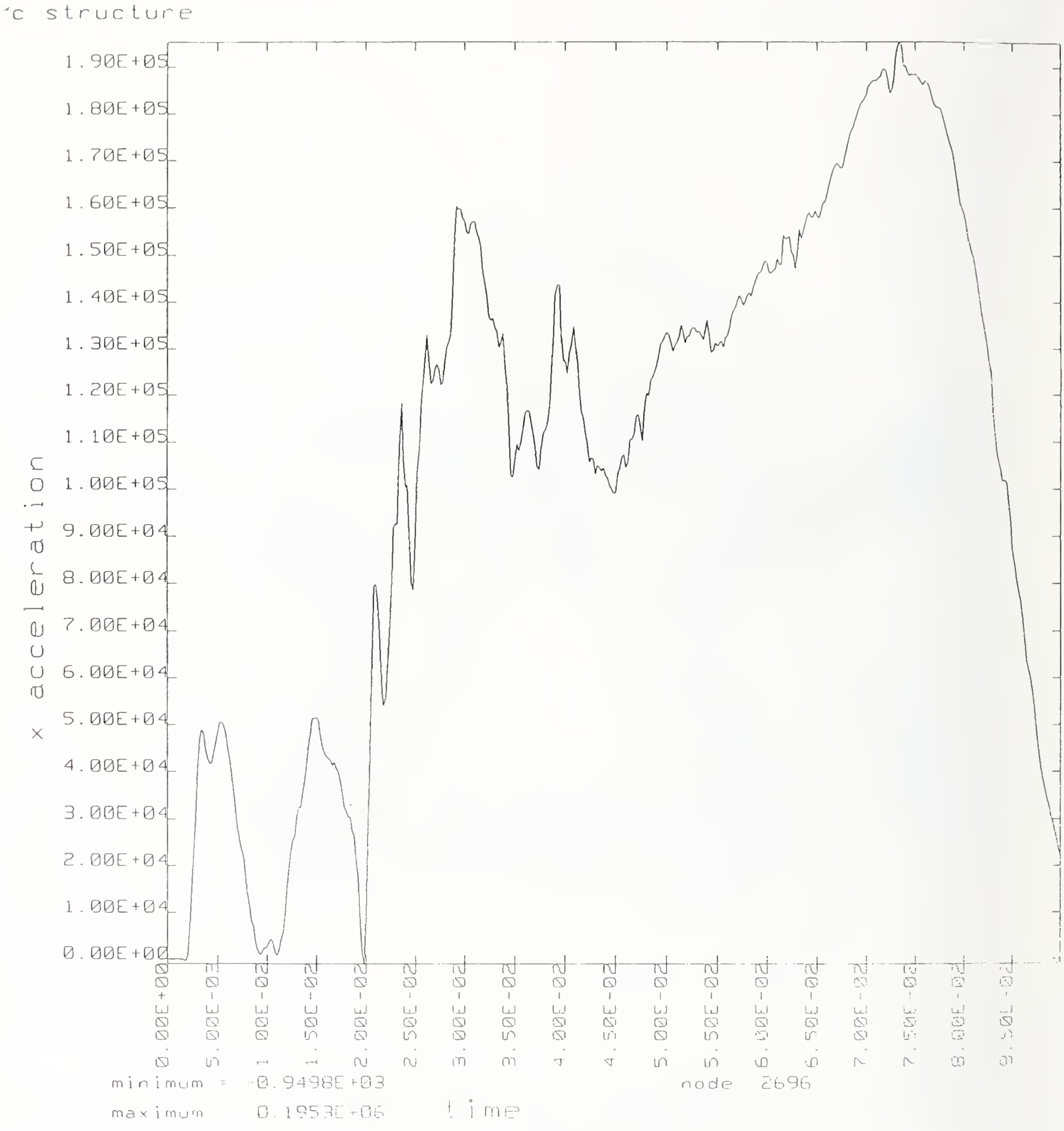


Figure 47. Floorpan acceleration (node 2696), unsmoothed.

