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JULY 24, 1965

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FINAL ENGINEERING REPORT

ENERGY ABSORBING CHARACTERISTICS OF CRUSHABLE ALUMINUM STRUCTURES IN A SPACE ENVIRONMENT

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Advanced Structures Group
Bendix Products Aerospace Division
The Bendix Corporation
South Bend, Indiana 46620

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FOREWORD

This engineering report provides a documentation of the research work performed by Bendix Products Aerospace Division of The Bendix Corporation, South Bend, Indiana, for the National Aeronautics and Space Administration's Manned Spacecraft Center, Houston, Texas under Contract No. NAS 9-2074. This project was accomplished during the period from September 30, 1963 through July 24, 1965. This time included extensions to the original program schedule provided by two contract amendments.

Mr. George Sandars (Project Engineer in the Structural Mechanics Branch of the Structures and Mechanics Division) acted as NASA - MSC's technical representative for the contractor in administering the program.

Technical direction and project administration for Bendix was handled by P. O. Reidenbach. R. E. Schmidt of Bendix acted in a sales-liaison capacity with the NASA Contracts Administration Section. The following personnel made significant contributions to the study effort in the areas of equipment design, testing techniques, data analysis and report preparation: Mr. F. P. Mackrill, Mr. Gary Clawson, Mr. John Mikel, Mr. D. E. Hanna, Mr. Carl Dreesson, Mr. John Harvey and Mr. R. J. Black.

Valuable counsel was also rendered throughout the program by Mr. R. A. Price, Supervisor of the Advanced Structures Group, and by Mr. R. W. Smith, presently Manager of the Energy Absorption System Sales group who contributed some of the original thinking in regard to the areas into which the research work should be directed.

ABSTRACT

The research effort detailed in the subsequent sections of this report, involved the basic objective of obtaining quantitative design data concerning the characteristics of aluminum honeycomb materials when used in high L/D ratio crushable energy absorbing capsules. Nine configurations of honeycomb energy absorbing capsules using alloy 5056 were evaluated in this study effort. The nine basic configurations incorporated three (3) cross sectional shapes of high, medium, and low crush strength; each of which was fabricated with cell axes oriented at angles of 0°, 15° and 30°, to the capsule longitudinal axis. Particular characteristics which were studied included specific energy, load on-set rate, and rebound. Variations of these characteristics were investigated under controlled environmental conditions.

The capsules were subjected to both static and dynamic loads, impact velocities from 5 thru 20 feet per second, and impact weights varying from 760 lbs. thru 3750 lbs. The environmental extremes under which the specimens were tested spanned the temperature range from -260°F thru room temperature up to +300°F, and a vacuum of 3×10^{-1} TORR.

The two phase program was conducted on a "process of elimination" basis directed toward identification of the capsule configurations which would maximize the desired performance characteristics. All specimen types which crushed in the normal manner of progressive cell buckling, (for both the static and dynamic cases) exhibited the

characteristic rectangular shape load/stroke curves representative of high efficiency operation. Fluctuations in the average crush loads were as high as ± 15% for some specimens with angular cell axes, but were in the range of ±2% for the expanded hexagonal, 0° cell axis configurations.

Calculations of the specific energy in terms of ft. lbs./lb. indicate that the solid circular section with the expanded hexagonal 0° cell axis provided the highest value; however, the thickness efficiency (stroke available in terms of total capsule length) is highest for a solid circular section with cell axes at 15°, although by only a small margin.

A generalized statement regarding the effect that change in impact velocity and weight have on the load onset rate is not considered adequate. Therefore, a study of the individual plots of these values verses the various parameters, for the characteristics of interest will provide more meaningful information.

One characteristic of particular interest indicates that during subsequent impacts on partially crushed capsules, all configurations yield a greater rebound value as the uncrushed length of the capsule becomes shorter.

The effect of temperature variation on the specimens should be studied in the light of the various conditions to which they were subjected and the parameters against which the values were plotted. It may be generally stated, however, that there is an increase in average crush load of as much as 30% with a temperature decrease to -260°F and a decrease in average crush load of as much as 35% at a temperature of +300°F.

The information presented in this report provides a substantial source of data regarding the effects which changes in specimen configuration, cell geometry, test conditions, and environment have on the characteristics of crushable energy absorbing materials. It can also provide guidelines in preparation of the specifications for capsule designs which will provide efficient and reliable operation as spacecraft shock attenuators.

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SECTION I

INTRODUCTION

1.1 GENERAL

The requirements for soft landing space vehicles in a widely varying and unconventional environment have prompted the designers to consider many nonconventional means of shock attenuation. Those methods probably considered most often involve the controlled deformation of solid or plastic materials, although the compression of gas or fluid and the use of friction or the acceleration of a fluid have also been studied for this use. Potential advantages can be shown for each of the methods considered; however, many of the proposed concepts show inherent weaknesses in a comparative evaluation where space system reliability is recognized as being closely related to simplicity and freedom from critical design and operating factors.

Consideration of factors such as potential puncture by meteorite impact, variation of friction with environment, and maintenance of close tolerances on fits and alignment for other absorption methods led to the choice of crushable material in capsule form for a first detailed effort to solve this type of shock attenuation requirement. Company funded testing programs and a literature survey on the subject confirmed our prediction that aluminum honeycomb material offered the most practical potential for further development. Most of the surveyed tests were conducted in the earth ambient atmosphere with speculation as to the effect of cellular entrapped air, impact velocity, and mass under which a specimen is tested. The award to BPAD of Contract NAS 9-2074 involving the "Study of Energy Absorbing Characteristics of Crushable Aluminum Structures in a Space Environment," has resulted in a significant step forward in understanding the failure patterns, environmental effects, and application techniques for this material.

This final engineering report covers the information generated in both Phase I and Phase II of a two-phase program which was a logical extension of earlier studies. The program was designed specifically to investigate the behavior of previously selected "superior" materials when employed in "full scale" capsule sizes and tested in a vacuum environment in combination with those environmental extremes which are anticipated to have substantial influence on performance. Further exploration is needed regarding the variations in honeycomb structural capability which may occur as a result of exposure to the full range of space environments. It is expected, however, that spacecraft landing gear design efforts may proceed on a more sound basis with the data obtained from this research effort.

1.2 OBJECTIVE

The basic objective of this program was to obtain quantitative design data concerning the characteristics of certain selected materials when used in high length-to-diameter (L/D) ratio crushable energy absorbing capsules such as would be suitable for use in spacecraft alighting gear shock attenuators.

The idealized characteristics which are generally desired in such shock attenuating capsules are listed here:

1. High specific energy (ft. lbs. per lb. of capsule weight)
2. Moderate load on-set rate (lb. per second) consistent with vehicle mass and peak acceleration load rate limits.

3. Minimum rebound characteristics.
4. Minimum variation in characteristics with environmental extremes.
5. Repeatability of characteristics.

1.3 SCOPE OF TESTS

The program efforts were directed toward identification of the honeycomb cell orientation and geometry and capsule configuration which would provide an optimized combination of the desired characteristics as defined under Objective, paragraph 1.2.

The capsule property variations were studied using a special test fixture (Figure 3-4) incorporating a viewing window with capability for a temperature spectrum ranging from a high of +300°F thru room temperature down to a low of -260°F, to satisfy the maximum expected temperature variation for a lunar mission. All testing of the full-length test articles was conducted with specimens exposed to an initial ambient atmospheric pressure of $3x10^{-1}$ TORR (300 microns). This vacuum environment was not meant to simulate the hard vacuum of outer space, but only to eliminate the effect which cellular entrapped air might exert on the capsule reactions. The characteristics of interest were studied under both static and dynamic loading conditions, and the effect of impact velocity and mass variation was observed specifically through the following ranges.

1. With drop weight remaining constant at 1920 lbs. - impact velocities were varied, using 5, 10, 14, and 20 feet per second.
2. With impact velocity remaining constant at 10 feet per second the drop weight was varied as follows: 760 lbs., 1920 lbs., 2850 lbs., and 3750 lbs.

The program was accomplished on a "process of elimination" basis. The nine full-length capsule configurations used in the initial part of the program were determined by the static testing of short, 6-inch length, preproduction control specimens under ambient temperature and atmospheric pressure. Those control specimen designs exhibiting satisfactory potential in regard to the basic specimen criteria were then selected for fabrication of multiple quantities of that configuration in full-length specimens. Increasingly severe environmental conditions were imposed on those full-length specimens. The original nine configurations of Phase IA were reduced to four configurations for Phase IB and subsequently to the two configurations exhibiting the greater potential regarding optimal combinations of the desired performance characteristics. In Phase II these specimens were subjected to the full range of temperatures as shown below.

	No. of Specimen Configurations	Vacuum	Temperature
Phase IA	9	$3x10^{-1}$ TORR	Room Temperature
Phase IB	4	$3x10^{-1}$ TORR	-260°F
Phase II	2	$3x10^{-1}$ TORR	+300°F, +150°F, -150°F, -260°F

Details of the test program are outlined in Sections VI, VII and VIII.

SECTION II

TEST SPECIMENS

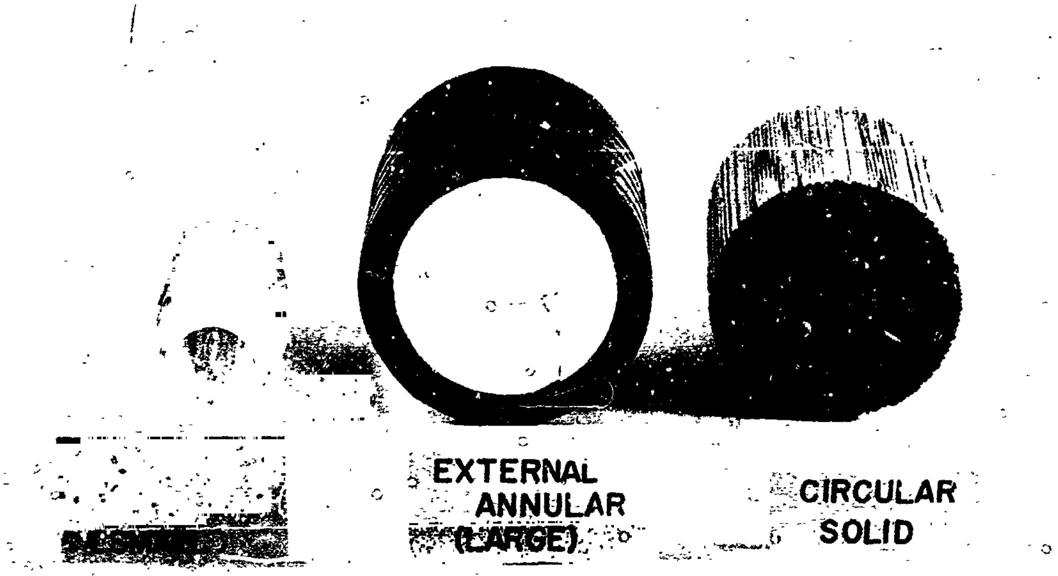
2.1 GENERAL

The basic criteria for defining the test specimens was established with the following guidelines.

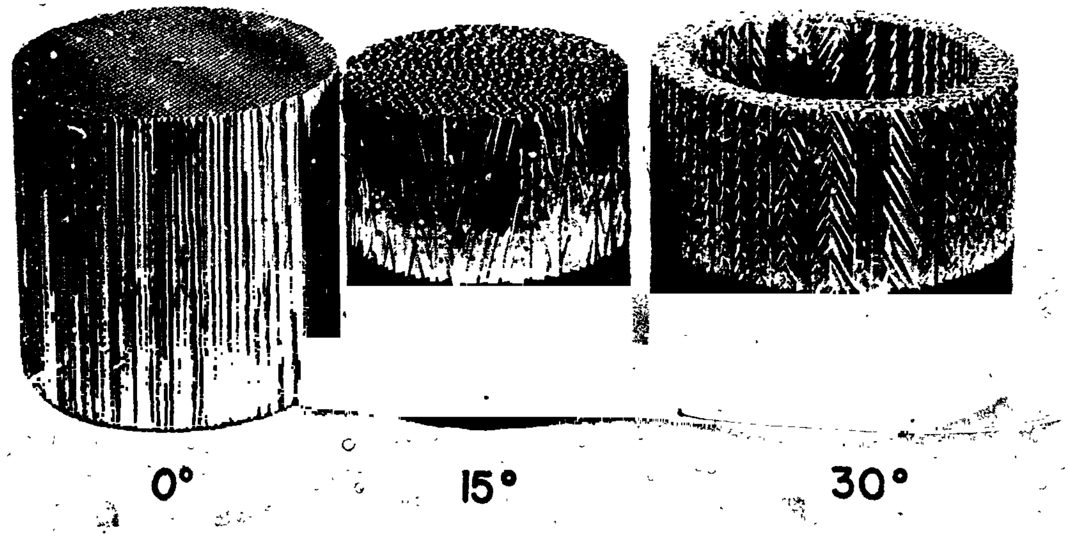
1. Aluminum alloy honeycomb capsules of three (3) crush strength levels (high, moderate, and low), each of which would be fabricated with three (3) cell axis orientations, making a total of nine (9) configurations. (Reference Figure 2-1 A & B).
2. Capsule configurations were designed such that cross-sectional area was consistent with crush strength level to yield a crushing load of approximately 5500 pounds for all capsules.
3. Capsule length was allowed to vary slightly to insure a minimum stroke length of 40 inches.

The parameter variations offered characteristics which would allow some trade-off studies or compromise when considering the energy absorbing capacity, elastic deformation per unit load, peak loads to initiate crushing action, and load on-set rates.

A landing gear strut outer cylinder bore of 6.25 to 6.50 inches in combination with a 6.00 outside diameter piston was assumed in selecting the size of the shock attenuating capsules.



A. Cross Section Shapes



B. Cell Angle Variations

Figure 2-1. Basic Specimen Configurations

The three (3) crush strength levels were planned to span the range from 1400 PSI (high) down to 180 PSI (low). These upper and lower limits of crush strength level lend themselves best to "internal" type capsules, designated as those housed inside the strut outer cylinder and guided on the outside diameter; (Figure 2-2).

The high strength capsule (1400 PSI) requiring a relatively small cross-sectional area was designated as an annulus section to gain a reasonable L/D column ratio, and the outside diameter was limited by cell size and practical annulus width (Figure 2-3).

The low strength capsule (180 PSI) requires a solid circular cross-section of a diameter somewhat less than the assumed outer cylinder bore to develop the required load; (Figure 2-3).

The moderate crush strength level (700 PSI) selected permits fabrication as either an "internal" or "external" capsule configuration in the chosen shock attenuator size range. The "external" configuration placed around a strut piston outside diameter offers certain capsule replacement advantages for reusable gear systems. To gain experience with this type capsule, guided on the inside diameter, the moderate strength capsule was designed in annular cross-section in a size consistent with external mounting (Figure 2-3).

A key has been established to readily identify the basic capsule configurations as they are discussed and as data plots are made throughout this report. This key is explained in the following table, with a circular symbol indicating the cross-sectional shape and a number identifying the cell axis orientation, e.g. ⊙ indicates "internal annular (small)" and 15 indicates angular cell axis orientation with respect to vertical axis."

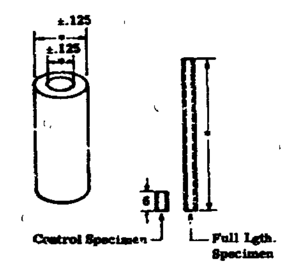
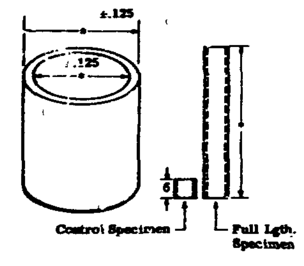
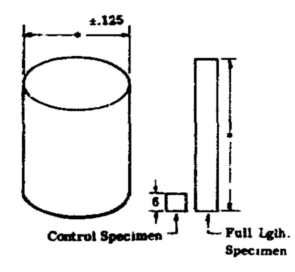
Relative Size	Key to Configuration		Bendix Part No. Above - Control Spec. Below - Full Lgth. Spec.	Core Type	Cell Siz (In.)	*Dimensions (In.) O.D. I.D. Lgth.	Crush Stress (PSI)	Load Tolerance 5500# Desired 5900#Max. 5100#Min.	Material (Alum..Al. 5056-H39) Foil Thickness (In.)		NOTES
									Corrug.	Flat	
	1	A ⊙ 15	SPX - 165A SPX - 168A	15-0-15 Cross-Core	1/16 x 1/8	3.00 2.00 52.50 NC	1400	Crush load of all specimens in this config. to be within ±5% of the group avg. & within the Max. & Min. Limits	.0026	.0009	Ref. Fig. 2-4
		B ⊙ 30	SPX-165B SPX-168B	30-0-30 Cross-Core	1/16 x 1/8	3 00 2.00 52.50	1400	Crush load of all specimens in this config. to be within ±5% of the group avg. & within the Max. & Min. Limits	.0023	.0009	Ref. Fig. 2-5
		C ⊙ 0	SPX-165C SPX-168C	Tube-Core Sine Corrug.	3/32 x 3/16	3.00 2.00 56.00	1400	Crush load of all specimens in this config. to be within ±5% of the group avg. & within the Max. & Min. Limits	.0026	.0026 (Double thickness)	Ref. Fig. 2-6
	2	A ○ 15	SPX-164A SPX-167A	15-0-15 Cross-Core	3/32 x 3/16	6.90 5.50 51.00	405	Crush load of all specimens in this config. to be within ±5% of the group avg. & within the Max. & Min. Limits	.0014	.0009	Ref. Fig. 2-7
		B ○ 30	SPX-164B SPX-167B	30-0-30 Cross-Core	3/32 x 3/16	7.00 5.50 51.00	370	Crush load of all specimens in this config. to be within ±5% of the group avg. & within the Max. & Min. Limits	.0014	.0009	Ref. Fig. 2-8
		C ○ 0	SPX-164C SPX-167C	Tube-Core Sine Corrug.	3/32 x 3/16	7.19 5.50 50.50 NC	330	Crush load of all specimens in this config. to be within ±5% of the group avg. & within the Max. & Min. Limits	.0014	.0014	Ref. Fig. 2-9
	3	A ● 15	SPX-163A SPX-166A	15-0-15 Cross-Core	1/8 x 1/4	5.50 - 50.00	230	Crush load of all specimens in this config. to be within ±5% of the group avg. & within the Max. & Min. Limits	.0014	.0009	Ref. Fig. 2-10
		B ● 30	SPX-163B SPX-166B	30-0-30 Cross-Core	1/8 x 1/4	5.90 - 50.00	200	Crush load of all specimens in this config. to be within ±5% of the group avg. & within the Max. & Min. Limits	.0014	.0009	Ref. Fig 2-11
		C ●	SPX-163C SPX-166C	Expanded Honeycomb	1/8 Hexagonal cell	6.25 - 52.00	180	Crush load of all specimens in this config. to be within ±5% of the group avg. & within the Max. & Min. Limits	.0009 (Expanded)		Ref. Fig 2-12

Figure 2-2. Test Specimen Configuration Summary

Configuration		Nominal Crush Stress	Nominal Size	Approx. Cell Size	Cell Orientation	
No.	Type	(PSI)	(Inches)	(Inches)	∠respect to capsule vertical axis.	Key
1 (Internal Annular-Small)	A	1400	3.00 O.D. 2.00 I.D.	1/16 x 1/8	15°	⊙ 15
	B	1400	3.00 O.D. 2.00 I.D.	1/16 x 1/8	30°	⊙ 30
	C	1400	3.00 O.D. 2.00 I.D.	3/32 x 3/16 (1/16)	0°	⊙ 0
2 (External Annular-Large)	A	405 (700)	6.90 O.D. (6.80 O.D.) 5.50 I.D. (6.00 I.D.)	3/32 x 3/16 (1/16 x 1/8)	15°	◎ 15
	B	370 (700)	7.00 O.D. (6.80 O.D.) 5.50 I.D. (6.00 I.D.)	3/32 x 3/16 (1/16 x 1/8)	30°	◎ 30
	C	325 (700)	7.19 O.D. (6.80 O.D.) 5.50 I.D. (6.00 I.D.)	3/32 x 3/16 (1/16)	0°	◎ 0
3 (Circular Solid)	A	230 (180)	5.50 Dia. (6.25 Dia.)	1/8 x 1/4 (1/16 x 1/8)	15°	● 15
	B	200 (180)	5.90 Dia. (6.25 Dia.)	1/8 x 1/4 (1/16 x 1/8)	30°	● 30
	C	180	6.25 Dia.	1/8 or 1/16 Half Hex.	0°	● 0

NOTES: Intensive research and development efforts by the capsule supplier fell short in some cases of meeting the original stringent requirements for capsules with satisfactory crush characteristics. Negotiated adjustments, coordinated with NASA-MSC (Cont.)

Figure 2-3. Table of Finalized Basic Specifications for the Specimen Configurations which would still permit attainment of the basic program objectives were incorporated as previously indicated, with the original desired requirements being shown in parentheses.

Materials:

(a) 5056-H39 Aluminum Alloy foil.

(b) Adhesives were not specified in detail. The specimen supplier was advised that the environment which the specimens would encounter included both vacuum and extreme temperatures of +300°F and -260°F. The supplier elected to use adhesives which are generally described by specification MIL-A-5090D, Type I. Those adhesives used are specifically noted under the description of the several configurations.

(c) Tape Wrapping - No outer covering was specified for the specimens. On certain configurations the specimen supplier elected to wrap them with Minnesota Mining and Mfg. Cos.' No. 870 glass filament tape. This was added primarily to prevent peeling of the outer cells during crushing action and secondarily to stabilize the cylinder walls as well as to prevent expansion of the capsules without significantly affecting the crush strength. Those capsules incorporating this tape are defined under the detail description of individual configurations (Figures 2-4 thru 2-12).

Crush Load: The nominal crush stress provides an average crush load of 5500 lbs. for all configurations. The average crush load for all specimens of a particular configuration was specified to fall within ±5% of the group average for that configuration with the further stipulation that this average load should not be above a maximum of 5900 lbs. nor below a minimum of 5100 lbs.

Capsule Length: The uncrushed length was specified as that length which will provide a crushing stroke capability of 40.00 $\frac{-.00}{+.50}$ inches and the total length was not to exceed 60 inches.

Figure 2-3. Table of Finalized Basic Specifications for the Specimen Configurations (Cont.)

KEY

⊙ 15	=	"internal annular (small)":	cell axis @ —15°
⊙ 30	=	"internal annular (small)":	cell axis @ —30°
⊙ 0	=	"internal annular (small)":	cell axis Vertical (0°)
◎ 15	=	"external annular (large)":	cell axis @ —15°
◎ 30	=	"external annular (large)":	cell axis @ —30°
◎ 0	=	"external annular (large)":	cell axis Vertical (0°)
● 15	=	"circular solid":	cell axis @ —15°
● 30	=	"circular solid":	cell axis @ —30°
● 0	=	"circular solid":	cell axis Vertical (0°)

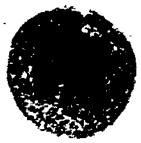
Further reference for the various configurations may be seen in Figure 2-3, "Table of Finalized Basic Specifications for the Specimen Configurations", pictorially in Figure 2-2, "Test Specimen Configuration Summary", and in the individual "Specimen Configuration" Figures numbered 2-4 thru 2-12.

Specimen (Internal Annular - Small)

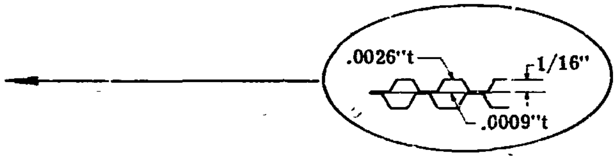
Key = ◉ ::

Pre-Production
Control Specimen
(Bendix Part No. SPX-165A)

Full Length
Test Specimen
(Bendix Part No. SPX-168A)



Cross-Sectional
View



Construction Details

Core Type - - - - -15-0-15 'Crosscore'
Material - - - - -Aluminum Alloy (5056-H39)
Foil Config:
Corrugated - 1/16' Hexagonal (1/8" Cell) .0026" t
Interleaf - Flat .0009" t
Adhesive -- Reichold Epotuf Code #SF 5473-1
Wrapping - 3 M Glass filament tape No. 870

Nominal Dimensions (in.)	SPX-165A	SPX-168A
Outside Diameter	3.00 ± .125	3.00 ± .125
Inside Diameter	2.00 ± .125	2.00 ± .125
Area (Nominal)	3.93 in.^{2}	3.93 in.^{2}
Length	6.00 ± .125	*52.50

* Length of TEST specimens was specified as that required to give 40.00" $^{-.00}_{+.50}$ stroke but max. length was not to exceed 60.00".

Average crush strength = 1400 PSI (This stress with a specimen of nominal dimensions gives a crush load of 5500 lbs.)

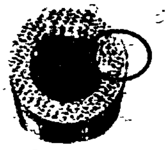
Figure 2-4. Specimen Configuration 1A

Specimen (Internal Annular - Small)

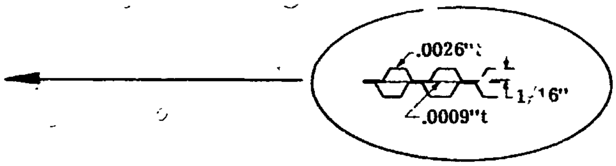
Key = ◉ 3C

Pre-Production
Control Specimen
(Bendix Part No. SPX-165B)

Full Length
Test Specimen
(Bendix Part No. SPX-168B)



Cross-Sectional
View



Construction Details

Core Type - - - 30-0-30 'Cross Core'
Material - - - Aluminum Alloy (5056-'39)
Foil Config:
Corrugated - 1/16" Hexagonal (1/8" cell) .0026"t
Interleaf - Flat .0009"t
Adhesive - - - Reichold Epotuf Code #SF5473-1
Wrapping - - - 3M Glass filament tape No. 870

Nominal Dimensions (in.)	SPX-165B	SPX-168B
Outside Diameter	3.00 ± .125	3.00 ± .125
Inside Diameter	2.00 ± .125	2.00 ± .125
Area (Nominal)	3.93 in.^{2}	3.93 in.^{2}
Length	6.00 ± .125	* 52.50

Average crush strength - - - 1400 PSI (This stress with a specimen of nominal dimensions provides a crush load of 5500 lbs.)

* Length of 'TEST' specimen is specified as that required to give 40.00 $^{-.00}_{+.50}$ stroke but maximum length is not to exceed 60.00".

Figure 2-5. Specimen Configuration 1B

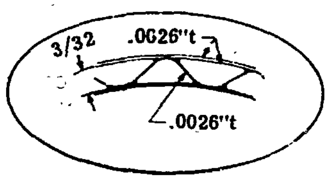
Specimen (Internal Annular - Small)

Key = ⊙

Pre-Production
Control Specimen
(Bendix Part No. SPX-165C)

Full Length
Test Specimen
(Bendix Part No. SPX-168C)

Cross-Sectional
View



Construction Details

Core Type - - - 'Tubecore'
Material - - - Aluminum Alloy (5056-H39)
Foil Config:
Corrugated - 3/32" Sine Wave .0026"t
Interleaf - Flat (2 thicknesses) .0026"t (each)
Adhesive - - - Reichold Epotuf Code #SF5473-1
Wrapping - - - 3M Glass filament tape No. 870

Nominal Dimensions (in.)	SPX-165C	SPX-168C
Outside Diameter	3.00 ± .125	3.00 ± .125
Inside Diameter	2.00 ± .125	2.00 ± .125
Area (Nominal)°	3.93 in.^{2}	3.93 in.^{2}
Length	6.00 ± .125	* 56.00

Average crush strength - - - 1400 PSI (This stress with a specimen of nominal dimensions provides a crush load of 5500 lbs.)

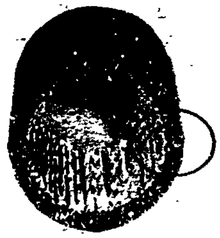
* Length of 'TEST' specimen is specified as that required to give 40.00 $^{-.00}_{+.50}$ stroke but maximum length is not to exceed 60.00".

Figure 2-6. Specimen Configuration 1C

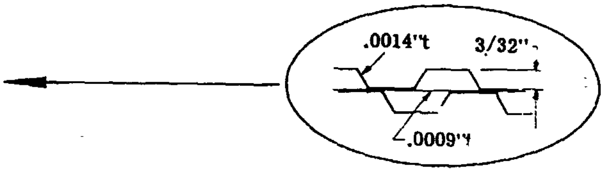
Specimen (External Annular - Large)
Key = ◯ 15

Pre-Production
Control Specimen
(Bendix Part No. SPX-164A)

Full Length
Test Specimen
(Bendix Part No. SPX-167A)



Cross-Sectional
View



Construction Details

Core Type - - - 15-0-15 'Crosscore'
Material - - - Aluminum Alloy (5056-H39)
Foil Config:
Corrugated - 3/32" Hexagonal (3/16" cell) .0014 "t
Interleaf - Flat .0009"t
Adhesive - - - Reichold Epotuf Code # SF5473-1
Wrapping - - - 3M Glass filament tape No. 870

Nominal Dimensions (in.)	SPX-164A		SPX-167A
Outside Diameter	6.90 ± .125		6.90 ± .125
Inside Diameter	5.50 ± .125		5.50 ± .125
Area (Nominal)	13.63 in.^{2}		13.63 in.^{2}
Length	6.00 ± .125	*	51.00

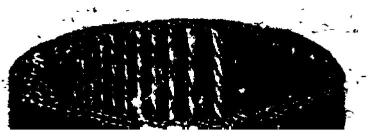
Average crush strength - - - 405 PSI (This stress with a specimen nominal dimensions provides a crush load of 5500 lbs.)

* Length of 'TEST' specimen is specified as that required to give $40.00^{-.00}_{+.50}$ stroke but maximum length is not to exceed 60.00".

Figure 2-7. Specimen Configuration 2A

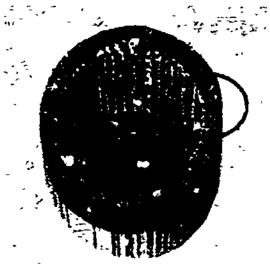
Specimen (External Annular - Large)

Key = O 30

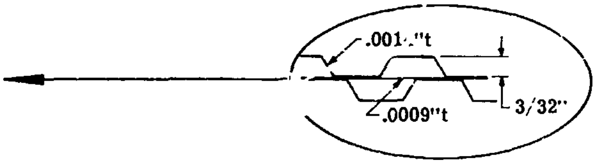


Pre-Production
Control Specimen
(Bendix Part No. SPX-164B)

Full Length
Test Specimen
(Bendix Part No. SPX-167B)



Cross-Sectional
View



Construction Details

Core Type - - - 30-0-30 'Crosscore'
Material - - - Aluminum Alloy (5056-H39)
Foil Config:
Corrugated - 3/32" Hexagonal (3/16" cell) .0014"t
Interleaf - Flat .0009"t
Adhesive - - - Reichold Epotuf Code #SF 5473-1
Wrapping - - - 3M Glass filament tape No. 870

Nominal Dimensions (in.)	SPX-164B	SPX-167B
Outside Diameter	7.00 ± .125	[illegible] ± .125
Inside Diameter	5.50 ± .125	± .125
Area (Nominal)	14.73 in.^{2}	14 3 in.^{2}
Length	6.00 ± .125	* 51.00"

Average crush strength - - - 370 PSI (This stress with a specimen of nominal dimensions provides a crush load of 5500 lbs.)

* Length of 'TEST' specimen is specified as that required to give $40.00^{-.00}_{+.50}$ stroke but maximum length is not to exceed 60.00".

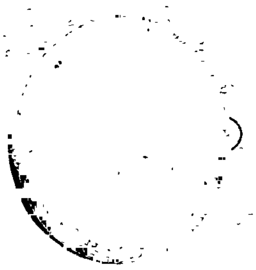
Figure 2-8. Specimen Configuration 2B

Specimen (External Annular - Large)

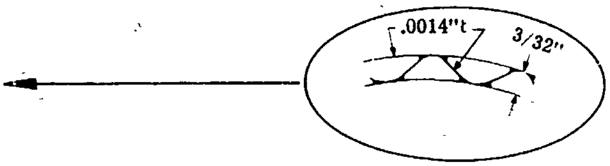
Key = C

Pre-Production
Control Specimen
(Bendix Part No. SPX-164C)

Full Length
Test Specimen
(Bendix Part No. SPX-167C)



Cross-Sectional
View



Construction Details

Core Type - - - 'Tubecore'
Material - - - Aluminum Alloy (5056-H39)
Foil Config:
Corrugated - 3/32" Sinewave .0014"t
Interleaf - Flat .0014"t
Adhesive - - -3M EC-1386
Wrapping - - 3M Glass filament tape No. 870

Nominal Dimensions (in.)	SPX-164C	SPX-167C
Outside Diameter	7.19 ± .125	7.19 ± .125
Inside Diameter	5.50 ± .125	5.50 ± .125
Area (Nominal)	16.82 in.^{2}	16.82 in.^{2}
Length	6.00 ± .125	* 50.50

Average crush strength - - - 330 PSI (This stress with a specimen of nominal dimensions provides a crush load of 5500 Lbs.)
* Length of 'TEST' specimen is specified as that required to give 40.00 $^{-.00}_{+.50}$ stroke but maximum length is not to exceed 60.00".

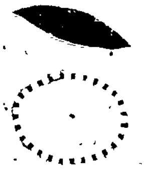
Figure 2-9. Specimen Configuration 2C

Specimen (Circular Solid)

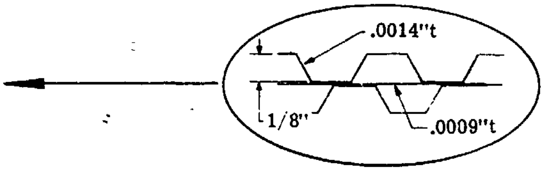
Key = ● 15

Pre-Production
Control Specimen
(Bendix Part No. SPX-163A)

Full Length
Test Specimen
(Bendix Part No. SPX-166A)



Cross-Sectional
View



Construction Details

Core type - - - 15 - 0 - 15 'Crosscore'
Material - - - Aluminum Alloy (5056-H39)
Foil Config:
Corrugated - 1/8" Hexagonal (1/4" cell) .0014" ±
Interleaf - Flat .0009"t
Adhesive - - - Reichold Epotuf Code #SF5473-1
Wrapping - - - 3M Glass filament tape No. 870

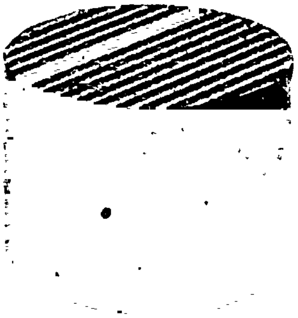
Nominal Dimensions (in.)	SPX-163A	SPX-166A
Outside Diameter	5.50 ± .125	5.50 ± .125
Area (Nominal)	23.76 in.^{2}	23.76 in.^{2}
Length	6.00 ± .125	* 50.00

Average crush strength - - - 230 PSI (This stress with a specimen of nominal dimensions provides a crush load of 5500 Lbs.)

* Length of 'TEST' specimen is specified as that required to give $40.00^{-.00}_{+.50}$ stroke but maximum length is not to exceed 60.00".

Figure 2-10. Specimen Configuration 3A

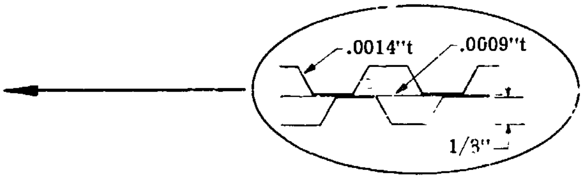
Specimen (Circular Solid)
Key = ● 30



Pre-Production
Control Specimen
(Bendix Part No. SPX-163B)

Full Length
Test Specimen
(Bendix Part No. SPX-166B)

Cross-Sectional
View



Construction Details

Core Type - - - 30-0-30 'Crosscore'
Material - - - Aluminum Alloy (5056-H39)
Foil Config:
Corrugated - 1/8" Hexagonal (1/4" Cell) .0014"t
Interleak - Flat .0009"t
Adhesive - - - Reichold Epotuf Code #SF5473-1
Wrapping - - - 3M Glass filament tape No. 870

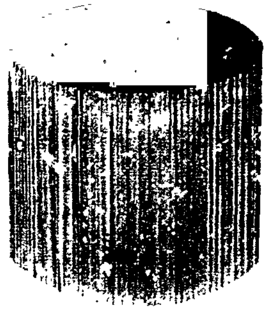
Nominal Dimensions (in.)	SPX-163B	SPX-166B
Outside Diameter	5.90 ± .125	5.90 ± .125
Area (Nominal)	27.34 in.^{2}	27.34 in.^{2}
Length	6.00 ± .125	* 50.00

Average crush strength - - - 200 PSI (This stress with a specimen of nominal dimensions provides a crush load of 5500 Lbs.)

* Length of 'TEST' specimen is specified as that required to give 40.00 $^{-.00}_{+.50}$ stroke but maximum length is not to exceed 60.00".

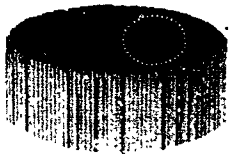
Figure 2-11. Specimen Configuration 3B

Specimen (Circular Solid)
Key = ● ○

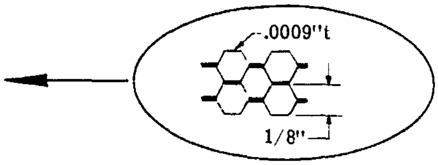


Pre-Production
Control Specimen
(Bendix Part No. SPX-163C)

Full Length
Test Specimen
(Bendix Part No. SPX-166C)



Cross-Sectional
View



Construction Details

Core Type - - -Expanded Honeycomb
Material - - - Aluminum Alloy (5056 - H39)
Foil Config: Expanded 1/16" Hexagonal (1/8" Cell) .0009"t
Core Adhesive - - - Reichold Epotuf Code #SF5473-1

Full Length Specimens (SPX-166C) were fabricated from two sections joined at the center using a perforated aluminum plate of .012" thickness and Shell Epon 931 Adhesive.

Nominal Dimensions (In.)	SPX-163C	SPX-166C
Outside Diameter	6.25 ± .125	6.25 ± .125
Area (Nominal)	30.68 in.^{2}	30.68 in.^{2}
Length	6.00 ± .125	52.00

Average crush strength - - - 180 PSI (This stress with a specimen of nominal dimensions provides a crush load of 5500 Lbs.)

* Length of "TEST" specimen is specified as that required to give 40.00 $^{-.00}_{+.50}$ stroke but maximum length is not to exceed 60.00".

Figure 2-12. Specimen Configuration 3C

2.2 MATERIAL

The selection of material to be used in fabricating the several test articles was an important consideration for this program. For optimum landing gear design, consistency in shock attenuator performance over the complete operating spectrum is desired. A honeycomb foil alloy that will exhibit high strength and maintain this strength level as consistently as possible over the temperature range was the sought after goal. Loss of strength at elevated temperature requires extra gear stroke compromises to insure adequate energy absorption capacity, and increased strength at cryogenic temperatures may adversely affect vehicle landing stability. The aluminum foils used almost exclusively in honeycomb applications at the time this project was initiated included alloys of 3003, 5052, and 5056, some of which could be obtained in various strain-hardened and stabilized tempers. To obtain the added temperature stability and higher strength level of a heat treated alloy for this important study, this contractor originally selected and requested, through the major honeycomb and foil producers, that the specimens be furnished in a 2024 aluminum alloy. The foil and honeycomb fabricators advised at that time that the foil processing state-of-the-art had not yet progressed to a point where this alloy could be furnished in the necessary foil thickn . Since the primary foil alloy selected was not available, it became necessary to select an alternate in the form of 5056-H39 for this program. This strain-hardened and stabilized alloy offers superior properties, relating to crush strength, over the temperature spectrum of -260°F to +300°F provided the exposure to +300°F does not exceed approximately 10 minutes. Comparative data on the pertinent mechanical properties (Modulus of Elasticity and Tensile Yield Strength) of the three alloys considered

NOTE: Volume demand of a large aircraft program has subsequently provided the impetus to extend development of the foil processing equipment and a number of 2024 foil thicknesses are currently available.

are shown in Figures 2-13 and 2-14.

Comments concerning the adhesives used in fabricating the specimens and the tape wrapped covering on certain specimens may be found in the notes following the finalized basic specifications for the specimen configurations (Figure 2-3).

2.3 SPECIMEN PROCUREMENT

The original basic specifications (Figure 2-3), defining the test specimens, were supplied to three recognized manufacturers of quality aluminum honeycomb, and their proposals were requested. Full consideration was given to all responses from these fabricators and largely on the basis of cost the following vendor was selected:

Hexcel Products Inc.
2332 Fourth Street
Berkeley, California

The first task of the specimen vendor, following initiation of orders for 5056-H39 foil, was to supply "core configuration samples" which would demonstrate their capabilities in providing the specimens of the specified cross sectional shapes and cell angle orientations. These sample specimens were made from an alloy foil, available in their plant, which possessed strength characteristics similar to those specified. Figure 2-15 shows the result of this effort. These specimens were not tested by Bendix to determine the crush loads, since our interest here was primarily in quality of fabrication techniques and also the presently available foil would almost certainly have resulted in a higher crush load than desired.