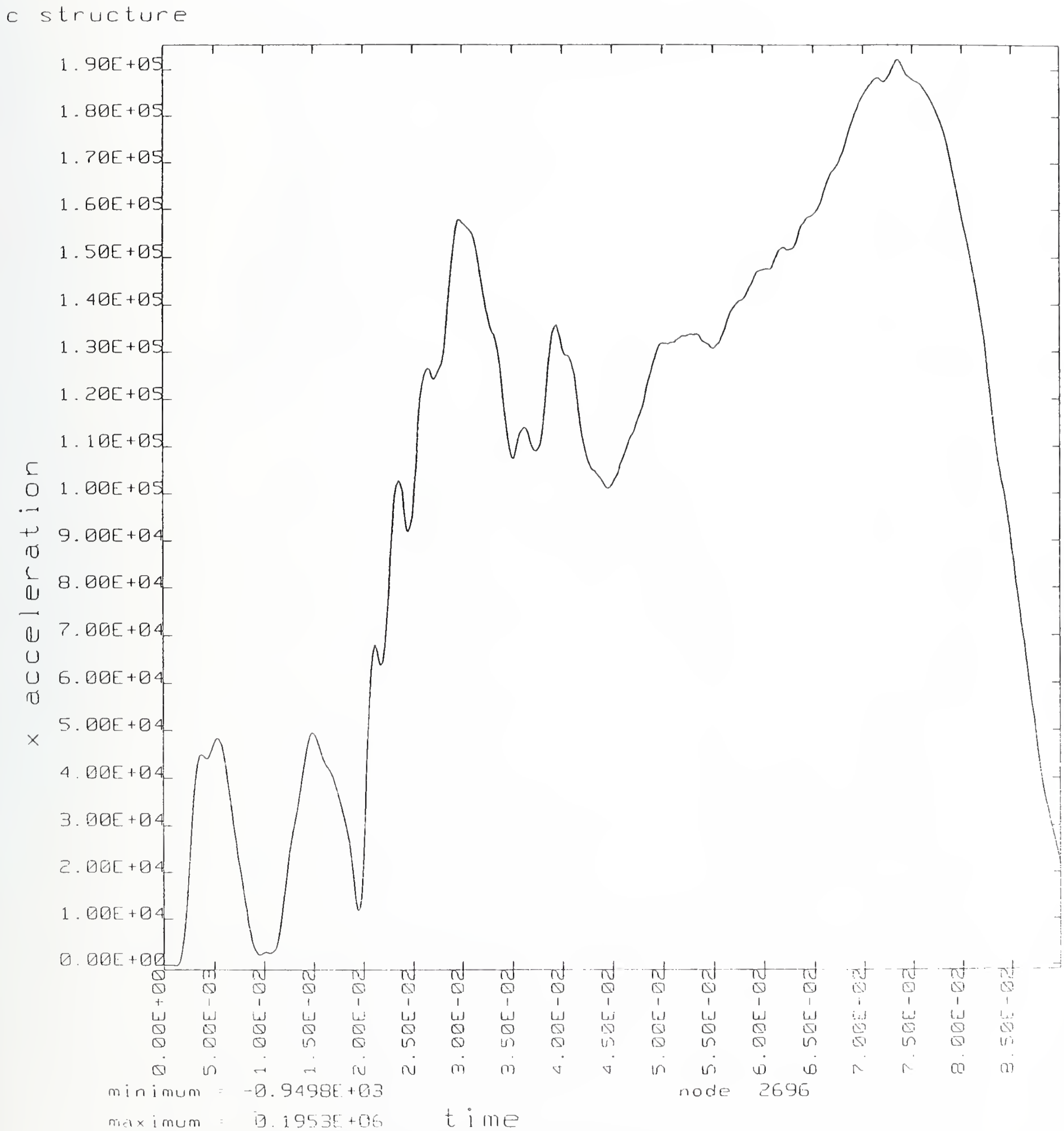


Figure 48. Floorpan acceleration (node 2696), smoothed.

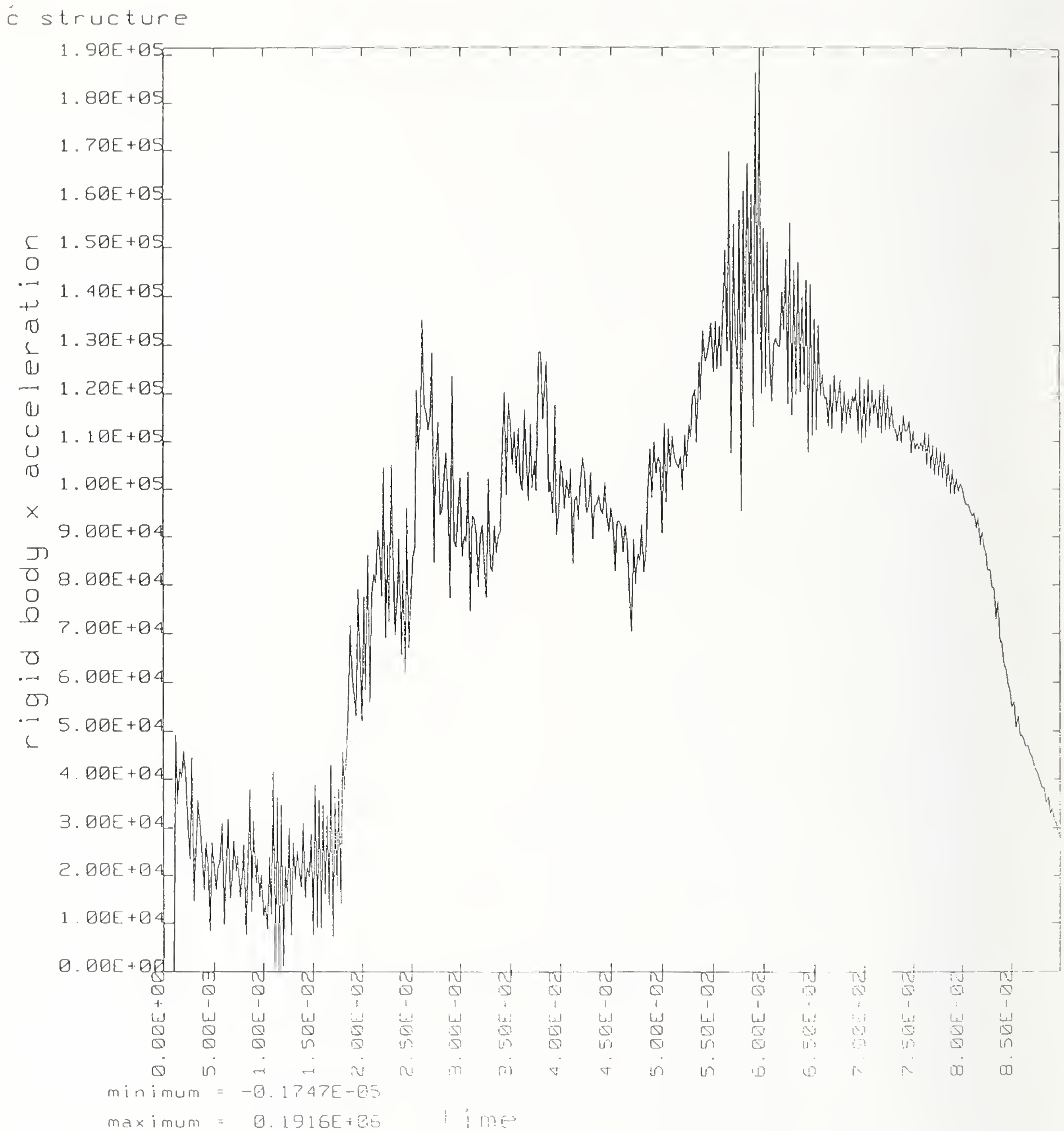


Figure 49. Rigid body acceleration, unsmoothed.

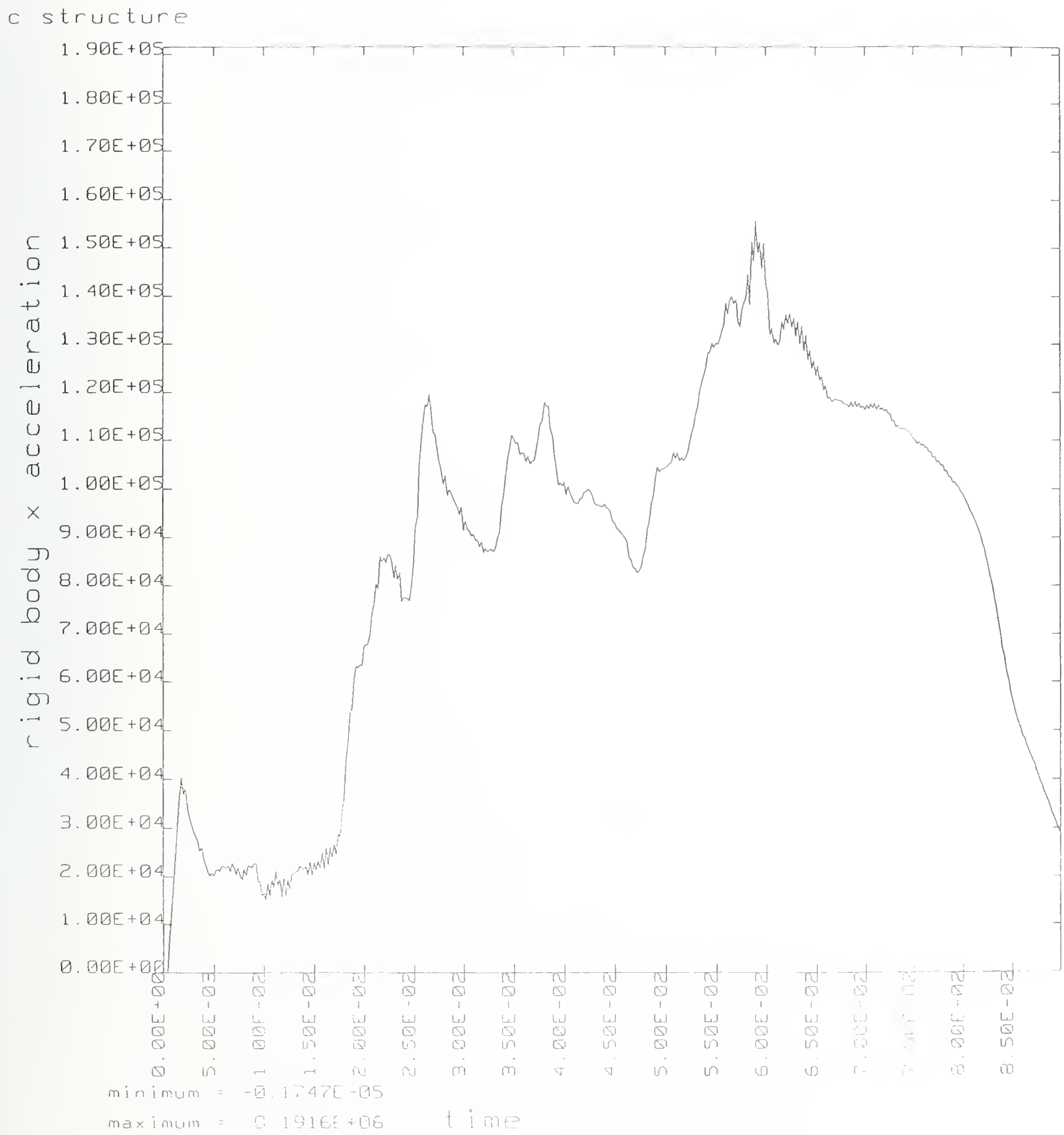


Figure 50. Rigid body acceleration, smoothed.