Following the visual evaluation of these core configuration samples by Bendix and NASA - MSC personnel and the procurement of the specified aluminum alloy foil (5056-H39), the vendor embarked on the second task of producing "pre-production control specimens"

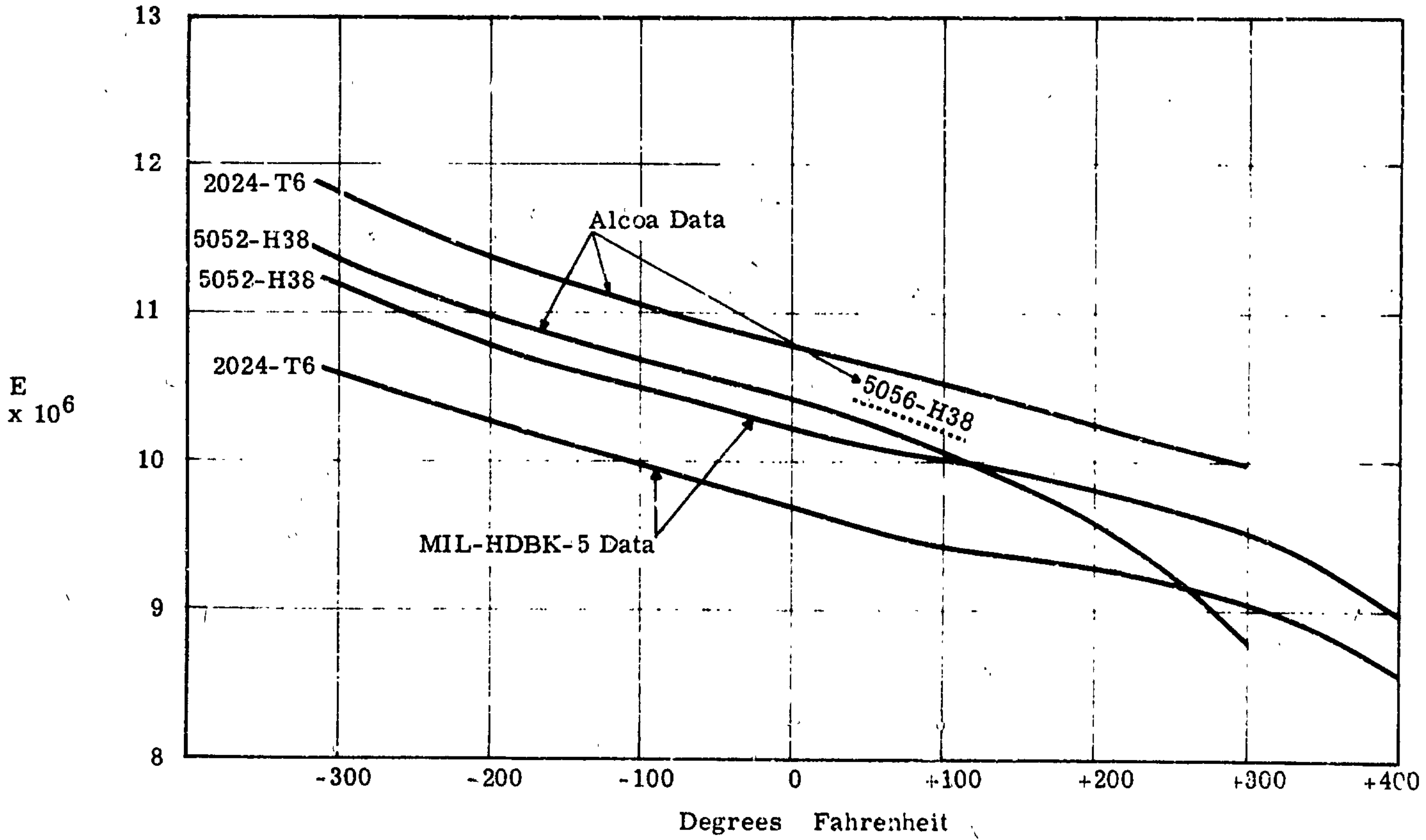


Figure 2-13. Modulus of Elasticity vs Temperature (5052, 5056, 2024 Alum. Alloys)

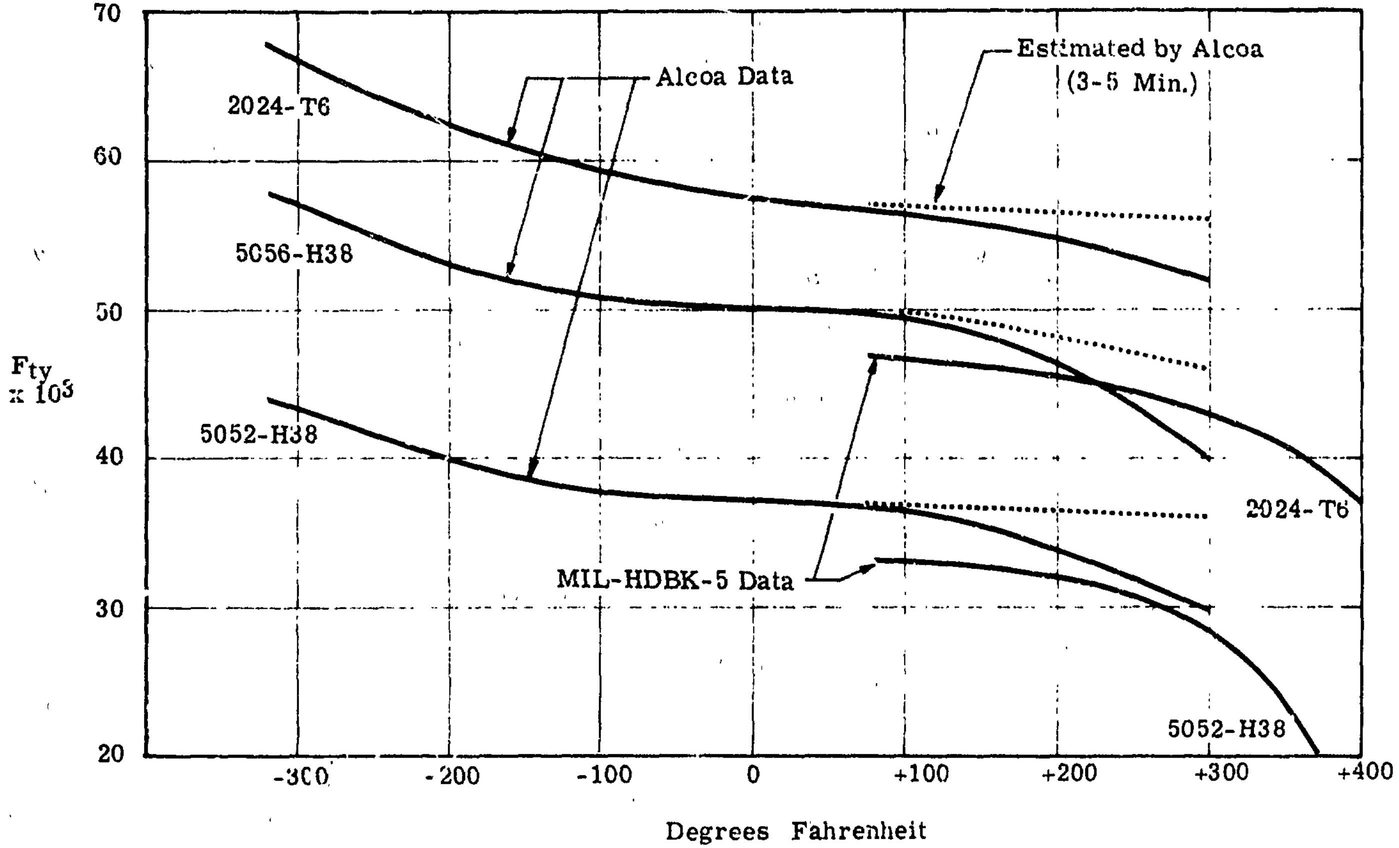


Figure 2-14. Tensile Yield Stress vs Temperature (5052, 5056 and 2024 Alum. Alloys)

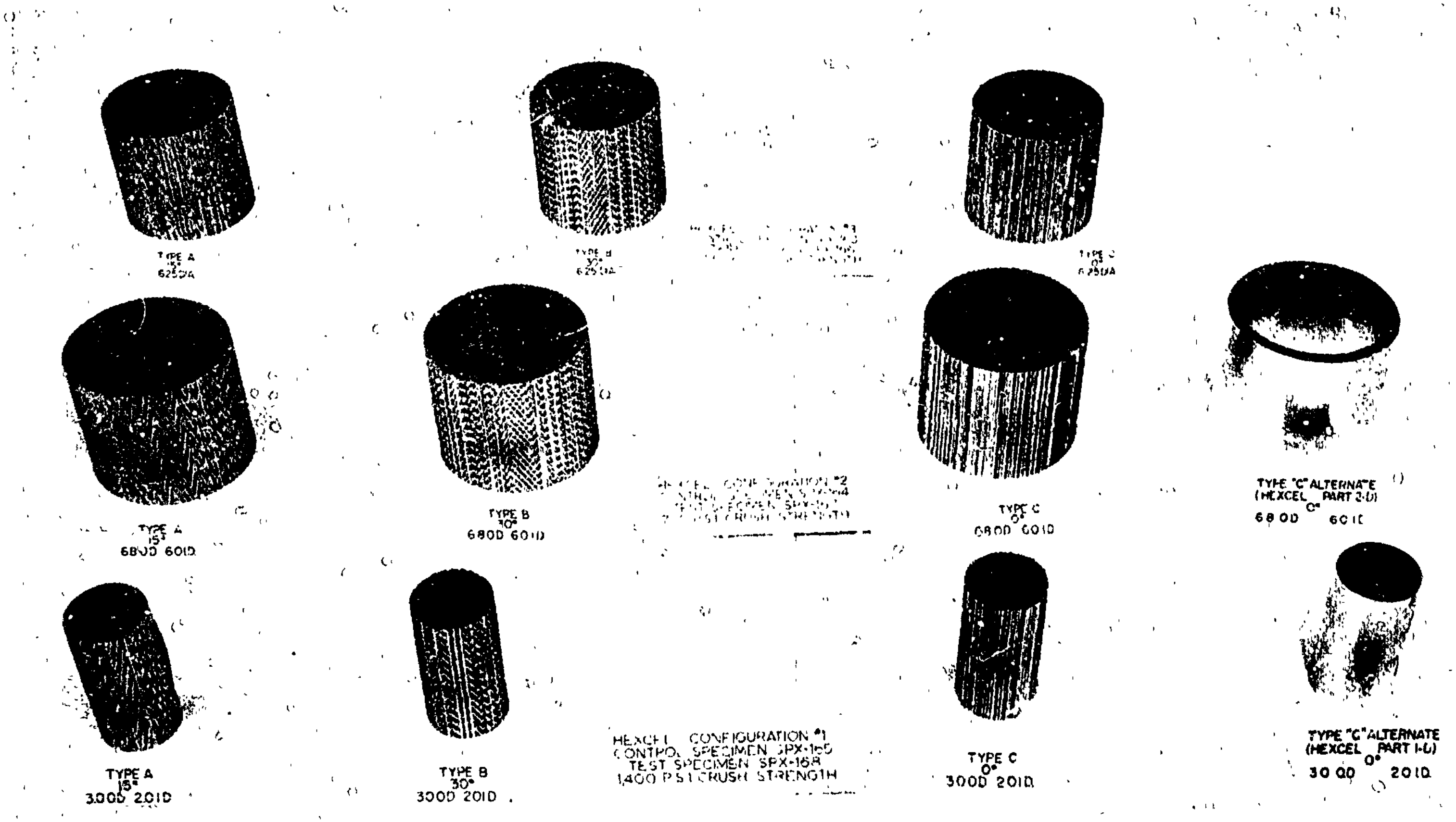


Figure 2-15. Core Configuration Samples for Study of Crushable Aluminum Energy Absorbers-Contract Number NAS 9-2074

(Figure 2-2). The control specimens which were (6) six-inch length miniature versions of the future full length (approx. 50-56 inches) test specimens were to be indicative in every manner (except that affected by L/D) of those characteristics to be obtained with the final specimen configurations. This, of course, included material, foil thickness, adhesive, cell size and orientation, cross-sectional area, outer covering (if any), and the crush strength. After the vendor had demonstrated to his satisfaction that he could construct such a "pre-production control specimen" in accordance with the specifications, four specimens of each configuration were supplied to Bendix where two of each configuration were evaluated in static crush tests. Visual observation of test specimen quality and successful demonstration of crush loads falling within the specified limits led to a design release for each individual configuration. This permitted the vendor to initiate quantity fabrication of that particular configuration in the necessary length to produce a forty (40) inch stroke. Photographs of the pre-production control specimens and the test results obtained are shown in Section VII.

After an intensive eleven (11) month development effort, involving many trial fabrication techniques and several conferences between Bendix, NASA-MSC, and Hexcel personnel ultimately leading to basic specification revisions (see Figure 2-3) and extension of the contract completion date, the design release was provided for the last of the nine (9) configurations. These minor adjustments in the basic specifications still permitted attainment of the basic program objectives. It is apparent that the state of the art in manufacturing aluminum honeycomb capsules was less advanced than originally believed when the project was initiated.

Adverse crush characteristics experienced during the development period were concerned with:

1. Control of adhesive quantity which varied with crush strength.
2. Large load fluctuations particularly in cross-core with angular cells.
3. Failure of splices when attempting to make long capsules from several sections.
4. Stroke efficiencies were less than desired.
5. Inability to meet the specified average crush loads & cross-sectional area adjustments because of the limited number of foil thicknesses available.

Some additional comments about specimen characteristics may be found in the conclusions. For those who may be interested in the development cycles of the individual Specimen Configurations, Hexcel's Final Materials Report is included as Addendum No. 2 to this report and is listed in the References (Section XI).

The specimen vendor ultimately provided ten (10) full-length specimens of the nine (9) configurations (and other development type specimens) for the Phase I Test Program. Subsequent evaluation resulted in elimination of certain test specimens. The final Phase II tests involved procurement of 70 specimens (33 each of two configurations and 2 each of two other configurations) making a total of 160 full-length specimens for the entire program.

2.4 CONFIGURATION DETAILS

A general description of the several specimen configurations utilized in this research effort is summarized in Table form (Figure 2-2) and all pertinent details for each of the configurations are provided in Figures 2-4 thru 2-12.

SECTION III

TEST EQUIPMENT

3.1 GENERAL

The test equipment used in this project is located in Bendix Products Aerospace Division's Energy Absorption Test Laboratory. All special fixturing and equipment was designed by BPAD personnel, and in large measure, fabricated within our own manufacturing facilities. Personnel from the Corning Glass Works and the W. S. Shamban Company were utilized as technical consultants on the special viewing window and the various seals used throughout the primary test fixture.

The development of the special fixturing for testing the crushable material capsules under extreme environmental conditions has resulted in a facility with unique capabilities. However, the designers, thru observation and use of the unit, now recognize that further improvements may be incorporated to enhance the efficiency and reliability under these conditions.

3.2 PRE-PRODUCTION CONTROL SPECIMEN TEST EQUIPMENT

An Instron materials test machine was used to "slow crush" the six-inch long pre-production control specimens of each configuration to determine their load stroke characteristics. Figure 3-1 is a schematic of the Instron machine used and Figure 3-2 shows the machine set up to "slow crush" a test specimen.

The test specimen was placed directly on the compression load cell and the load applied by lowering the cross head at a selected rate. The cross head is powered by an electric motor, coupled to a gear box, which drives the cross head lead screws. The head speed can be varied from a minimum of 0.02 inches per minute to a maximum of 20 inches per minute. The machine has a maximum compression load capability of 10,000 lbs. The crush load was recorded directly from the load cell by the direct reading recorder. The

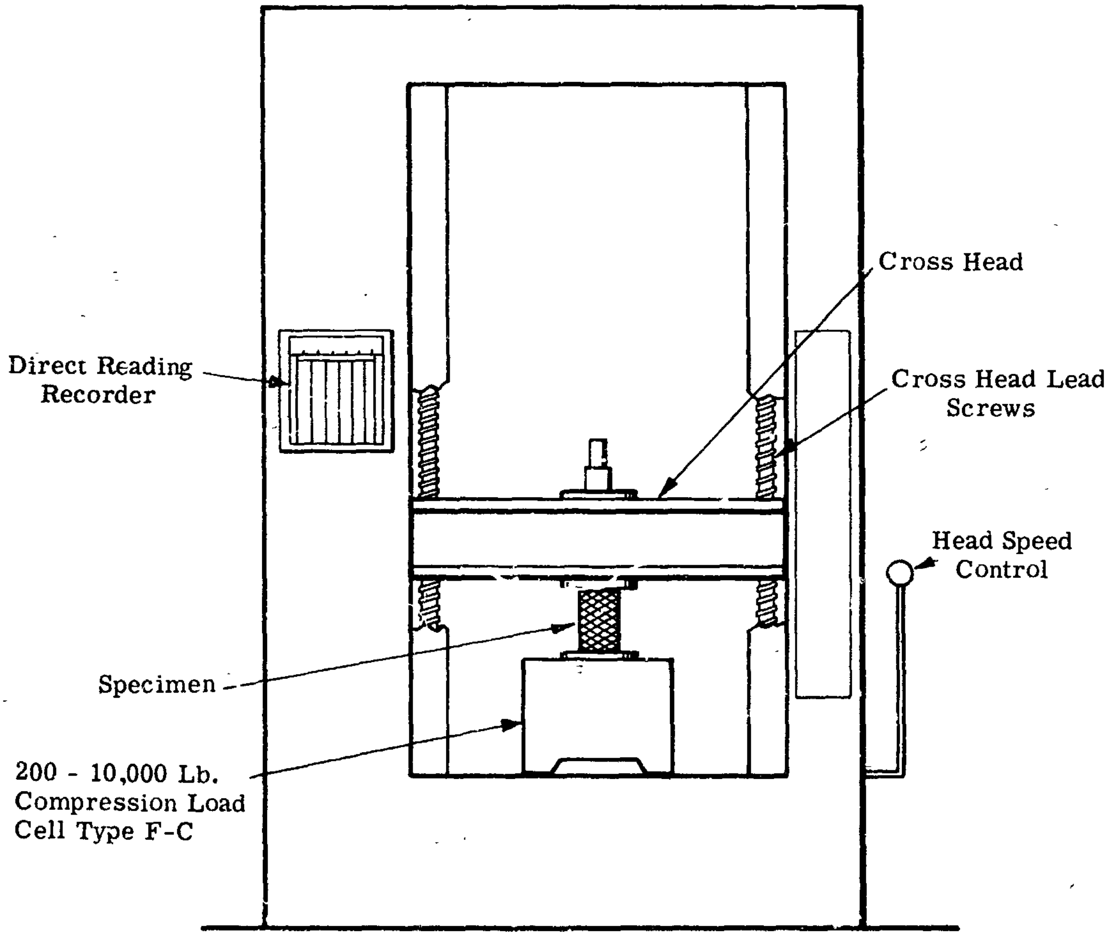


Figure 3-1. Schematic of Instron Materials Test Machine

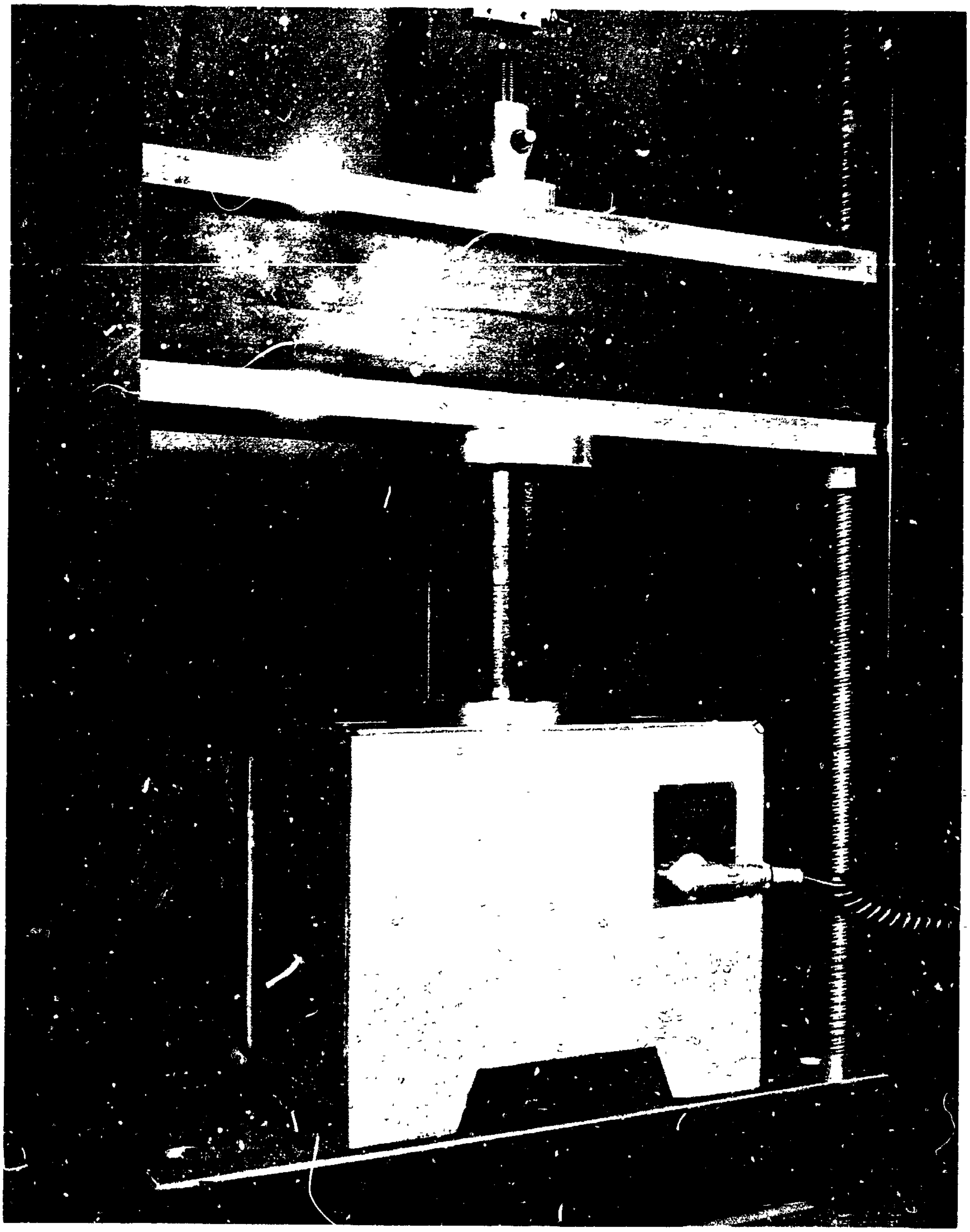


Figure 3-2. Pre-Production Test Specimen in Instron Test Machine

paper speed of the recorder may be varied. In the tests conducted the cross head speed used was 1/2 inch per minute. The paper speed was 10 inches per minute until the load became constant, and one inch per minute during the remainder of the crush stroke.

3.2.1 Test Fixture: (Bendix Dwg. No. SPX-170 Chg. D) Unit Assy. Crushable Material Energy Absorber. Figure 3-3

Full length specimens were tested in a specially designed test fixture positioned below a small drop test tower as shown in Figure 3-4. The aluminum honeycomb capsules were housed in the evacuated cylinder and subjected to temperatures ranging from +300°F to -260°F. Dynamic testing was conducted by dropping the rig mass through a selected distance onto the fixture inner cylinder. The weight of the rig mass was changed for certain tests to study the effect of impact mass variation on the honeycomb energy absorbing characteristics. This was accomplished by adding or subtracting lead shot from the drop rig. For static testing, i.e. "slow crushing", two hydraulic actuators were attached to the drop rig and the rig pulled down at a controlled rate. The rig could be stopped at any desired point of the crush stroke to study spring rate, load drop off at fixed stroke position, etc. Crushing characteristics were recorded using an X-Y plotter for static tests and an oscillograph for dynamic tests. Observations and photographs (including standard and high speed movies) of the crushing action were made through the large window in the fixture outer cylinder.

Figure 3-3 shows the details of the test fixture and Figure 3-5 shows a general view of the test fixture components. In this program it was required to accurately determine the static and dynamic characteristics of the various honeycomb specimens. It was therefore important to isolate (as much as possible) the dynamic effects of the test fixture from the recorded test data.

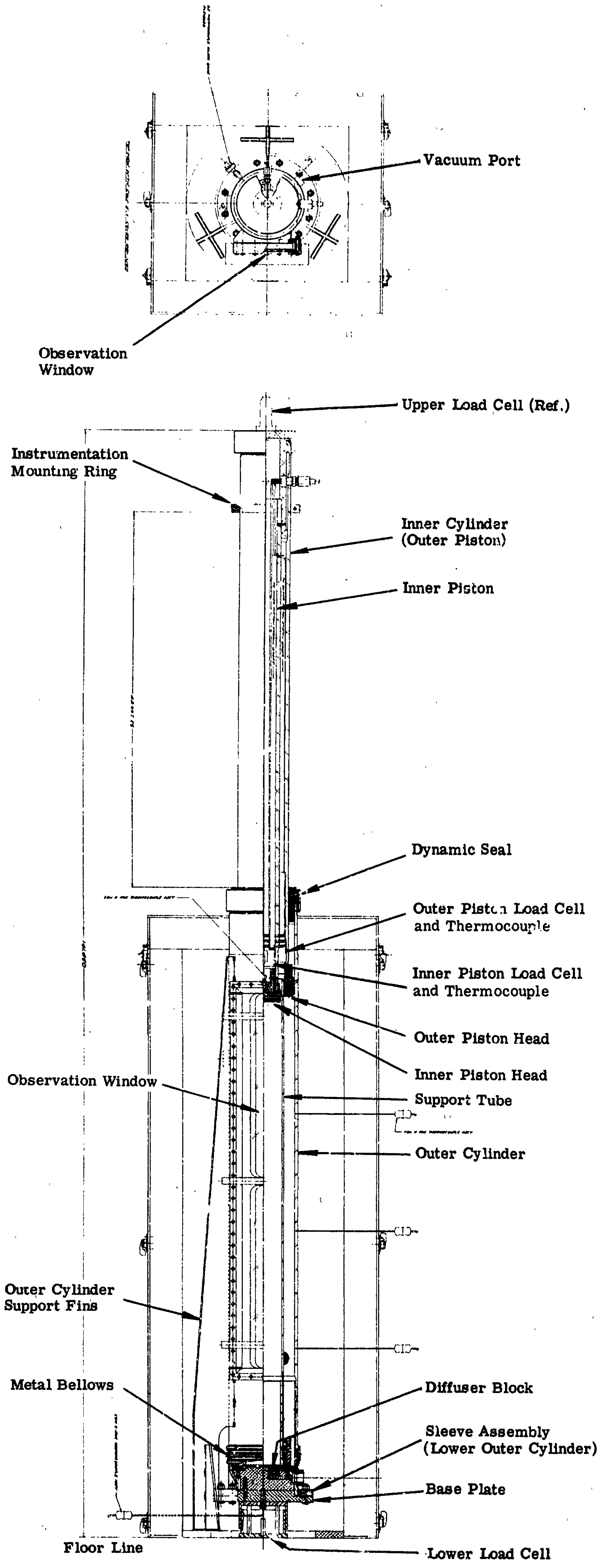


Figure 3-3. Test Fixture

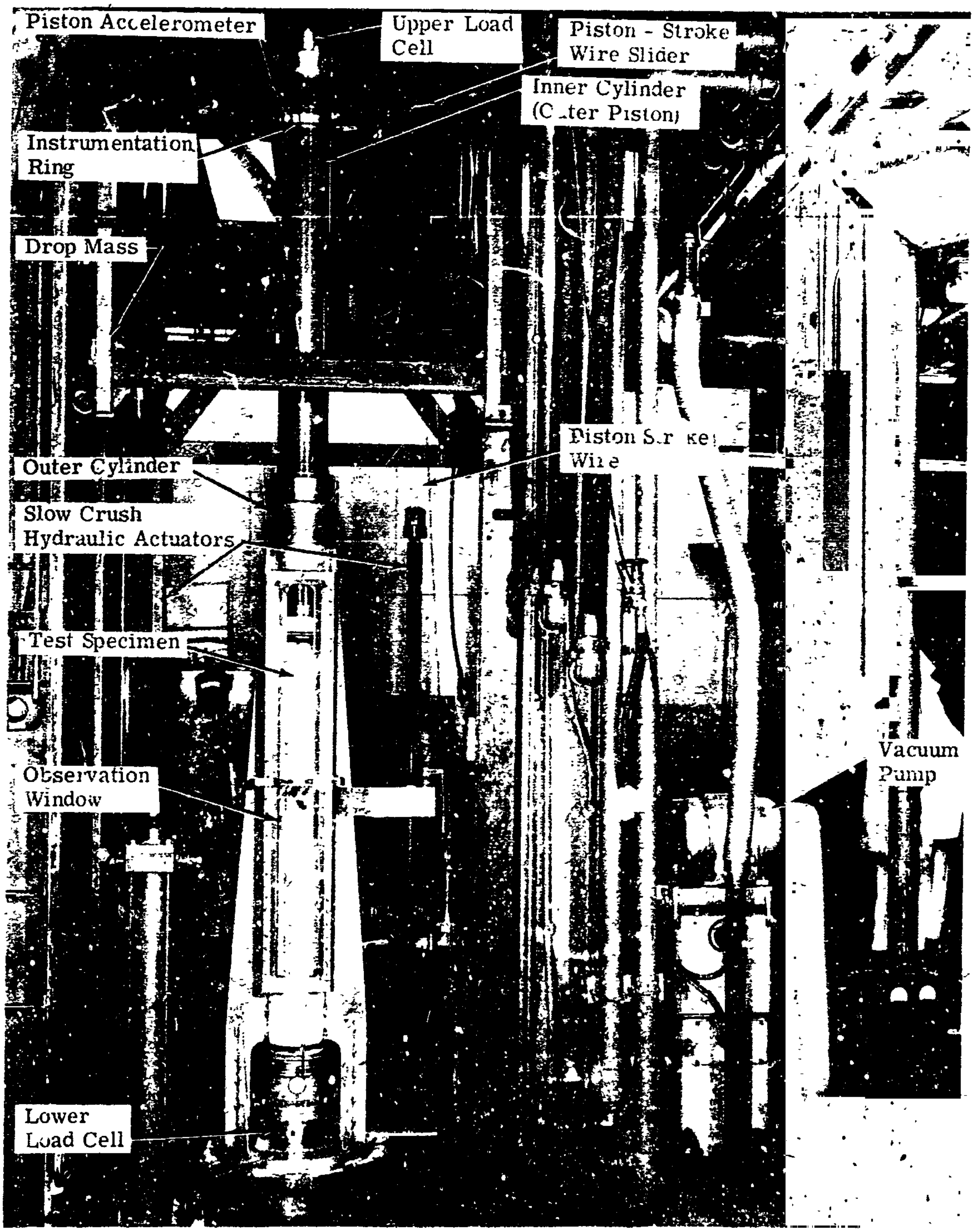


Figure 3-4. Test Setup

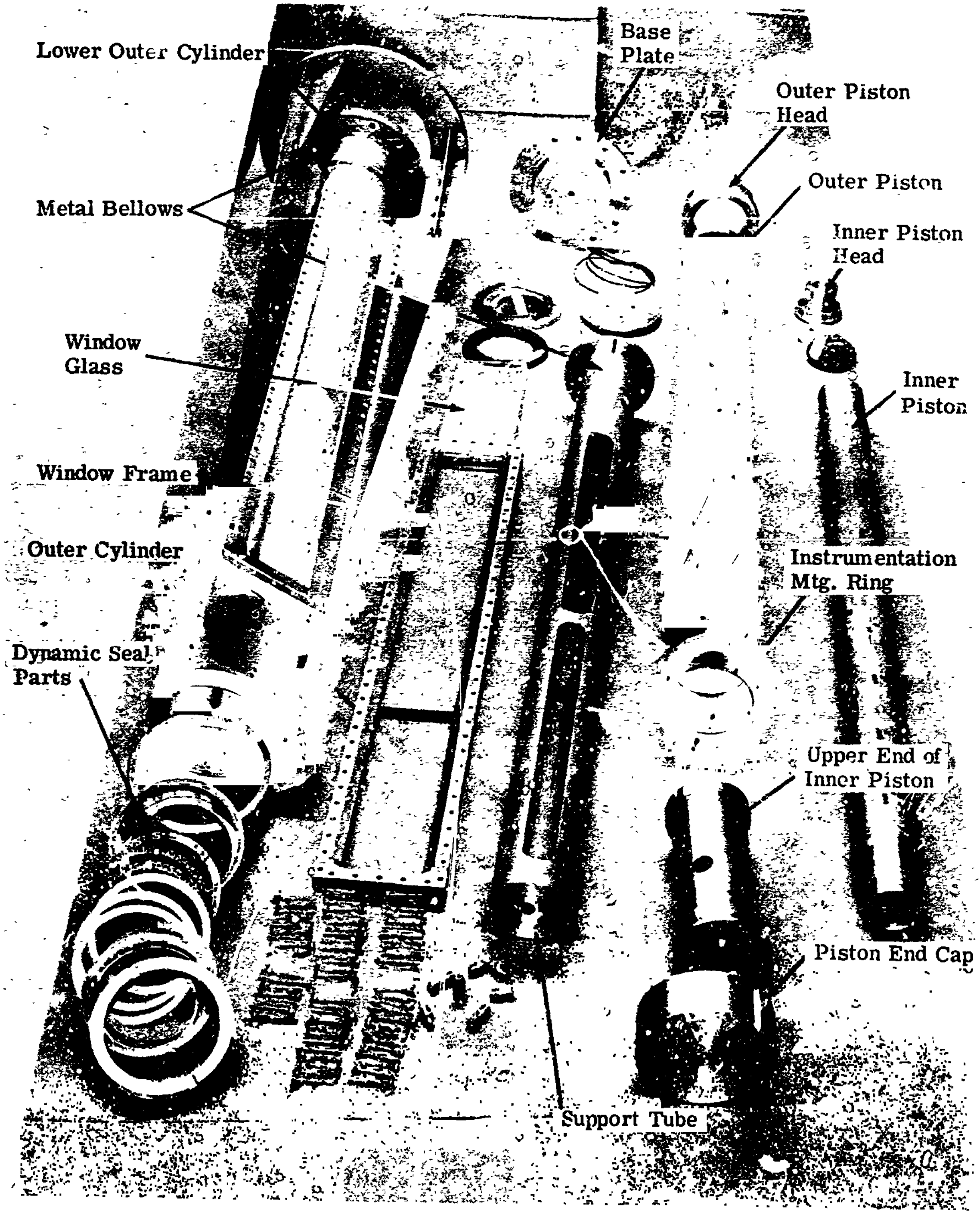


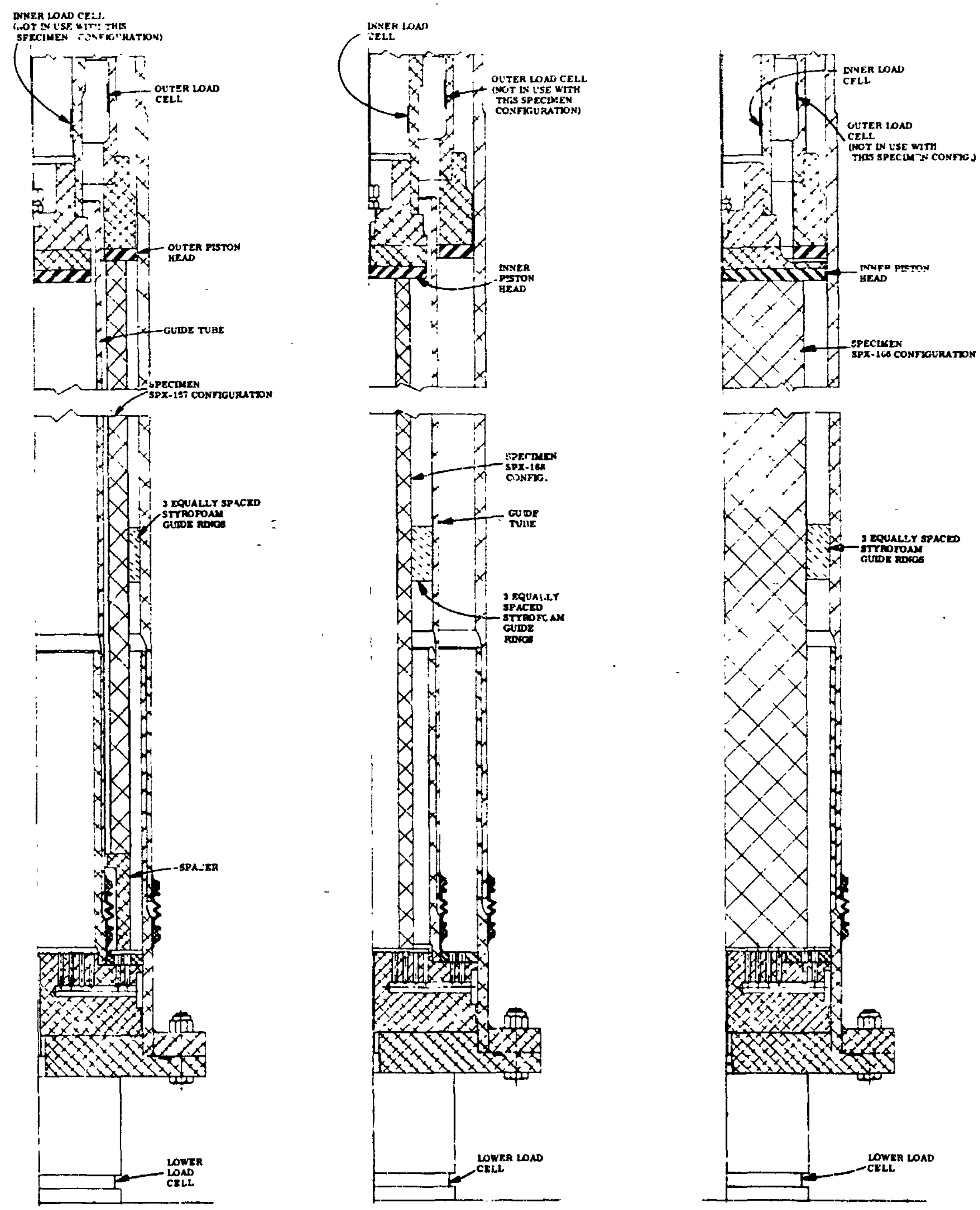
Figure 3-5. General View of Test Fixture Components

This was accomplished by carrying the outer cylinder loads directly to the floor through "fins" welded to the outer cylinder. The bottom of the outer cylinder was cut away and a moving sleeve assembly, attached to the outer cylinder by metal bellows to provide a vacuum seal, carried the capsule and inner cylinder loads into a load cell which was positioned between the sleeve and the floor. A dynamic analysis of the fixture using an analog computer was made to determine the effect of the rig dynamics on the load cell readings. This analysis is described fully in Section IV of this report.

The fixture was designed so that set up time would be minimized for the three basic capsule configurations when changing from one configuration to another. The fixture, as shown in Figure 3-3, can be used to test both the large annular (external) specimens (SPX-167) and the small annular (internal) specimens (SPX-168). The large annular specimens were guided on their inside diameter by the support tube outside diameter and were crushed by the outer piston, as shown in Figure 3-6A. The small annular specimens were guided on their outside diameter by the support tube inside diameter and were crushed by the inner piston, as shown in Figure 3-6B. The support tube was cut away in the area of the observation window so that the crushing characteristics of the small annular specimens could be observed. For testing the solid cross-section specimens (SPX-166), the support tube was removed and a large piston head was attached to the inner piston. The specimen was guided on its outside diameter by the outer cylinder inside diameter, as shown in Figure 3-6C.

The fixture was evacuated to a pressure of $3x10^{-1}$ TORR or less by a positive displacement oil diffusion pump connected to the lower end of the outer cylinder.

A hard compound insulating material on the outer piston head provides a moving bearing. The dynamic vacuum seal also serves the purpose of the fixed bearing in the outer cylin-



Configuration of Fixture For Testing Specimens Type SPX-167

(A)

Configuration of Fixture For Testing Specimens Type SPX-168

(B)

Configuration of Fixture For Testing Specimens Type SPX-166

(C)

Figure 3-6. Test Fixture Configuration for each Specimen Type der. The dynamic vacuum seal is a "Vee" type as shown in Figure 3-7. An outer nut retains the seal assembly in place in the outer cylinder, and a nut, inside the seal retaining nut, allows the pressure on the seal to be adjusted. Figure 3-7 configuration (1) shows the seal assembly used for most room temperature to +300°F testing. This seal design will hold a vacuum of 3×10^{-1} TORR or less with the seal temperatures up to +300°F. Figure 3-7, configuration (2) shows the seal assembly used for most of the testing at -150°F and -260°F. Although this seal design will hold a vacuum at -260°F, it will only do so if the vacuum is initially obtained before the seal reaches -20°F. Due to this problem, it was necessary to use the following procedure in obtaining the required low temperature test conditions. Initially the outer cylinder and specimen were cooled down to -100°F with the piston and seal assembly removed. The liquid nitrogen supply into the outer cylinder was then shut off and the piston and dynamic seal assembled to the outer cylinder. The vacuum pump was then started and a vacuum of 3×10^{-1} TORR pulled in the fixture before the dynamic seal reached -20°F. The fixture and specimen temperature was then reduced to -260°F and the specimen crushed. Later in the program, the seal assembly was changed to the configuration shown in Figure 3-8. This assembly gives a longer bearing length and uses a teflon ring as a scraper. The same procedure as described above is required to attain a seal at cryogenic temperature. This seal assembly was used during testing at +300°F toward the end of the program and performed satisfactorily. A brief discussion of the dynamic seal development is included at the end of this section.

All materials used in the construction of the fixture were 6061 aluminum alloy except for the outer piston which was hard coated 2024-T4 aluminum alloy. Aluminum alloy was selected for use in this fixture design for its high heat transfer properties which make

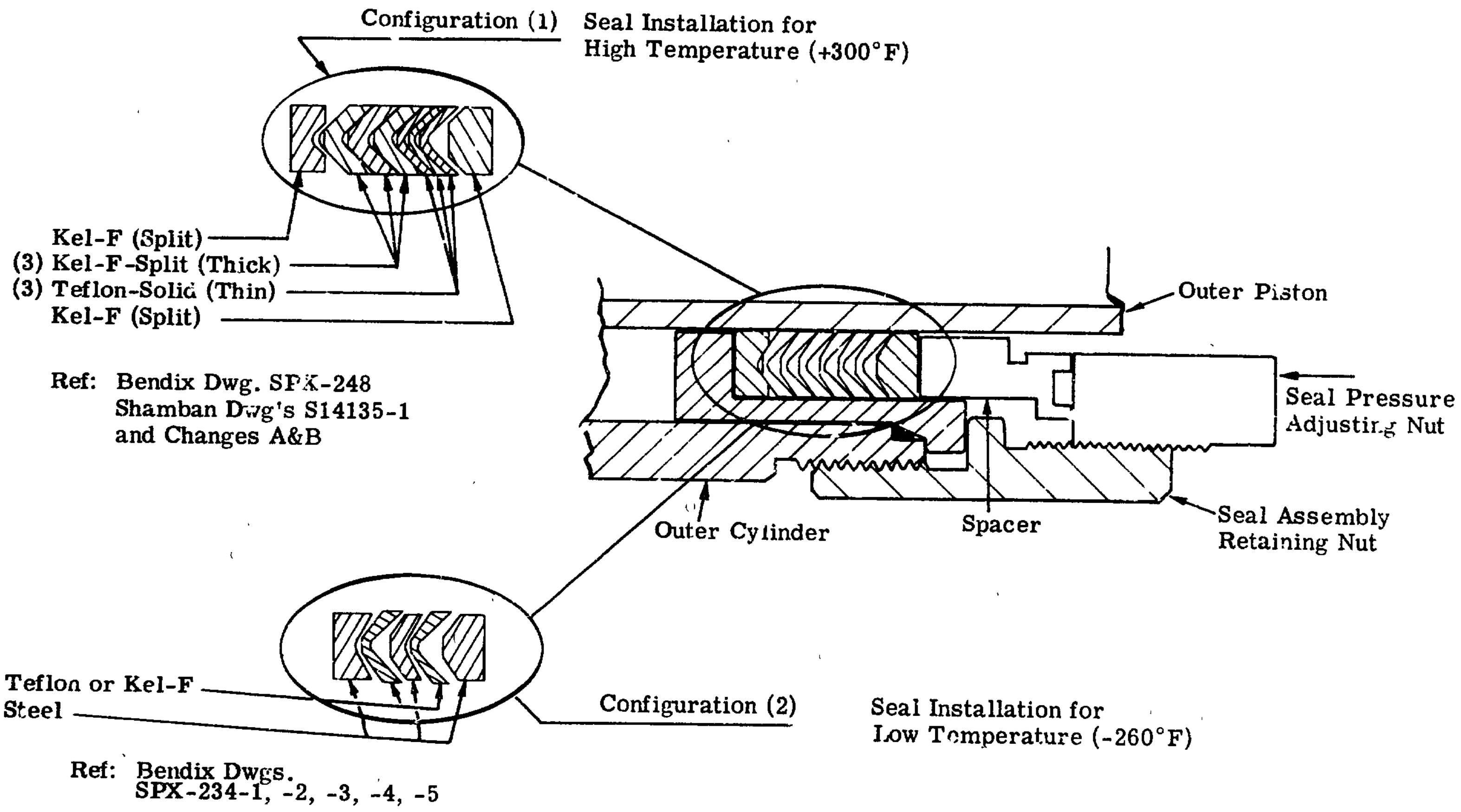


Figure 3-7. Dynamic Vacuum Seal Assembly

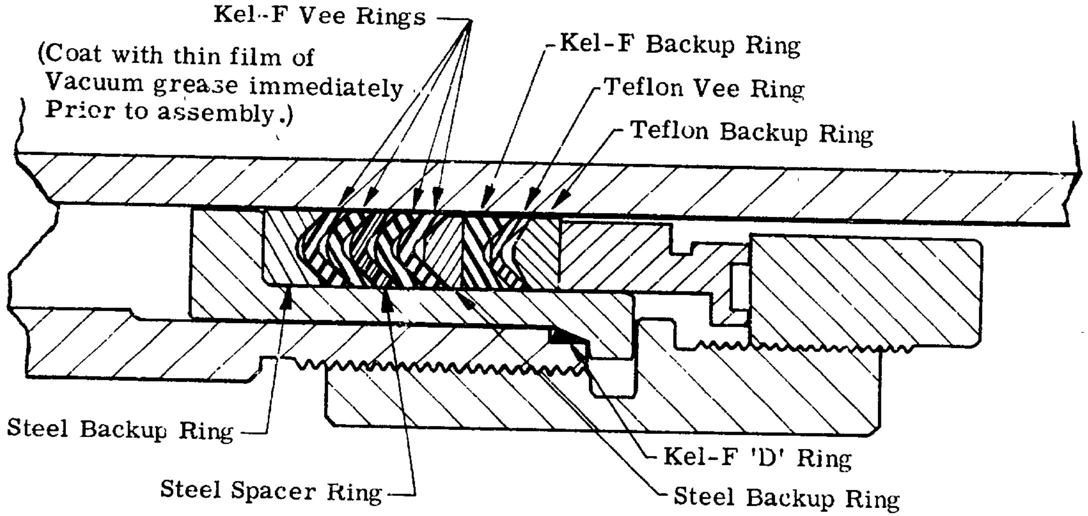


Figure 3-8. Dynamic Vacuum Seal Assembly - Final Configuration for Low Temperature Testing

it possible to rapidly heat or cool the fixture for the extreme environment tests. The static seals for the base plate and seal retaining nut were Kel-F. The outer piston cap seal was silicone rubber. Instrumentation outlets in the upper end of the outer piston were sealed with teflon and in the base plate by lava and teflon seals. The vacuum gage, vacuum line, and gas inlet and exhaust lines were wet assembled into standard pipe threads and coated with vacuum grease. Cryogenic vacuum valves were used to close off the gas inlet and exhaust ports prior to pulling a vacuum. The observation window was made from Corning Glass Work's annealed borosilicate glass (No. 7740) and the window seal of thin sheet virgin teflon. The differential expansion between the glass and the aluminum frame was used to provide a high seal pressure (4,490 psi) at -260°F and a low seal pressure (500 psi) at +300°F. The low seal pressure at +300°F prevents the teflon from "cold flowing" out of position. The gradual increase in seal pressure as the fixture is cooled down maintains the vacuum seal obtained at room temperature. It should be noted that the window seal will not seal at cryogenic temperature if a good seal is not first obtained at room temperature. The high seal loads at -260°F coupled with the unequal cooling and reheating of the fixture caused the window frame to twist excessively. This resulted in the breaking of several windows and cracking of the window frame corner welds. This problem was overcome by stiffening the window frame by welding on three horizontal bars as shown in Figures 3-4 and 3-9.

Marshall Eclipse compound A5-105 was used as insulation on the piston heads, to reduce the heat transfer to the dynamic vacuum seal and outer piston, and below the lower load cell to reduce the temperature gradient across the load cell pins.

3.3 HIGH TEMPERATURE TESTING

For conducting tests at +150°F and +300°F the fixture and specimen were heated

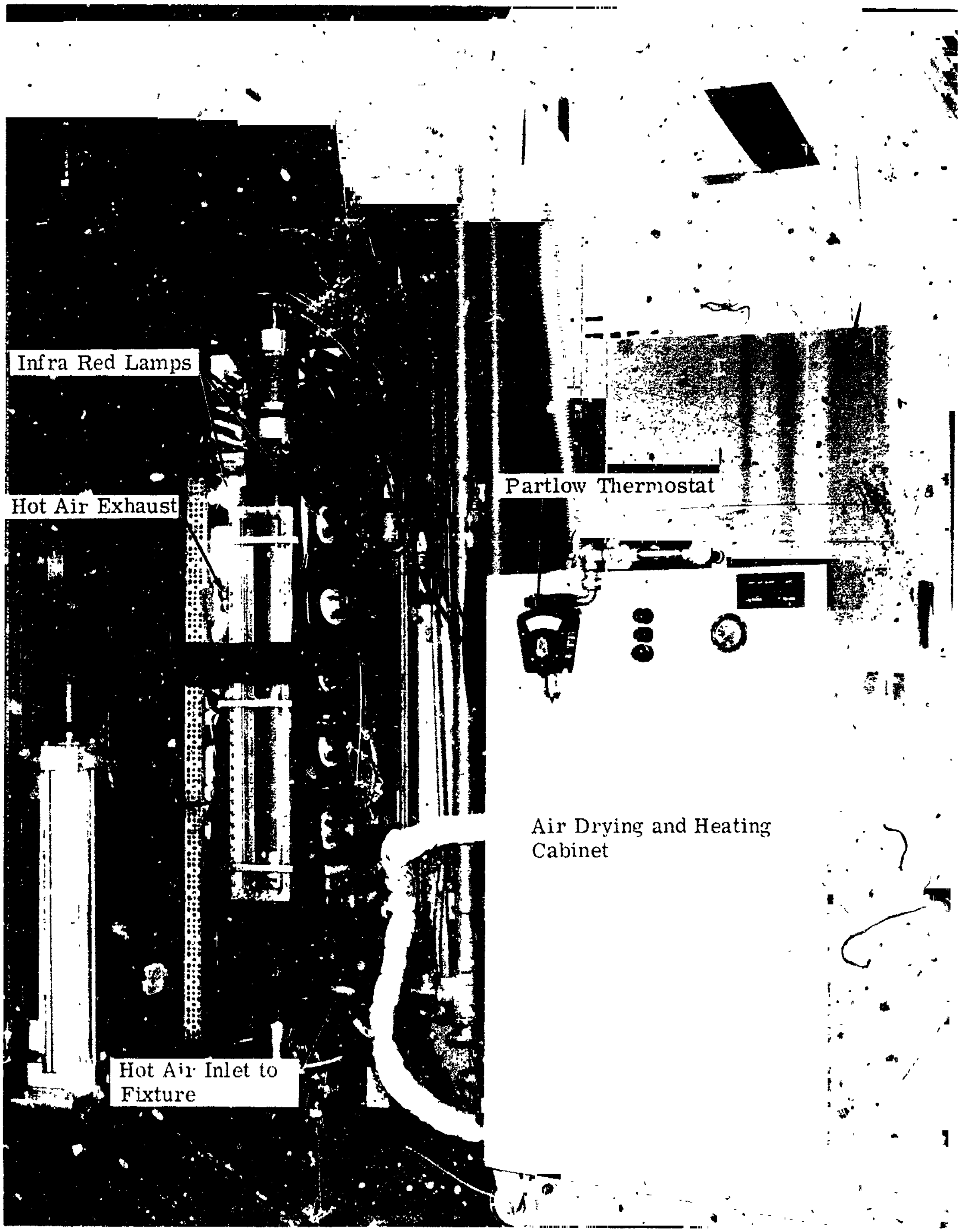


Figure 3-9. High Temperature Test Setup

using the apparatus shown schematically in Figure 3-10. The actual test setup is shown in Figure 3-9. One bank of 8 infra red lamps and one bank of 6 infra red lamps were used to heat the fixture close to the test temperature. High temperature dry air was then fed into the lower end of the test fixture and exhausted from the top to bring the specimen and fixture up to the required test temperature and to reduce the thermal gradiants in the specimen and fixture. When the required temperature was reached, the air flow was shut off, the vacuum valves closed, and the fixture evacuated. The heat lamps were kept on until after crushing of the specimen to maintain the test temperature.