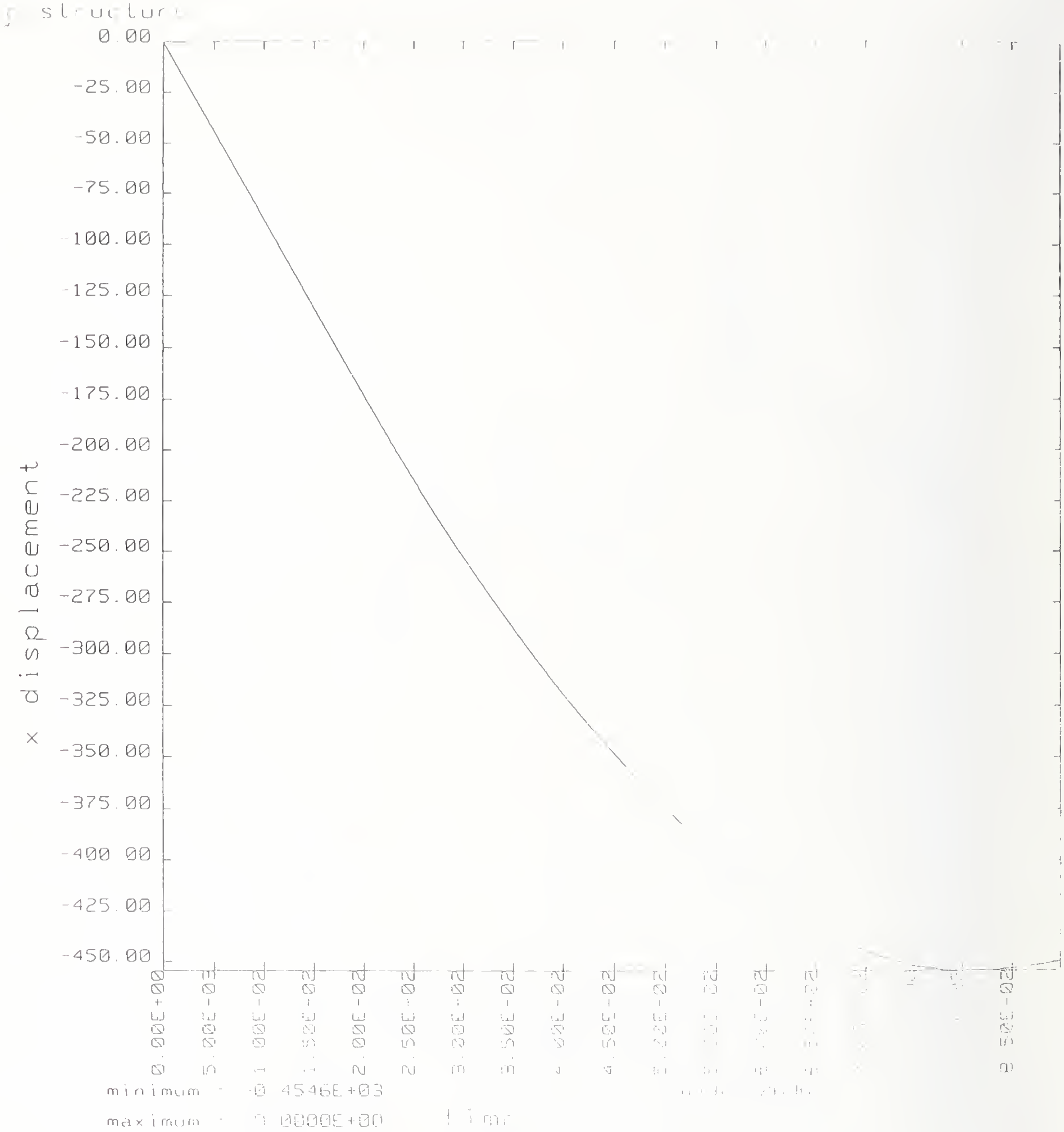


Figure 51. Nodal displacement, node 2696.