3.4 LOW TEMPERATURE TESTING

The test setup used for -150°F and -260°F testing is shown schematically in Figure 3-11. Figure 3-12 is a photograph of the actual test setup. As described previously in this section, it was necessary to cool the fixture and specimen with the piston and seal removed. The opening at the top of the outer cylinder was covered with a polystyrene sheet and an exhaust line fed cold air from the top of the fixture into the polystyrene cold box surrounding the fixture. The fixture was first purged by passing dry nitrogen through the system and then cooled by flowing low temperature nitrogen gas into the cold box and fixture. Low temperature nitrogen gas was also fed through a vaporizer coil and sprayed across the observation window to alleviate the window frost problem. When the fixture reached -100° the nitrogen flow into the fixture was shut off by closing the cryogenic vacuum valve, the piston and seal assembly inserted, and the vacuum pulled in the fixture. Low temperature nitrogen gas was continuously sprayed on the back of the fixture and across the observation window and the specimen crushed when the fixture reached the test temperature (-150°F or -260°F).

3.5 DYNAMIC SEAL DEVELOPMENT

In the design of the test fixture, the problem of providing a dynamic sliding vacuum seal

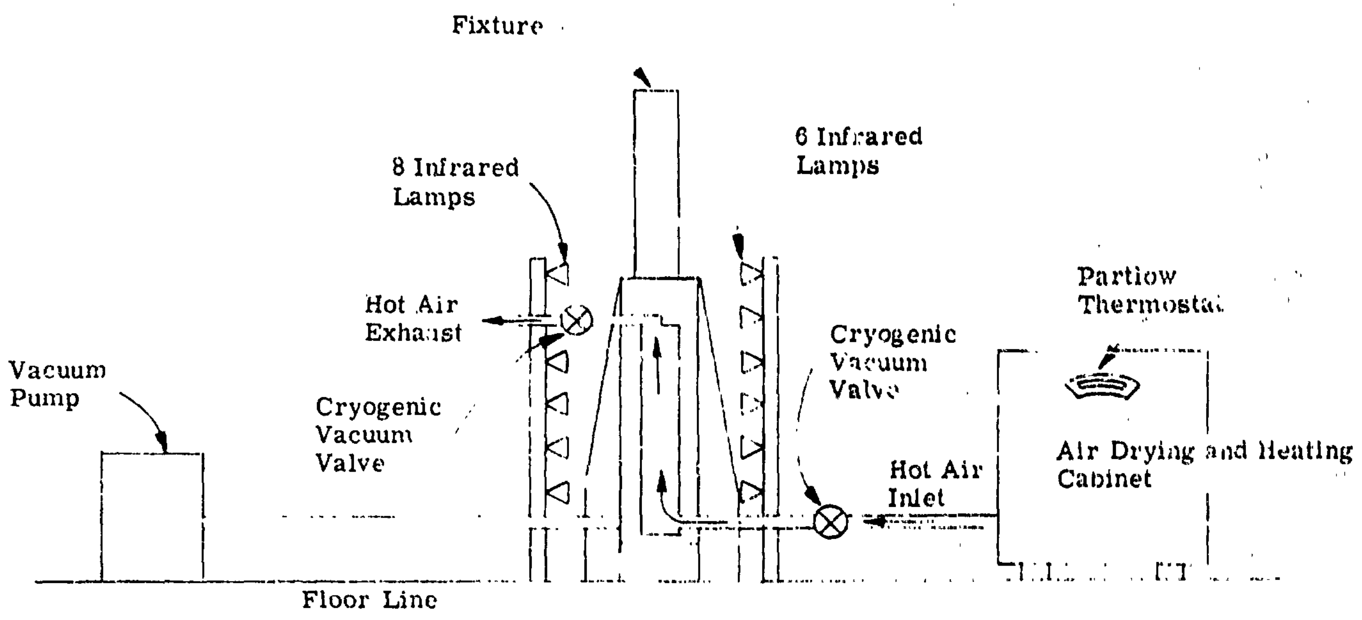


Figure 3-10. Schematic of High Temperature Test

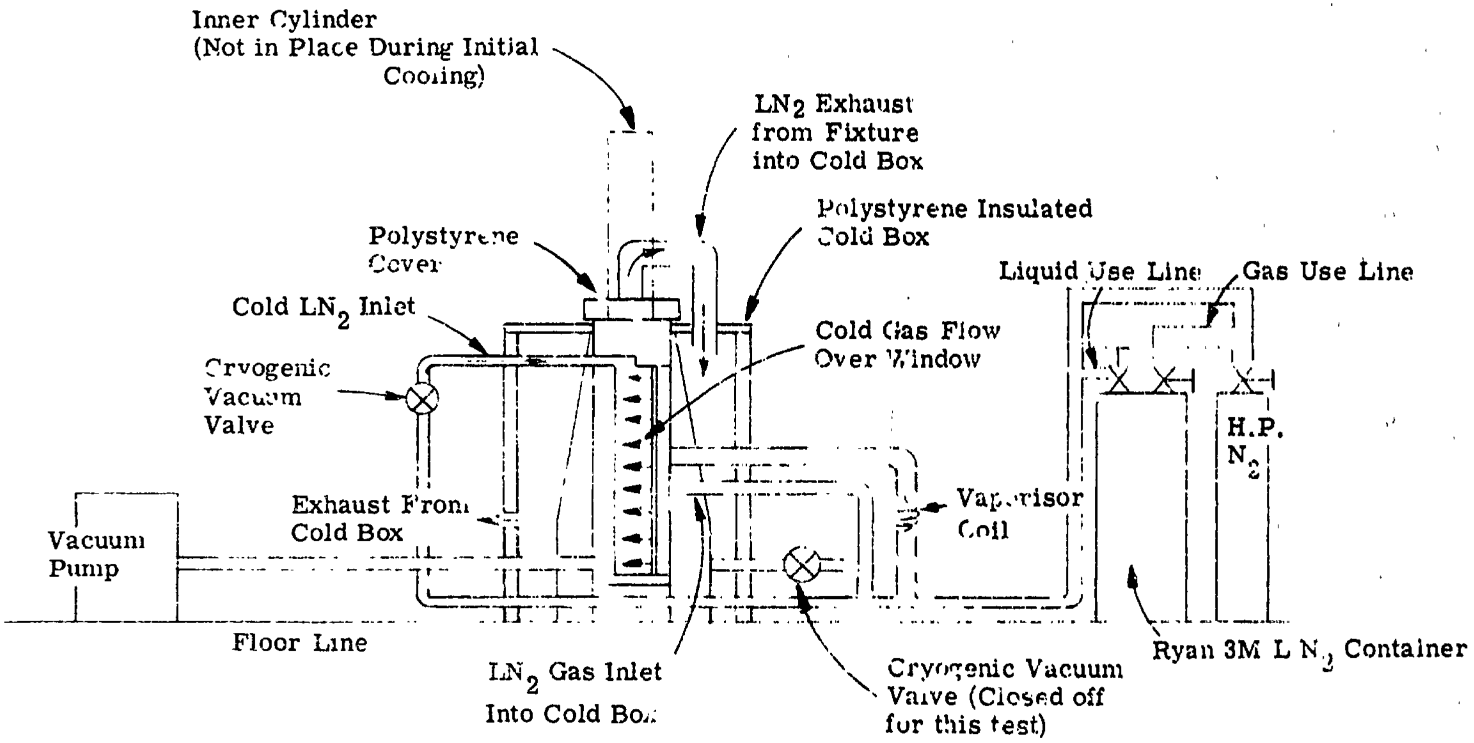


Figure 3-11. Schematic of Low Temperature Test Setup

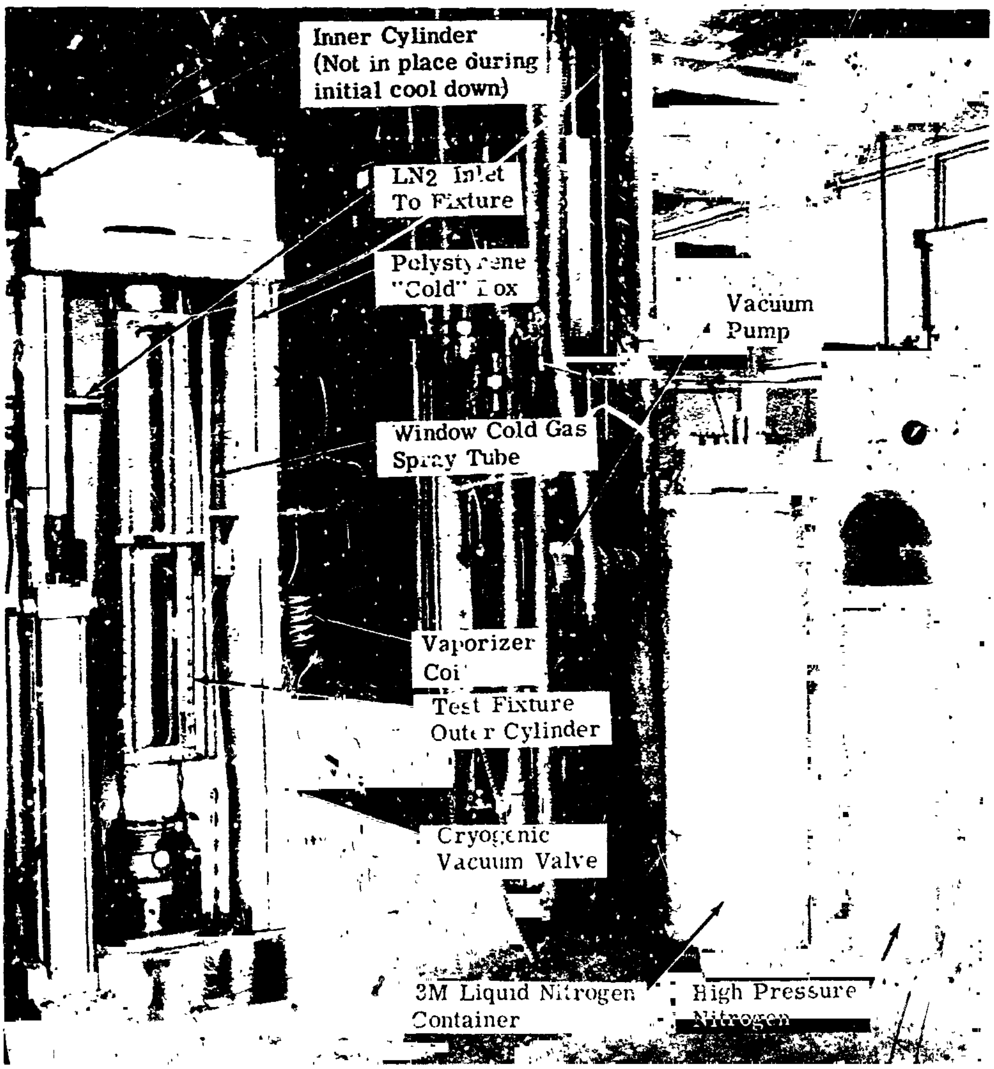


Figure 3-12. Low Temperature Test Setup

for operation over a temperature range of +300°F to -260°F was found to be a formidable one. An additional problem was presented in the seal design, with the possibility that the projected temperature gradient along the length of the outer piston could probably be as high as 300°F for tests with a specimen temperature of -260°F. Such a condition would therefore require a seal and outer cylinder bearing which could accomodate the change in outer piston diameter during stroking. In order to test the static seals, the dynamic seal design, and the cryogenic vacuum valves to be used in the test fixture, a small seal evaluation fixture was constructed. Figure 3-13 shows this fixture. The outer cylinder was made with upper and lower ends which are identical to those on the actual test fixture. The dynamic seal gland parts and the base plate were the actual parts for the full size test fixture. The dynamic seal parts and the base plate were later replaced in order to continue development of the dynamic seal for cryogenic testing while room temperature and high temperature specimen tests were being conducted in the drop test fixture. No sealing problems were encountered with the static seals or the cryogenic vacuum valve when tested in this fixture over the required environmental temperature range. The first dynamic seal design tested, shown in Figure 3-14, was a teflon "Vee" ring packing which also acted as the outer cylinder bearing. This design utilized split teflon "Vee" rings, to allow for circumferential expansion and contraction, and also incorporated teflon back up rings. Axial load was applied to the seal through a spring ring. This allowed the seal to deflect axialy during stroking with only a small axial load change. It was determined to be impractical to machine the "Vee" rings accurately enough to create a vacuum tight seal all around each ring, or to apply sufficient pressure to deform the rings to create a seal at room temperature. A new set of teflon "Vee" rings was then manufactured with a thinner cross section without the split and the spring ring was removed. Again it was not possible to deflect the "Vee" ring stack sufficiently to create a vacuum

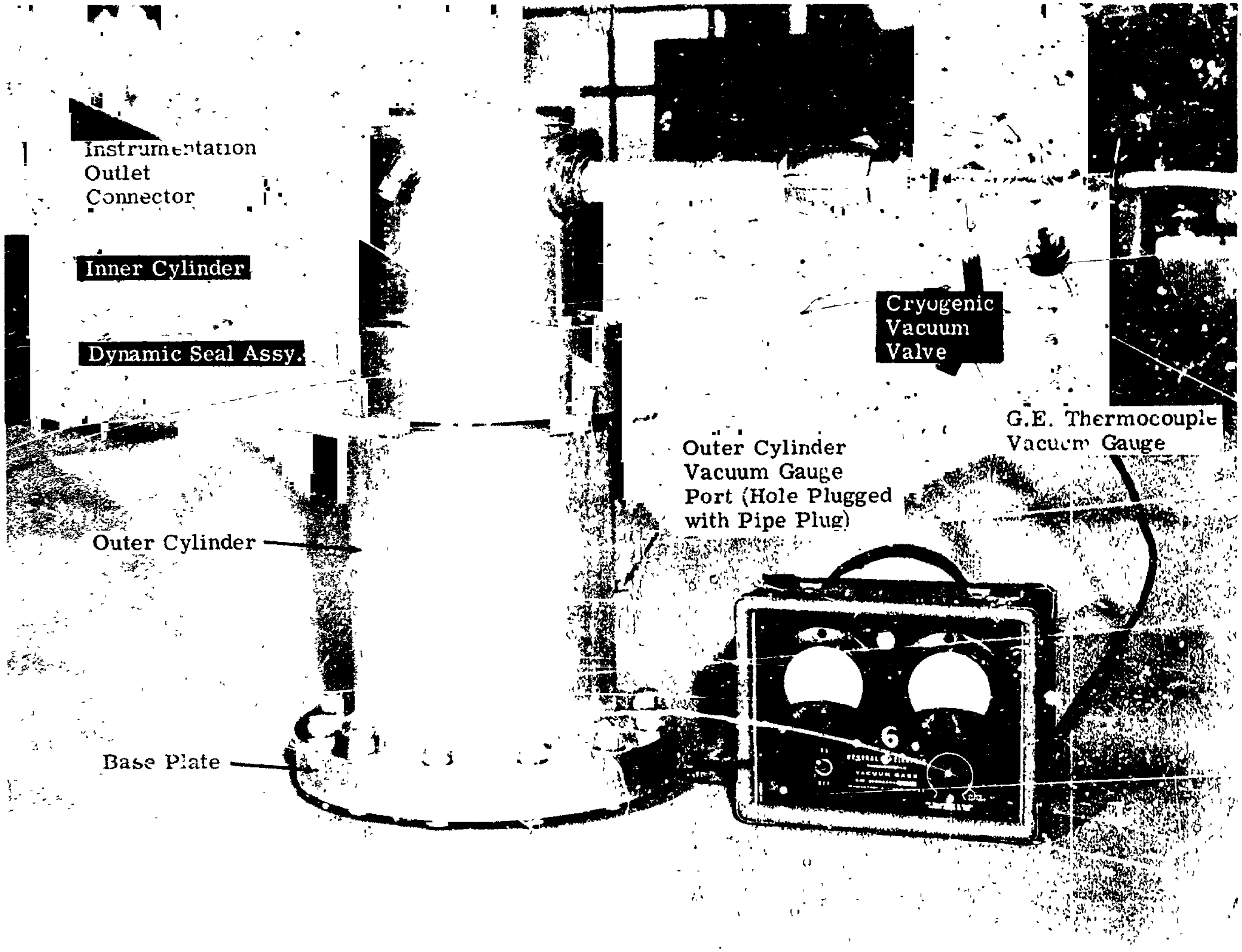


Figure 3-13. Seal Evaluation Test Fixture

seal below about +20°F. Differential contraction between the seal outside diameters and the aluminum housing accentuates this problem, requiring greater seal deflection as the temperature decreases and much higher seal pressure as the material is becoming more rigid. A further change was made using split Kel-f adaptors, split thick Kel-f "Vee" rings and thin solid teflon "Vee" rings. This design was found to operate satisfactorily from room temperature up to +300°F but would not operate satisfactorily at cryogenic temperatures. This design was then used for the room temperature to +300°F testing (see Figure 3-7 configuration 1), while a separate study was conducted to determine a seal configuration that would operate in the low temperature range.
In order to use the differential expansion between the teflon and aluminum to help instead of hindering the sealing, aluminum alloy adaptors were tried in conjunction with teflon "Vee" rings. This design proved better but was still not able to seal a vacuum at -260°F. The "Vee" ring seal was then redesigned to create a "knife edge" contact area as shown in Figure 3-15. The cross section was thinned out and the mating adaptors designed to apply loads to keep the seal pressed against the outside and inside diameters. Two teflon "Vee" rings seals were used with steel male and female adaptors with a special steel adaptor between the two seals as shown in Figure 3-7, configuration 2. The steel adaptors were used in order to make the gap between the adaptor and the aluminum outer cylinder decrease due to differential contraction and hence use this contraction to its maximum in creating high sealing pressures at low temperature. Each seal was coated with a thin film of vacuum grease prior to assembly. It was found that this design could be made to work and was used for most of the -150°F and -260°F testing. The final configuration used in the latter part of the program is shown in Figure 3-8. It uses two extra Kel-f "Vee" rings to increase the bearing and seal area and a teflon "Vee" ring to act as a scraper. Each seal was coated with a thin film of vacuum grease

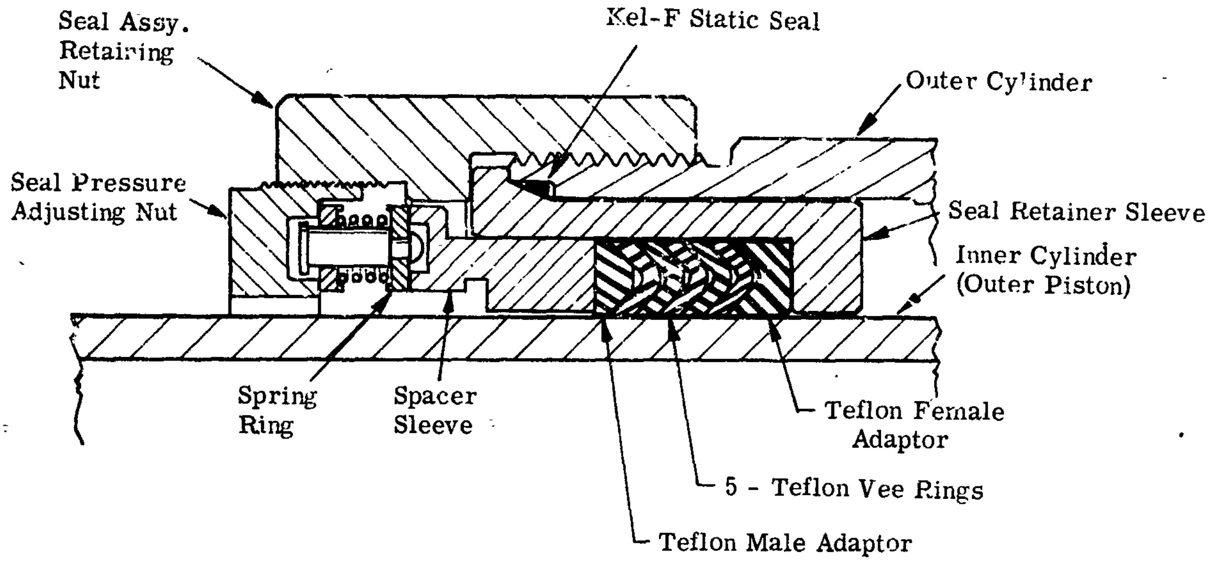


Figure 3-14. First Dynamic Seal Design

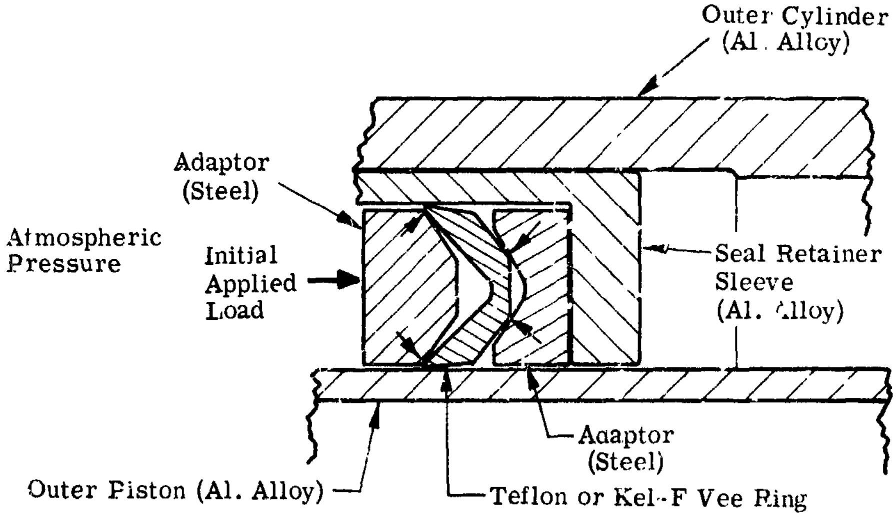


Figure 3-15. Loading on "Knife Edge" Seal Design

prior to assembly. In order to make the seal work satisfactorily it was determined experimentally that a vacuum seal must first be obtained before the seal assembly reaches a temperature of -20°F, as below this temperature the seal becomes too stiff to flow into small irregularities. Once the seal has been established the differential contraction increases the seal pressure sufficiently during the succeeding cool down period to maintain a vacuum of $3x10^{-1}$ TORR or less at a seal temperature of -260°F. A more detailed account of the dynamic seal development is contained in the monthly progress reports for this program.

3.6 INSTRUMENTATION

3.6.1 Temperature Measurement

Temperature measurements were made using seven con-o-pack copper constantan wire thermocouples with aluminum sheaths. Temperature readings were made at the inner and outer load cells, the inner piston head, three equally spaced positions on the outer cylinder wall, and in the center of the diffuser block at the bottom of the outer cylinder as shown in Figure 3-4. The thermocouples were wired through a switching box to a Wheeler model 310 potentiometer.

3.6.2 Pressure Measurement

The pressure in the test fixture was measured with a General Electric thermocouple vacuum gage (Type 8651860G) mounted in the center of the outer cylinder wall and read out on a General Electric thermocouple vacuum gage reader type #8298238G. This instrument (shown in Figure 3-13) gives a direct pressure reading in microns. The gage has a range from 500 to 5 microns.

3.6.3 Accelerometers .

Statham Model A-5-A silicon fluid damped seismic mass accelerometers were used to measure the drop mass and piston accelerations. The drop mass accelerometer had a rating of 10g's and a natural frequency of 250 c.p.s. The piston accelerometer had a rating of 500g's and a natural frequency of 1500 c.p.s. The piston accelerometer was mounted to the instrumentation ring at the upper end of the outer piston as shown in Figure 3-4. The accelerometer signals were fed through an amplifier and galvanometer into an oscillograph recorder. The dynamic response characteristics and accuracy of this equipment is given at the end of this section and in Table 3-1.

3.6.4 Stroke Measurement

Drop mass travel and piston stroke were measured using a variable resistance slide wire. The moving clip, attached to the fixed slide wire, utilized a wheatstone bridge circuit wired so that the bridge was temperature compensated. The wires for both mass travel and piston travel were positioned as far as practical from the test fixture to keep the temperature change along the wire as small as possible. For the low temperature test, where the cold box was used, the slide wires were outside the box (see Figures 3-4, 3-10, and 3-12). The piston slider was attached to the instrumentation ring at the upper end of the outer piston as shown in Figure 3-4.

3.6.5 Load Measurement

Strain gage load cells were built into the outer piston for use with the large annular specimens and into the inner piston for use with the small annular and solid specimens. A three pin strain gage load cell was positioned under the lower outer cylinder. Figure 3-3 shows the location of these load cells in the fixture. During rig check out and initial testing an additional load cell was attached to the top of the inner cylinder, as shown in

Figure 3-4 for use in determining the rig dynamic characteristics. The strain gages in the inner and outer load cells were Budd Alloy #1 backless gages bonded with GA 5 cement. The lower load cell used Budd C-12-124 constanton alloy gages with epoxy fiberglass backing. These gages were bonded with GA-60 cement and calibrated from +290°F to -300°F. Figure 3-15 is the calibration curve for this load cell. As can be seen the load vs strain curve is linear for all temperatures with an increase in slope occuring with a decrease in temperature. The change in slope with temperature is due to the change in Young's modulus for the material and the change in strain gage sensitivity. The change in modulus accounts for the majority of the slope change. The compression modulus varies from 11.1×10^6 lb./in.^{2} at -260°F to 9.6×10^6 lb./in.^{2} at +300°F. In order to determine the gage and bonding agent to use for operation from +300°F to -300°F several types of gages and bonding materials were tested. Calibration of the gages was obtained by loading the load cell in an Instron machine (see Figure 3-1) at the temperatures shown on the calibration curve Figure 3-16. Similar calibrations were made for the other load cells and are reported in section V of this report.

Dynamic test data for the mass travel, piston travel and load cells was obtained by feeding the signals through amplifiers and galvanometers to an oscillograph recorder. The dynamic response characteristics and accuracy of this equipment is given at the end of this section and in Table 3-1.

During static testing, the piston stroke and lower load cell were wired to an Electronic Associates Inc. Model 1110-99.60 plotting board to obtain a direct plot of load vs stroke. The inner and outer load cells were not used during these tests. The Model 1110-99.60 plotting board has a static accuracy of 0.1% and a maximum slew rate of 20 inches/second. When recording amplitudes of 10 inches, the maximum frequency response is limited

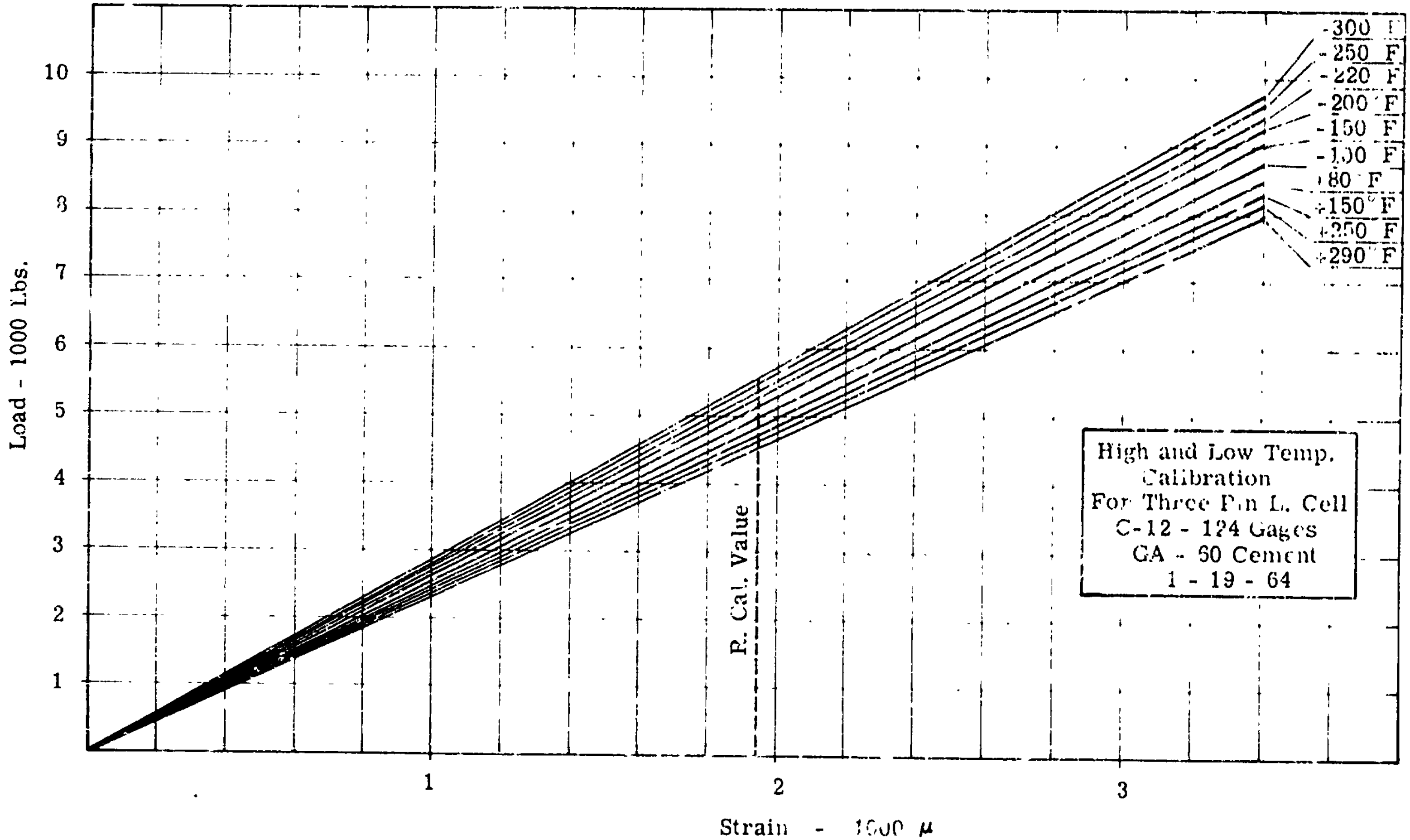


Figure 3-16. Lower Load Cell Calibration over Test Temperature Range

to 0.3 c.p.s., but at a recording amplitude of one inch the frequency response of the board would not reach its limit until 2.5 c.p.s. During the crushing portion of the stroke, the amplitudes were considerably less than one inch.

3.6.6 Oscillograph Recorder and Associated Equipment

Accelerometer, mass travel, piston stroke, and load cell signals were fed into Consolidated Electro-Dynamic Corporation Model 113B bridge balance amplifiers with a 3KC carrier power supply. The signals were then fed through galvanometers to a Consolidated Electro-Dynamics Corporation Type 5-114-P4 oscillograph recorder. The amplifier will drive a load corresponding to four inch double amplitude deflection, on a 323 galvanometer, within ±2% of the maximum output. The amplifier output amplitudes, with the amplifier properly loaded, are constant to 2% for modulating frequencies from 0 to 500 c.p.s. Matching networks were used where necessary, between the amplifier and galvanometer, to insure the correct amplifier loading and galvanometer damping.

Parameter	Galvanometer Type	Natural Frequency c.p.s.	Flat Response 5% c.p.s.
Inner Load Cell	323	1,000	600
Outer Load Cell	323	1,000	600
Lower Load Cell	323	1,000	600
Mass Travel	323	1,000	600
Piston Stroke	323	1,000	600
Drop Mass Acceleration 50g Accelerometer 600 c.p.s. Nat. Freq.	339	50	30
Piston Acceleration 500g Accelerometer 1500 c.p.s. Nat. Freq.	345	335	200

Table 3-1. Galvanometer Dynamic Response

SECTION IV

DYNAMIC ANALYSIS OF DROP TEST FIXTURE

4.1 INTRODUCTION

In order to obtain the true crushing characteristics of the honeycomb test specimens, it was necessary to determine the influence of the test fixture dynamics on the output of the load cells. To accomplish this, a dynamic analysis of the test fixture was performed using a mathematical model of the fixture on an analog computer. A hypothetical honeycomb load-stroke curve was used in the input to the computer and the resulting load cell output enabled the effect of the fixture dynamics to be determined.

4.2 DESCRIPTION OF MATHEMATICAL MODEL

Figure 3-4 (Section III) shows the test fixture assembly and the position of the load cells on the fixture. The physical system was simulated by the mathematical model shown in Figure 4-1 in conjunction with the forces acting on the system due to vacuum in the fixture and a pre-load applied to the bellows as shown in Figure 4-2. The mathematical model is for the configuration used for testing the solid section capsules SPX-166 as shown in Section III, Figure 3-6c. The equations of motion for the systen are:

$$M_0\ddot{X}_0 + f_0 = M_0 g \qquad (1)$$

$$M_4\ddot{X}_4 - K_5(X_5 - X_4) + K_4(X_4 - X_7) = PA_1 + M_4 g \qquad (2)$$

$$M_7\ddot{X}_3 - K_7(X_7 - X_3) + f_3 = M_7 g \qquad (3)$$

$$(M_1 + M_3)\ddot{X}_1 + (C_1 + C_2)\dot{X}_1 + (F + K_1 X_1) + P(A_2 - A_1) = (M_1 + M_3)g$$
$$+ f_3 + (F - K_5 X_1) - PA_1 \qquad (4)$$

$$(X_7 - X_3) = \frac{K_4}{K_7 + K_4}(X_4 - X_3) \qquad (5)$$

Table 4-1 lists the parameters and the numerical values used in the computer solution. Figure 4-3 is the hypothetical honeycomb load/stroke curve input to the computer. The load f_3 is determined by the value $(X_3 - X_1)$ in conjunction with the maximum previous value of this function;

when $(X_3 - X_1) < (X_3 - X_1)_{MPV} - (F_3)_0 / K_3$

Then $f_3 = 0$

when $(X_3 - X_1)_{MPV} - (F_3)_0 / K_3 < (X_3 - X_1) < (X_3 - X_1)_{MPV}$

then $f_3 = K_3 \left\{ (X_3 - X_1) - (X_3 - X_1)_{MPV} + \frac{(F_3)_0}{K_3} \right\}$

when $(X_3 - X_1)_{MPV} \leq (X_3 - X_1)$

then $f_3 = (F_3)_0$

Figure 4-4 is the load-deflection characteristic of the rubber impact pad positioned below the drop mass. This curve was obtained by static testing of the impact pad. An equation was obtained for the hysteresis loop by a force fit to the experimental data. The load f_0 is determined by the value $(\dot{X}_0 - \dot{X}_5)$ and the maximum previous value of $(X_0 - X_5)$:

If $(\dot{X}_0 - \dot{X}_5)$ is positive then $f_0 = F_5 = (X_0 - X_5) K_0$

If $(\dot{X}_0 - \dot{X}_5)$ is negative then $f_0 = F_5 = \frac{K_0 (X_0 - X_5)^3}{(X_0 - X_5)^2_{MPV}}$

The foregoing equations were programed for an analog computer. the flow diagram for which is shown in Figure 4-5

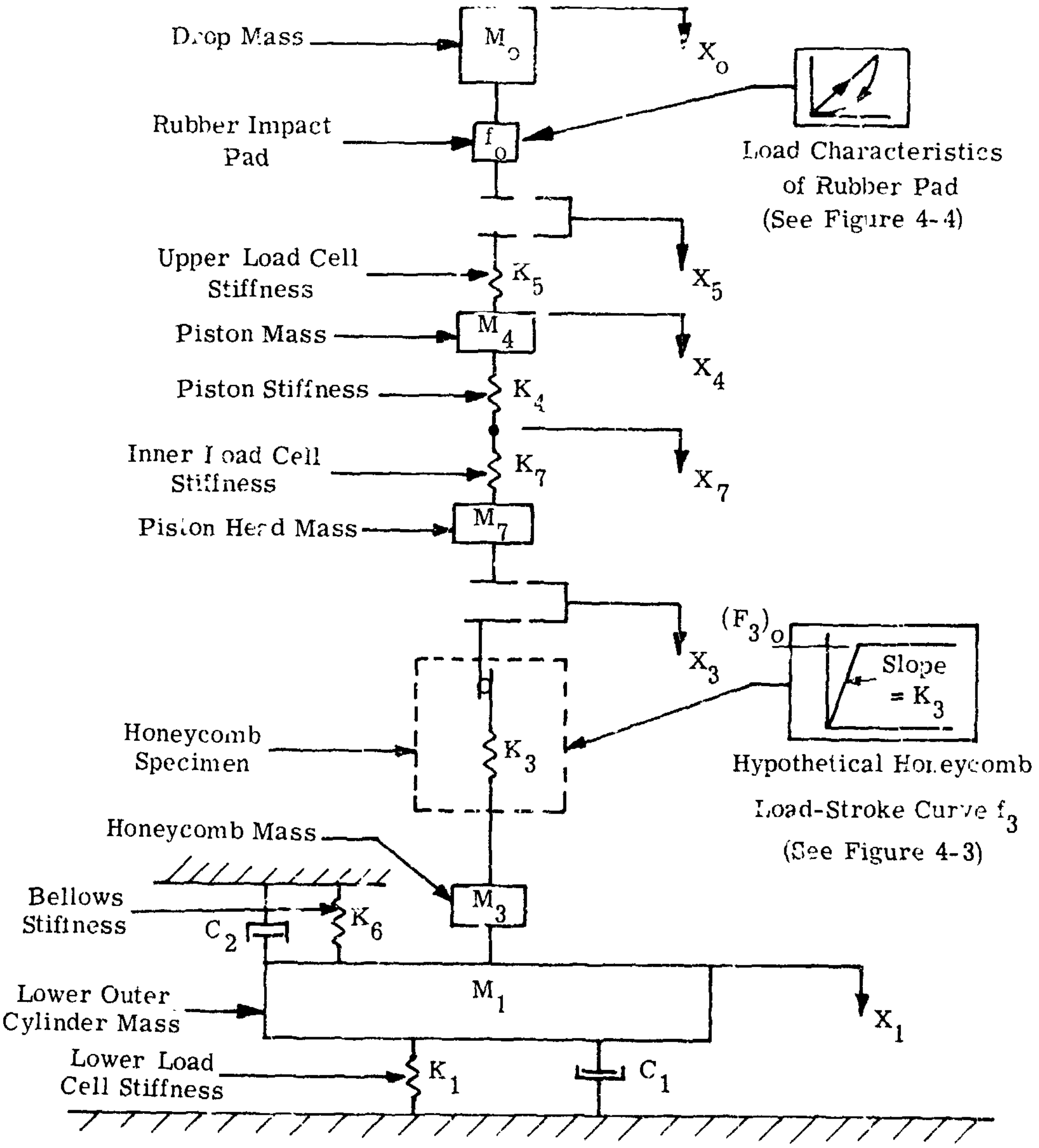


Figure 4-1. Mathematical Model of Test Fixture

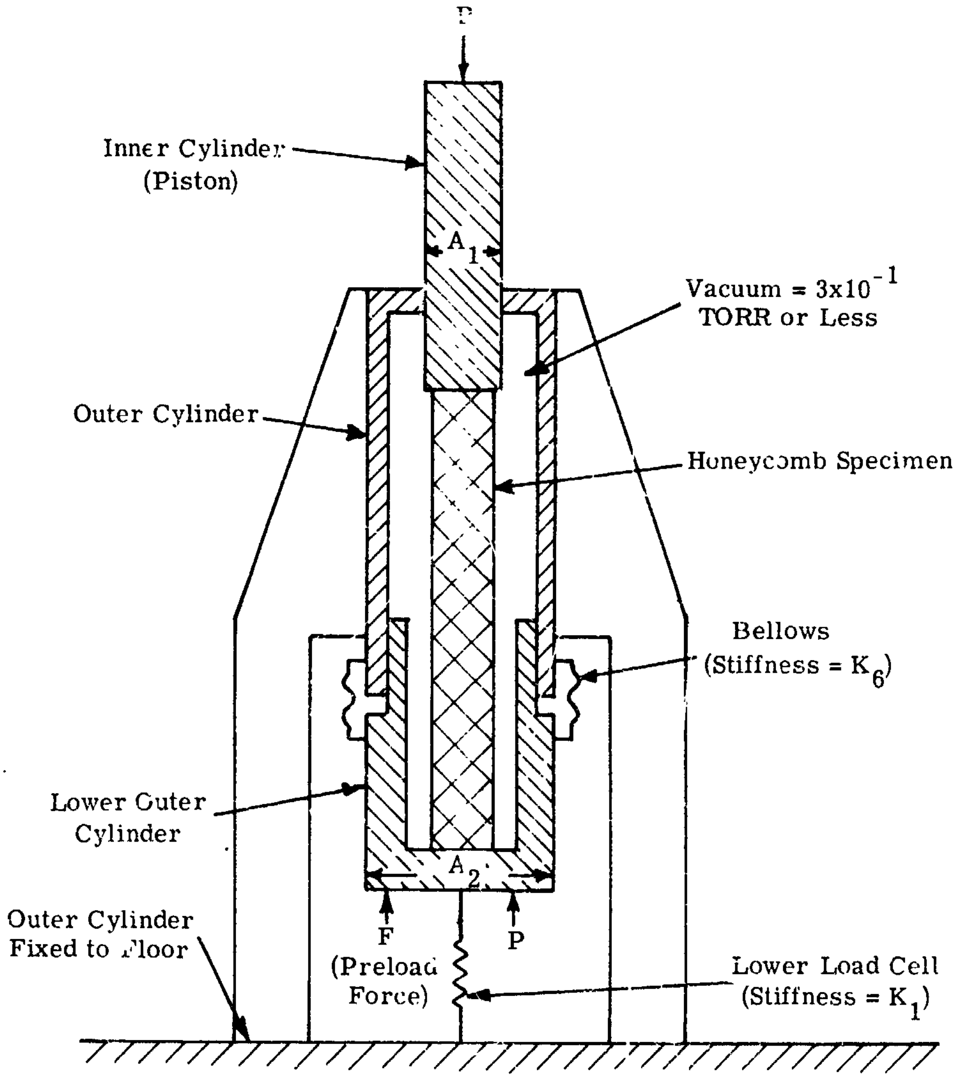


Figure 4-2. Schematic of Test Fixture Showing Forces Due to Vacuum and Bellows Pre-Load

Table 4-1. Parameters and Numerical Values

Parameter	Description	Numerical Value	How Obtained
M_0	Drop Mass	4.98 lbs. sec^2/in	Selected drop mass
M_1	Lower outer cylinder mass	0.116 lb. $sec.^2$/in	Calculated
M_3	Honeycomb test specimen mass	0.0073 lb.sec^2/in	Calculated
M_4	Piston Mass	0.317 lb.sec^2/in	Weighed
M_7	Piston head mass	0.018 lb.sec^2/in	Calculated
K_1	Stiffness-lower load cell	1.76×10^6 lbs./in	Calculated
K_3	Stiffness - honeycomb specimen	55,000 lbs./in	Estimated
K_4	Stiffness - piston	0.90×10^6 lbs./in	Calculated
K_5	Stiffness - upper load cell	2.0×10^6 lbs./in	Calculated
K_6	Stiffness - bellows	0.11×10^6 lbs./in	From test data
K_7	Stiffness - inner load cell	5.34×10^6 lbs./in	Calculated
K_0	Compression Stiffness - rubber impact pad.	91,700 lbs./in	From test data
C_1	Damping coeff. lower load cell	$0.2 \sqrt{K_1 M_1} \frac{lbs.sec}{in}$	
C_2	Damping coeff. bellows	$0.2 \sqrt{K_6 M_1} \frac{lbs.sec}{in}$	
P	Differential pressure on fixture	14.7 lbs/in^2	
A_1	Inner cylinder area	30.63 in^2	Calculated
A_2	Effective area below bellows	56.45 in^2	Calculated
F	Preload on bellows	1050 lbs.	Calculated Min.

Table 4-1. Parameters and Numerical Values (Concluded)

Parameter	Description	Numerical Value	How Obtained
$(F_3)_0$	Honeycomb crush load	5,500 lbs.	Selected
f_3	Honeycomb crush characteristics	See Fig. 4-3	Hypothetical
f_0	Rubber impact pad characteristics	See Fig. 4-4	From test data

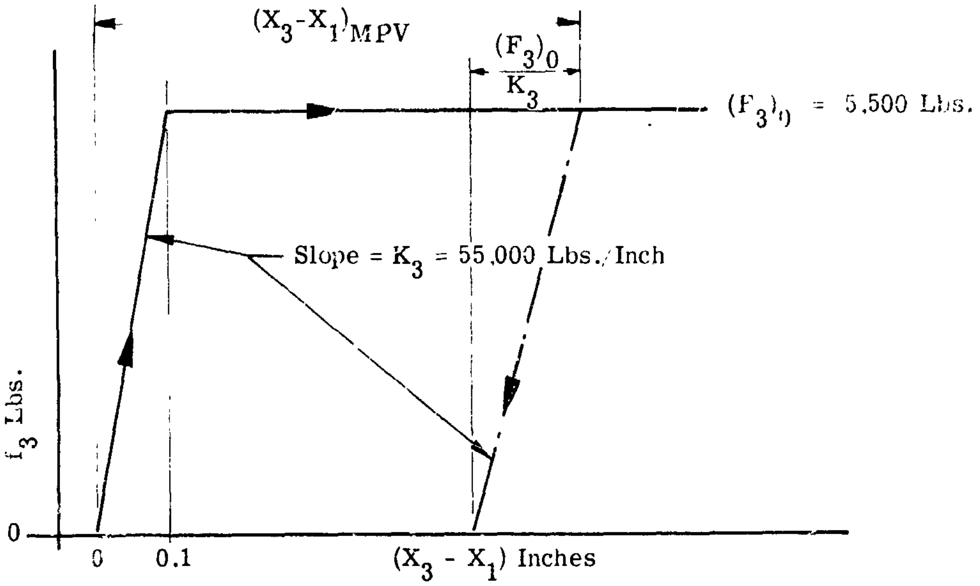


Figure 4-3. Hypothetical Load Stroke Curve

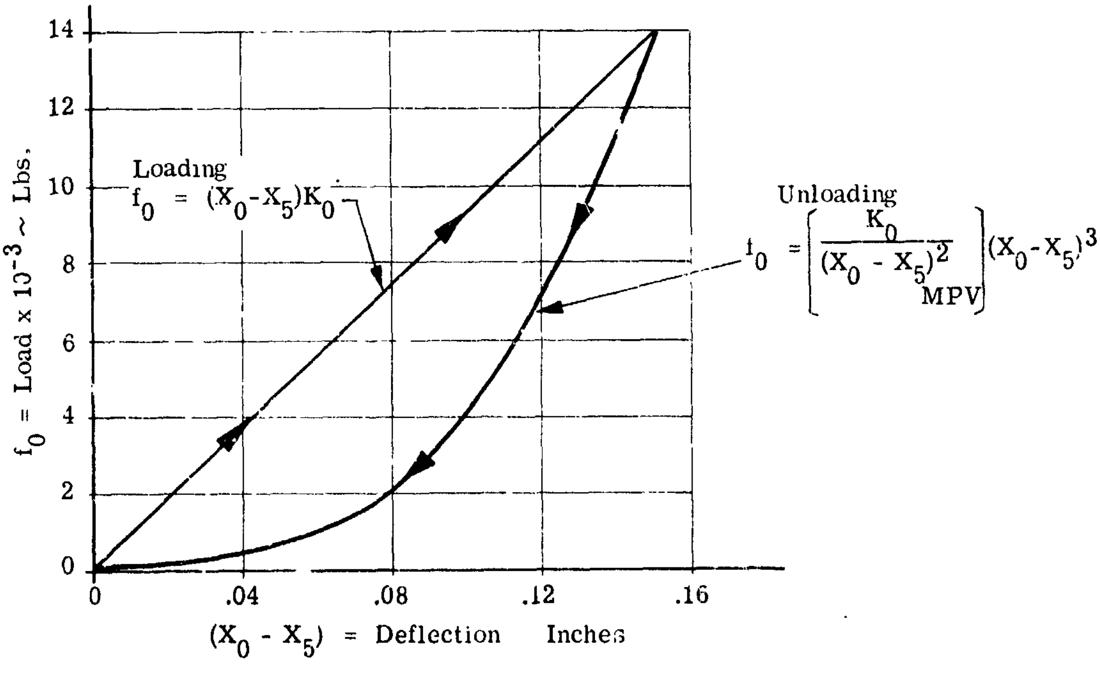


Figure 4-4. Rubber Pad Load Characteristics

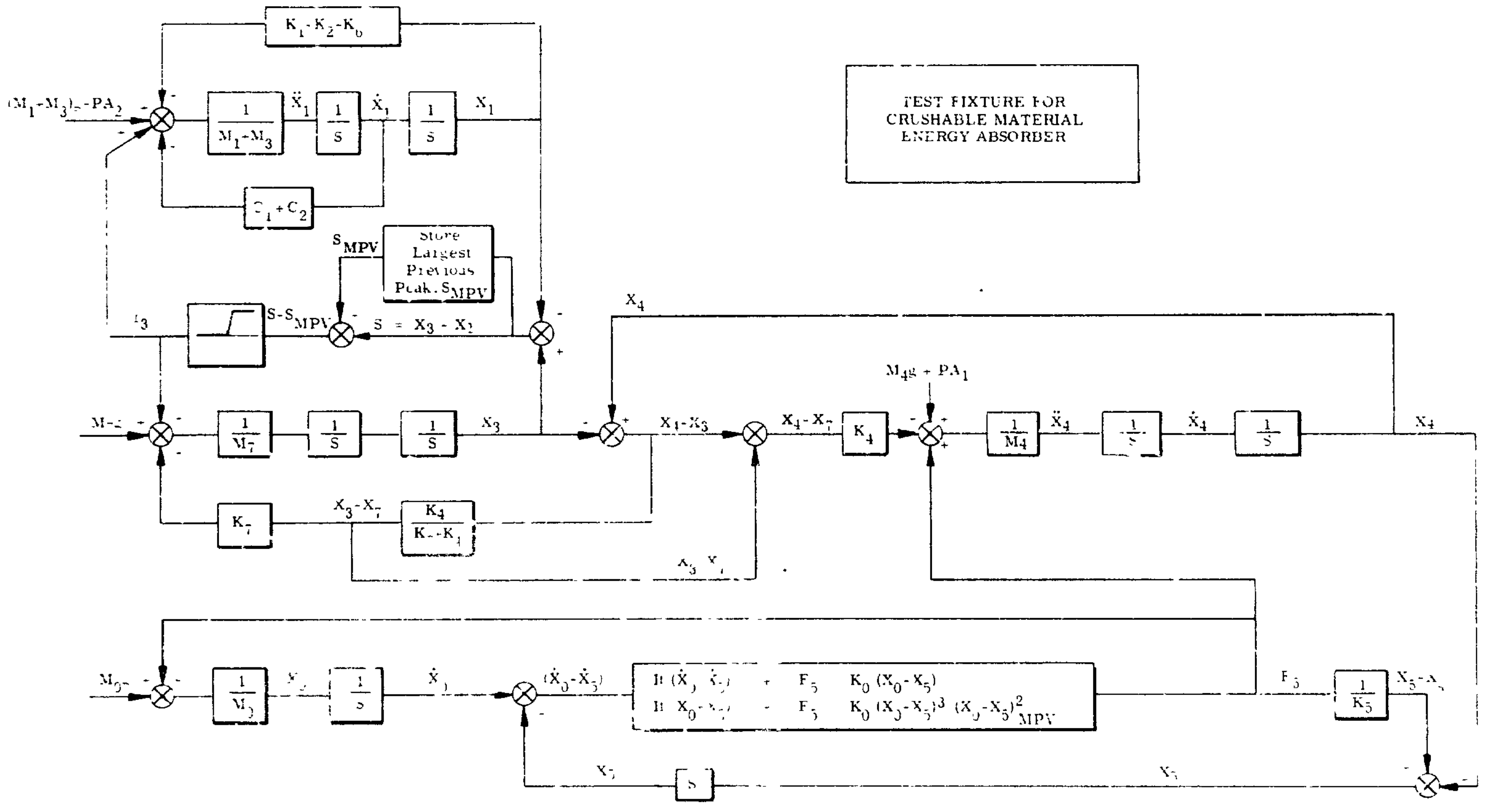


Figure 4-5. Analog Computer Flow Diagram

4.3 RESULTS AND CONCLUSIONS

Figure 4-6 is the output of the analog computer program for a drop weight of 1920 pounds at an impact velocity of 120 in/sec. The lower curve is the output of $(K_1 + K_6)\ X_1$ which is equal to:

$$\text{(lower load cell output)} \left\{ \frac{1}{\left[1 - \frac{K_6}{(K_1+K_6)} \right]} \right\}$$

Figure 4-7 is an enlarged plot of this trace. As is to be expected the rig dynamic influence is both cyclic and transient, the measured load cell force being alternately greater and smaller than the specimen input characteristic, with the discrepancy vanishing as the transient dynamic influence decays. The wave form generated is a decaying sinusoidal such that the average of the upper and lower envelopes (Figure 4-7) should represent, with good accuracy, the true specimen characteristic. Comparing the result thus obtained in Figure 4-7 with the analog output of load cell load versus stroke superimposed on the specimen input load versus stroke, shown in Figure 4-8, it can be seen that the envelope average gives an accurate value of the specimen input characteristic. Figure 4-9 is an oscillograph record for a test at the same impact conditions as the analog output in Figure 4-6 on a specimen of type SPX-166. Comparing the oscillograph record with the analog output of the lower load cell it can be seen that the wave form generated is of the same type but with a different frequency. Comparing the upper load cell trace (Figure 4-9) with the force output of the rubber pad (F_0)(Figure 4-6) it can be seen that the piston and impact mass do not separate in the actual test as they do in the analog simulation. The half wave of the impact force has a frequency of 83 cps, which is the natural frequency of the piston - rubber pad spring mass system, and is close to the lower load cell frequency seen on the oscillograph trace. In the analog simulation the piston moves away from the drop mass, hence this frequency will not propogate through the system, while in the actual test contact is maintained as shown by the upper

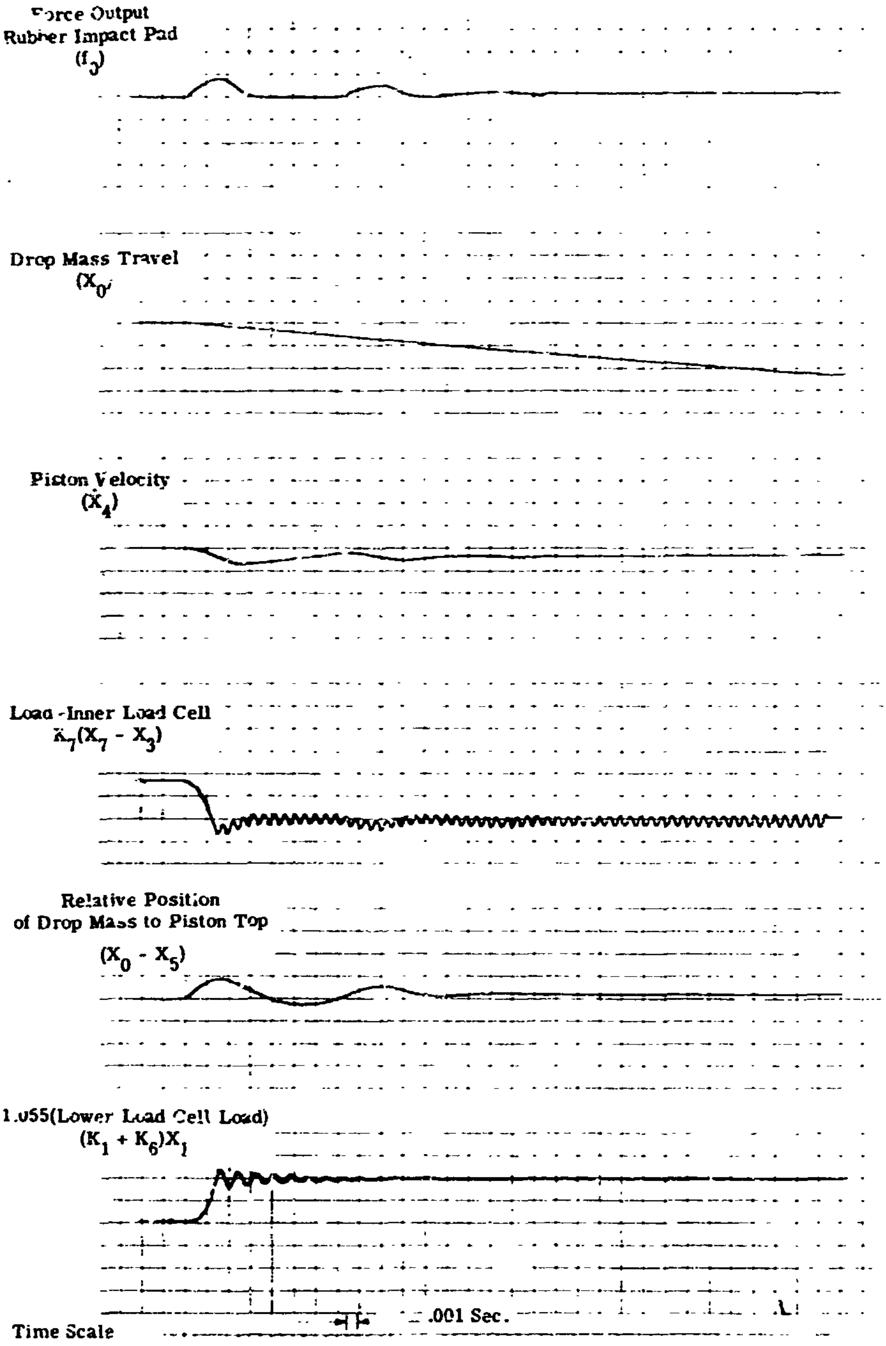


Figure 4-6. Analog Computer Output (Drop Weight = 1920 lbs., Impact Velocity 120 ins./sec.)

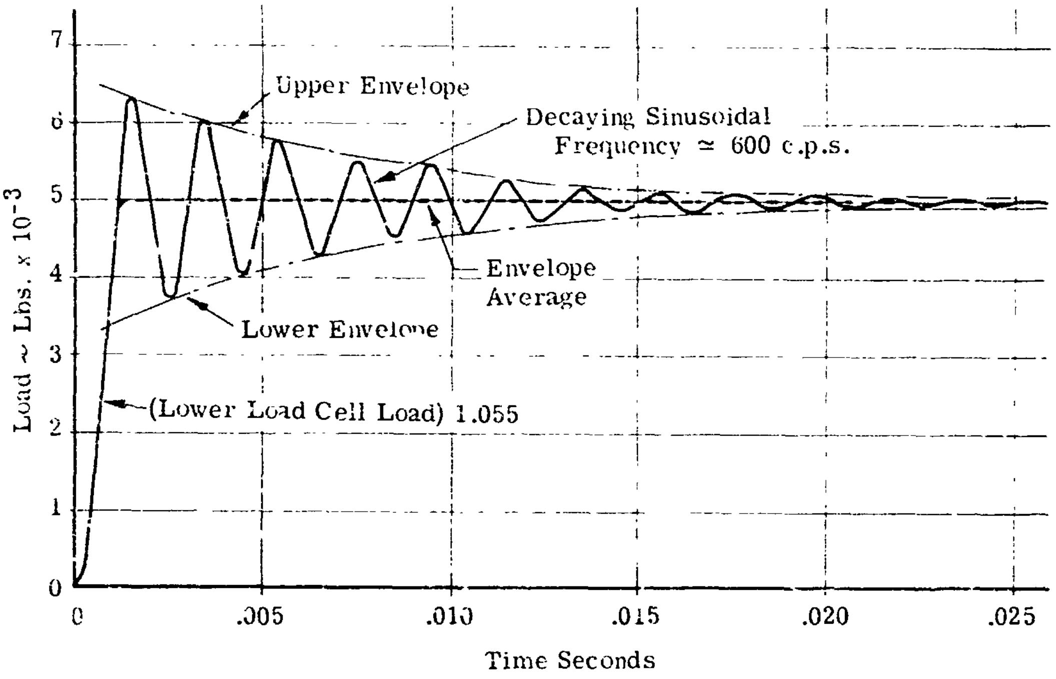


Figure 4-7. Analysis of Typical Analog Computer Output for the Lower Load Cell

load cell reading. The traces Figure 4-9, for the upper load cell, piston acceleration, inner load cell and lower load cell, all have this frequency indicating that the excitation is propogating from the top of the fixture. The inner load cell trace on Figure 4-6 does show this frequency, which matches the rubber pad frequency, with a superimposed frequency of 1,000 cps which can also be seen on the oscillograph record Figure 4-9. The reason for the piston leaving the drop mass in the analog simulator is that no coulomb friction damping of the piston was included in the mathematical model, which is present in the actual system at the dynamic seal and piston head bearing. As it was intended to make only a limited dynamic study of the fixture, in order to determine the correct method of interpreting the test data, it was not felt necessary to change the

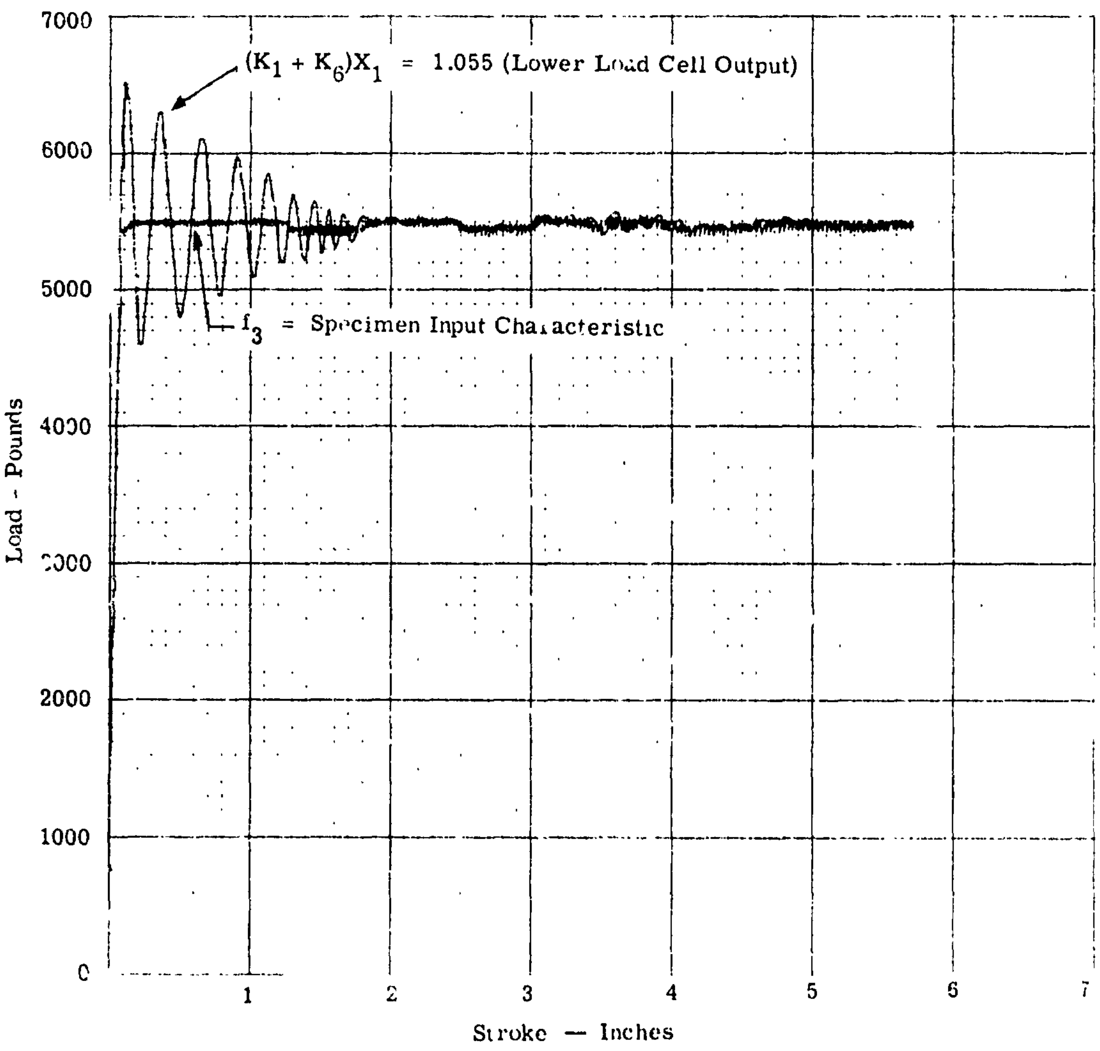


Figure 4-8. Load Versus Stroke

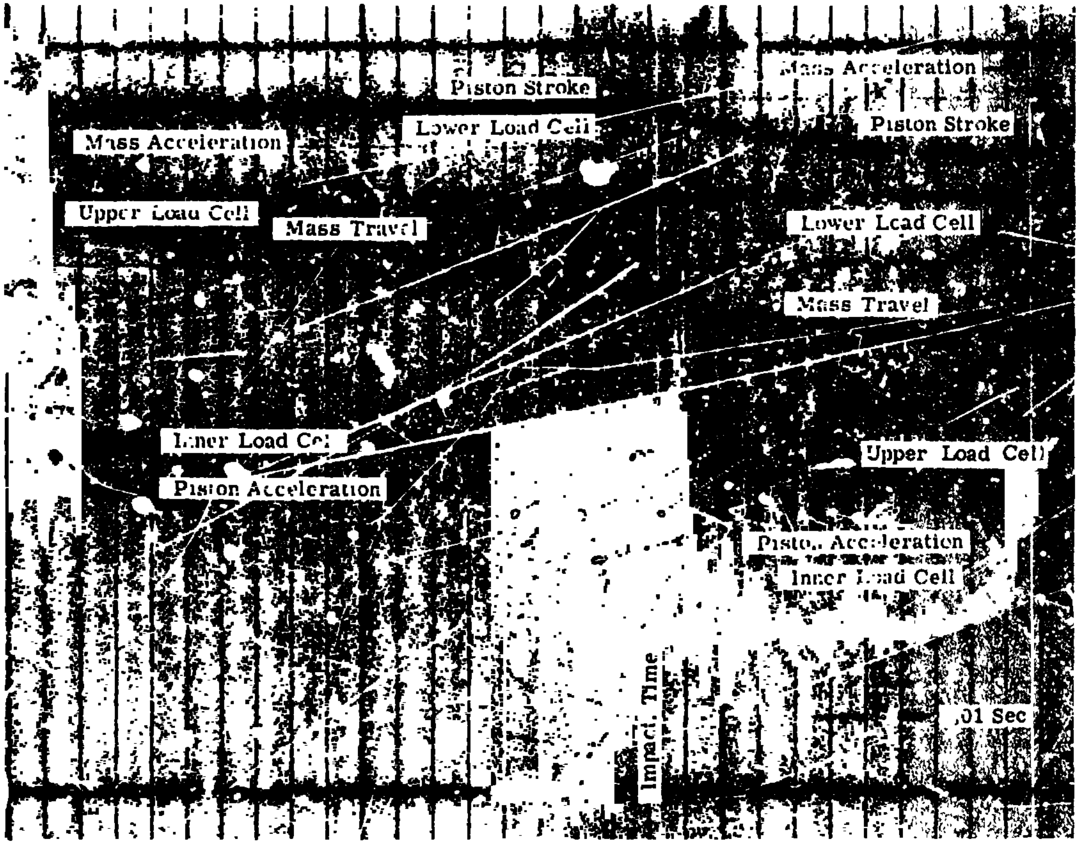


Figure 4-9. Oscillograph Record of Drop Test

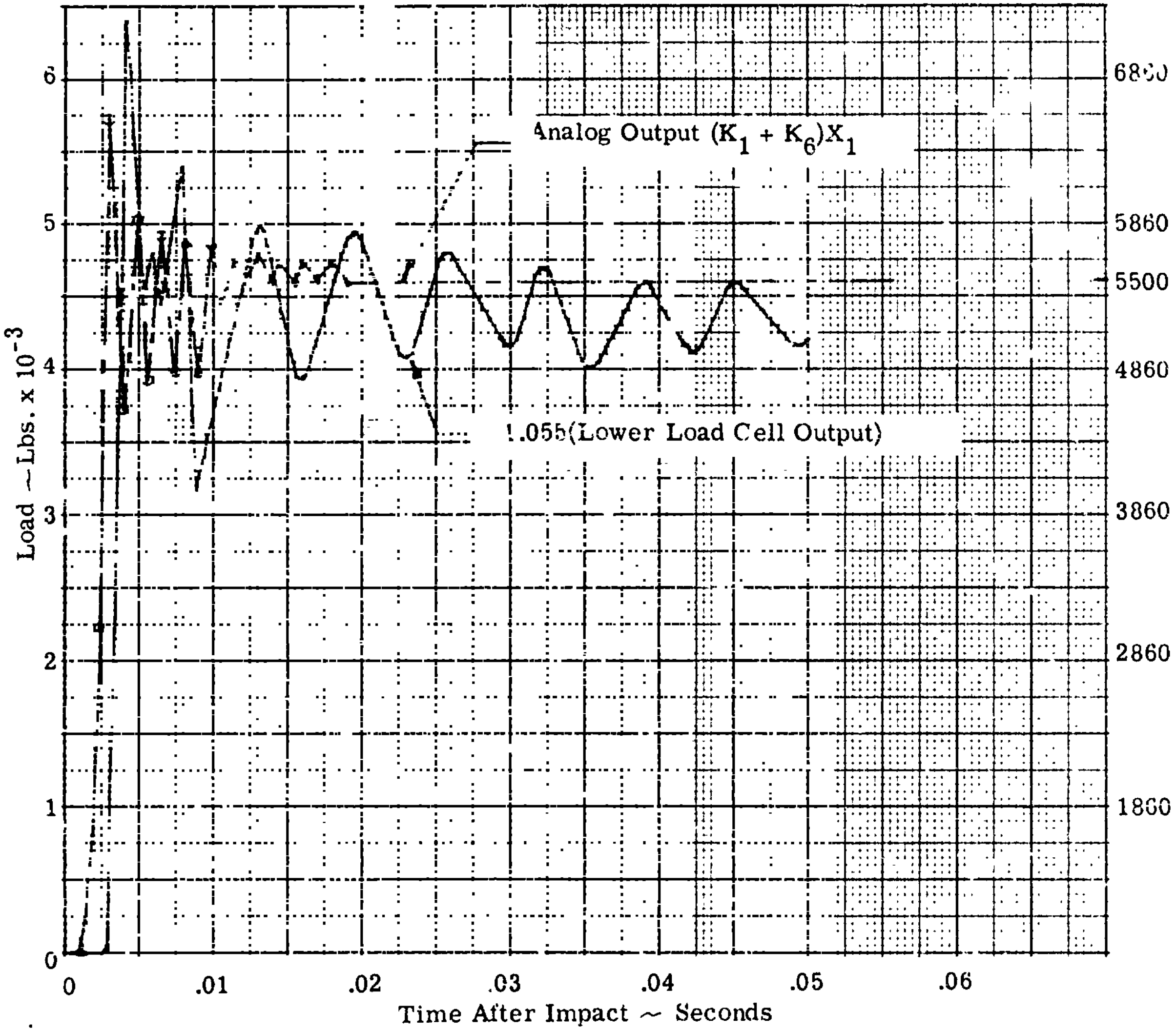


Figure 4-10. Comparison Plot of Analog and Oscillograph Data for the Lower Load Cell

program to include this effect. Figure 4-10 is a comparison plot of the lower load cell data from Figure 4-9 and the analog output from Figure 4-6. Except for the difference in frequency, due to the piston leaving the drop mass in the analog simulation, the two plots compare very closely and substantiate the accuracy of the dynamic analysis and hence the method of fairing the oscillograph data. The derivation of the equation used to correct the faired lower load cell reading, due to the effect of the bellows and vacuum pressure on the load cell, is given in Section V of this report.

SECTION V

DATA REDUCTION TECHNIQUES

5.1 DETERMINATION OF LOAD ON SPECIMEN FROM LOWER LOAD CELL READINGS

In order to obtain the true load output from the honeycomb specimen the physical effects of the fixture must be corrected for in reducing the oscillograph data. Figure 5-1 is a schematic of the test fixture showing the forces acting on the system. These forces along with the dynamic effects described in Section IV must therefore be removed from the oscillograph data to obtain the honeycomb load characteristics.

Considering a free body of the lower outer cylinder

$$F_b + F_s = F_L + (PA_2) \tag{1}$$

where F_b is the force due to the bellows

F_s is the force output of the specimen

F_L is the lower load cell force

(PA_2) is the force acting on the lower outer cylinder due to the differential pressure between the inside and outside of the fixture.

In order to maintain a load on the lower load cell, when the vacuum is pulled in the fixture, and to use the linear section of the bellows load-deflection curve, a pre-load was placed on the bellows and load cell, hence,

$$F_b = F_{ib} - X_1K_6 \tag{2}$$

and $$F_L = F_{iL} + X_1K_1 \tag{3}$$

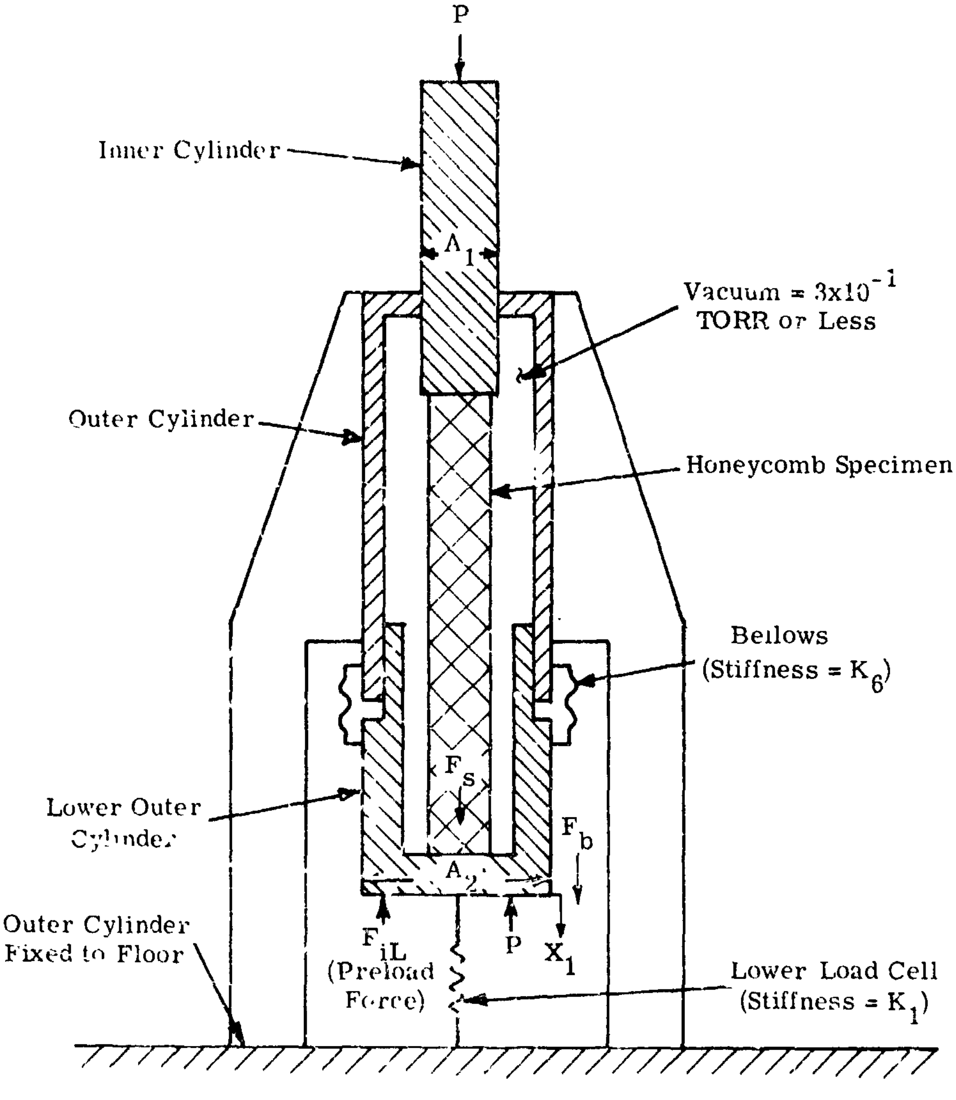


Figure 5-1. Schematic of Test Fixture

where F_{ib} = bellows preload

F_{iL} = load cell preload

X_1 = deflection of lower outer cylinder under test conditions

K_6 = Spring rate of bellows

K_1 = Spring rate of lower load cell

Substituting equations (2) and (3) in equation (1)

$$F_{ib} - X_1K_6 + F_s = F_{iL} + X_1K_1 + (PA_2) \tag{4}$$

The preload force in the bellows and lower load cell must be equal, therefore $F_{ib} = F_{iL}$

$$\therefore X_1K_1 = \left[F_s - (PA_2)\right] \left[1 - \frac{K_6}{(K_1 + K_6)}\right]$$

The lower load cell was zero calibrated with the preload (F_{iL}) on the load cell, therefore the lower load cell reading will be X_1K_1.

$$\text{Load on specimen} = F_s \frac{X_1K_1}{\left[1 - \frac{K_6}{(K_1+K_6)}\right]} + (PA_2) \tag{5}$$

The numerical values for these parameters are

K_6 = .11 x 10^6 lbs./in.

K_1 = 1.76 x 10^6 lbs./in.

A_2 = 56.45 in^2

P = 14.7 lbs./in^2

Load on specimen = (Lower load cell load x 1.055) + 860 (6)

The effect of the rig dynamics in the lower load cell output was removed by fairing the oscillograph trace in the manner described at the end of Section IV.

Hence the readings made from the oscillograph give the lower load cell reading including the effects of pressure and bellows forces. The load output of the specimen is given by the following expression

$$\text{Specimen load} = \left[\frac{\text{(D-F) (R-Cal load)}}{\text{(R-Cal deflection)}} \right] 1.055 + 860$$

where

(D-F) = Distance from trace zero to faired curve, 'D' Figure 5-3. and 'F' Figure 5-4.

(R-Cal load) = Load value of resistance calibration

(R-Cal deflection) = Distance between trace at zero and trace under resistance calibration load.

Data reduction of the other load cells and accelerometers uses standard procedures and is described in the following paragraphs of this section.

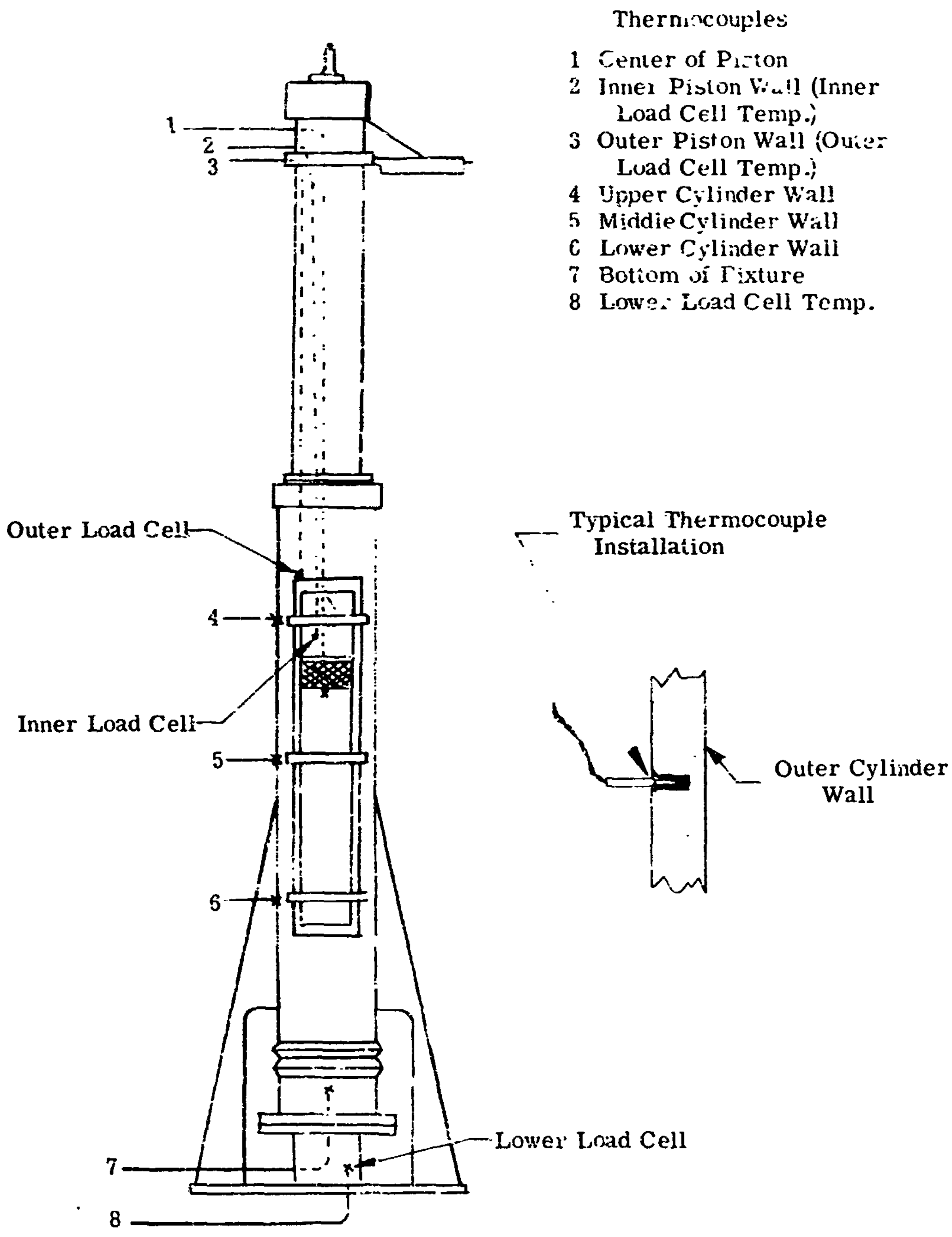
5.2 PROCEDURES FOR REDUCING OSCILLOGRAPH DATA OF DYNAMIC TESTS

The parameters shown in Table 5-1 were recorded on a Consolidated Electrodynamics Corporation oscillograph recorder as described in Section III. The temperature at each load cell, the positions of which are shown in Figure 5-2, were recorded prior to each high or low temperature drop for use in determining the correct calibration value for the particular load cell.

Prior to each series of drops and with the fixture at atmospheric pressure, a zero and resistance calibration was recorded on the oscillograph. The deflection of the oscillograph traces, for the load cells and accelerometers, from the zero to R-Cal position is the measure of galvanometer deflection for the particular resistance calibration switched into the circuit. The value of the resistance calibration for each parameter recorded are given in Table 5-1 and Figures 5-6 through 5-8 inclusive.

TABLE 5-1. RESISTANCE CALIBRATION VALUES

Parameter		Lower Load Cell	Outer Load Cell	Mass Accel.	Piston Stroke	Piston Accel.	Mass Travel	Inner Load Cell	Upper Load Cell or 2nd Mass Accel.
Break Number		1	2	3	4	5	6	7	8
Resistance-Cal. Value	+300°F	4,550 lbs.	4,350 lbs.	2g's	No R-Cal. Used	100g's	No R-Cal. Used	4,950 lbs.	Used during rig checkout for upper load cell or second mass accelerometer.
	+150°F	4,800 lbs.	4,350 lbs	2g's		100g's		4,950 lbs.	
	+ 80°F	4,900 lbs.	4,350 lbs.	2g's		100g's		4,950 lbs.	
	-150°F	5,200 lbs.	4,500 lbs.	2g's		100g's		4,800 lbs.	
	-260°F	5,600 lbs.	4,500 lbs.	2g's		100g's		4,700 lbs.	



Thermocouples

1 Center of Piston
2 Inner Piston Wall (Inner Load Cell Temp.)
3 Outer Piston Wall (Outer Load Cell Temp.)
4 Upper Cylinder Wall
5 Middle Cylinder Wall
6 Lower Cylinder Wall
7 Bottom of Fixture
8 Lower Load Cell Temp.

Figure 5-2. Sketch of Thermocouple Locations

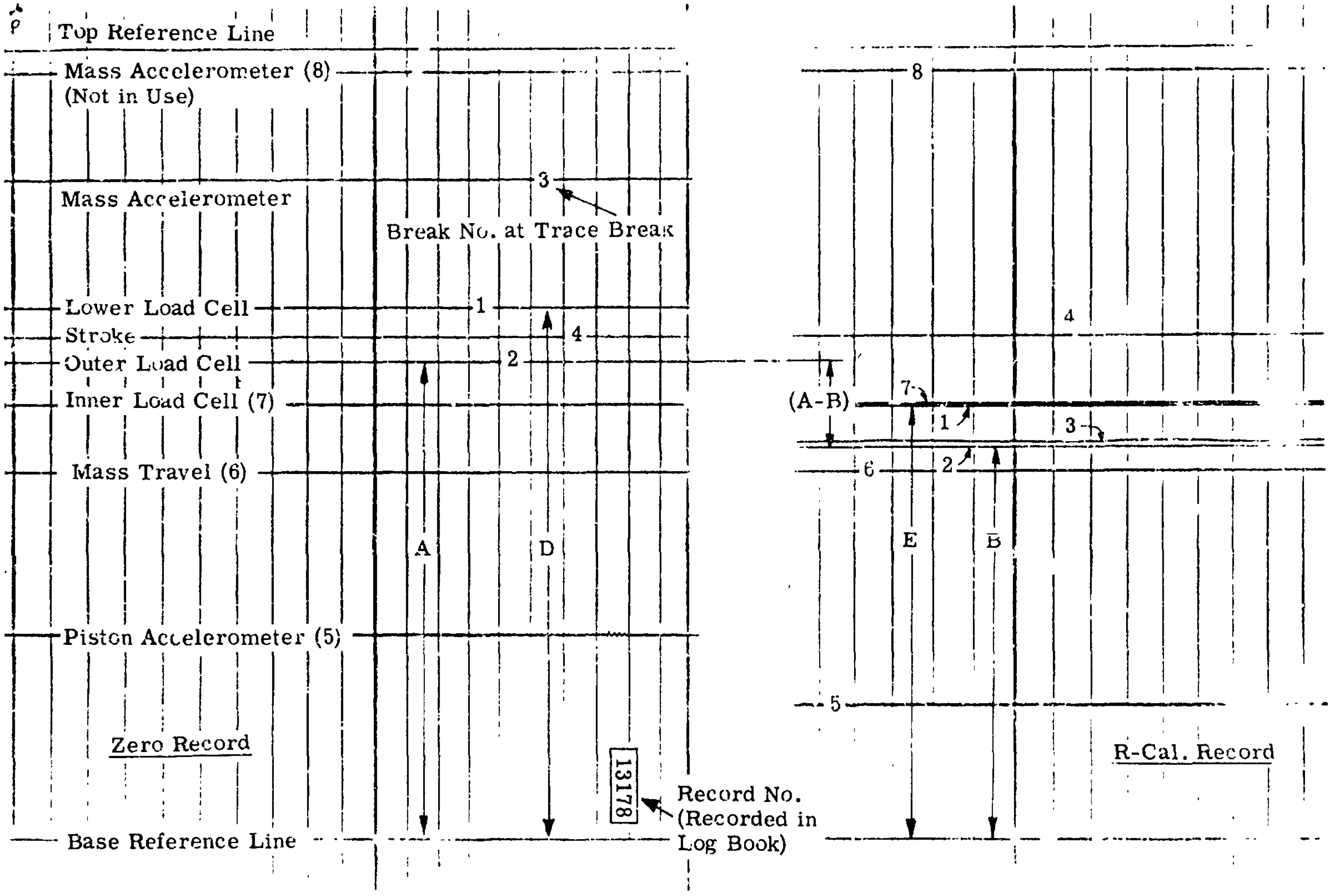


Figure 5-3. Calibration Portion of an Oscillograph Record

The parameters associated with the galvanometer traces on the oscillograph record are identified by the position of the break in the trace. The break number is determined by the position of the break in each tract with increase in time, but excluding the top and base reference lines, as shown on the sample oscillograph record, Figure 5-4. The parameter associated with the particular break number is identified in Table 5-1. 5-1.

5.2.1 General Procedure

To determine the R-Cal. deflection: - Figure 5-3 is the calibration portion of an oscillograph record. To determine the R-Cal deflection, measure the distance from the zero trace (on the zero record) to the R-Cal trace (on the R-Cal record). For break 2 (outer load cell) the R-Cal deflection is (A-B) inches.

Figures 5-6 through 5-8 are the calibration curves for the load cells. The R-Cal value is obtained by entering the curve on the ordinate at the strain R-Cal value and reading the load on the abscissa for the intersection with the calibration curve corresponding to the load cell test temperature. The R-Cal value for the accelerometers does not change with temperature and is given in Table 5-1. E.g. For break 2 (outer load cell) the R-Cal value for room temperature from Figure 5-7, is 4,350 pounds.

To determine the calibration factor: - The calibration factor is determined by dividing the R-Cal value by the R-Cal deflection. E.g. For break 2 (outer load cell) at room temperature, the calibration factor $= \frac{4,350}{(A-B)} =$ lbs./inch of oscillograph deflection.