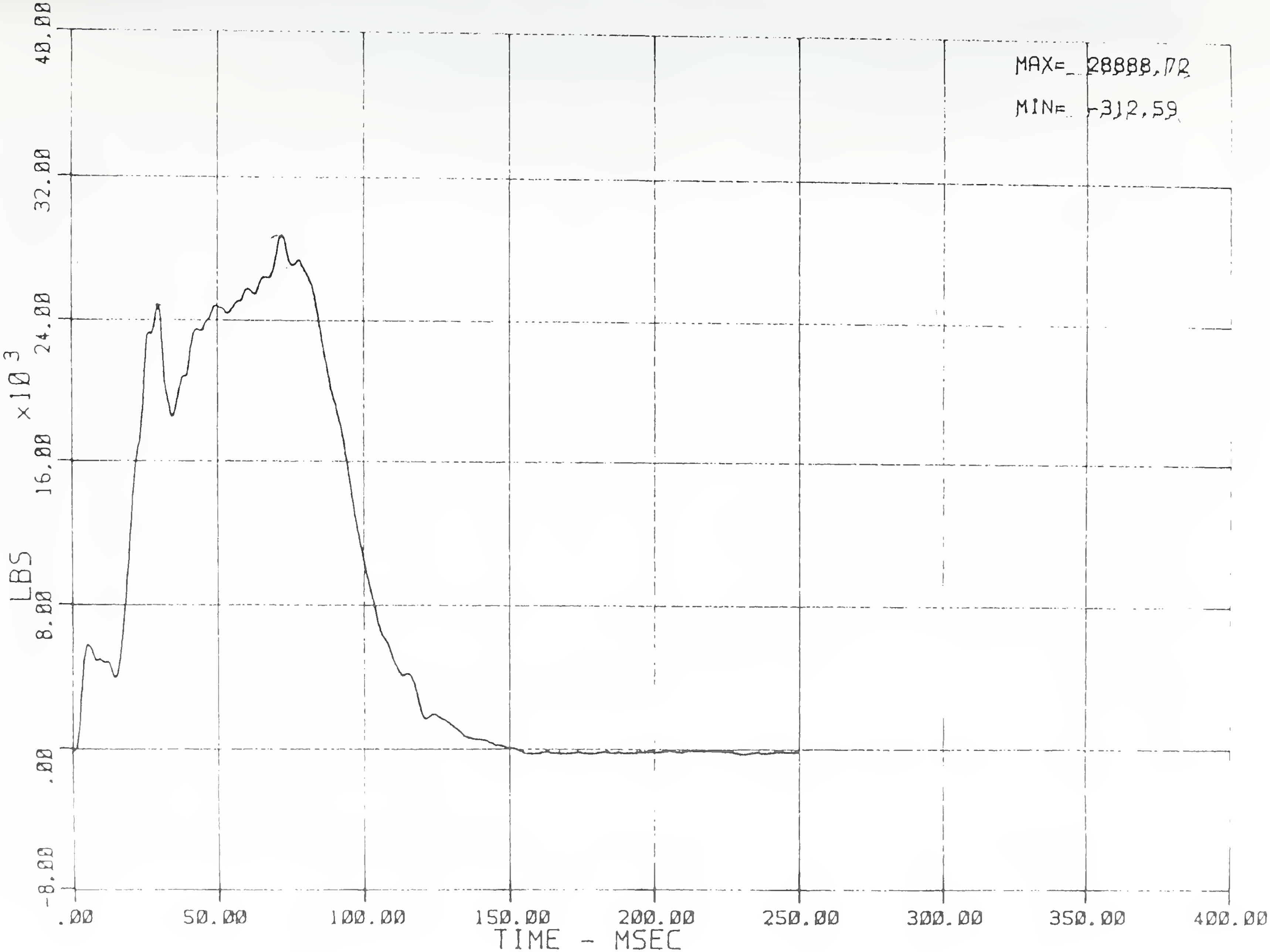


Figure 52. Pole impact force from crash test

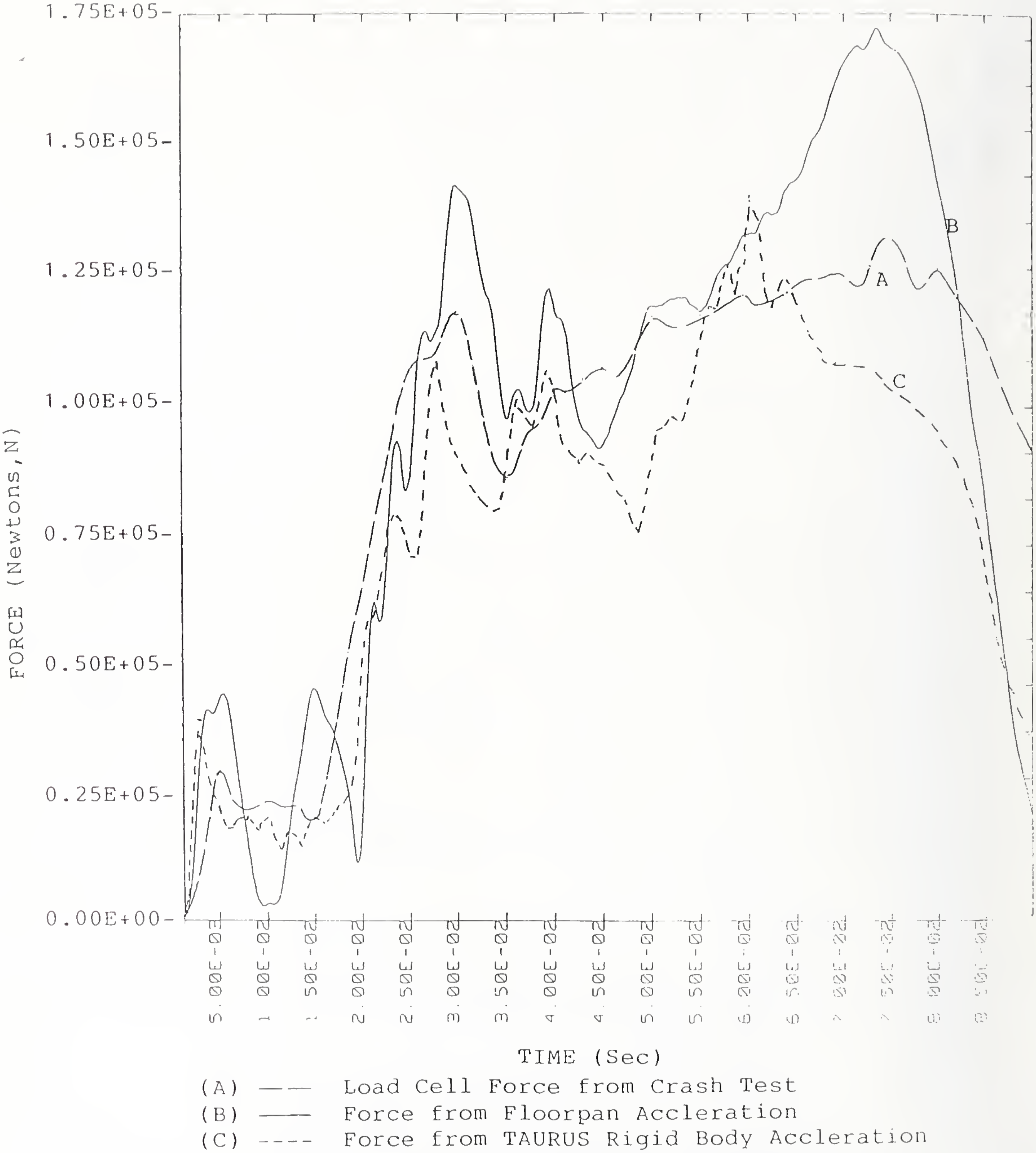


Figure 53. Comparison of pole force estimates.