To determine the value at a particular time: - Measure the distance from the base line to the trace, on the "run" portion of the oscillograph record, and subtract the base line to zero value. (This gives the trace deflection). This value multiplied by the calibration

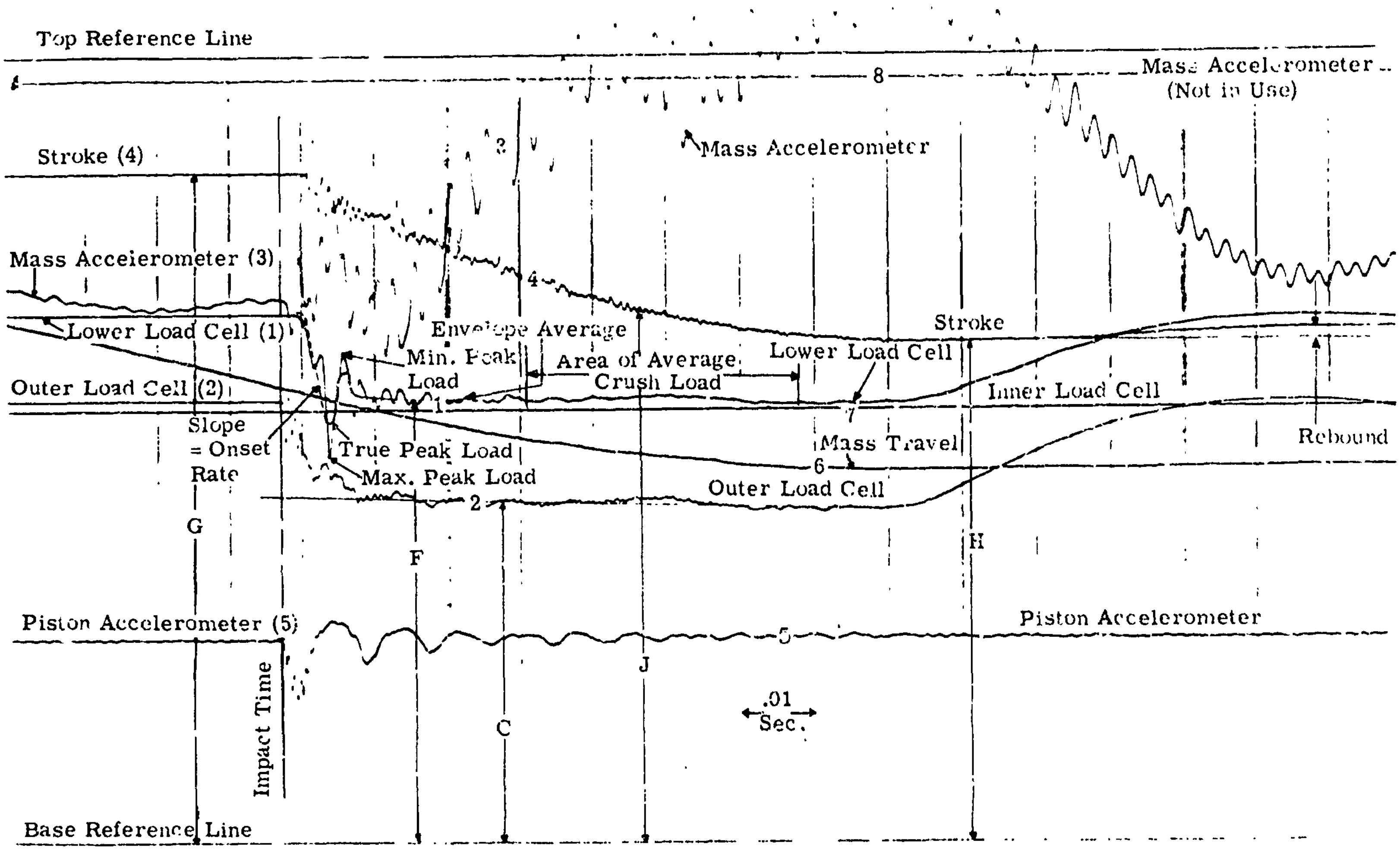


Figure 5-4. "Run" Portion of an Oscillograph Record (Test Specimen SPX-167C-35, Drop No. 7)

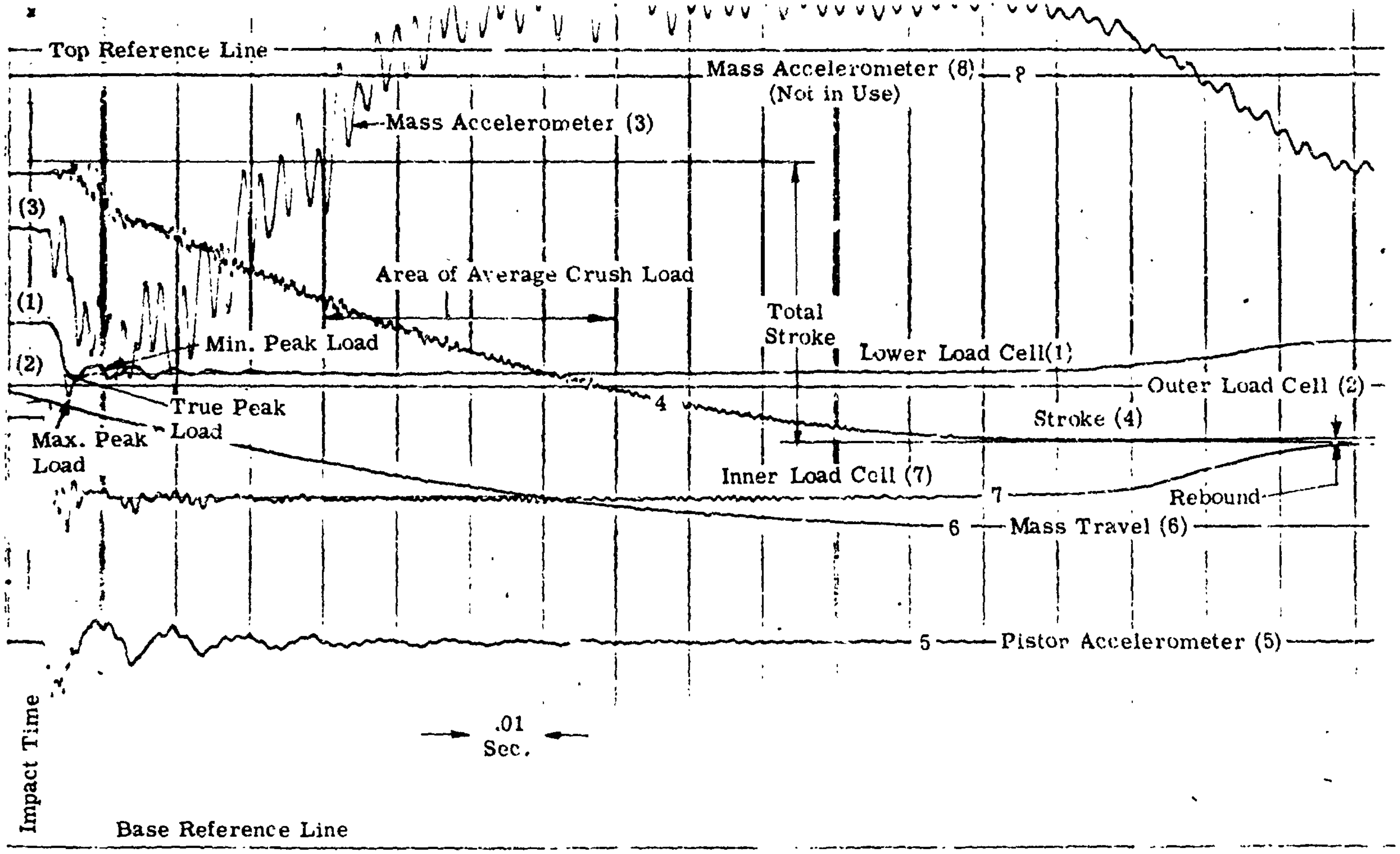


Figure 5-5. "Run" Portion of an Oscillograph Record (Test Specimen SPX-166C-35, Drop Test No. 3)

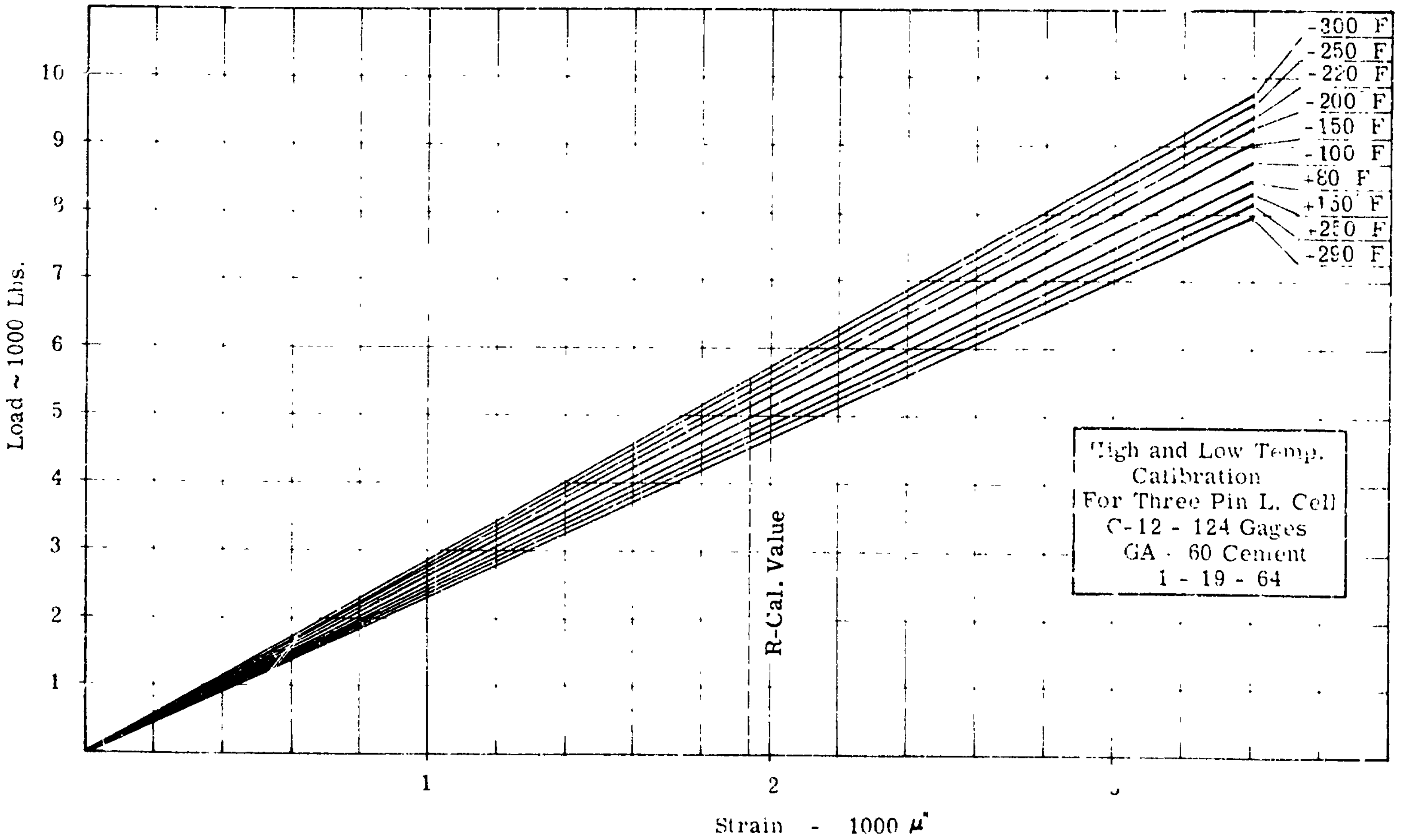


Figure 5-6. Lower Load Cell Calibration

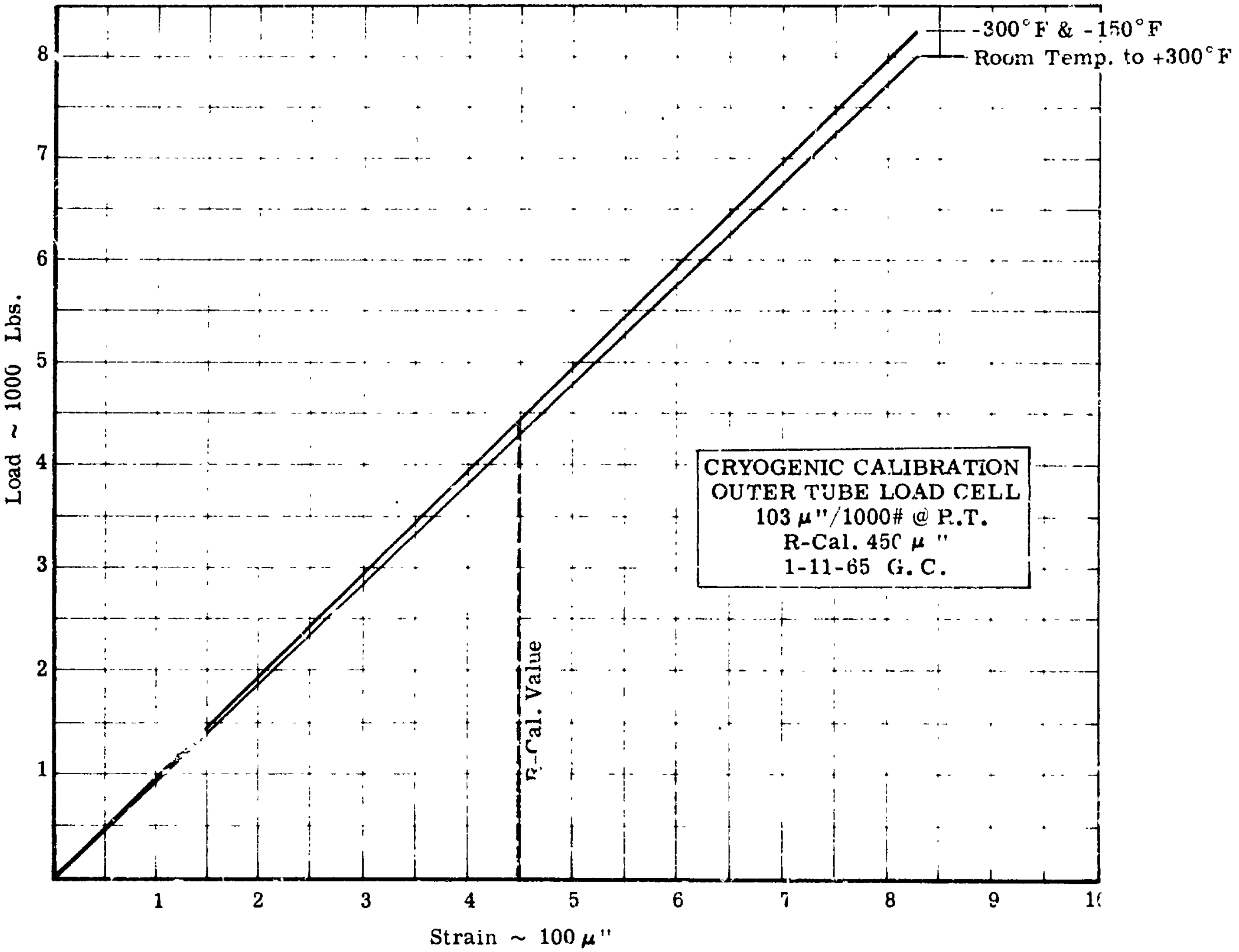


Figure 5-7. Outer Load Cell Calibration

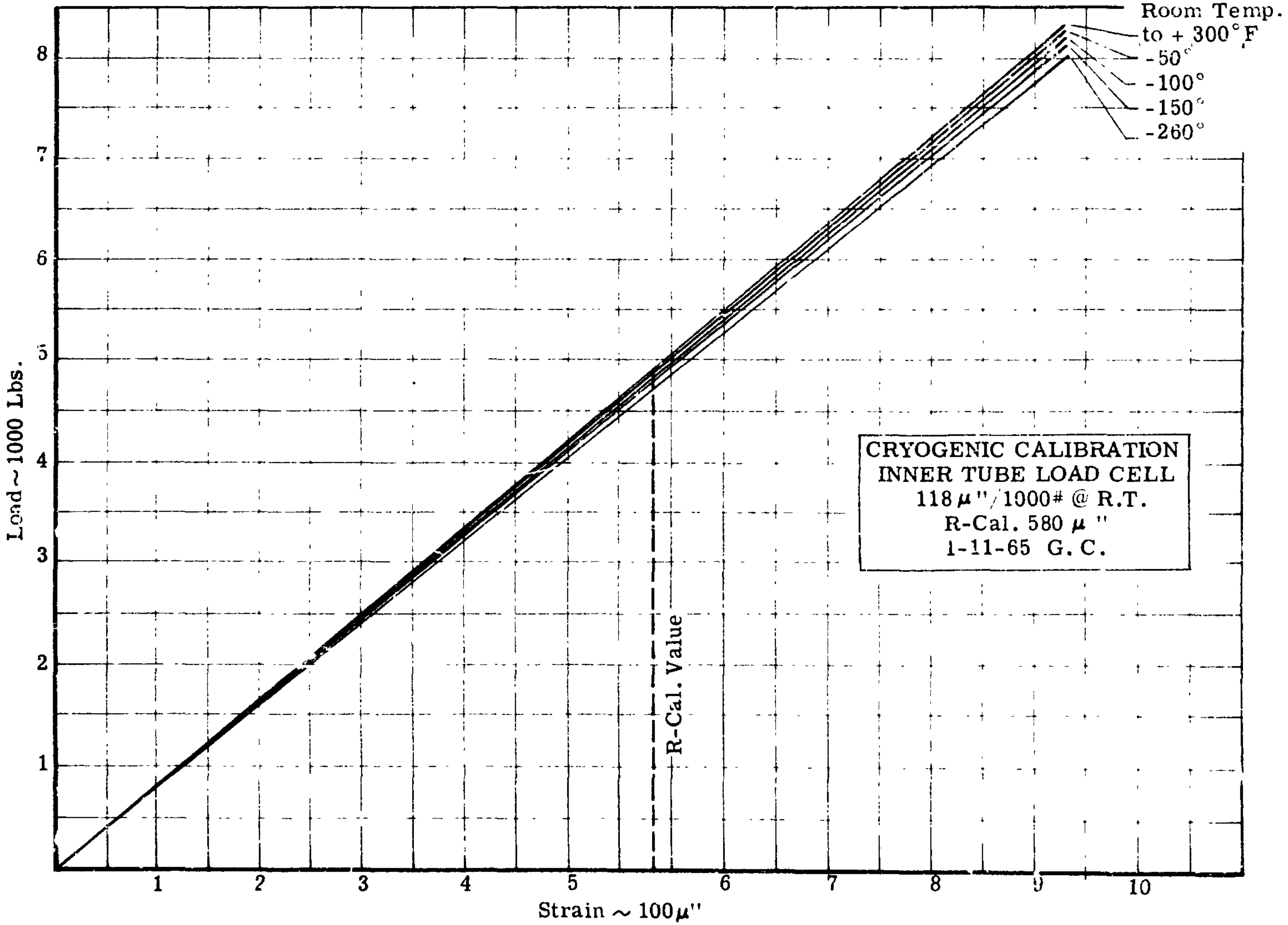


Figure 5-8. Inner Load Cell Calibration

factor gives the value of the parameter at that time. E.g. From Figure 5-4 for break 2 (outer load cell) during a room temperature test, the value at .03 seconds after impact is given by

$$\text{Load (Lbs.) at } t = .03 \text{ Seconds} = \frac{4{,}350\ (A-C)}{(A-B)} = (A-C) \times \text{Calibration factor}$$

5.2.2 Lower Load Cell

To determine the honeycomb specimen load from the lower load cell it is necessary to modify the load read from the oscillograph record due to the effect of the bellows load and vacuum pressure as described in paragraph 5.1.

The procedure used for the lower load cell is to first determine the calibration factor as described above. The oscillograph trace is then faired using the procedure described in Section IV, which gives the envelope average shown by the dotted line on break 1, Figures 5-4 and 5-5. The oscillograph deflection is then read in the usual manner and the value obtained corrected for bellows and vacuum pressure effects.

$$\text{Specimen Load} = \left[(D-F) \frac{\text{R-Cal value}}{\text{R-Cal deflection}} \right] 1.055 + 860$$

where

D = distance from the base line to the zero trace Figure 5-3.

F = distance from the base line to the envelope average line, Figure 5-4.

R-Cal value = Load value of R-Cal resistance at load cell test temperature, see Figure 5-6.

R-Cal deflection = distance (D-E) Figure 5-3

1.055 = correction factor for load due to bellows

$$= \frac{1}{\left[1 - \frac{K_6}{(K_1 + K_6)} \right]}$$

860 = correction due to differential pressure = (PA_2)

The lower load cell data was used to obtain the maximum peak load (including rig dynamics), the minimum load including rig dynamics (identified in Figure 7-36 and other data listings as the "minimum peak load"), the true honeycomb specimen peak load (from the faired curve) and the load onset rate.

The outer load cell (Break number 2) was used when testing samples SPX 167 (external annular) configuration. The inner load cell (Break Number 7) was used when testing samples SPX 166 (Solid circular) and SPX 168 (internal annular) configuration. The loads read with these load cells were used to check the load values obtained from the lower load cells. The mass acceleration (Break Number 3) was integrated to obtain impact velocity.

The mass acceleration was calculated as follows,

$$\text{Mass acceleration} = \frac{\text{R-Cal value}}{\text{R-Cal deflection}} \times \text{trace deflection}$$

$$= \frac{2g}{\text{R-Cal deflection}} \times \text{trace deflection}$$

NOTE: The R-Cal deflection and trace deflection are obtained as described under General Procedures

A further accelerometer on the drop mass (Break Number 8) was used in initial testing for comparison purposes. This trace was also used in initial drops for the upper load cell, for checking the rig dynamics.

The piston stroke (Break Number 4) was calculated as follows,

$$\text{Stroke} = \frac{(G-J)}{(G-H)} \times \text{Total stroke}$$

where

(G-J) = trace deflection at point being measured, see Figure 5-4.

(G-H) = Total trace deflection, see Figure 5-4.

Total Stroke = Total piston travel measured after test. (Recorded on log sheet.)

The mass travel (Break Number 6) measures the total travel of the drop mass. The mass travel distance is obtained by the same procedure used for the piston stroke. The mass travel data was used to check the energy balance during rig checkout, and used later to check the mass drop height when required.

The piston acceleration (Break Number 5) was not reduced, but was used to determine the impact time.

5.3 TEMPERATURE RECORDINGS

Thermocouples were located throughout the test fixture as per the discussion in Section III and the sketch in Figure 5-2, to determine the specimen and instrumentation temperatures. The capsule temperature was determined by averaging the readings of thermocouples 4, 5, and 6 (see Figure 5-2). The temperature was recorded in the tabular data for Phase IB and Phase II tests (Ref: Figures 7-63 and 8-51 through 8-56). (A special test was conducted with extra thermocouples in the test capsule to confirm that recording of the temperature at these points on the cylinder wall would give a true indication of the capsule temperature).

SECTION VI

TEST PROCEDURES

6.1 GENERAL

The program objectives were attained by conducting the test program in two (2) phases. Following static tests of the preproduction control specimens and design releases for the individual configurations,the specimen supplier forwarded the full-length test specimens for each of the nine (9) configurations.

Phase IA testing involved screening tests of each of the various configurations under both static and dynamic test conditions at room temperature (Figure 6-1). Following selection of the four (4) superior capsule configurations from Phase IA tests, specimens were checked under cryogenic temperature conditions (-260°F) with use of a brief static and dynamic test series in Phase IB (Figure 6-1). From these latter tests two (2) configurations were selected to undergo the full range of the temperature environment (+300°F, +150°F, -150°F and -260°F) under both static and dynamic load applications (Figure 6-1).

All testing of these full-length test articles was conducted under a reduced atmospheric pressure of $3x10^{-1}$ TORR. This vacuum value was not intended to simulate the more severe vacuum conditions of the outer space environment but only to eliminate the trapped air from the honeycomb cells which could conceivably, during testing, cause a rupture of the individual cells in a manner which would affect the crushing load characteristics of the capsule.

PHASE 1

	CONFIG.	QUANTITY	TESTS	VACUUM	TEMPERATURE
A	1. A ⊙ B ⊙ C ⊙	8 Each	Static test one specimen; dynamic test 7 specimens at varying mass and velocities.	$3x10^{-1}$ TORR	Ambient
	2. A ○ B ○ C ○	8 Each	Static test one specimen: dynamic test 7 specimens at varying mass and velocities.	$3x10^{-1}$ TORR	Ambient
	3. A ○ B ○ C ○	8 Each	Static test one specimen; dynamic test 7 specimens at varying mass and velocities.	$3x10^{-1}$ TORR	Ambient
B	1B ⊙ 1C ⊙ 2C ○ 3C ●	2 Each	Static test one specimen; dynamic test one specimen at one mass and 3 impact velocities.	$3x10^{-1}$ TORR	-200°F

PHASE II

TYPE	QUANTITY	TESTS	VACUUM	TEMPERATURE
2C ○	31	Static test 3 specimens; dynamic test 28 specimens at varying mass and impact velocities.	$3x10^{-1}$ TORR	-260°F -150°F
3C ●	31	Static test 3 specimens; dynamic test 28 specimens at varying mass and impact velocities.	$3x10^{-1}$ TORR	+150°F +300°F

Figure 6-1. Test Program Outline

6.2 PHASE IA TEST OUTLINE

The initial test efforts on the full-length test articles encompassed the testing of eight (8) each of the nine configurations. One specimen of each configuration was subjected to a static test and seven specimens were subjected to dynamic tests involving various test weights and impact velocities (Figures 6-1 and 6-2). The maximum impact velocity of 20 feet per second was calculated to utilize the full stroke capability (approx. 40") of the specimens. The other impact velocities of 14, 10, and 5 feet per second allowed repeated impacts to be made on the same specimen to determine how its characteristics changed as the total length of the specimen decreased. This amounted to as many as 15 impacts on some specimens at the 5 foot per second impact velocity. The lower range of drop weight variations also allowed multiple impacts on the same specimen at a constant impact velocity of 10 feet per second.

6.3 PHASE IB TEST OUTLINE

Two specimens each of the four configurations demonstrating the most satisfactory combination of characteristics in Phase IA were subjected to additional static and dynamic tests at a cryogenic temperature of -260°F (Figure 6-1). One specimen of each configuration used (1B, 1C, 2C, and 3C) was static tested and the second specimen of each type was dynamically loaded at successive impact velocities of 5, 10, and 14 feet per second using a drop weight of 1,920 lbs. (Figure 6-2).

6.4 PHASE II TEST OUTLINE

The Phase II program utilized the two configurations which were evaluated with study of Phase IB data as having maximized combinations of the desired performance characteristics. Thirty one (31) specimens of each type were subjected to the same type of static and dynamic tests as outlined in Phase IA with eight each of the specimens

		Specimen Configuration	Bendix Dwg. No.	Key	Core Type	Test Temp. F	Static Test	Dynamic Test 1920 Drop Wt.				Dynamic Test 10 fps			
								5 fps	10 fps	14 fps	20 fps	Drop Wt 760	Drop Wt 1920	Drop Wt 2850	Drop Wt 3750
PHASE I	A	No. 1	SPX-168A	• 15	Cross-Core 15	Room Temp.	1	2	3	4	5	6	3	7	8
			SPX-168B	• 30	Cross-Core 30	Room Temp.	1	2	3	4	5	6	3	7	8
			SPX-168C	• 0	Tubecore 0	Room Temp.	1	2	3	4	5	6	3	7	8
		No. 2	SPX-167A	15	Cross-Core 15	Room Temp.	1	2	3	4	5	6	3	7	8
			SPX-167B	30	Cross-Core 30	Room Temp.	1	2	3	4	5	6	3	7	8
			SPX-167C	0	Tubecore 0	Room Temp.	1	2	3	4	5	6	3	7	8
		No. 3	SPX-166A	● 15	Cross-Core 15	Room Temp.	1	2	3	4	5	6	3	7	8
			SPX-166B	● 30	Cross-Core 30	Room Temp.	1	2	3	4	5	6	3	7	8
			SPX-166C	● 0	Expanded Honeycomb 0	Room Temp.	1	2	3	4	5	6	3	7	8
	B	No. 1	SPX-168B	• 30	Cross-Core 30°	-260 F	9	10	10	10					
			SPX-168C	• 0	Tubecore 0	-260 F	9	10	10	10					
		No. 2	SPX-167C	0	Tubecore 0	-260 F	9	10	10	10					
		No. 3	SPX-166C	● 0	Expanded Honeycomb 0	-260 F	9	10	10	10					
PHASE II		No. 2	SPX-167C	0	Tubecore 0	+300 F	34	35	36	37	38	39	36	40	41
						+150 F	26	27	28	29	30	31	28	32	33
						-150 F	16	19	20	21	22	23	20	24	25
						-260 F		11	12	13	14	15	12	16	17
		No. 3	SPX-166C	● 0	Expanded Honeycomb 0	+300 F	34	35	36	37	38	39	40	40	41
						+150 F	26	27	28	29	30	31	28	32	33
						-150 F	18	19	20	21	22	23	20	24	25
						-260 F		11	12	13	14	15	12	16	17

Figure 6-2. Cross Reference of Test Program Summary with Dash Numbers Identifying Particular Test Specimens

tested at temperatures of +300°F, +150 F, and -150 F and seven each tested at a temperature of -260°F (Figure 6-1). The full range of test conditions was covered (in addition to the static tests) with the impact velocity varying from 5 thru 20 FPS and the drop weights spanning the range of 760 lbs. thru 3,750 lbs. (Figure 6-2).

6.5 DETAILS OF TEST PROCEDURE

The details of test procedure used in satisfying the various test conditions, covering static and dynamic applications of load, changes in impact velocity and drop weight, and adjustments in the test temperature are described in the succeeding paragraphs.

6.5.1 Static Tests

The static tests were conducted with the equipment described in paragraph 3.2.1 and followed the sequence indicated in the outline below:

1. Applied sufficient load to determine effective spring rate (in the elastic range) prior to initiation of crush action.
2. (a) Applied load to crush specimen thru 10% of its estimated total stroke capability. Observed the peak load to initiate crush action and the average crush load after it had stabilized.

   (b) Stroke position held to observe drop-off in load over a period of 30 seconds or until load became steady. (Note: Measurement of this value was extremely difficult for the full length specimens on which it was attempted. However this load drop-off value under a fixed position was readily recorded and summarized in the short preproduction control specimen data as indicated in Section VII.

   (c) Load was removed and observations of load drop-off vs stroke were made. During application of the load for the next increment of crush stroke spring rate was again observed during the load buildup period.

3. Applied load to crush specimen to a total of 25% of its stroke capability. Repeated procedures of 2(b) and (c).
4. Applied load to crush specimen to a total of 50% of its stroke capability. Repeated procedures of 2(b) and (c).
5. Applied load to crush specimen to a total of 75% of its stroke capability. Repeated procedures of 2(b) and (c).
6. Applied load to crush specimen to a total of 100% of its stroke capability, (until sharp load rise). Repeated procedures of 2(b) and (c).

The detailed events of a particular static test are described here for the various temperature conditions.

6.5.1.1 Room Temperature

A. Installed Specimen

B. Zeroed load on X-Y plotter and calibrated stroke.

C. Vacuum pumped to test value.

D. Attached hydraulic jacks to base of drop rig.

E. Attached dial indicator to cylinder with pointer on piston.

F. Loaded specimen by pulling down on jacks to 4,000 lbs. read and recorded loads and deflection every 500 lbs.

G. When 4,000 lbs. was attained, the dial indicator was removed and crushing continued to 4".

H. Unloaded jacks and raised rig off piston.

I. Repeated E, F, and G crushing 6" more on total of 10".

J. Repeated E, F, G, H but crushed 10" more or total stroke of 20".

K. Repeated (J) twice to total stroke of 30" and 40" respectively.

6.5.1.2 Cryogenic Temperature (-150°F and -260°F)

A. "Zeroed" load and set stroke for "X-Y" plotter.

B. Cooled outer cylinder specimen to -100 F.

C. Shut off flow of LN_2 to inside of fixture (gas flow continued into insulated box surrounding outer cylinder).

D. Assembled piston into cylinder and pumped vacuum to test value.

E. After reaching the test temperature Items D thru K of paragraph 6.5.1.1 were followed.

6.5.1.3 High Temperature (+150°F and +300°F)

A. Heated fixture outer cylinder with hot-air heater and heat lamps to +150°F or +350°F depending on the test temperature.

B. Installed specimen and heated to test temperature. (Note: Test procedure was planned such that specimen was not at the higher temperature (+300°F) for more than 10 minutes. Some of the time figures are shown in the Test Data Summary.)

C. Shut off air flow to inside of fixture and assembled piston.

D. "Zeroed" load and set stroke on X-Y plotter.

E. Followed Items C thru K of paragraph 6.5.1.1.

6.5.2 Dynamic Tests

The dynamic tests were conducted with use of the equipment illustrated in Figure 3-4 and followed the procedure provided in the outline below. It was planned that a series of tests would be run on one configuration at a constant drop weight of 1,920 lbs. with successive specimens undergoing repeated impact velocities of 5, 10, and 14 FPS respectively and one specimen being subjected to a 20 FPS velocity. A second group of specimens of the same configuration were tested under a constant 10 FPS impact velocity with successive specimens undergoing repeated impacts using drop weights of 760, 1920 and 2850 lbs. respectively and one specimen being subjected to a single impact at a 3,750 lb. weight. The above variations in velocities and weights provided ample opportunity to study how these changes in parameters would affect the capsule performance characteristics.

The detailed events of a particular dynamic test are described here for the various temperature conditions.

6.5.2.1 Room Temperature

A. Installed specimen.

B. "Zero" and "Calibrate" oscillograph records obtained.

C. Vacuum pumped to test value.

D. Raised drop rig to test height and dropped rig with oscillograph in operation.

E. Measured total stroke.

6.5.2.2 Cryogenic Temperature

A. Cooled outer cylinder and specimen to -100°F.

B. Shut off LN_2 flow to inside of fixture (Gas flow continued into insulated box surrounding outer cylinder).

C. Assembled piston into cylinder and pumped vacuum to test value.

D. Cooled fixture to test temperature.

E. Raised drop rig to test height and dropped rig with oscillograph in operation.

F. Measured total stroke.

G. "Zero" and "Calibrate" oscillograph records obtained at atmospheric pressure.

6.5.2.3 High Temperature

A. Heated fixture outer cylinder with heat lamps and hot air heater to +150°F or +350°F dependent on the test temperature.

B. Installed specimen and heated to test temperature (Note: Test procedure was planned such that specimen was not at the higher temperature (+300°F) for more than 10 minutes. Some of the time figures are shown in the Test Data Summary).

C. Shut-Off flow of hot air through inside of fixture and installed piston.

D. Took "Zero" and "Calibrate" oscillograph records.

E. Vacuum pumped to test value.

F. Raised drop rig to test height and dropped rig with oscillograph in operation.

G. Measured total stroke.

6.6 TEST SPECIMEN INSTALLATION

All full length test specimens were tested in the test fixture (Figure 3-4) which is fully described in Section III.

The specimens were installed in the test fixture using guide tubes which necessitated minor changes when proceeding from a configuration with one cross-sectional area to that of another cross-sectional area (Figure 3-6) . Guide rings, fabricated from Styrofoam or balsa wood as the test temperature dictated, were loosely fitted to the specimens as shown in Figure 6-3. The "internal annular" high crush strength specimens (Configurations 1A, B and C) were guided by placing the guide rings between the specimen outside diameter and the guide tube inside diameter. The "external annular" medium crush strength specimen (Configuration 2A. B & C) utilized guide rings between the specimen inside diameter and the guide tube outside diameter. The "circular solid" low crush strength specimens (Configuration 3A, B & C) were guided with the rings located between the specimen outside diameter and the guide tube inside diameter.

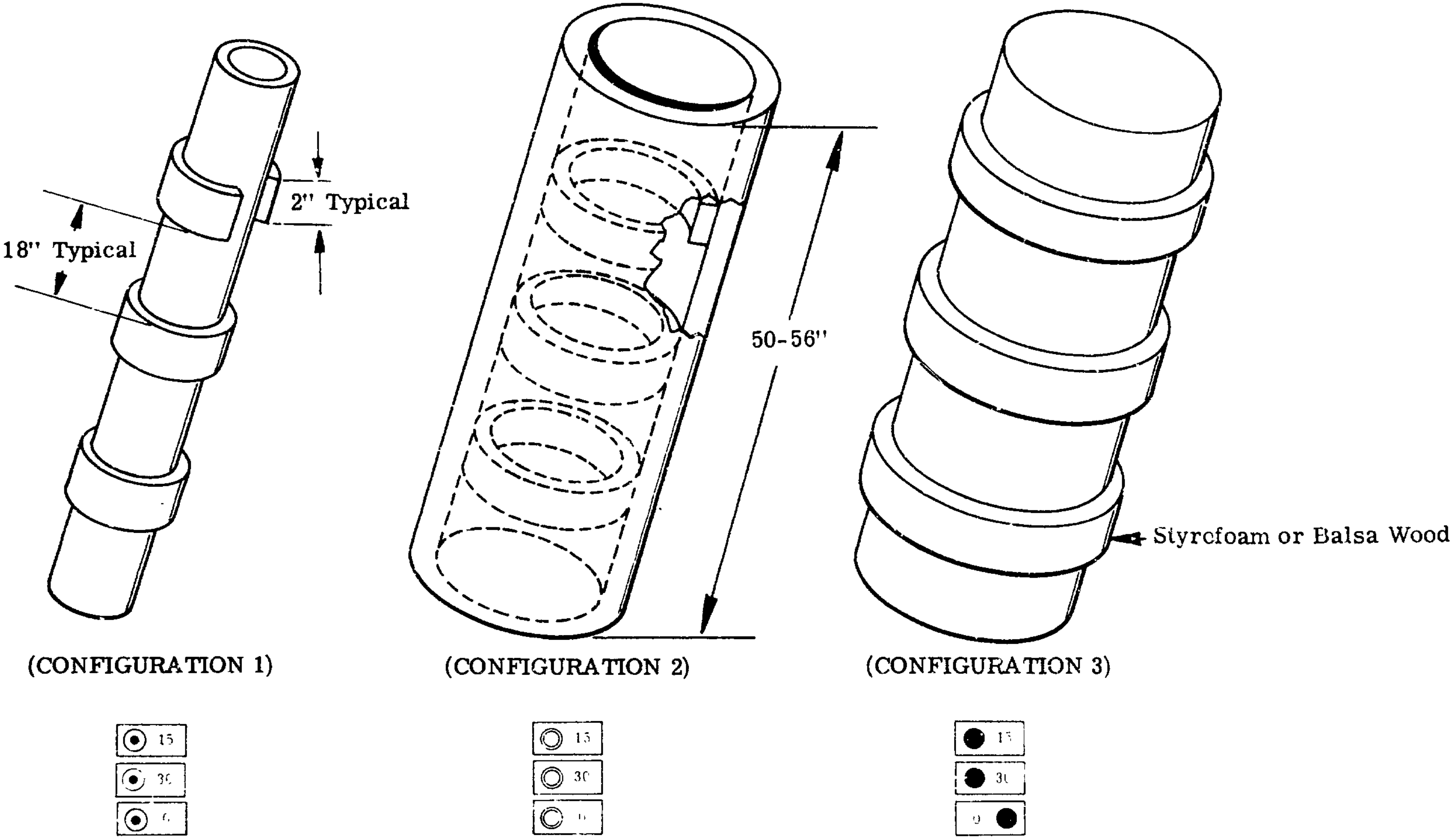


Figure 6-3. Specimen Configurations Showing Guide Rings

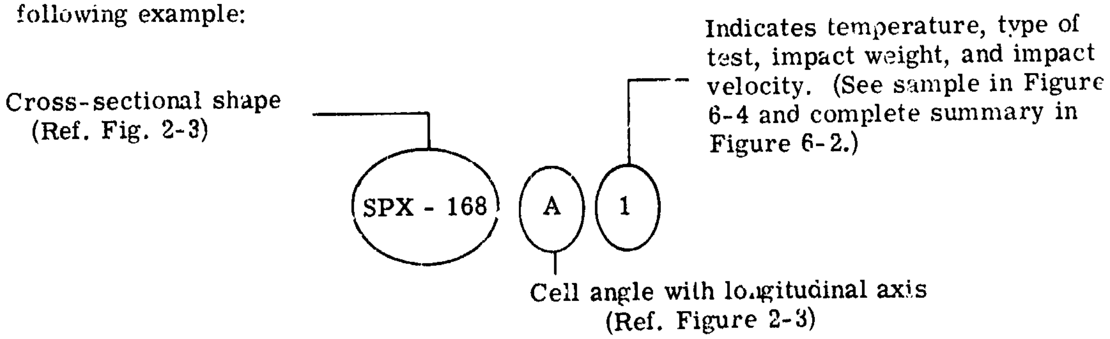
Most of the guide rings used for the room temperature and cryogenic temperature tests were fabricated from styrofoam with a crush strength of approximately 50 PSI. The high temperature tests required the use of some other material which was capable of enduring this environment without excessive deterioration. Balsa wood rings of 1200 PSI crush strength, which were presently available, proved to be the answer for this requirement.

Three rings, evenly spaced along the length of the capsule, proved to be entirely adequate for most specimens to insure that the capsules would initiate their regular crush patterns without buckling. On isolated cases which had any tendency to buckle, shear, or fail in an unusual or catastrophic manner the addition of more rings (anywhere from five to eight) , or a change to hard wood rings in one case, was not sufficient to prevent such failures.

6.7 IDENTIFICATION OF TEST SPECIMENS

The magnitude of the program and the number of specimens involved made it necessary to establish a system of individual specimen identification which would allow easy cross-reference when comparing data from the various specimens. A system was used which permits this comparison to be made.

Each group of specimen configurations is identified by the nomenclature shown in the following example:



Specimen No.	Temperature	Test	Impact Weight (Lbs.)	Impact Velocity (FPS)
SPX-168 A1	Room	Static		
SPX-168 A2	Room	Dynamic	1920	5
SPX-168 A3	Room	Dynamic	1920	10
SPX-168 A4	Room	Dynamic	1920	14
SPX-168 A5	Room	Dynamic	1920	20
SPX-168 A6	Room	Dynamic	760	10
SPX-168 A7	Room	Dynamic	2850	10
SPX-168 A8	Room	Dynamic	3750	10

Figure 6-4. Sample of Numbering System for Identification of Test Specimens (For full test program summary with identifying specimen No's. see Figure 6-2.)

Some of the configurations tested in the early part of the program were identified with an additional dash number (ie. SPX-166C3-4). This second dash number (-4) indicates the subsequent number of specimens of the same configuration which were tested under that set of conditions identified by the number (3).

SECTION VII

PHASE I TESTS

7.1 GENERAL

Following the fabrication of core configuration samples and procurement of the specified 5056 foil material, the test specimen supplier proceeded with construction and test of the preproduction control samples. Attainment of satisfactory results for the various configurations as listed under the basic specimen requirements (Figure 2-3) resulted in shipment of that configuration to Bendix for initiation of static tests on these articles. These Bendix test results, when confirming that the specimens were meeting the prescribed requirements, resulted in a design release for fabrication of the full length test specimens of that configuration. Receipt of the full length specimens then allowed the initiation of Phase I tests in two parts. The following outline provides a sequence of events leading through Phase I.

1. Fabrication of core configuration samples.
2. Fabrication of preproduction control specimens.
3. Vendor test of preproduction control specimens.
4. Bendix test of preproduction control specimens.
5. Design release for fabrication of full length specimens.
6. Fabrication of full length specimens.
7. Phase IA tests (9 configurations - 8 specimens of each, room temperature).
8. Evaluation of data and selection of the (4) four most satisfactory configurations.

9. Phase IB tests (4 configurations - 2 specimens of each, cryogenic temperature).
10. Evaluation of data and selection of the (2) two most satisfactory configurations for further testing under cryogenic & high temperatures in Phase II.

7.2 BENDIX TESTS OF PREPRODUCTION CONTROL SPECIMENS

Following the receipt of (4) four specimens of each configuration (Figures 2-2 and 7-1) (2) two of these specimens were subjected to a static crush test with use of an Instron Model TT-C Test Machine (Figure 7-2). One each of these crushed and uncrushed specimens of each configuration were forwarded to NASA-MSC for evaluation and concurrence with Bendix selection of satisfactory configurations.

The specimens were placed between the heads of the test machine as shown in Figure 7-2 and tested as per the conditions as outlined in paragraph 7.2.1. The specimens were not attached to the heads at either end and no guide tubes were used to contain the specimens during the crushing action.

7.2.1 Test Conditions for Preproduction Control Specimen Tests

Test Machine	Instron-Model TT-C (Ref: Figure 7-2,
C-F Load Cell	Range 200-10,000 Pounds Measuring & recording accuracy over the entire load range ±0.5%
Loading Conditions	Axially applied load Unguided specimen (Ref.: Figure 7-2) Ambient temperature Ambient atmospheric pressure
Head Speed	.5 inch/minute
Chart Speed	First Crush = 10 inches/minute Second Crush = 1 inch/minute

NOTE: The second crush on specimen SPX-165C2 (Test No. 1) is the only test run with a chart speed of 2"/minute. All other second crush tests were run at a chart speed of 1"/minute. (Paragraph 7.2.2).

1A ◉ 15 1B ◉ 30 1C ◉ 0

"Internal Annular" - High Crush Strength

2A ◎ 15 2B ◎ 30 2C ◎ 0

"External Annular" - Medium Crush Strength

3A ● 15 3B ● 30 3C ● 0

Circular Solid - Low Crush Strength

Figure 7-1. Crushed and Uncrushed Examples of Preproduction Control Specimens In the Finalized Configurations

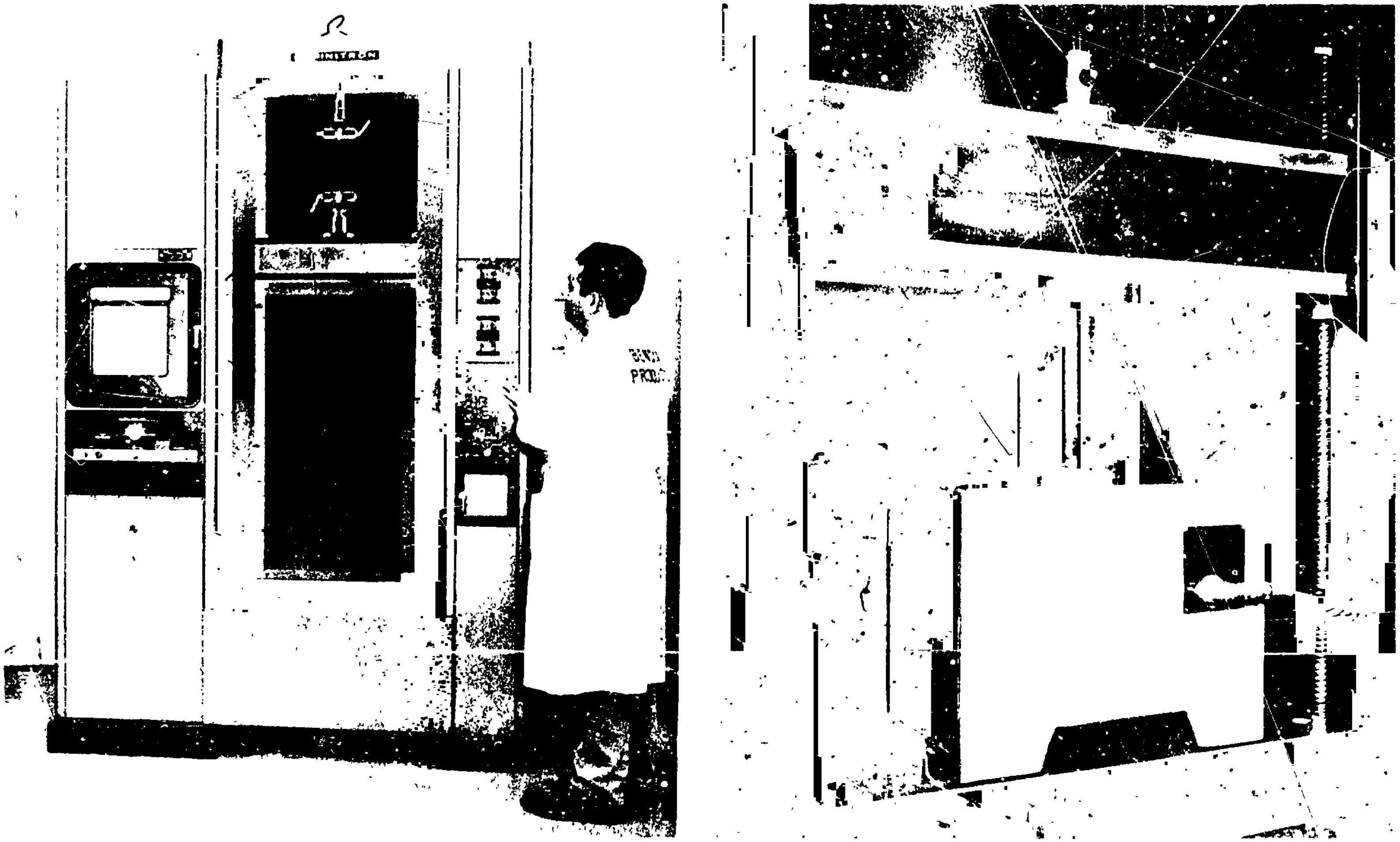


Figure 7-2. Instron Static Test Machine and Typical Test Specimen Installed (Before Crushing)

7.2.2 Log of Preproduction Control Specimen Testing

TEST 1 SPX-165-C-2 ⦿ 0

Chart Speed: 10"/Min First Crush; 2"/min Second Crush.

Head Speed: 1/2"/min.

Weight: 81.5 grams = .180#

Dimensions before Crushing: 3"O.D. x 2-1/8"I.D. x 6.0" Long.

Condition of Specimen: Foil was bent over on both ends in two, 45° quadrants 45° apart.

NOTES ON TEST: Crinkle pattern occurs on outer skin. Specimen crushed from the top.

Dimensions after Crushing: 3"O.D. x 2-1/6"I.D. x 1-11/16" Long.

TEST 2 SPX-165-C-3 ○ 0

Chart Speed: 10"/min First Crush; 1"/min Second Crush.

Head Speed: 1/2"/min.

Weight: 81.0 grams = .179#

Dimensions before Crushing: 2-15/16"O.D. x 2-1/16"I.D. x 6.0" Long.

Condition of Specimen: Foil was bent over on both ends in two, 45° quandrants 45° apart.

NOTES ON TEST: Crinkle pattern occurs in outer skin. Specimen crushed from the top.

Dimensions after Crushing: 3"O.D. x 2-1/16"I.D. x 1-11/16" Long.

TEST 3 SPX-163-C-2 ● 0

Chart Speed: 10"/min First Crush; 1"/min Second Crush.

Head Speed: 1/2"/min.

TEST 3 **SPX-163-C-2** (Continued)

Weight: 140.5 grams = .31#

Dimensions before Crushing: 6-1/8" Diameter x 6.0" Long.

Condition of Specimen: Slight dent 2" from one end approximately 1" long.

NOTES ON TEST: Foil has running wrinkles in visible parts of foil. This is not so apparent on center of corrugations.

Specimen crushed from the bottom.

Dimensions after Crushing: 6-1/8" Diameter x 1-3/8" long.

TEST 4 **SPX-163-C-3** ● 0

Chart Speed: 10"/min First Crush; 1"/min Second Crush.

Head Speed: 1/2"/min.

Weight: 142.5 grams = .316#

Dimensions before Crushing: 6-1/8" Diameter x 6.0" Long.
Conditions of Specimen: Good.
NOTES ON TEST: Foil had running wrinkles as in Test 3. Specimen crushed from top.

Dimensions after Crushing: 6-1/8" Diameter x 1-3/8" Long.

TEST 5 **SPX-164-C-1** ○ 6

Chart Speed: 10"/min First Crush; 1"/min Second Crush.

Head Speed: 1/2"/min.

Weight: 108.5 grams = .24#

Dimensions before Crushing: 6-3/4"O.D. x 6.0"I.D. x 6.0" Long.

Condition of Specimen: Ends of foil slightly laid over- probably due to cutting.

NOTES ON TEST: Foil had running wrinkles as in Test 3. Specimen crushed from the bottom.

Dimensions after Crushing: 6-3/4"O.D. x 5-15/16"I.D. x 1-1/4" Long.

TEST 6 **SPX-164-C-4** ○ 0

Chart Speed: 10"/min First Crush; 1"/min Second Crush.

Head Speed: 1/2"/min.

Weight: 109.8 grams = .242#

Dimensions before Crushing: 6-11/16"O.D. x 6-1/16"I.D. x 6.0" Long.

Condition of Specimen: Ends of foil slightly laid over - probably due to cutting
1/4" long cut in side of outer wrapping parallel to end,
and 1-3/8" from end.

NOTES ON TEST: Split in outer foil was positioned with split 1-3/8" from top. Split became wider just as crush reached area. Specimen crushed from the top. Specimen buckled in at the bottom before being fully crushed, with load falling off rapidly. Test was terminated at this point. (POINT C ON RECORD).

Dimensions after Crushing: Diameters at top (crushed end) 6-3/4"O.D., 6.0"I.D.
Diameters at bottom (buckled end) - 6-3/4"O.D., 6.0"I.D.
Length after crushing: 1-7/8".

TEST 7 **SPX-165-B-1** ⊙ 30

Chart Speed: 10"/min First Crush; 1"/min Second Crush.

Head Speed: 1/2"/min.

Weight: 105.5 grams = .233#

Dimensions before Crushing: 3-3/32"O.D. x 2.0"I.D. x 6.0" Long.

Condition of Specimen: Foil at one end bent over slightly.

TEST 7 SPX-165-B-1 (Continued)

NOTES ON TEST: Specimen crushed from the bottom.

Dimensions after Crushing: 3-1/8"O.D. x 1-15/16"I.D. x 1-11/16" Long.

TEST 8 SPX-165-B-2 ⊙ 30

Chart Speed: 10"/min First Crush; 1"/min Second Crush.

Head Speed: 1/2"/min.

Weight: 105.2 grams = .232#

Dimensions before Crushing: 3-1/16"O.D. x 2.0"I.D. x 6.0" Long.

Condition of Specimen: Good.

NOTES ON TEST: Specimen crushed from the bottom.
Foil started buckling out at bottom at one side after about 3/4" of stroke and then stopped.

Dimensions after Crushing: 3-1/8"O.D. x 2"I.D. x 1-3/4" Long.

TEST 9 SPX-165-C-5 ⊙ 0

Chart Speed: 10"/min. First Crush
1"/min Second Crush

Head Speed: 1/2"/min.

Weight: 95 grams

Dimensions before Crushing: 3"O.D., 2"I.D., 6" Long.

Condition of Specimen: Good.

NOTES ON TEST: Specimen crushed uniformly, slight bulging in inner foil wrap.

Dimensions after Crushing: 3"O.D., 2"I.D., 1-5/8" Long.

TEST 10 SPX-165-C-6 ⊙ (

Chart Speed: 10"/min. First Crush

1"/min. Second Crush

Weight: 97 grams

Dimensions before Crushing: 3"O.D., 2"I.D., 6" Long.

Condition of Specimen: Good.

NOTES ON TEST: Specimen crushed uniformly, excessive bulging of inner foil.

Dimensions after Crushing: 3"O.D., 1-15/16"I.D., 1-5/8" Long.

TEST 11 SPX-165-A-1 ⊙ 15

Chart Speed: 10"/min First Crush; 1"/min. Second Crush.

Head Speed: 1/2"/min.

Weight: 90 grams

Dimensions before Crushing: 3"O.D. x 2"I.D. x 6.0" Long.

Condition of Specimen: Good.

NOTES ON TEST:

Dimensions after Crushing: 3-1/16"O.D. x 1-15/16"I.D. x 1-3/8" Long.

TEST 12 SPX-165-A-2 ⊙ 15

Chart Speed: 10"/min. First Crush; 1"/min. Second Crush.

Head Speed: 1/2"/min.

Weight: 90 grams

Dimensions before Crushing: 3"O.D. x 2"I.D. x 6.0" Long.

Condition of Specimen: Good.

NOTES ON TEST:

Dimensions after Crushing: 3-1/16"O.D. x 1-15/16"I.D. x 1-7/16" Long.

TEST 13 SPX-165-B-5 ⊙ 30

Chart Speed: 10"/min. First Crush; 1"/min. Second Crush.

Head Speed: 1/2"/min

Weight: 99 grams.

Dimensions before Crushing: 3-1/8"O.D. x 2"I.D. x 6" Long.

Condition of Specimen: Good.

NOTES ON TEST:

Dimensions after Crushing: 3-3/16" O.D. x 2"I.D. x 1-7/16" Long.

TEST 14 SPX-165-B-6 ⊙ 3

Chart Speed: 10"/min. First Crush; 1"/min. Second Crush.

Head Speed: 1/2"/min.

Weight: 100 grams

Dimensions before Crushing: 3-1/8"O.D. x 2"I.D. x 6" Long.

Condition of Specimen: Good.

NOTES ON TEST:

Dimensions after Crushing: 3-5/32"O.D. x 2"I.D. x 1-7/16" Long.

TEST 15 SPX-165-C-11 ⊙

Chart Speed: 10"/min. First Crush; 1"/min. Second Crush.

Head Speed: 1/2"/min.

Weight: 152 grams.

Dimensions before Crushing: 3-1/8"O.D. x 2"I.D. x 6" Long.

Condition of Specimen: Good.

NOTES ON TEST:

Dimensions after Crushing: 3-3/16"O.D. x 1-7/8"I.D. x 1-3/4" Long.

TEST 16 SPX-165-C-12

Chart Speed: 10"/min. First Crush; 1"/min. Second Crush.

Head Speed: 1/2"/min.

Weight: 148.5 grams.

Dimensions before Crushing: 3-1/8"O.D. x 2"I.D. x 6" Long.

Condition of Specimen: Good.

NOTES ON TEST:

Dimensions after Crushing: 3-1/4"O.D. x 2"I.D. x 1-3/4" Long.

TEST 17 SPX-164-C-7

Chart Speed: 10"/min. First Crush; 1"/min. Second Crush.

Head Speed: 1/2"/min.

Weight: 175.5 grams.

Dimensions before Crushing: 6-9/16"O.D. x 5-1/2"I.D. x 6" Long.

Condition of Specimen: Good.

NOTES ON TEST:

Dimensions after Crushing: 6-3/4"O.D. x 5-1/2"I.D. x 1-7/16" Long.

TEST 18 SPX-164-C-8

Chart Speed: 10"/min. First Crush; 1"/min. Second Crush.

Head Speed: 1/2"/min.

Weight: 174 grams.

Dimensions before Crushing: 6-9/16"O.D. x 5-1/2"I.D. x 6" Long.

Condition of Specimen: Good
NOTES ON TEST:
Dimensions after Crushing: 6-9/16"O.D. x 5-7/16"I.D. x 1-7/16" Long.

TEST 19 **SPX-163-B-1** ● 30

Chart Speed: 10"/min. First Crush; 1"/min. Second Crush

Head Speed: 1/2"/min.

Weight: 198.6 grams.

Dimensions before Crushing: 6" O.D. x 6" Long.

Condition of Specimen: Good crush from bottom.

NOTES ON TEST: Uniform Crush.

Dimensions after Crushing: 6" O.D. x 1-1/8" Long.

TEST 20 **SPX-163-B-2** ● 30

Chart Speed: 10"/min. First Crush; 1"/min. Second Crush

Head Speed: 1/2"/min.

Weight: 203 grams.

Dimensions before Crushing: 5-15/16" O.D. x 6" Long

Condition of Specimen: Good.

NOTES ON TEST: Uniform Crush

Dimensions after Crushing: 6"O.D. x 1-1/8" Long

TEST 21 **SPX-163-A-2** ● 15

Chart Speed: 10"/min. First Crush; 1"/min. Second Crush

Head Speed: 1/2"/min.

Weight: 175 grams

Dimensions before Crushing: 5-9/16"O.D. x 6" Long.

Condition of Specimen: Good.

NOTES ON TEST: Sample caved in on side.
Dimensions after Crushing: 5-9/16"O.D. x 1-1/16" Long.

TEST 22 SPX-163-A-1 ● 15

Chart Speed: 10"/min. First Crush; 1"/min. Second Crush.

Head Speed: 1/2"/min.

Weight: 176.6 grams

Dimensions before Crushing: 5-7/16"O.D. x 6" Long.

Condition of Specimen: Good.

NOTES ON TEST: Good crush.

Dimensions after Crushing: 5-7/16"O.D. x 1-1/16" Long.

TEST 23 SPX-164-A-1 ◎ 15

Chart Speed: 10"/min. First Crush; 1"/min. Second Crush.

Head Speed: 1/2"/min.

Weight: 159 grams

Dimensions before Crushing: 6.9"O.D. x 5.5"I.D. x 6-3/8" Long.

Condition of Specimen: Good.

NOTES ON TEST: Good crush from bottom.

Dimensions after Crushing: 7"O.D. x 5-1/2"I.D. x 1-1/8" Long

TEST 24 SPX-164-A-2 ◎ 15

Chart Speed. 10"/min. First Crush; 1"/min. Second Crush.

Head Speed: 1/2"/min.

Weight: 167.1 grams

Dimensions before Crushing: 7"O.D. x 5.5"I.D. x 6.25" Long

Condition of Specimen: Good.

NOTES ON TEST:

Dimensions after Crushing: 7-1/8"O.D. x 5-1/2"I.D. x 1-1/8" Long.

TEST 25 **SPX-164-B-1** O 30

Chart Speed: 10" min. First Crush; 1"/min. Second Crush.

Head Speed: 1/2"/min.

Weight: 169.5 grams

Dimensions before Crushing: 7"O.D. x 5.5"I.D. x 6" Long.

Condition of Specimen: Good.

NOTES ON TEST: Uniform crush.

Dimensions after Crushing: 7"O.D. x 5-1/2"I.D. x 1-1/8" Long.

TEST 26 **SPX-164-B-2** O 3

Chart Speed: 10" min. First Crush; 1"/min. Second Crush.

Head Speed: 1/2"/min.

Weight: 164.5 grams

Dimensions before Crushing: 7"O.D. x 5-1/2"I.D. x 6" Long

Condition of Specimen: Flat 1/2" wide along O.D.

NOTES ON TEST: Good crush.

Dimensions after Crushing: 7"O.D. x 5-1/2"I.D. x 1-3/16" Long.

TEST 27 **SPX-164-C-9** C

Chart Speed: 10"/min. First Crush; 1"/min. Second Crush.

Head Speed: 1/2"/min.

Weight: 200.8 grams

Dimensions before Crushing: 6-15/16"O.D. x 5-1/2"I.D. x 6-3/8" Long.

Condition of Specimen: Loose foil on I.D. 2 $inch^2$

NOTES ON TEST: Local buckling on outside of tape. Internal failure of glue.

Dimensions after Crushing: 7"O.D. x 4-1/2"I.D. x 1-1/4" Long.

TEST 28 **SPX-164-C-10** C

Chart Speed: 10"/min. First Crush; 1"/min. Second Crush.

Head Speed: 1/2"/min.

Weight: 182.7 grams

Dimensions before Crushing: 6-3/4"O.D. x 5-1/2"I.D. x 6-3/8" Long.

Condition of Specimen: Good.

NOTES ON TEST: Good crush.

Dimensions after Crushing: 6-7/8"O.D. x 5-1/4"I.D. x 1-5/16"Long.

TEST 29 **SPX-164-C-11** C

Chart Speed: 10"/min. First Crush; 1" min. Second Crush.

Head Speed: 1/2" min.

Weight: 192.7 grams

Dimensions before Crushing: 6.858"O.D. x 5.520"I.D. x 6.1"Long.

Condition of Specimen: Good crush top to bottom

NOTES ON TEST: Uniform crush.

Dimensions after Crushing: 6.950"O.D. x 4.330"I.D. x 1.376" Long.

TEST 30 **SPX-164-C-12** C

Chart Speed: 10"/min. First Crush; 1"/min. Second Crush.

Head Speed: 1/2"/min.

Weight: 191.7 grams

Dimensions before Crushing: 6.952"O.D. x 5.523"I.D. x 6.250" Long.

Condition of Specimen: Good crush top to bottom.

NOTE ON TEST: Uniform crush.

Dimensions after Crush: 6.975"O.D. x 4.975"I.D. x 1.350" Long.

TEST 31 SPX-164-C-15 C

Chart Speed: 10"/min. First Crush: 1"/min. Second Crush.

Head Speed: 1/2"/min.

Weight: 204 grams

Dimensions before Crushing: 7.1875"O.D. x 5.5"I.D. x 5.875" Long.

Condition of Specimen: Good crush top to bottom.

NOTES ON TEST: Uniform crush.

Dimensions after Crush: 7.1875"O.D. x 5.4375"I.D. x 1.312" Long.

TEST 32 SPX-164-C-16 C

Chart Speed: 10"/min. First Crush: 1"/min. Second Crush.

Head Speed: 1/2"/min.

Weight: 210 grams

Dimensions before Crushing: 7.187"O.D. x 5.5"I.D. x 6.025" Long.

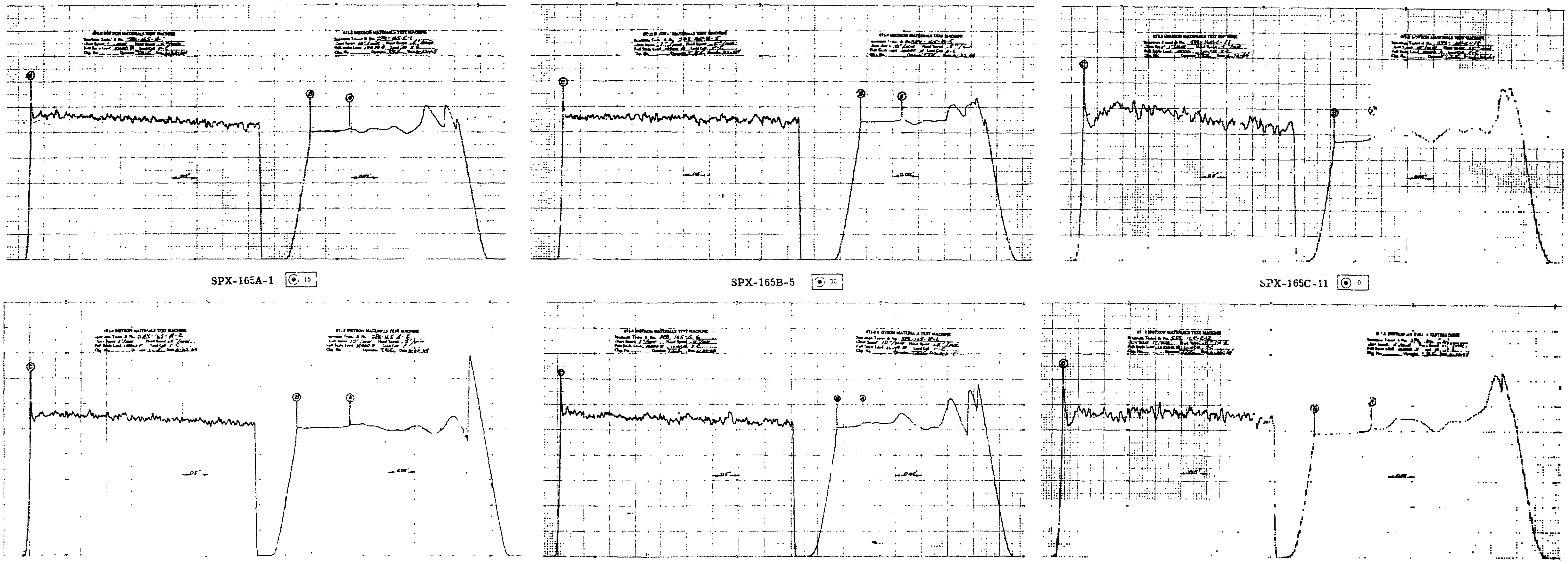
NOTES ON TEST: Uniform crush.

Dimensions after Crush: 7.3125"O.D. x 5.25"I.D. x 1.375" Long.

7.2.3 Test Records and Data

The Instron test records for specimens meeting the specification requirements are found in Figures 7-3 through 7-5. These records are read from right to left with the first crush starting at the extreme right. A key for interpretation of these records may be found in Figure 7-6. Tables of the Static Crush Data for all 6 inch length preproduction Control Specimens is found in Figures 7-7 through 7-10.

NOTE: Other test records for specimens not meeting the specification requirements may be found in Section II of Addendum No. 1.



SPX-165A-1 ⊙ 15

SPX-165B-5 ⊙ 30

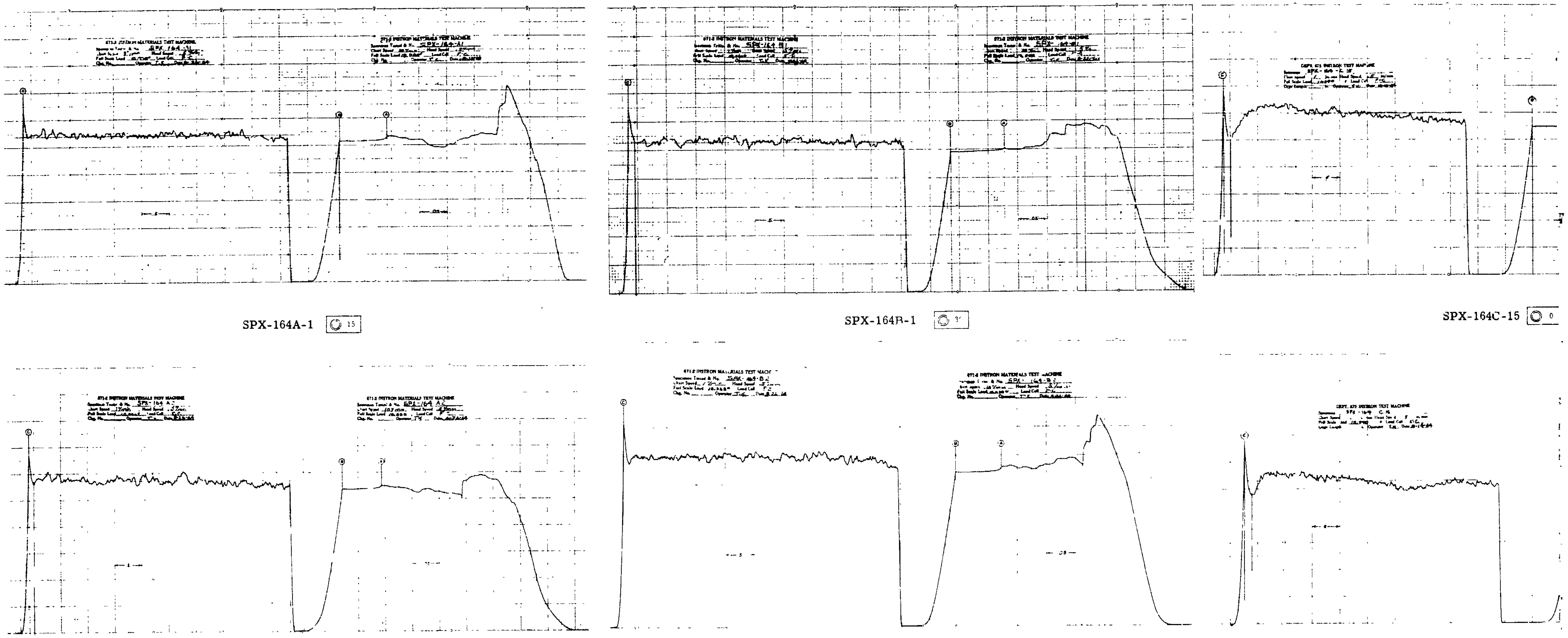
SPX-165C-11 ⊙ 0

SPX-165A-2 ⊙ 15

SPX-165B-6 ⊙ 30

SPX-165C-12 0 ⊙

Figure 7-3. Static Crush Test Records for Preproduction Control Specimens of the "Internal Annular" Configuration (1)



SPX-164A-1 ◯ 15

SPX-164B-1 ◯ 30

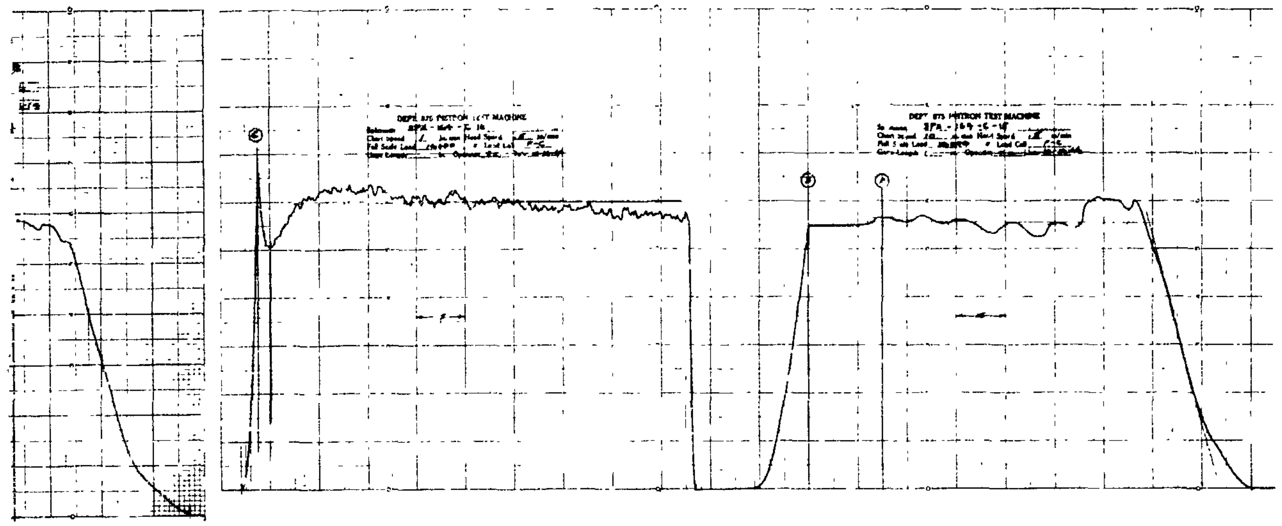
SPX-164C-15 ◯ 0

SPX-164A-2 ◯ 15

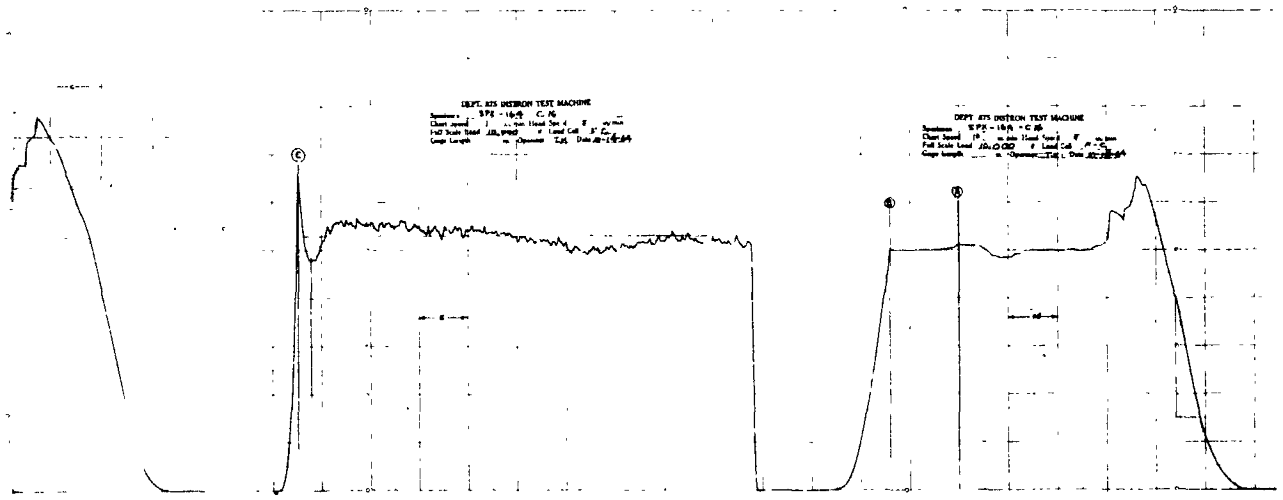
SPX-164B-2 ◯ 30

SPX-164C-16 ◯ 0

Figure 7-4. Static Crush Test Records for Preproduction Control Specimens of the "External Annular" Configuration (2)

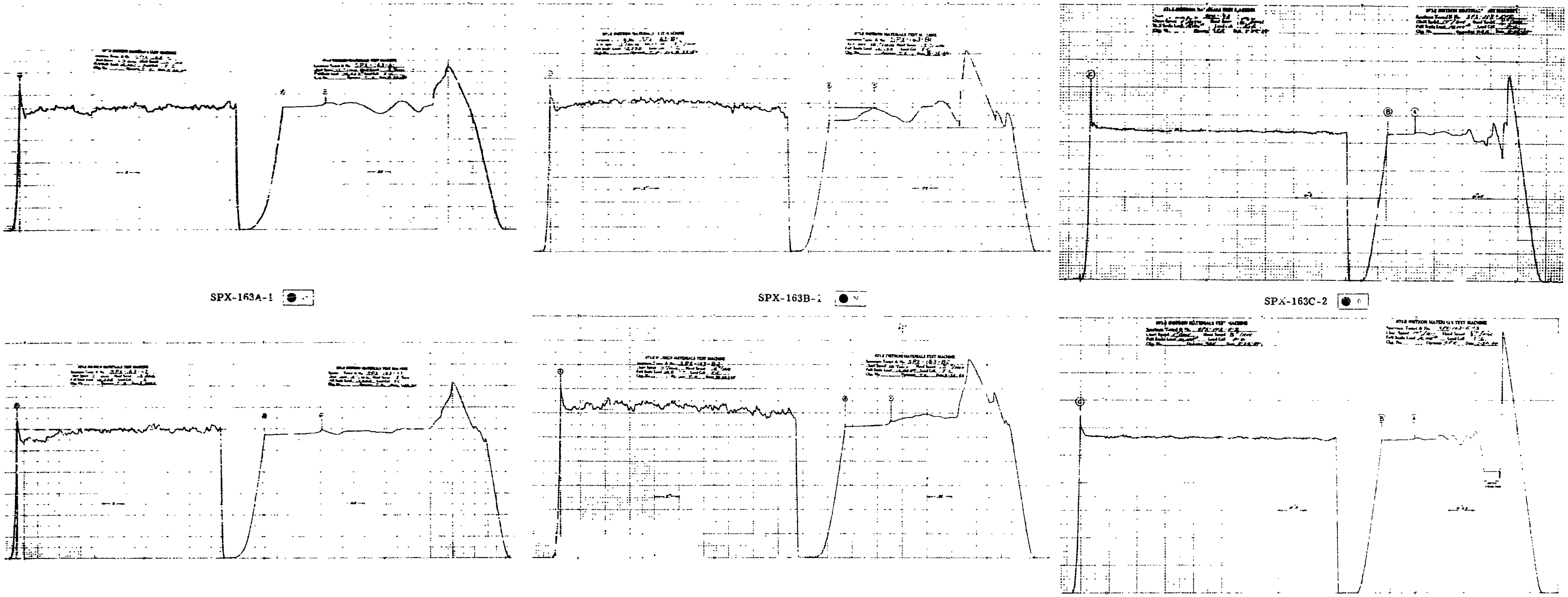


SPX-164C-15 ◎ 0



SPX-164C-16 ◎ 0

rol Specimens



SPX-163A-1 ●

SPX-163B-1 ●

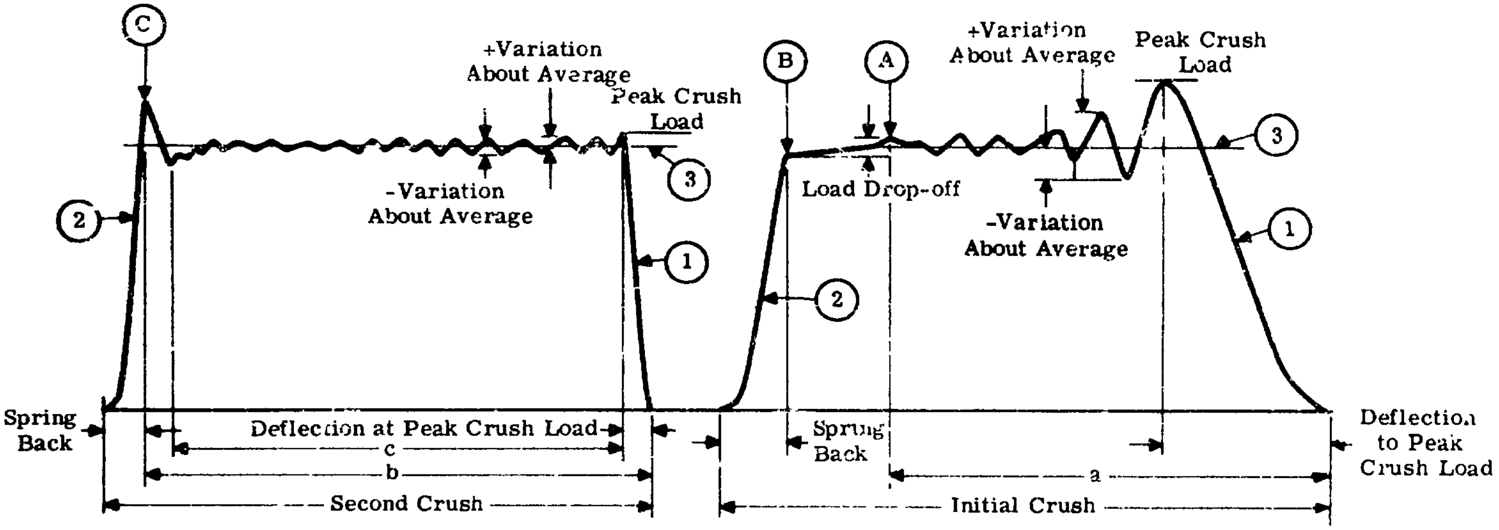
SPX-163C-2 ● 0

SPX-163A-2 ● 15

SPX-163B-2 ● 30

SPX-163C-3 ● 0

Figure 7-5. Static Crush Test Records for Preproduction Control Specimens of the "Circular Solid" Configuration (3)



Initial Stroke = (a - Spring Back)
Second Crush Stroke = (b - Spring Back)
Total Stroke = (Initial Stroke) + (Second Crush Stroke)
Usable Stroke = (a + c)

$$\% \text{ Crushed} = \frac{(a + c)}{(\text{Orig. Length})} \times 100\%$$

Point Ⓐ Stroke Held (Head Speed Zero)	① Slope = Spring Rate (Load Buildup)
Point Ⓑ Load Removed at a Head Speed of 1/2 inch per minute	② Slope = Spring Rate (Load Dropoff)
Point Ⓒ Load Removed at a Head Speed of 1/2 inch per minute	③ Average Crush Load

Figure 7-6. Key for Static Crush Data (Instron Records)

Test No. Specimen (Article) No.	(1) SPX-165-C-2	(2) SPX-165-C-3	(3)* SPX-163-C-2	(4)* SPX-163-C-3	(5) SPX-164-C-1	(6) SPX-164-C-4	(7) SPX-165-B-1	(8) SPX-165-B-2
1) Dimensions								
Outside Diameter (In.)			6.125	6.125				
Inside Diameter (In.)								
Length (In.)			6.00	6.00				
2) Area (In.^{2})			29.465	29.465				
3) Volume (In.^{3})			176.9	176.9				
4) Weight (Lbs.)			.310	.314				
5) Density (Lbs./Ft.^{3})			3.02	3.07				
6) Energy Absorbed (Ft.-Lbs.)			2,130	2,392				
7) Specific Energy (Ft.-Lbs./Lb.)			6,867	6,506				
INITIAL CRUSH								
8) Peak Crush Load (Lbs.)	6,140	5,800	7,450	9,500	5,030	6,110	7,880	9,620
9) Deflection to Peak Crush Load (In.)	0.0915	0.0425	0.0625	0.0675	0.0925	0.105	0.0700	0.0850
10) Spring Rate - Load Buildup (Lbs./Inch)	91,666	92,500	148,500	150,500	75,000	85,000	122,000	130,000
11) Average Crush Load (Lbs.)	5,300	5,350	5,400	5,650	4,500	5,200	6,000	5,900
12) Variation of Crush Load (Average) (Lbs.)	+380-640	+200-1050	350-920	±250	-900	350-250	±400	-1750
13) Load Drop Off (Points A to B) Lbs.	80	60	50	80	70	150	180	260
14) Spring Rate - Load Drop Off (Lbs In)	131,500	130,000	142,500	149,000	122,000	120,000	125,000	135,000
15) Spring Back (Inches)	0.049	0.0450	0.0425	0.0425	0.0425	0.0425	0.0525	0.0550
16) Stroke (Inches)	0.318	0.223	0.188	0.200	0.158	0.248	0.183	0.400
SECOND CRUSH								
17) Peak Crush Load (Lbs.)	5,450	5,350	5,400	5,650	4,450	5,350	6,200	6,100
18) Deflection to Peak Crush Load (Inches)	0.0575	0.055	0.050	0.050	0.0750	0.150	0.0875	0.115
19) Spring Rate - Load Buildup (Lbs/Inch)	95,100	73,000	138,000	155 000	90,000	94,000	110 000	104,000
20) Average Crush Load (Lbs)	5,300	5,350	5,400	5,650	4,500	5,200	6,000	5,900
21) Variation of Crush Load (Average) (Lbs)	±150	230-270	300-100	100-120	+400	300-200	375-350	550-450
22) Spring Rate - Load Dropoff (Lbs/Inch)	88,333	82,000	84,000	77,500	84,000	42,000	80,000	70,000
23) Spring Back (Inches)	0.11	0.100	0.150	0.125	0.150		0.125	0.125
24) Stroke (Inches)	4.05	4.00	4.35	4.43	4.45		4.21	4.00
25) Total Stroke (Inches)	4.368	4.223	4.538	4.630	4.608		4.393	4.400
26) Usable Stroke (Inches)	4.3175	4.313	4.718	4.722	4.775		4.3485	4.395
27) Percent Crushed (%)	72	72	78.6	78.8	79.5		72.5	73.2
28) Percent Load Variation (Ref. Item 21)	+2.8	+4.3-5.0	+5.4-1.9	+1.8-2.1	±8.9	+5.7-3.8	+6.3-5.8	+9.3-7.6

NOTES 1. Refer to Key shown on Figure 7-6 for interpolation of tabular data headings.

2. Those specimens marked with an asterisk (*), and for which the pertinent identification is listed, were considered to have exhibited satisfactory crush characteristics when compared with the finalized specification requirements and full length test articles were produced in accordance with the fabrication techniques employed in construction of these "control type" specimens.

Figure 7-7. Table of Static Crush Data for all Six-Inch Length Preproduction Control Specimens

Test No. Specimen (Article) No	(9) SPX-165-C-5	(10) SPX-165-C-6	(11) • SPX-165-A-1	(12) • SPX-165-A-2	(13) • SPX-165-B-5	(14) • SPX-165-B-6	(15) • SPX-165-C-11	(16) • SPX-164-C-12
1) Dimensions								
Outside Diameter (In.)			3.00	3.00	3.125	3.125	3.125	3.125
Inside Diameter (In.)			2.00	2.00	2.00	2.00	2.00	2.00
Length (In.)			6.00	6.00	6.00	6.00	6.00	6.00
2) Area (In.^{2})			3.927	3.927	4.528	4.528	4.528	4.528
3) Volume (In.^{3}			23.55	23.55	27.20	27.20	27.20	27.20
4) Weight (Lbs.)			.199	.199	217	.221	335	.327
5) Density (Lbs./Ft.^{3})			14.60	14.60	13.83	14.04	21.25	20.75
6) Energy Absorbed (Ft.-Lbs.)			2170	2110	2200	2168	2027	2304
7) Specific Energy (Ft.-Lbs./Lb.)			10,908	10,600	10,093	9,808	6,058	7,050
INITIAL CRUSH								
8) Peak Crush Load (Lbs.)	7,300	6,220	5 500	7,950	6,375	6,800	6,900	7,320
9) Deflection to Peak Crush Load (In.)	0.068	0.065	.055	.073	.063	.067	.080	.085
10) Spring Rate - Load Buildup (Lbs. Inch)	107,300	97,000	109,000	120,000	100,000	120,000	126,500	120.000
11) Average Crush Load (Lbs.)	5,600	5,400	5,450	5,400	5,500	5,450	5,600	5,600
12) Variation of Crush Load (Average)(Lbs.)	±1,000	420-450	+300, -500	+100-550	+600, -180	+750, -700	+1200, -850	+1600, -600
13) Load Drop Off (Points A to B) (Lbs.)	100	170	100	130	120	130	260	270
14) Spring Rate - Load Dropoff (Lbs. Inch)	124,000	106,200	122,700	118,800	126,700	127,100	135,700	137,100
15) Spring Back (Inches)	0.0525	0.050	.047	.046	.048	.052	.051	.041
16) Stroke (Inches)	0.278	0.320	.219	.259	.173	.234	.294	.290
SECOND CRUSH								
17) Peak Crush Load (Lbs.)	5,900	5,500	5,400	5,250	5,600	5,320	5,530	5,500
18) Deflection to Peak Crush Load (Inches)	0.050	0.060	.065	.070	.060	.060	.110	.110
19) Spring Rate - Load Buildup (Lbs./Inch)	116,000	91,700	130,000	128,000	146,000	126,000	110,000	114,000
20) Average Crush Load (Lbs.)	5,625	5,400	5,450	5,400	5,500	5,450	5,600	5,600
21) Variation of Crush Load (Average)(Lbs.)	175-225	300-250	400	300	±250	350	±600	±400
22) Spring Rate - Load Dropoff (Lbs./Inch)	44,350	50 000	94,000	102,000	94,000	92,000	74,000	80,000
23) Spring Back (Inches)	0.150	0.120	.120	.110	.120	125	.150	.150
24) Stroke (Inches)	4.07	4.105	4.380	4.320	4.570	4.385	3.965	3.925
25) Total Stroke (Inches)	4.348	4.425	4.599	4.579	4.743	4.619	4.259	4.215
26) Usable Stroke (Inches)	4.443	4.470	4.619	4.608	4.701	4.706	4.350	4.293
27) Percent Crushed (%)	74.4	74.5	77.0	76.8	78.1	78.5	72.6	71.5
28) Percent Load Variation (Ref. Item 21)	+3-3.4	+5.5-4.6	7.3	+5.6	-4.55	6.4	10.7	-7.1

NOTES: 1. Refer to Key shown on Figure 7-6 for interpolation of tabular data headings.

2. Those specimens marked with an asterisk (*), and for which the pertinent identification is listed, were considered to have exhibited satisfactory crush characteristics when compared with the finalized specification requirements and full length test articles were produced in accordance with the fabrication techniques employed in construction of these "control type" specimens.

Figure 7-8. Table of Static Crush Data for all Six-Inch Length Preproduction Control Specimens (Continued)

Test No. Specimen (Article) No.	(17) SPX-164-C-7	(18) SPX-164-C-8	(19)* SPX-163-B-1	(20)* SPX-163-B-2	(21)* SPX-163-A-2	(22)* SPX 163 A-1	(23)* SPX-164-A-1	(24) * SPX-164-A-2
1) Dimensions								
Outside Diameter (In.)			6.00	5.938	5.562	5.437	6.9	7 0
Inside Diameter (In.)							5.5	5.5
Length (Inches)			6.00	6.00	6.00	6.00	6.375	6.25
2) Area (In.^{2})			28.275	27.683	23.221	24.301	13.634	14.726
3) Volume (In.^{3})			169.8	166.1	139.6	145.8	87.0	92.0
4) Weight (Lbs.)			.438	.447	.386	.389	.352	.368
5) Density (Lbs./Ft ^{3})			4.46	4.65	4.77	4.61	6.98	6.91
6) Energy Absorbed (Ft.-Lbs.)			2464	2496	2474	2291	2287	2392
7) Specific Energy (Ft.Lbs./Lb.)			5,625	5,383	6,417	5,900	6,504	6,506
INITIAL CRUSH								
8) Peak Crush Load (Lbs.)	7,140	6,940	8,120	8,110	8,140	8,120	7,140	5,880
9) Deflection to Peak Crush Load (in.)	.126	.80	.138	.135	.129	.1215	.1095	.1645
10) Spring Rate - Load Buildup (Lbs/Inch)	71,500	111,800	130,000	124,500	123,000	87,500	105,500	88,000
11) Average Crush Load (Lbs.)	6,000	5,500	5,830	6,140	5,970	5,400	5,380	5,710
12) Variation of Crush Load (Average) (Lbs.)	+0, -500	+500, -300	+250, -600	-200, -350	+40, -240	+280, -270	+40, -470	-240, -700
13) Load Drop Off (Points A to B)(Lbs.)	100	70	500	220	240	210	180	130
14) Spring Rate - Load Dropoff (Lbs/Inch)	140,800	142,600	124,500	128,500	124,000	115,000	173,500	120,000
15) Spring Back (Inches)	.050	.048	.064	.0705	.078	.0855	.0545	.074
16) Stroke (Inches)	.255	.205	.254	.221	.400	.308	.272	.2745
SECOND CRUSH								
17) Peak Crush Load (Lbs.)	5,810	5,340	5,880	6,200	6,100	5,590	5,390	5,570
18) Deflection to Peak Crush Load (Inches)	.070	.065	.23	.205	.075	.085	.05	.075
19) Spring Rate - Load Buildup (Lbs/Inch)	104,500	125,000	130,000	133,500	123,000	1[illegible],000	146 000	134,000
20) Average Crush Load (Lbs)	6,000	5,500	5,830	6,140	5,970	5,400	5,380	5,710
21) Variation of Crush Load (Average) (Lbs.)	+200,-1600	+300,-800	+410,-230	+500,-360	+280,-170	-300,-320	+330, 260	+350,-300
22) Spring Rate - Load Dropoff (Lbs/Inch)	68,500	77,000	68,500	75,000	62,000	63,000	73,000	71,000
23) Spring Back (Inches)	.125	.130	.21	.21	.165	.21	.15	.16
24) Stroke (Inches)	4.400	4.430	4.53	4.44	4.595	4.64	4.675	4.715
25) Total Stroke (Inches)	4.655	4.635	4.784	4.661	4.995	4.948	4.947	5.0195
26) Usable Stroke (Inches)	4.715	4.710	4.723	4.7015	5.008	5.0435	5.0265	5.1635
27) Percent Crushed (%)	78.6	78.5	78.8	78.4	83.4	84.1	80.2	82.1
28) Percent Load Variation (Ref. Item 21)	+3.4,-26.6	+5.5,-14.5	+7.05,-3.95	+8.14,-5.86	+4.69,-2.85	+5.55,-5.93	+5.95,-4.84	+6.13,-5.26

NOTES 1. Refer to Key shown on Figure 7-6 for interpolation of tabular data headings.