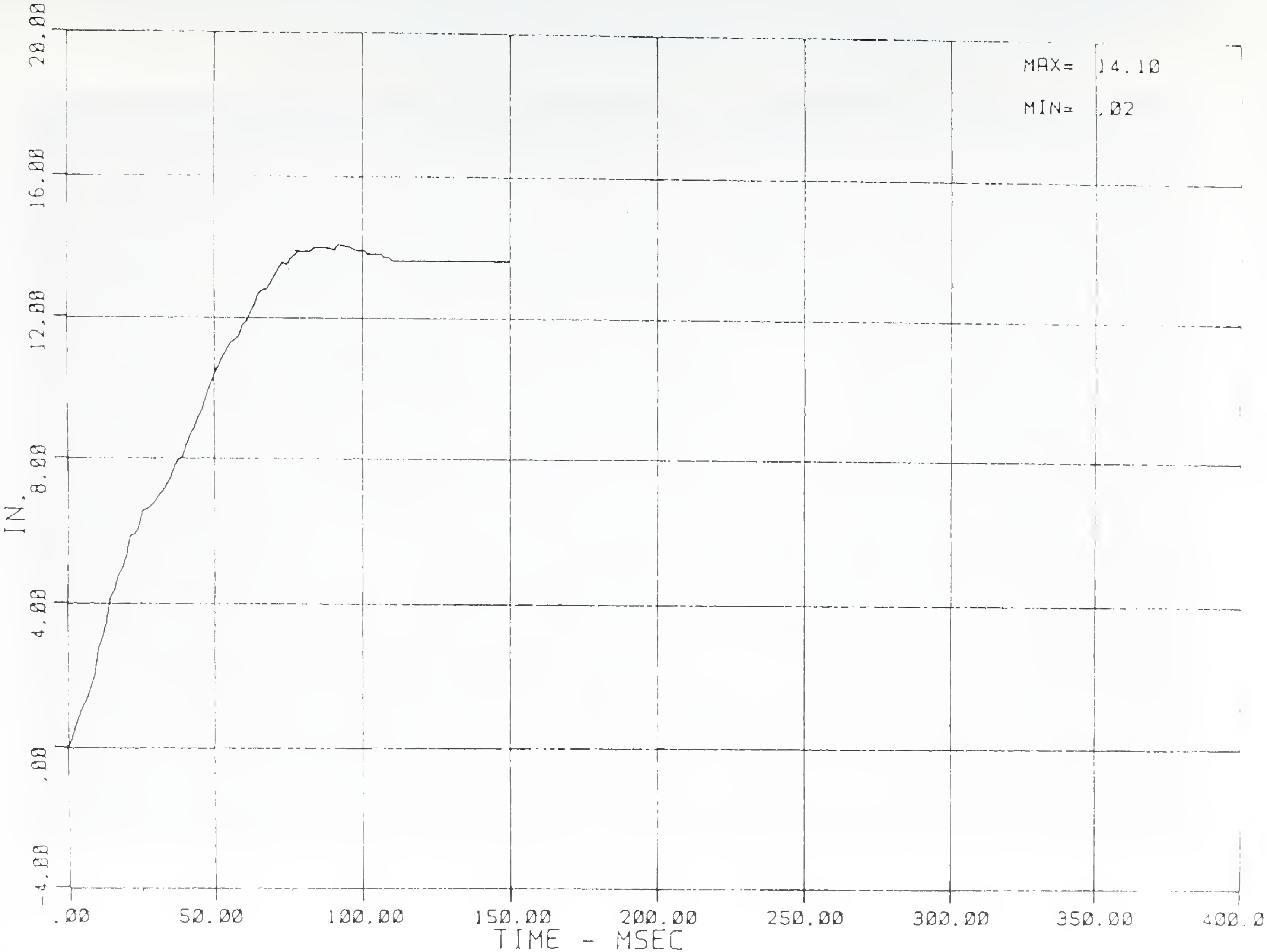


Figure 54. Pole intrusion from crash test film analysis.