2. These specimens marked with an asterisk (*), and for which the pertinent identification is listed, were considered to have exhibited satisfactory crush characteristics when compared with the finalized specification requirements and full length test articles were produced in accordance with the fabrication techniques employed in construction of these "control type" specimens

Figure 7-9. Table of Static Crush Data for Six-Inch Length Preproduction Control Specimens (Continued)

Test No. Specimen (Article) No.	(25) * SPX-164-B-1	(26) * SPX-164 B-2	(27) SPX 164-C-9	(23) SPX-164-C-10	(29) SPX-164-C-11	(30) SPX-164-C-12	(31) * SPX-164-C-15	(32) * SPX-164-C 16
1) Dimensions								
Outside Diameter (In.)	7.00	7.00					7.1875	7.187
Inside Diameter (In.)	5.50	5.50					5.50	5.50
Length (In.)	6.00	6.00					5.875	6.025
2) Area (In.^{2})	14 726	14.726					15.816	16.811
3) Volume (In.^{3})	88.4	68 4					98.8	101.3
4) Weight (Lbs.)	.374	.333					.450	.463
5) Density (Lbs./Ft.^{3})	7.31	7.10					7.87	8.10
6) Energy Absorbed (Ft.-Lbs.)	2145	2403					2267	2115
7) Specific Energy (Ft.-Lbs./Lb)	5,742	6,617					5,042	4,567
INITIAL CRUSH								
8) Peak Crush Load (Lbs.)	5,870	7,360	5,460	5,440	5,200	6,400	6,090	6,525
9) Deflection to Peak Crush Load (Inches)	.1705	.176	.16	.13	152	.1675	.153	.101
10) Spring Rate - Load Buildup (Lbs/Inch)	77,500	100,000	58,800	91,000	64,500	84,500	81,000	108,000
11) Average Crush Load (Lbs)	5,270	5,960	4,600	4,700	5,020	4,930	5 550	5,000
12) Variation of Crush Load (Average)(Lbs)	+260,-290	-60,-460	+250 -100	+230,-20	+400,-130	-100,-230	+540,-300	-100,-175
13) Load Dropoff (Points A to B)(Lbs.)	110	190	100	190	130	140	175	160
14) Spring Rate - Load Dropoff (Lbs/Inch)	119,000	119,000	125,000	128,000	122,500	120,900	125,300	132,300
15) Spring Back (Inches)	.0565	.066	.07	.0555	.06	.06	.051	.055
16) Stroke (Inches)	.2515	225	.20	.226	.3175	.333	.324	.154
SECOND CRUSH								
17) Peak Crush Load (Lbs)	5,370	5,600	4,740	4,910	5,100	4,860	5,750	5,300
18) Deflection to Peak Crush Load (Inches)	.185	.105	.07	.09	.06	.06	.10	20
19) Spring Rate - Load Buildup (Lbs/Inch)	124,000	168,000	120,000	150,000	83,400	83,400	158,000	150,000
20) Average Crush Load (Lbs)	5,270	5,960	4,600	4,700	5,020	4,930	5,980	5,300
21) Variation of Crush Load (Average)(Lbs)	+270,-220	+19[illegible]0	+400,-200	+180,-110	+240,-210	+180,-120	+400,-390	+275,-390
22) Spring Rate - Load Dropoff (Lbs/Inch)	67,000	74,000	50,000	57,200	50,000	42,800	58,700	54,700
23) Spring Back (Inches)	.29	.155	.235	.24	.195	.175	.143	.26
24) Stroke (Inches)	4.37	4.11	4.54	4.535	4.450	4.38	4.175	4.45
25) Total Stroke (Inches)	4.6215	4.335	4.74	4.761	4.7675	4.713	4.499	4.604
26) Usable Stroke (Inches)	4.902	4.878	4.755	5.0215	4.9425	4.803	4 584	4.559
27) Percent Crushed (%)	81.7	81.3	76.2	80.0	81	76.9	78.02	78.50
28) Percent Load Variation (Ref. Item 21)	+5.13,-4.36	+3.19,-4.7	+8.19,-4.34	+3 83,-2.34	+4.78,-4 18	+3.65,-2.44	+6.69,-6 52	-5.2,-7.36

NOTES: 1. Refer to Key shown on Figure 7-6 for interpolation of tabular data headings.

2. Those specimens marked with an asterisk (*), and for which the pertinent identification is listed, were considered to have exhibited satisfactory crush characteristics when compared with the finalized specification requirements and full length test articles were produced in accordance with the fabrication techniques employed in construction of these "control type" specimens.

Figure 7-10. Table of Static Crush Data for Six Inch Length Preproduction Control Specimens (Concluded)

7.3 PHASE IA TESTS ON FULL LENGTH TEST SPECIMENS

7.3.1 General

The recorded data and other information concerning the characteristics of interest which was obtained from testing 8 specimens each of 9 configurations (Figure 2-2) under the environmental conditions of room temperature in combination with a vacuum of 3 x 10^{-1} TORR is described herein. The test procedure utilized is outlined under Paragraph 6.2 and Figure 6-1.

All specimen types which crushed in the normal manner of progressive cell buckling, exhibited for both the static and dynamic load versus stroke curves, the typical rectangular shape characteristic of aluminum honeycomb materials in general. This shape is described by the sketch of typical load versus stroke curves as shown by the solid line in Figure 7-11. For some of the Crosscore configurations with the cells at angles of 15 & 30 degrees the fluctuation in average crush load amounted to a maximum of ±15% while the expanded honeycomb in the solid circular section with 0° cell orientation was very smooth with only a ±2% fluctuation (Figure 7-11). Loads to initiate crush action under the first impact (specimens were not pre-crushed) averaged approximately 20% higher than the average crush load, with several being roughly 45% higher and only a few exhibiting peaks as much as 100% higher. This peak load was usually reached within a time period of .001 seconds or less and at capsule strokes of less than .1 inch.

Some specimens which bound up on the guide tubes after secondary folding occurred, yielded an expected increase in the average crush load as displayed by the upper dashed line in Figure 7-11. Others which failed catastrophically due to shifting, shear failures, etc. provided a sharp drop off in the load as shown by the lower dotted line.

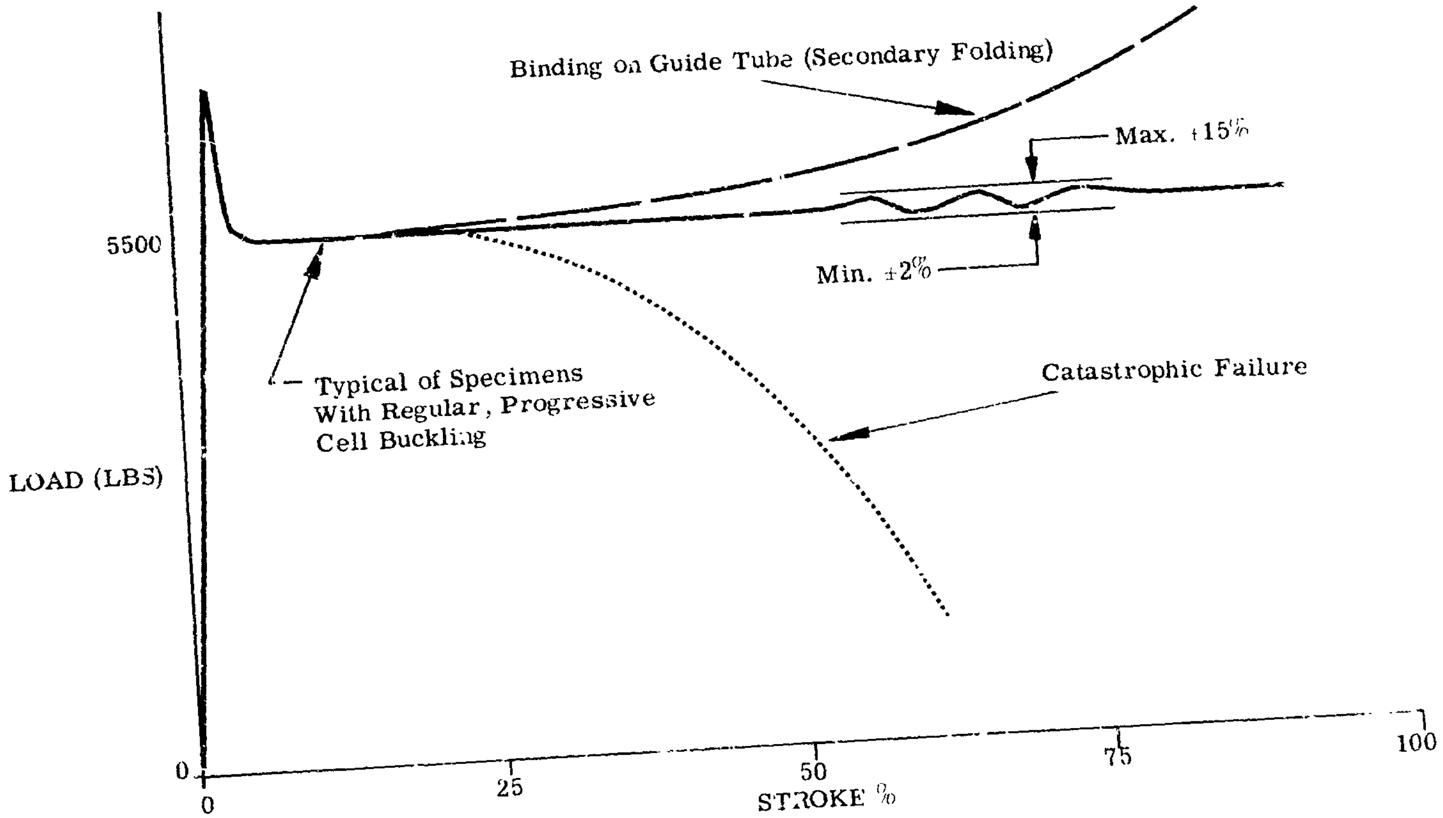


Figure 7-11. Sketch of Typical Load Versus Stroke Curves

7.3.2 Phase IA Test Specimen Configurations

Photos of the crushed specimens as well as a full length uncrushed specimen and a cross sectional example are shown for the nine configurations in Figures 7-12 through 7-20. The specimen numbering system (detailed in paragraph 6.7) and Figure 6-2 has been used in identifying the specimens in regard to the impact velocity, test weight and temperature. Some general comments about the data obtained and the condition of the various specimen configurations as illustrated in these photos is included in the Analysis of Test Results in the next paragraph.

7.3.3 Analysis of Phase IA Test Results

⊙ 15 Some good data was obtained from most of the specimens although several buckled and folded and one sheared.

⊙ 30 Most of the specimens yielded some good data although shearing and buckling led to erratic failure patterns on several.

⊙ 0 None of the catastrophic failure patterns exhibited by the small annular configurations with the 15° or 30° cell axes were in evidence although some gave indication of buckling instability.

◎ 15 Some usable data was derived but secondary folding led to binding on the guide tube and it was necessary to cut some for removal.

◎ 30 Folding was not quite so predominant as the large annular with 15° cells, but crush action was not good enough to warrant further testing of this configuration in the succeeding phase of the test program.

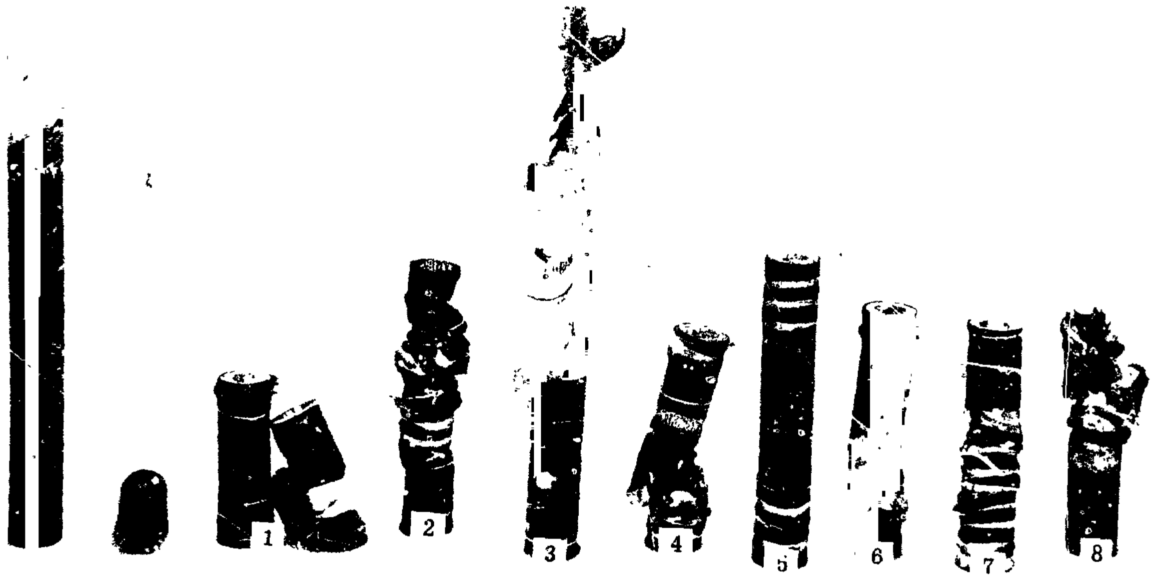


Figure 7-12. Pictorial Summary of Specimens (⊙ 15) Tested in Phase IA For Number Identification With Test Conditions, See Figure 6-2

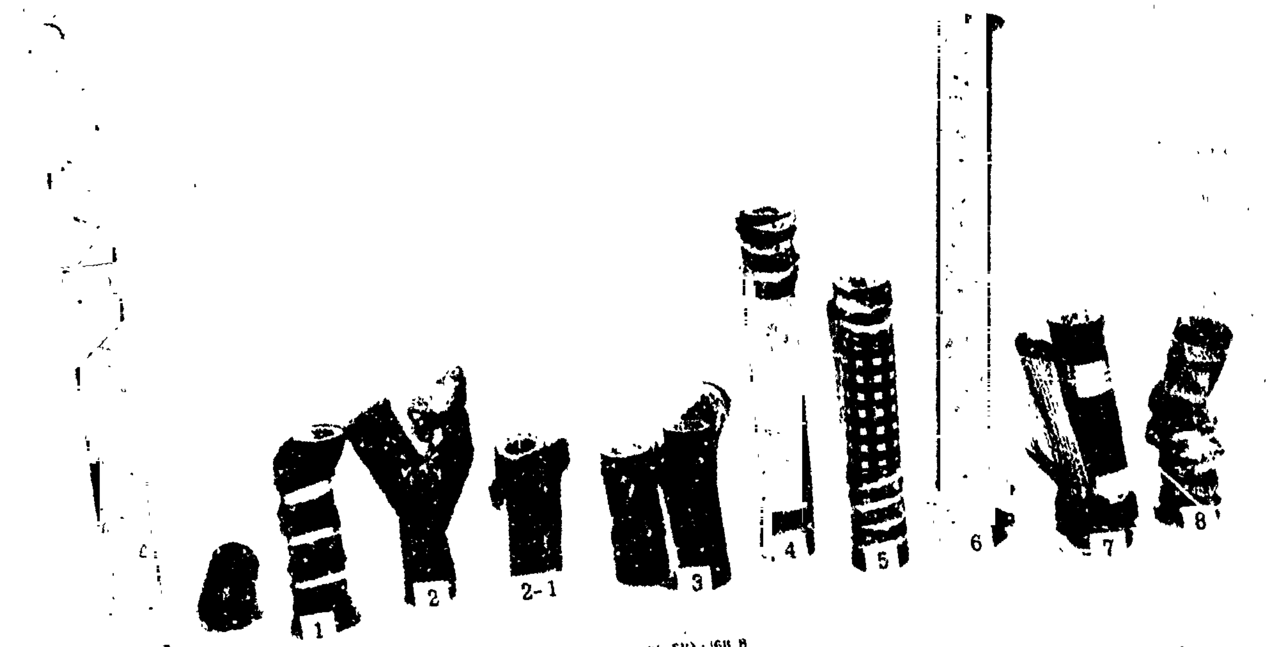
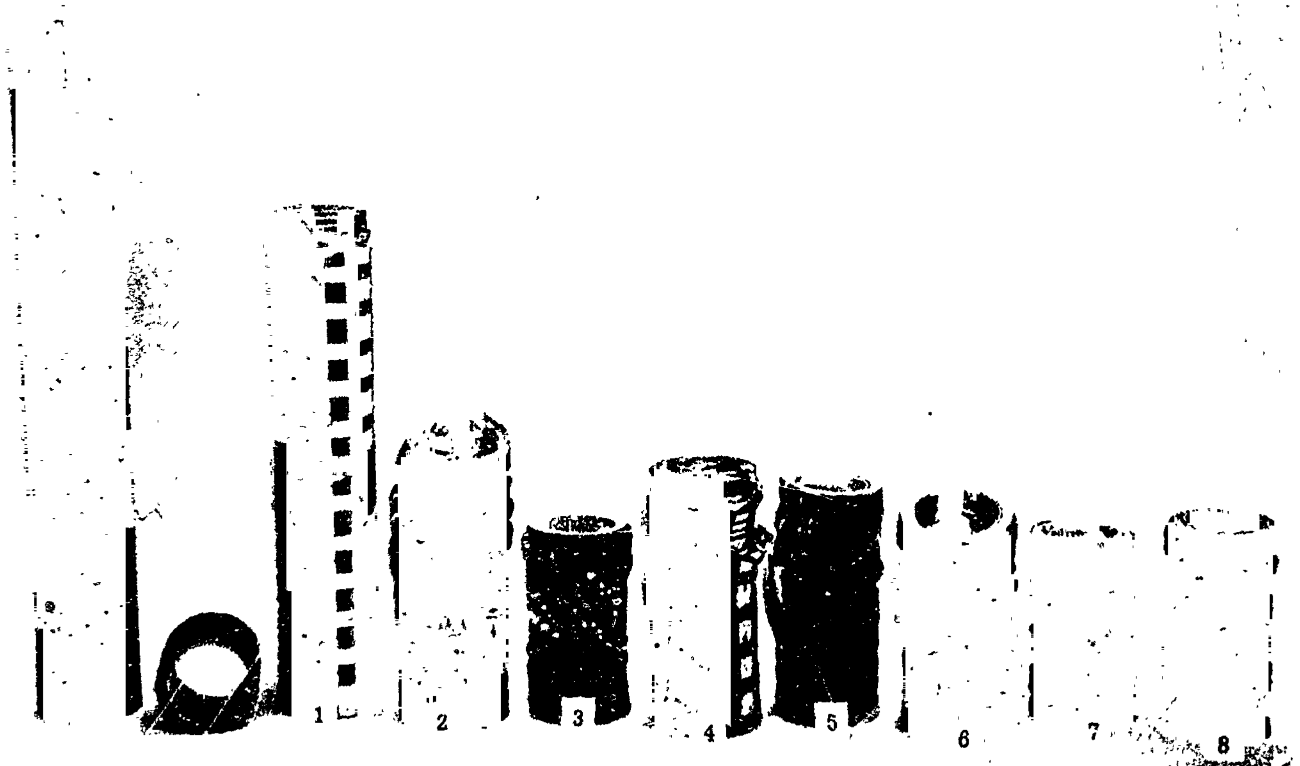


Figure 7-13. Pictorial Summary of Specimens (⊡) Tested in Phase IA For Number Identification With Test Conditions, See Figure 6-2

Figure 7-14. Pictorial Summary of Specimens (⊙) Tested in Phase IA For Number Identification With Test Conditions, See Figure 6-2

Figure 7-15. Pictorial Summary of Specimens (○ 1) Tested in Phase IA For Number Identification With Test Conditions, See Figure 6-2.



TYPE SPX-167-B

Figure 7-16. Pictorial Summary of Specimens (◎ 30) Tested in Phase IA For Number Identification With Test Conditions, See Figure 6-2

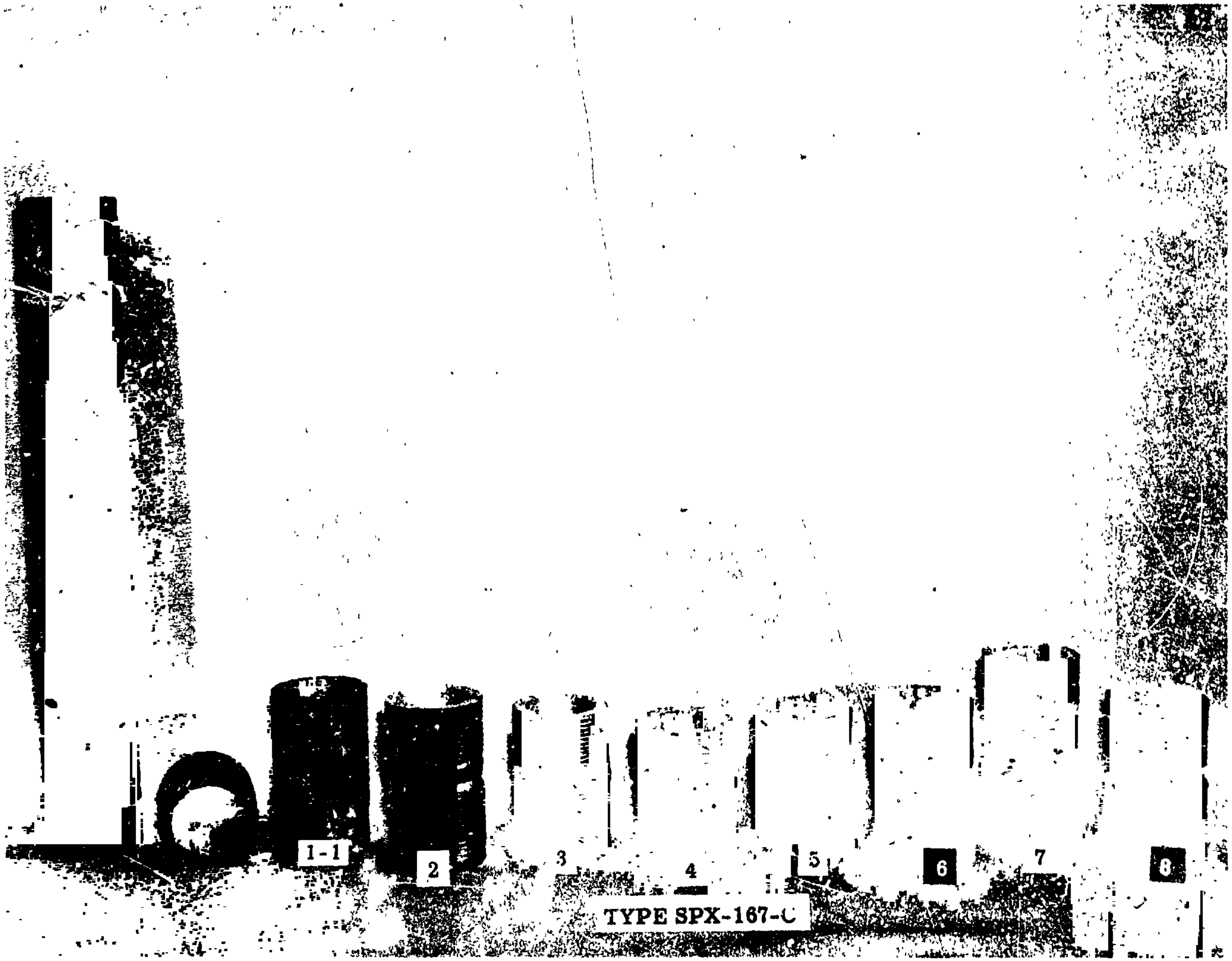


Figure 7-17. Pictorial Summary of Specimens ( ) Tested in Phase IA For Number Identification With Test Conditions, See Figure 5-2

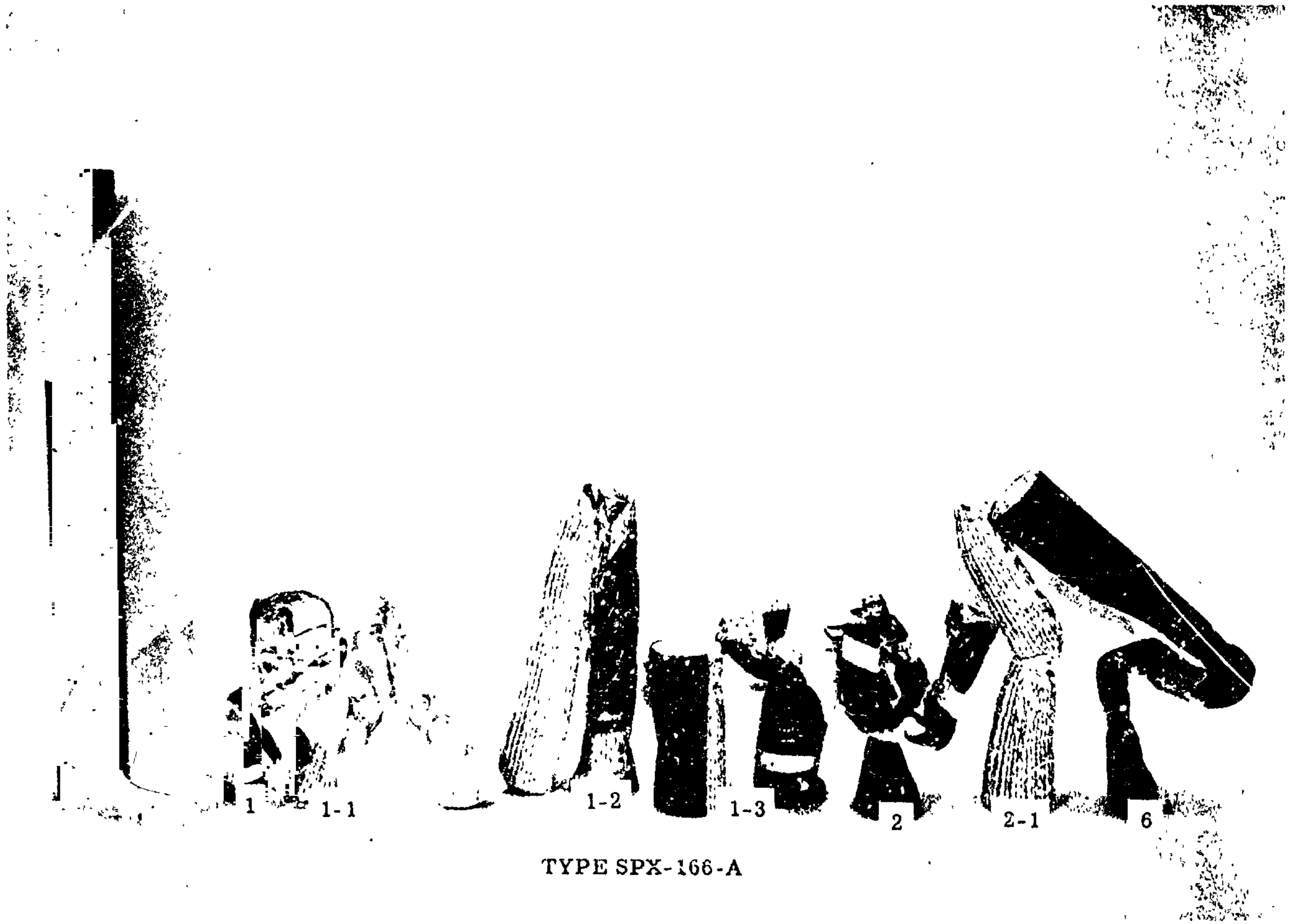


Figure 7-18. Pictorial Summary of Specimens (● [illegible]) Tested in Phase IA For Number Identification With Test Conditions, See Figure 6-2

TYPE SPX-166-B

Figure 7-19. Pictorial Summary of Specimens (● 30) Tested in Phase IA For Number Identification With Test Conditions, See Figure 6-2

TYPE SPX-166-C

Figure 7-20. Pictorial Summary of Specimens (●) Tested in Phase IA For Number Identification With Test Conditions, See Figure 6-2

◎ [illegible] Good uniform crush action on all except specimen No. 2 at 5 FPS impact velocity which showed shearing in the center during the latter drops of that series. All specimens of this configuration show a slight buckle and/or an uncrushed portion at the center due to crushing action usually starting at top, progressing to center and then continuing from bottom to center or alternating between the two crushing areas.

● 15 This configuration exhibits a mode of failure characterized by shearing, folding, and subsequent buckling. A minimum of usable data was obtained from these specimens, usually being obtained from the first impact on each specimen. The sequence of events occurring during this failure pattern is as listed here:

1. A shear plane, of approximately 45° with respect to the specimen vertical axis, develops across the full diameter and results in a section shift. (This may occur at top, center, or bottom of specimen).

2. The section where shear plane is projected to the fixture wall appears to bear hard against guide ring in that general area and results in a flattening of the cylindrical section into a flat plate section.

3. The flat plate section then begins to fold and causes further progressive flattening and folding of the remaining cylinder length with very little load resistance evident.

Some of the specimens did not develop this catastrophic failure pattern until after the specimen had partially crushed in a fairly uniform manner. Another photo of this failure pattern is shown in Section X.

● 30 Although not quite so severe as the solid circular 15° configuration this characteristic was still evident. These specimens may be on the borderline of a cell size, angle, density, relationhip which offers the possibility of a non-uniform type buckling leading to erratic failures. This is borne out by JPL report No. 32-639 where it was found that there is an upper limit on foil thickness/cell size ratio (t/s = .040) above which a gross shear failure occurred under static loading. The t/s ratio of these specimens is less but loading rate and material may also affect this failure mode.

Other tests conducted by this contractor with capsules of approximately the same density and having a higher t/s ratio but with the cells aligned at 45° resulted in very satisfactory crushing action.

● 0 This configuration gave the best indications of regular progressive cell buckling and uniform crush action. It also provides the highest specific energy (ft. lbs./lb.). The buckled out section in specimen No. 4-1 is the result of bottoming out hard and developing a high peak load on the fully crushed specimen in a test where the energy was not fully absorbed by the end of the planned stroke.

The test data from these specimens was obtained in two forms:
The static test records appear in the form of X-Y plots of load versus stroke. These records can be read in a manner similar to that described in the Key for Static Crush Data (Instron Records) Figure 7-6. Copies of these records for the first and second crush application are found in Figures 7-21 through 7-30 and the other static crush records for subsequent load applications on Phase IA test specimens is in Addendum No. 1.

Information from these static crush records has been incorporated into the various data plots subsequently shown throughout Phase I test results.

The dynamic test records appear in the form of oscillograms which were recorded with use of the oscillograph and associated power supplies as described under Test Equipment, Section III.Typical test records for the various test conditions have been reproduced in Figures 7-31 through 7-35 and the data from them tabulated in*Figures 7-36 through 7-42.

These particular records have been selected as illustrative of the type of reaction being obtained from the various configurations. Examples are shown of tests on the "internal annular" configuration with the three cell axis variations as well as both the "external annular" and "circular solid" configurations with the same cell axis variations.

The records indicate by the specimen numbering system, the various conditions under which they were tested.

To make the selection of configurations which would undergo the further evaluations of Phase IB and subsequently Phase II the data acquired to this point in the program was plotted in several ways. These included:

1. Specific Energy (both static and dynamic) in terms of ft. lbs./lb.
2. Load Onset Rate versus Impact Velocity
3. Load Onset Rate versus Test Weight
4. Rebound versus percentage of stroke uncrushed
5. Onset rate versus percentage of stroke uncrushed

*NOTE: Static test information is also included in this tabulated data.

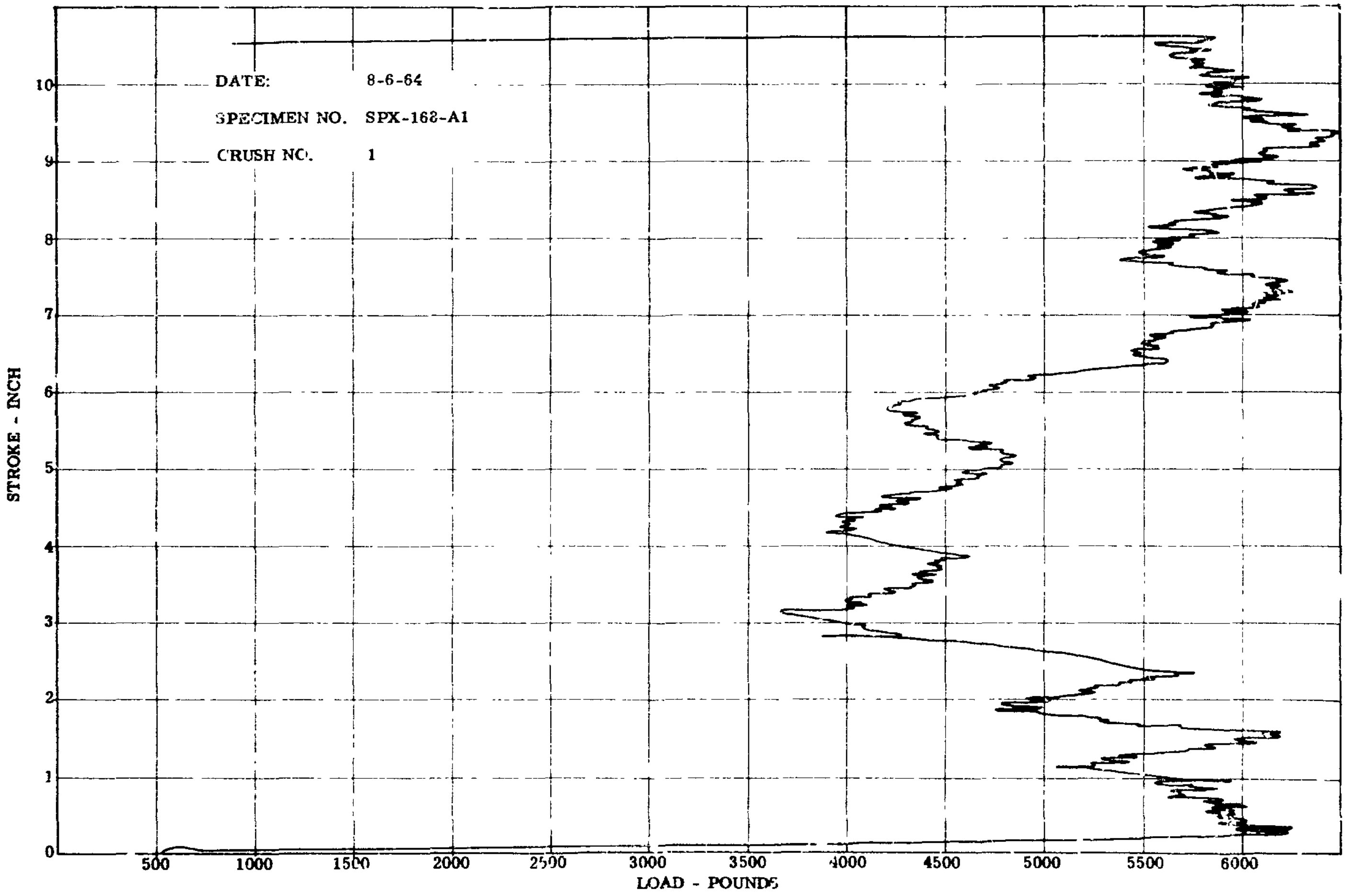


Figure 7-21. Static Crush Record for Phase IA Test Specimen (⊙ 15) for Number Identification With Test Conditions, See Figure 6-2

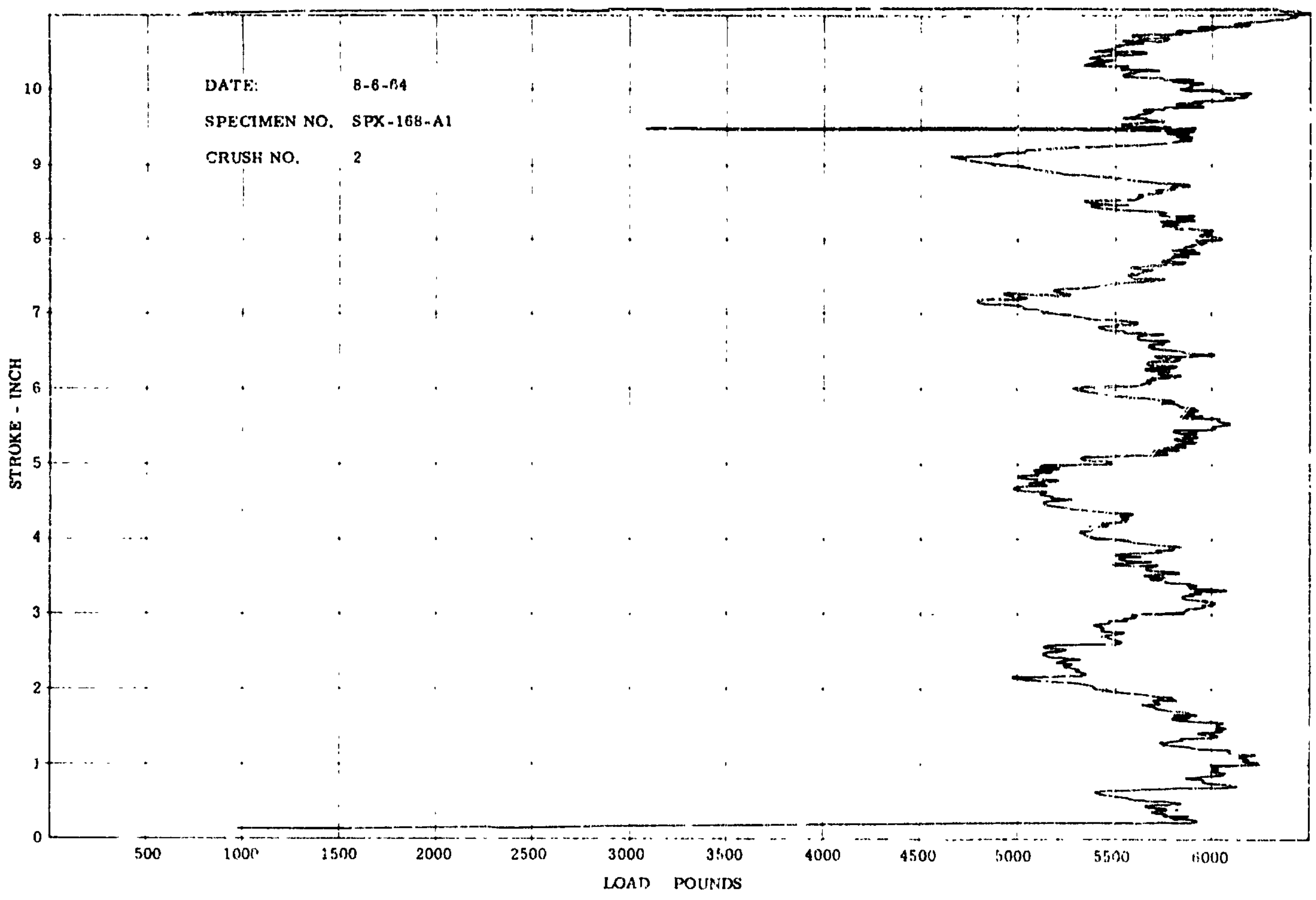


Figure 7-22. Static Crush Record for Phase IA Test Specimen ([◉ 1])
For Number Identification With Test Conditions, See Figure 6-2

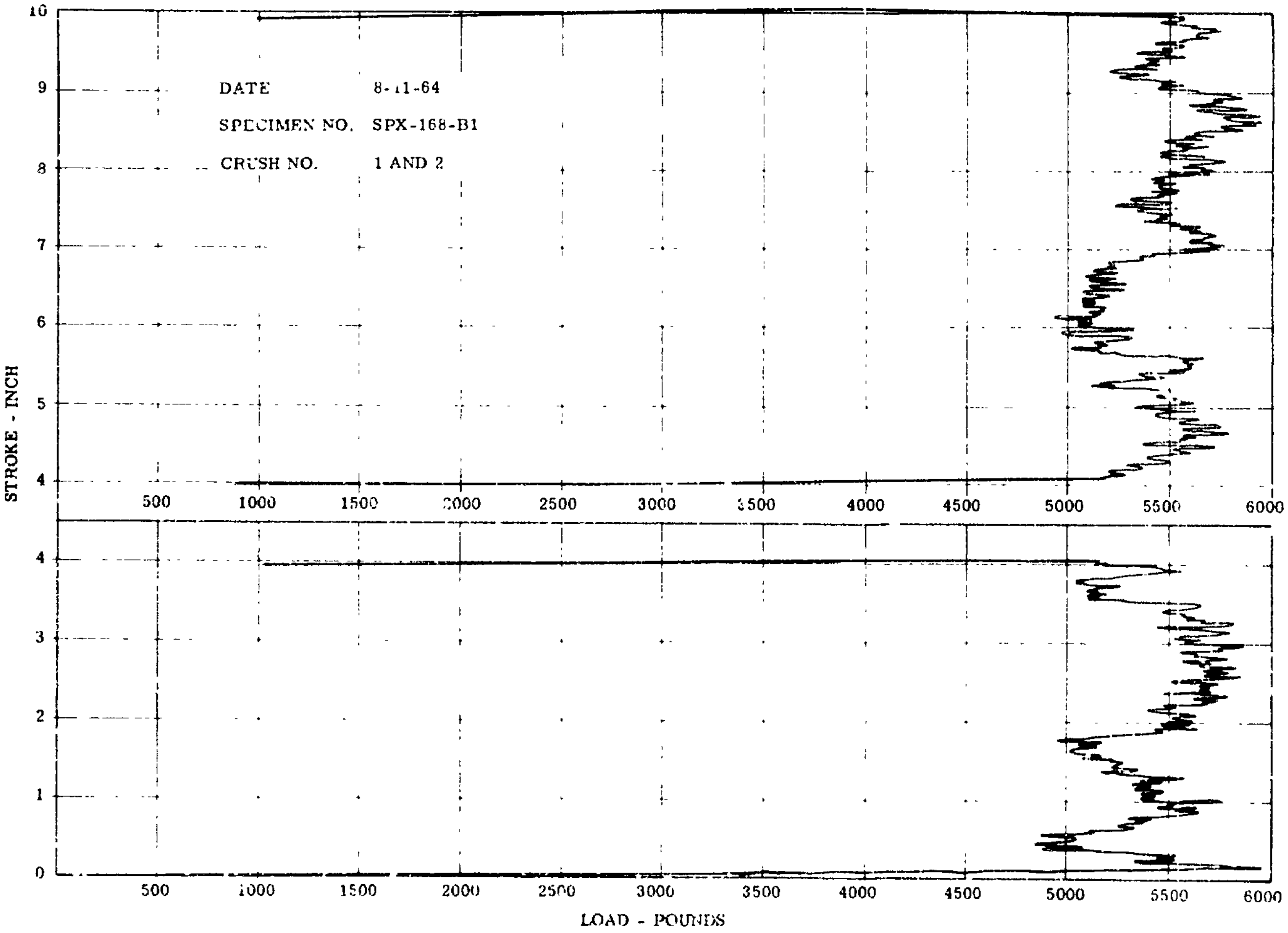
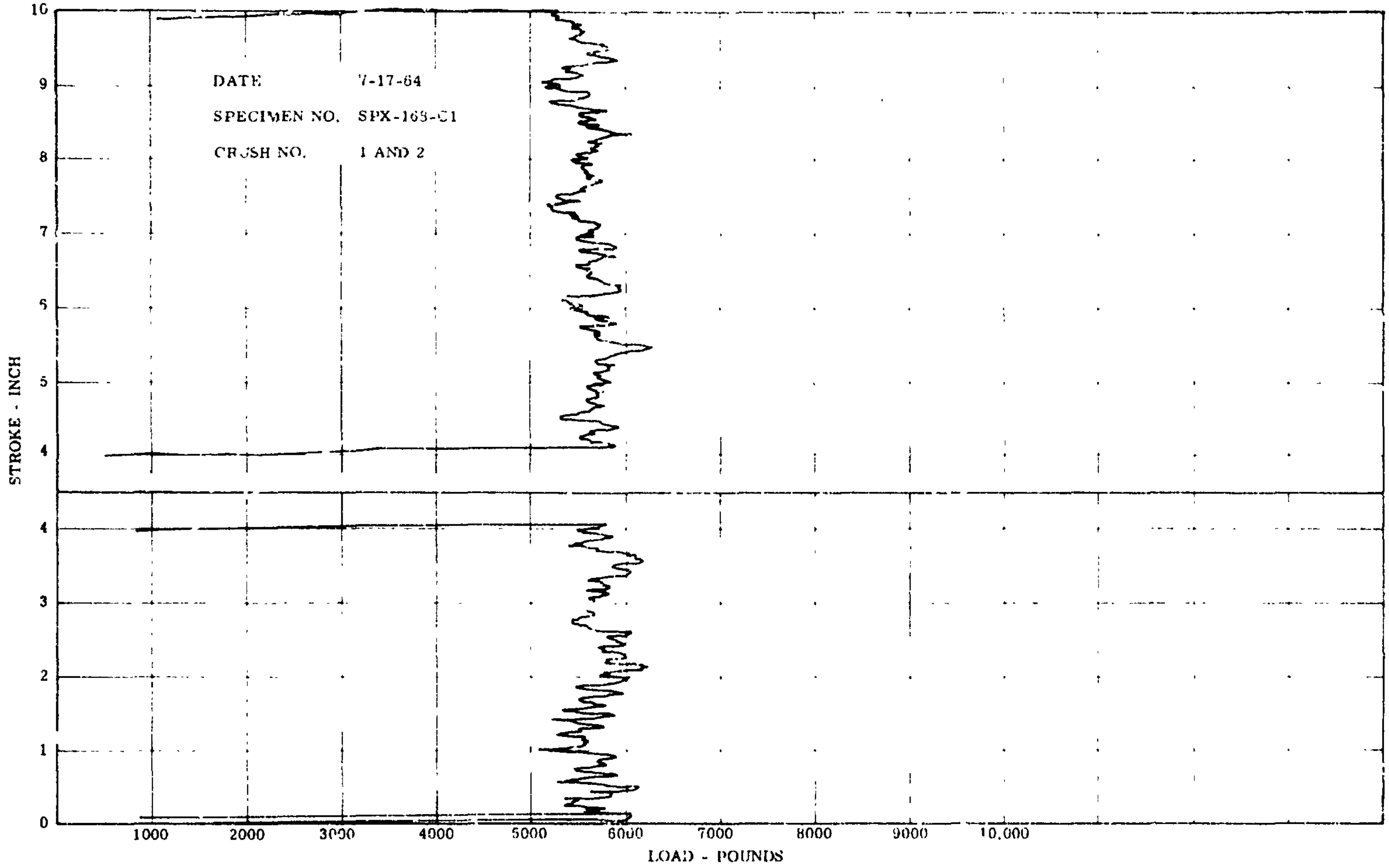


Figure 7-23. Static Crush Record for Phase IA Test Specimen (⊙ 30)
For Number Identification With Test Conditions, See Figure 8-2



DATE 7-17-64
SPECIMEN NO. SPX-163-C1
CRUSH NO. 1 AND 2

Figure 7-24. Static Crush Record for Phase IA Test Specimen (●)
For Number Identification With Test Conditions, See Figure 6-2