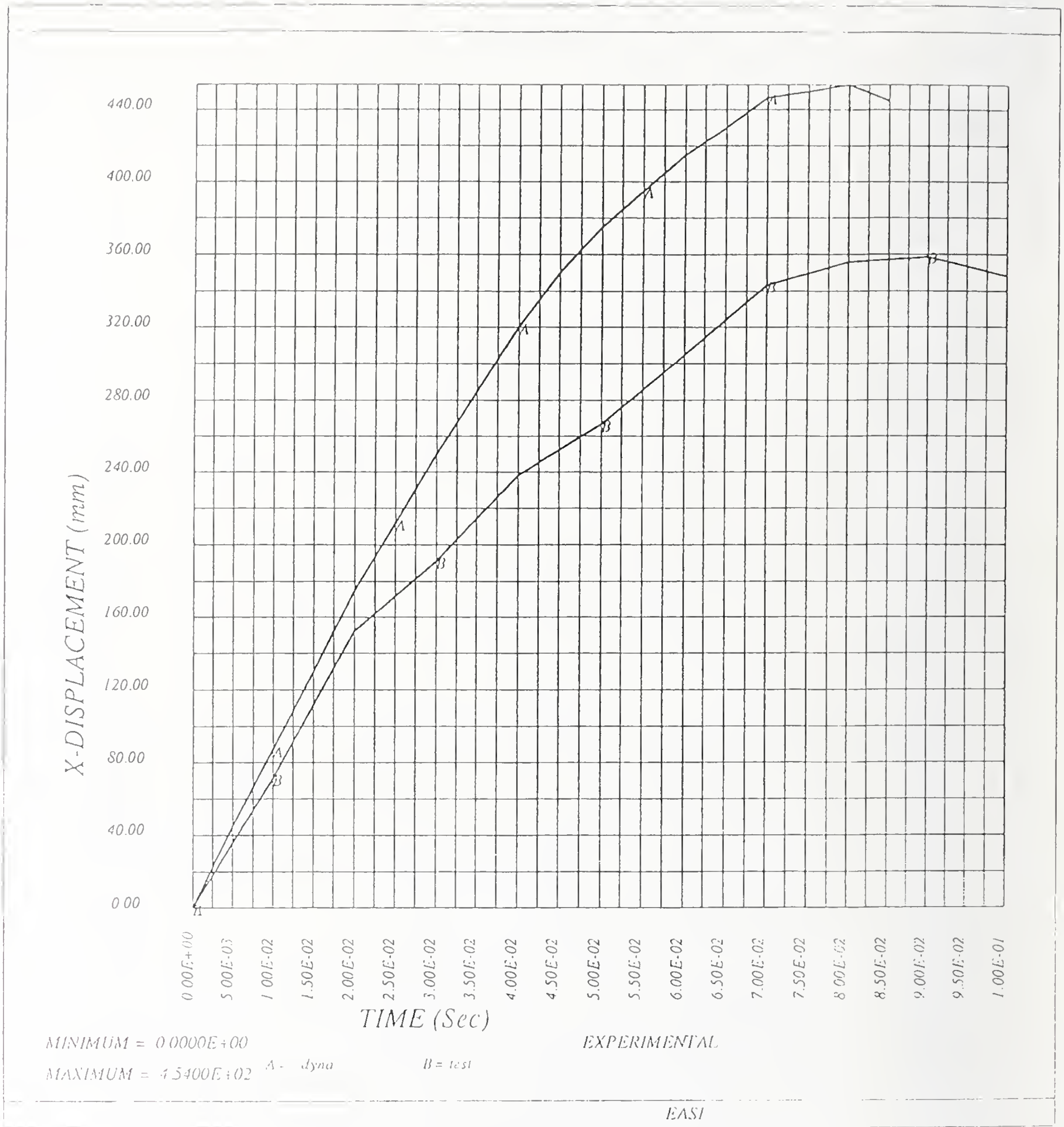


Figure 55. Comparison of FE model displacement with pole intrusion from film analysis.

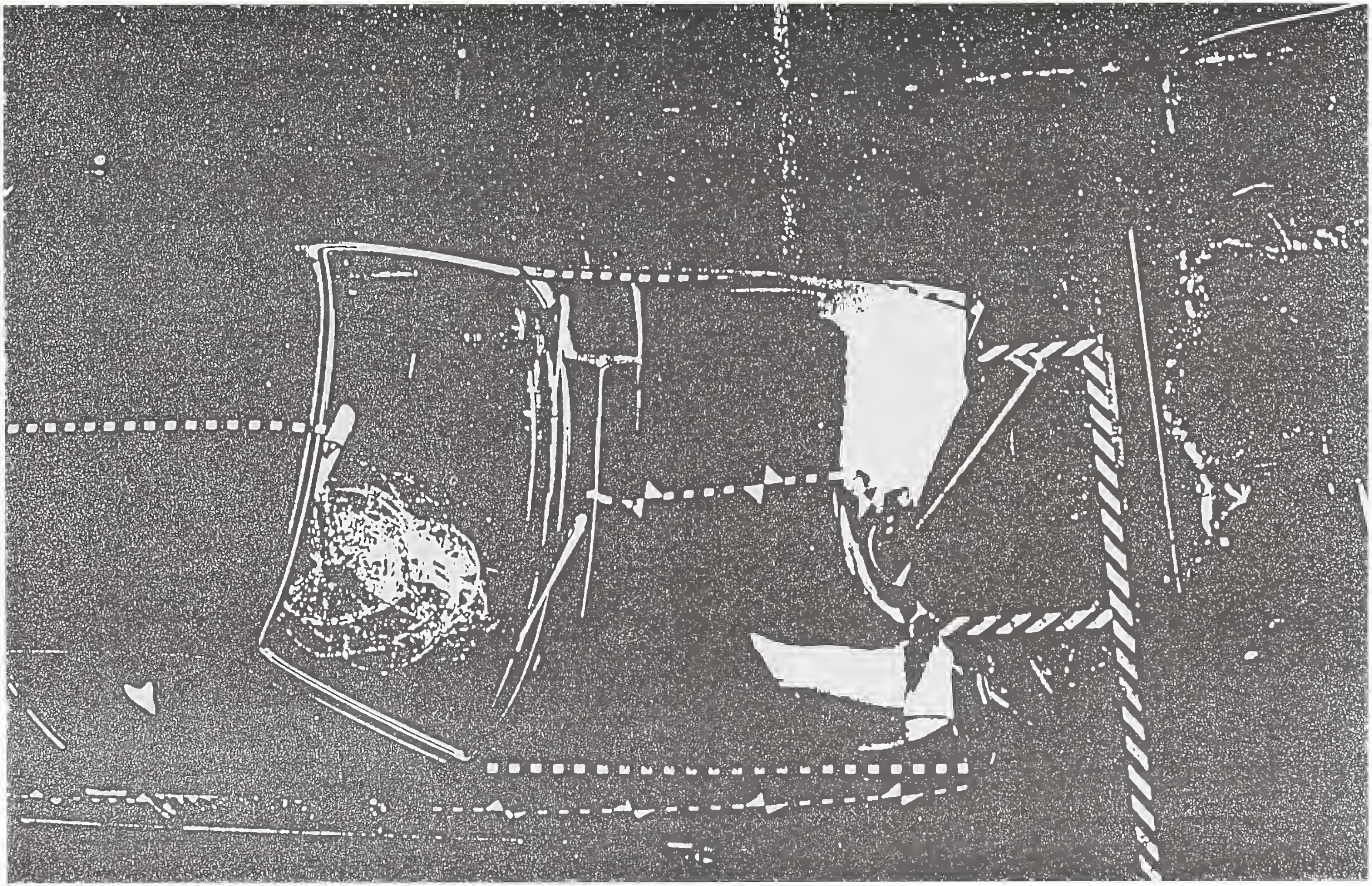


Figure 56. Top view of vehicle post crash.

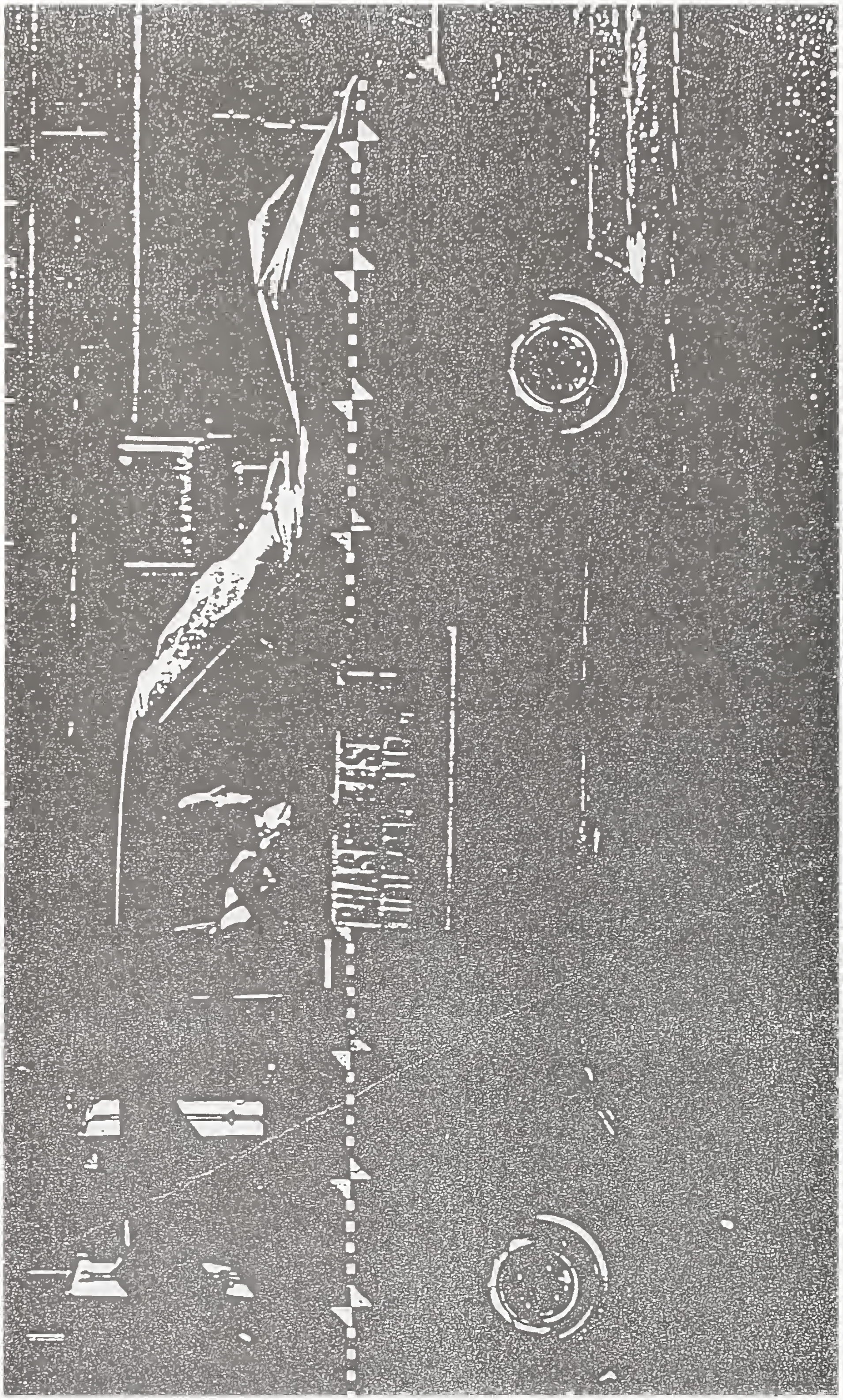


Figure 57. Side view of vehicle post crash.

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