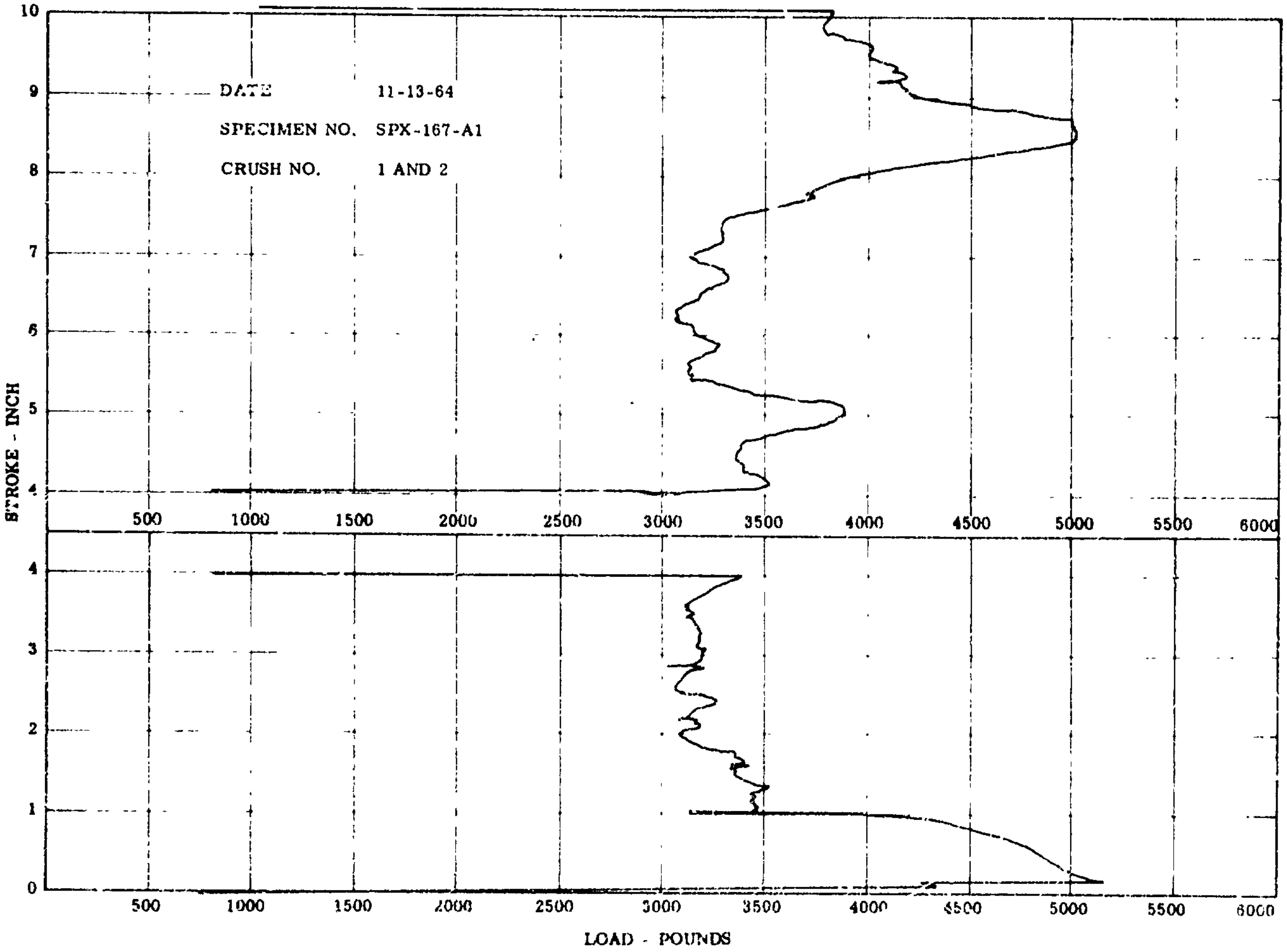


Figure 7-25. Static Crush Record for Phase IA Test Specimen (○ [illegible])
For Number Identification With Test Conditions, See Figure 6-2

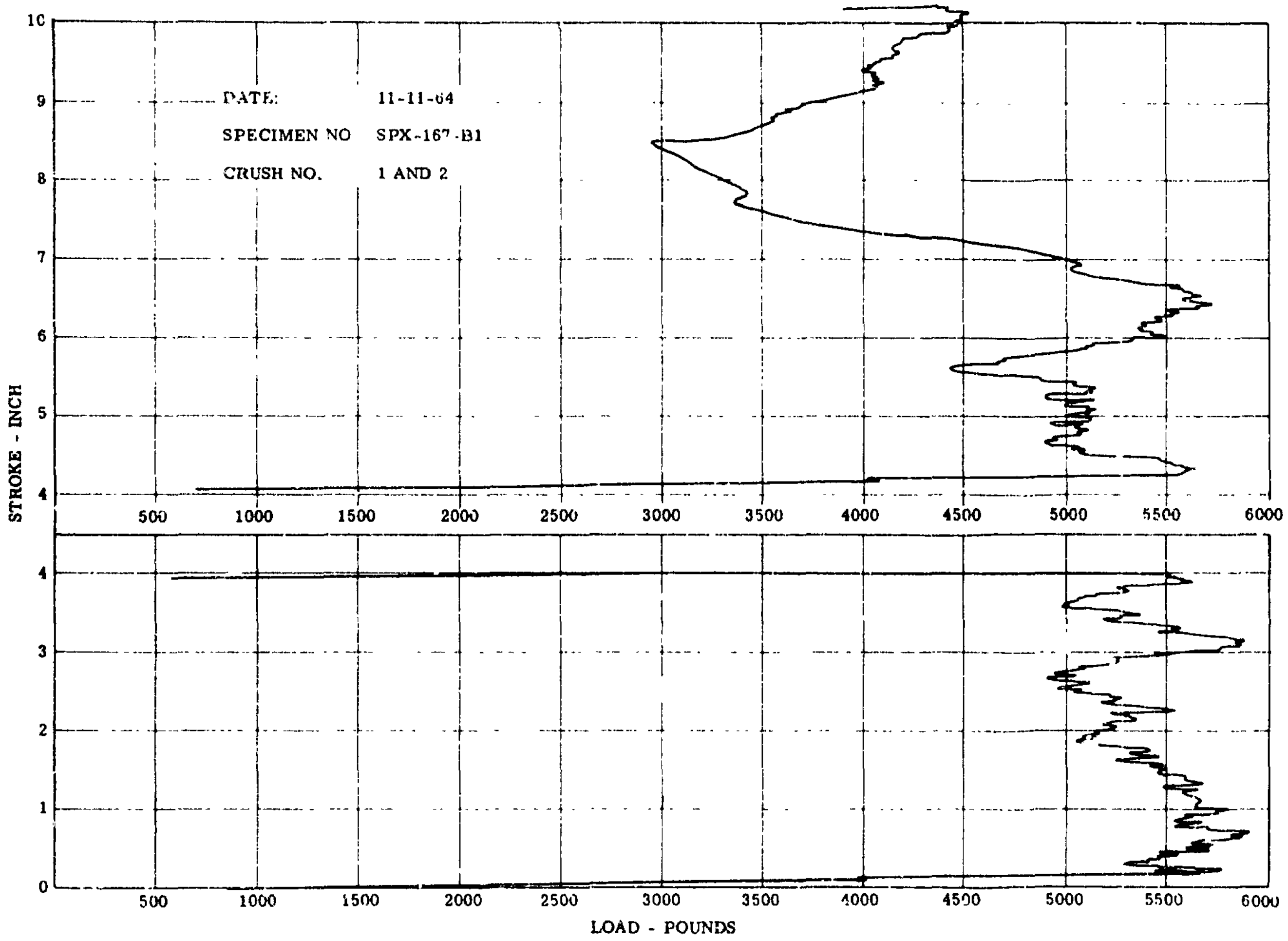


Figure 7-26. Static Crush Record for Phase IA Test Specimen ([illegible]) For Number Identification With Test Conditions, See Figure 6-2

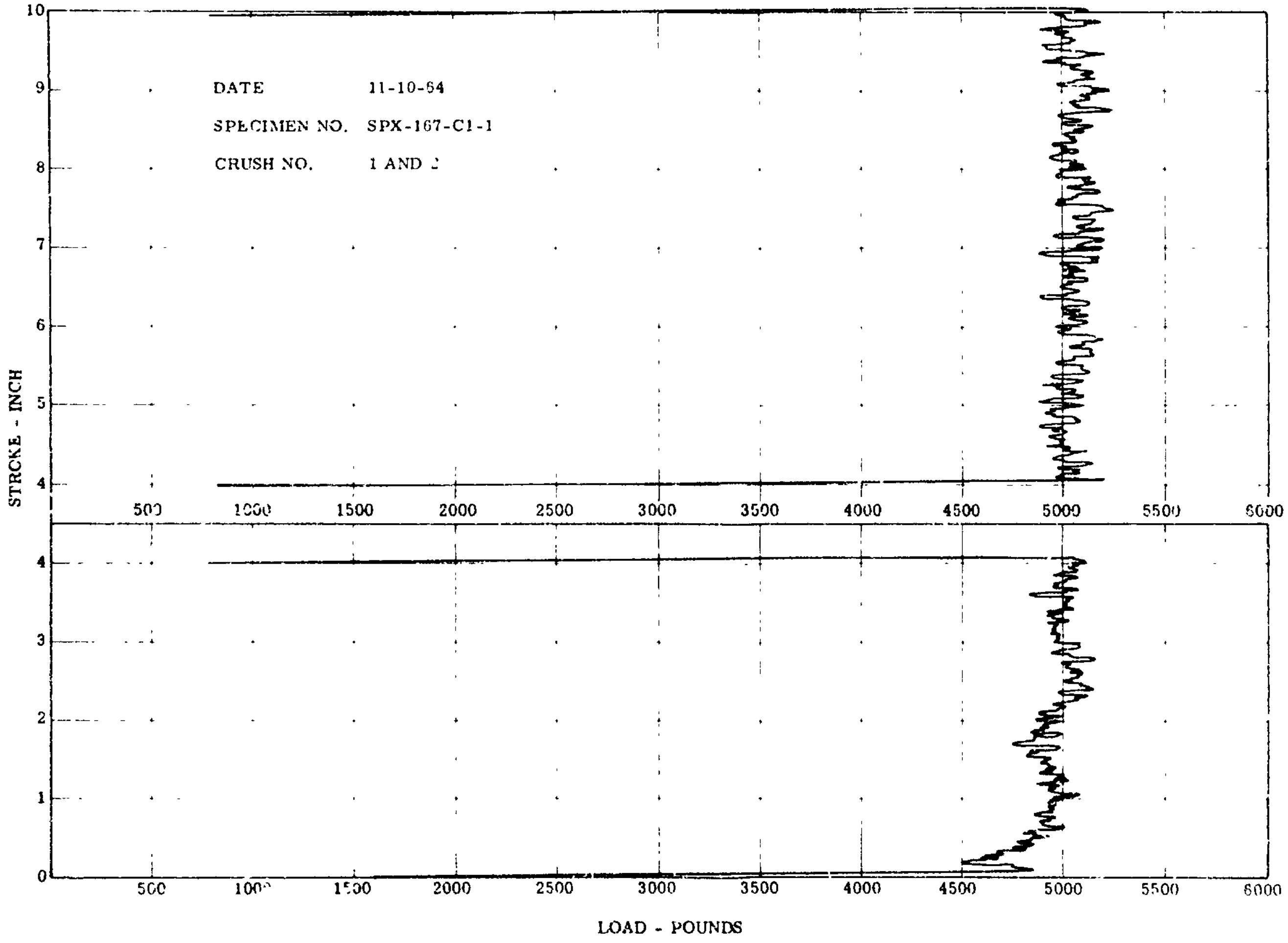


Figure 7-27. Static Crush Record for Phase IA Test Specimen (©)
For Number Identification With Test Conditions, See Figure 6-2

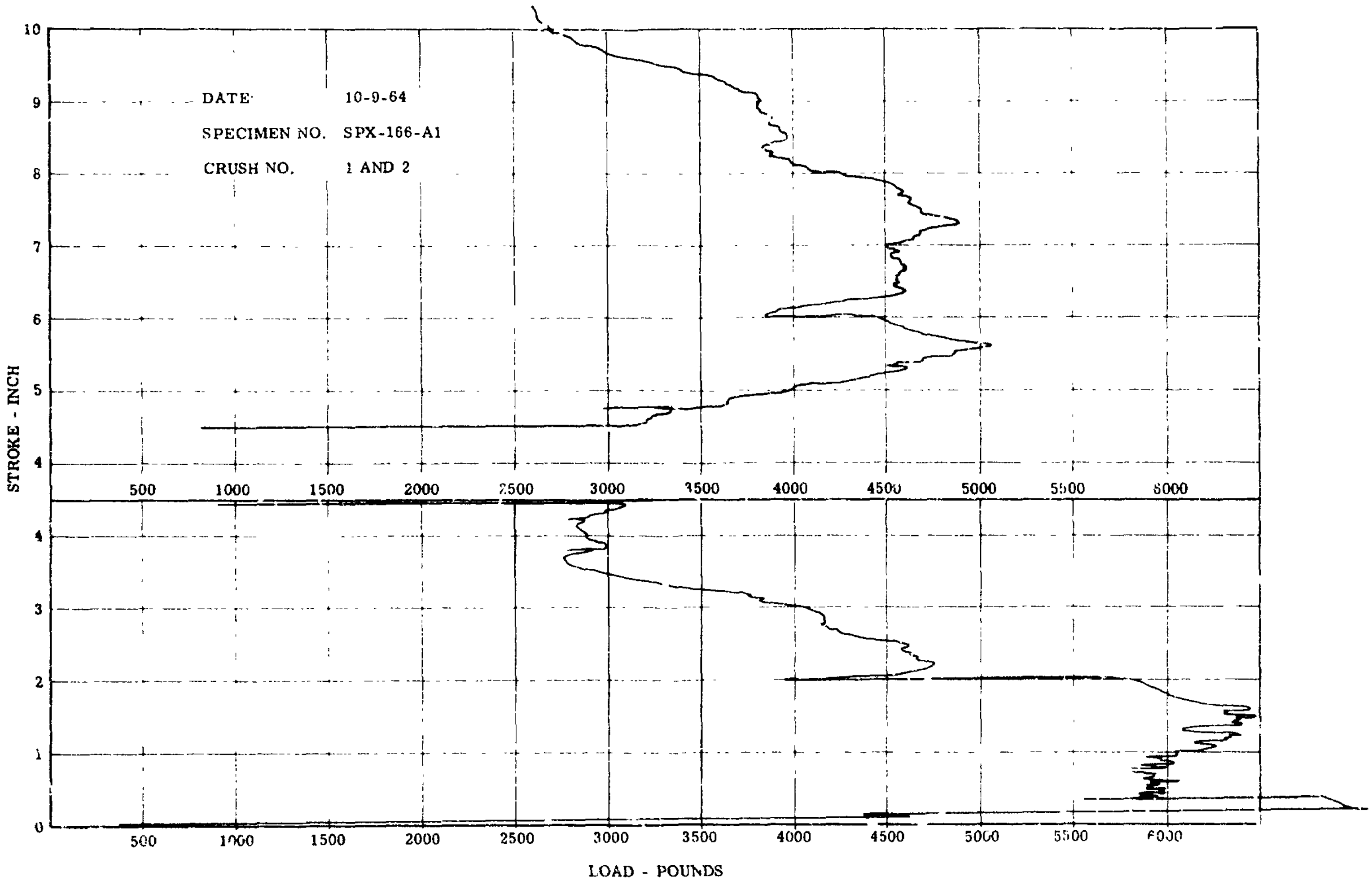


Figure 7-28. Static Crush Record for Phase IA Test Specimen (●)
For Number Identification With Test Conditions, See Figure 6-2

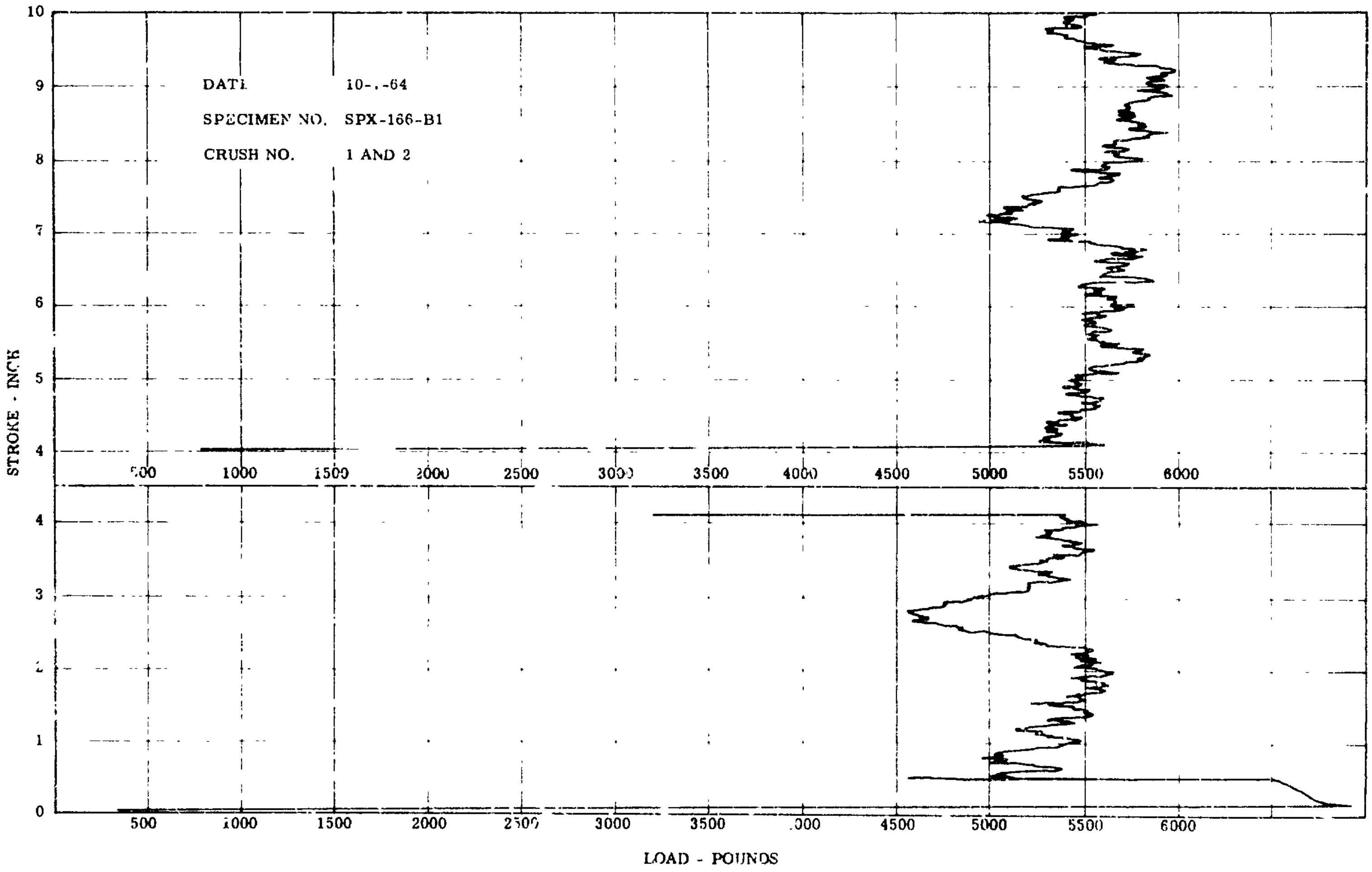


Figure 7-29. Static Crush Record for Phase IA Test Specimen (● 30)
For Number Identification With Test Conditions, See Figure 6-2

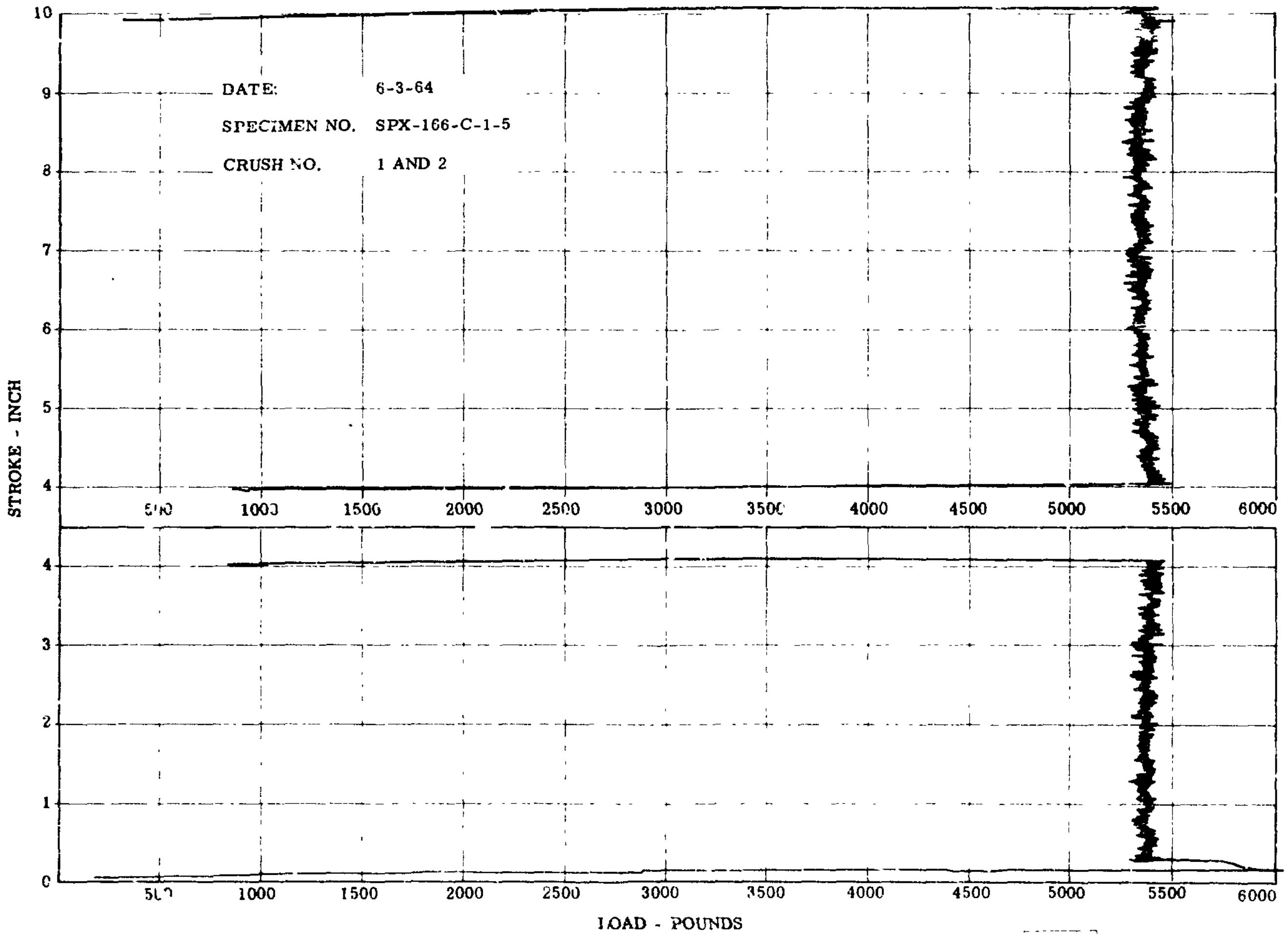
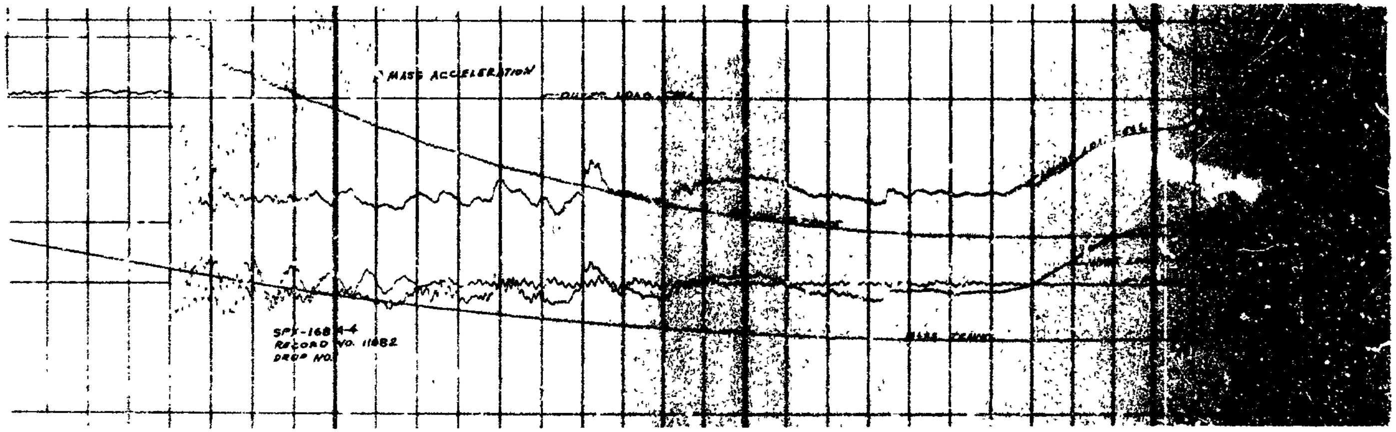


Figure 7-30. Static Crush Record for Phase IA Test Specimen (●)
For Number Identification With Test Conditions. See Figure 6-2

SPX-168A-4



SPX-168B-5

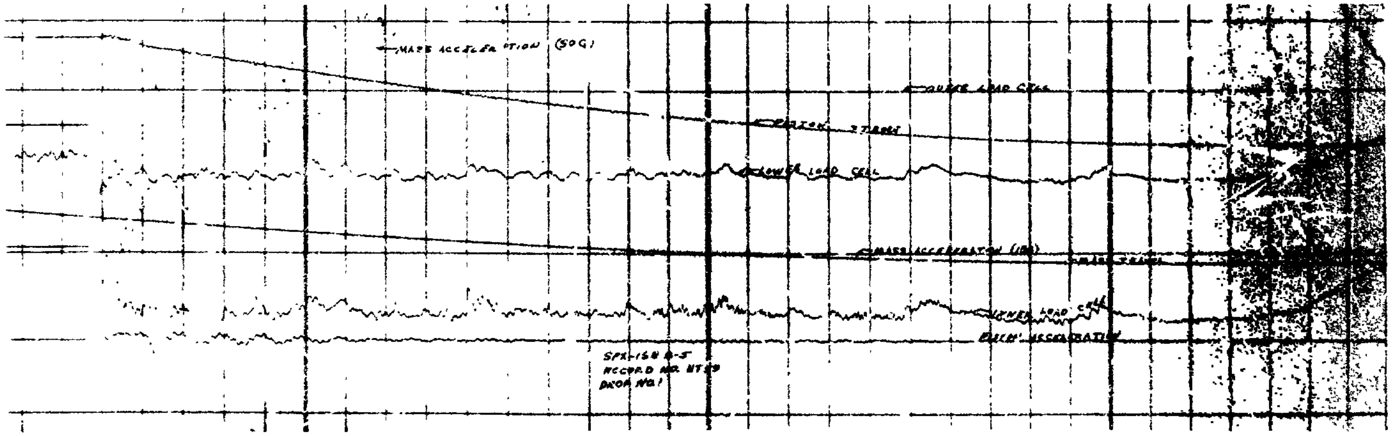
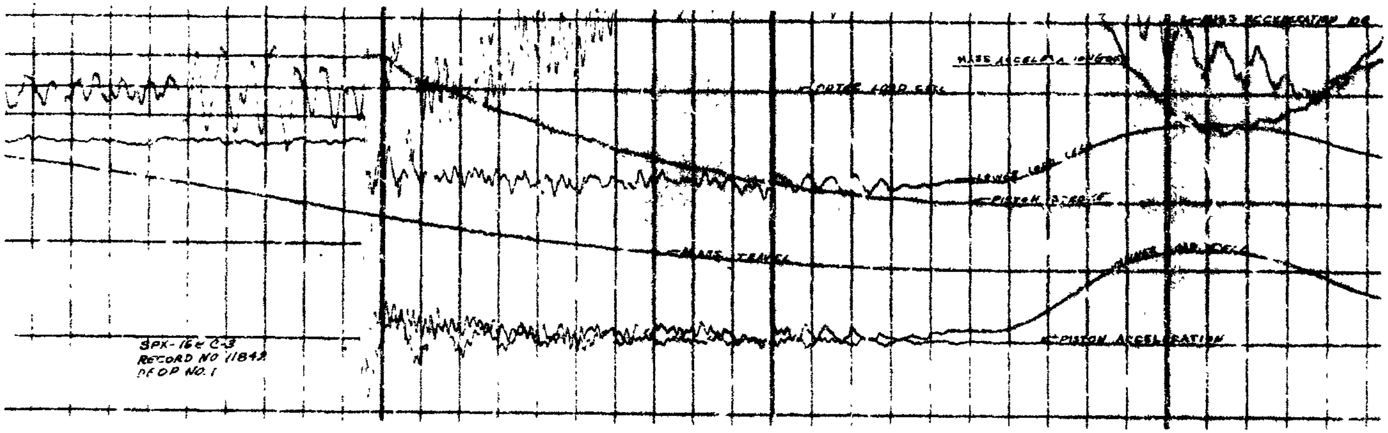


Figure 7-31. Oscillograph Records of Dynamic Tests on Phase IA Specimens for Number Identification With Test Conditions, See Figure 6-2; Upper: ◉ 15 Room Temp. Lower: ◉ 30 Room Temp.

SPX-168C-3



SPX-167A-2

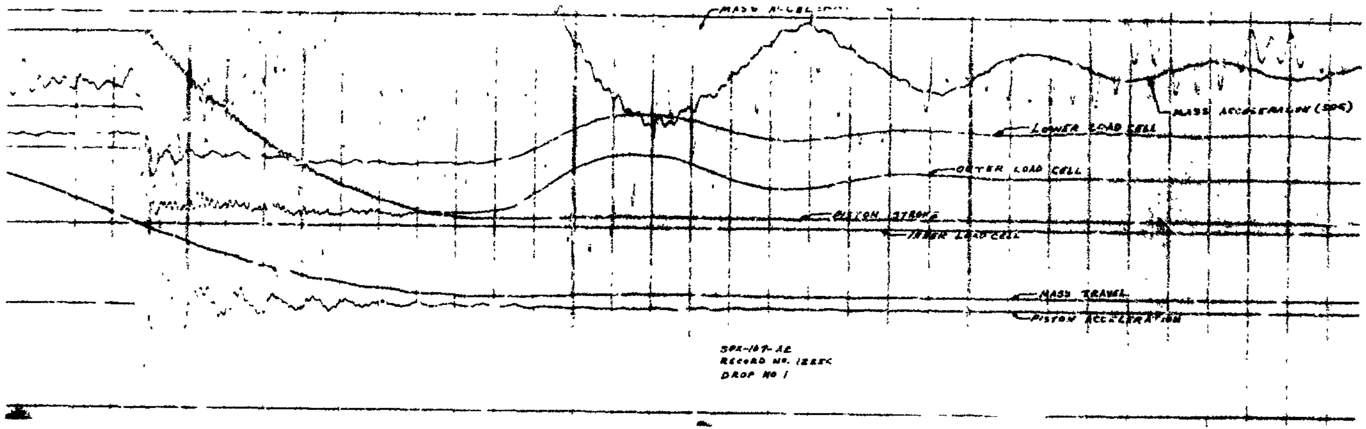
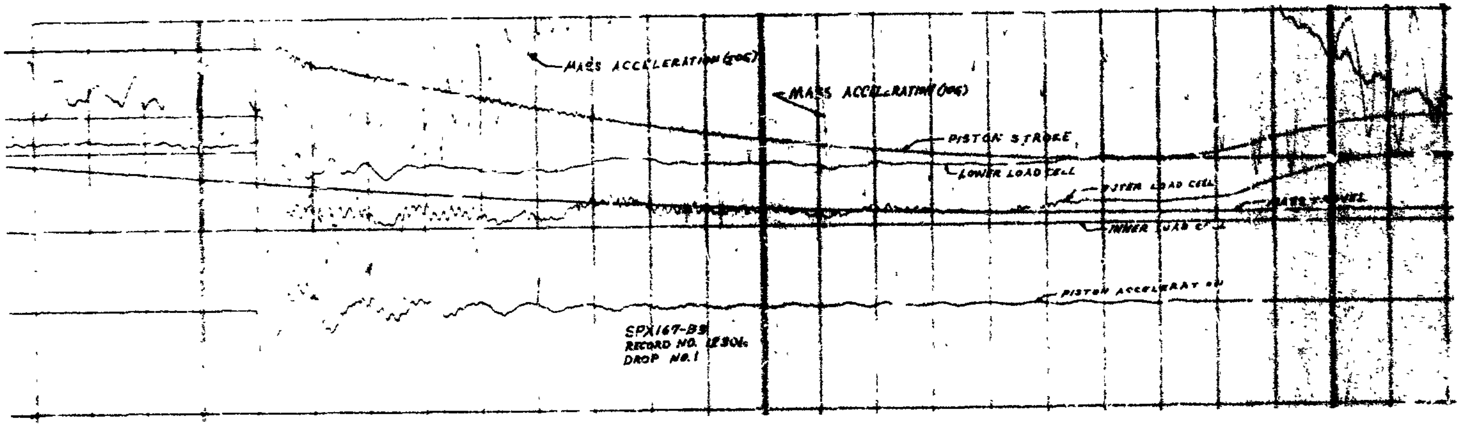


Figure 7-32. Oscillograph Records of Dynamic Tests on Phase IA Specimens for Number Identification With Test Conditions, See Figure 6-2; Upper: ◉ 6 Room Temp. Lower: ○ 1[illegible] Room Temp.

SPX-167B-3



SPX-167C-4

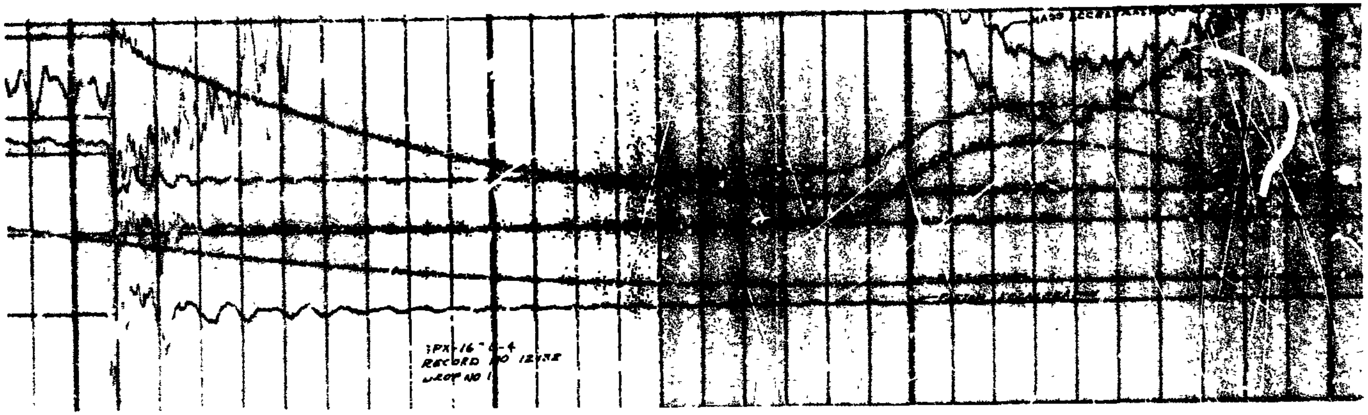


Figure 7-33. Oscillograph Records of Dynamic Tests on Phase IA Specimens for Number Identification With Test Conditions, See Figure 6-2; Upper: Room Temp. Lower: Room Temp.

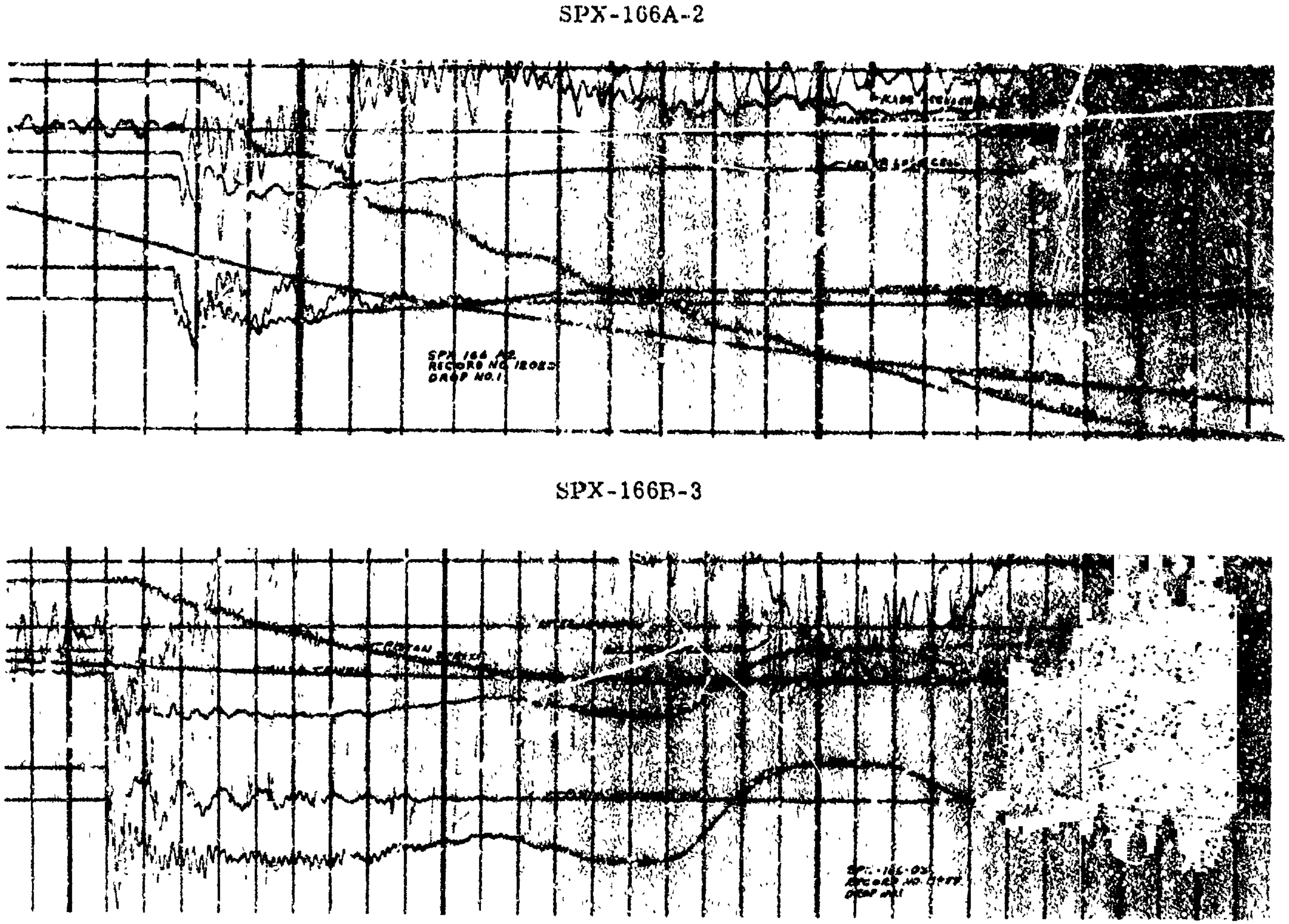


Figure 7-34. Oscillograph Records of Dynamic Tests on Phase IA Specimens for Number Identification With Test Conditions, See Figure 6-2; Upper: ● 15 Room Temp. Lower: ● Room Temp.

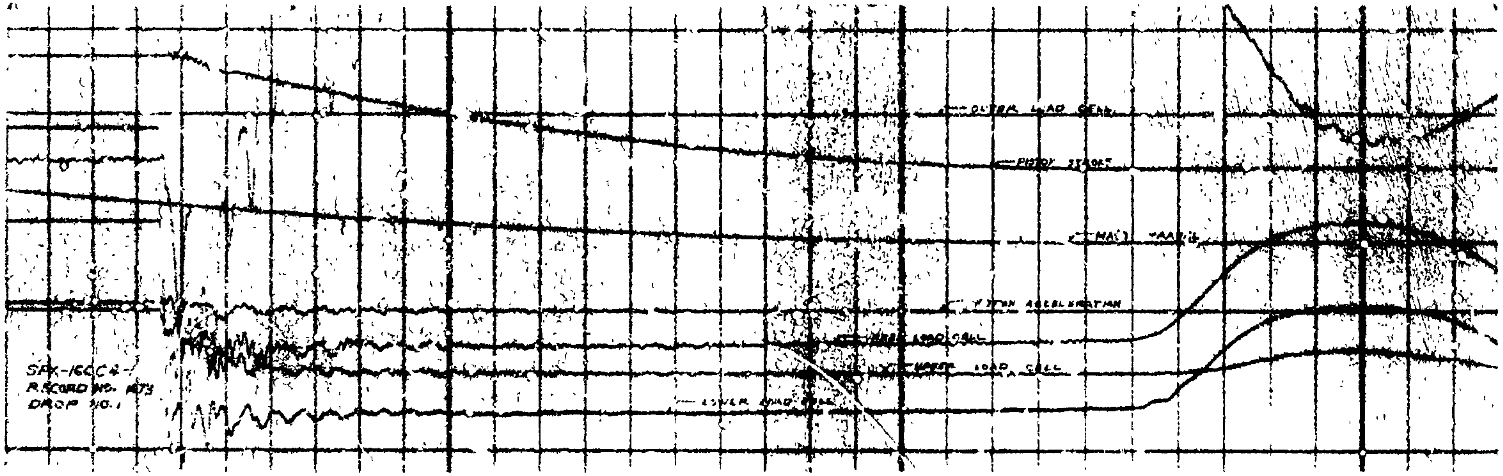


Figure 7-35. Oscillograph Records of Dynamic Tests on Phase IA Specimens for Number Identification With Test Conditions, See Figure 6-2; ● Room Temp.

(No's SPX168A1 Thru SPX168B4)

Specimen Number		Average Load of End Sample	Diameter		Cross Sectional Area	Length	Weight	Test No.	Impact Weight	Impact Velocity		Average Crush Load	Initial Peak Loads			Load Onset Rate		Stroke	Rebound	Vacuum 3x10⁻¹ Torr Req'd (Equal) to 100 Microns or Less)	Temperature		Time
Bendix	Nasa(l)	(Lbs.)	O.D. (In.)	I.D. (In.)	(In²)	(In.)	(Lbs.)		(Lbs.)	Target (FPS)	Actual (FPS)	(Lbs)	Max (Lbs.)	Min (Lbs.)	Trans (Lbs.)	(Lbs./Sec x 10⁶)	(G's/Sec x 10³)	(In.)	(In.)		Target (°F)	Actual (°F)	(Months)
SPX168A1	1A-10		3.00	2.00	15.69	52.25	1.94	1		Static								2.00		100	RM	RM **	
*SPX168A1	1A-10		3.00	2.00	15.69	52.25	1.94	1		Static								10.6			RM	RM	
								2		Static								11.2					
SPX168A2	1A-4	5,400	3.00	2.00	15.69	52.25	1.81	1	1,920	5	5.41		6,690	4,020	6,130	3.40	1.77	2.50	08	125	RM	RM	
								2					6,460	4,920	6,130	2.78	1.45	2.63	005	125			
								3			4.78		4,695	3,340	4,220	2.31	1.20	2.65	56	125			
								4										16.75		125			
*SPX168A2	1A-4	5,400	3.00	2.00	15.69	52.25	1.81	1	1,920	5	4.90		8,360	3,850	6,350	3.72	1.94	2.25	04	125	RM	RM	
								2										2.38		125			
								3										2.25		125			
								4										2.25		125			
								5										3.00		125			
SPX168A3	1A-3	5,500	3.00	2.00	15.69	52.25	1.78	1	1,920	10	10.98		7,890	1,850	7,000	4.13	2.15	30.50	0	[illegible]	RM	RM	
SPX168A4	1A-8	5,750	3.00	2.00	15.69	52.25	1.94	1	1,920	14	14.40		7,710	4,870	6,840	4.57	2.58	16.63		125	RM	RM	
								2										22.75		125			
SPX168A5	1A-5	5,250	3.00	2.00	15.69	52.5	1.75	1	1,920	20	20.93		12,140	4,390	7,010	5.84	3.03	23.75	0	100	RM	RM	
SPX168A6	1A-9	5,850	3.15	2.00	18.09	52.13	1.88	1	700	10	10.27				7,777	6.31	8.96	2.50		90	RM	RM	
								2										2.50		90			
								3										2.50		90			
								4										2.75		90			
								5										2.75		90			
								6										2.75		90			
								7										2.63		90			
								8										2.50		90			
								9										2.38		90			
								10										2.38		90			
								11										2.38		90			
								12										2.38		90			
								13										2.38		90			
								14										2.63		90			
								15										1.75		90			
SPX168A7	1A-2	5,590	3.00	2.00	15.69	52.25	1.81	1	2,850	10	10.4		9,290	4,380	6,580	4.85	1.70	19.83	0	125	RM	RM	
								2										18.19		125			
SPX168A8	1A-6	5,350	3.30	2.00	15.79	52.44	1.81	1	3,750	10	10.58		1,080	4,020	5,700	4.84	1.24	40.50	.10	150	RM	RM	
SPX168B1	1B-1		3.00	2.00	15.69	52.50	1.75	1		Static								4		150	RM	RM	
								2		Static								6		150			
								3		Static								10		150			
								4		Static								10		150			
								5		Static								10		150			
								6		Static								2		150			
SPX168B2	1B-2	5,250	3.00	2.00	15.69	52.50	1.69	1	1,920	5	4.98		6,750	4,610	6,020	2.86	1.49	2.38	14	150	RM	RM	
								2								2.75	1.43	2.50	25	150			
								3										17.38		150			
*SPX168B2	1B-2	5,250	3.00	2.00	15.69	52.50	1.69	1	1,920	5	4.88		6,700	2,990	4,490	1.54	80	9.75	03	150	RM	RM	
SPX168B3	1B-3	5,300	3.00	2.00	15.69	52.50	1.69	1	1,920	10	10.48		7,560	3,495	5,660	2.41	1.26	18.00	11	150	RM	RM	
*SPX168B3	1B-3	5,300	3.00	2.00	15.69	52.50	1.69	1	1,920	10	10.45		7,750	4,300	6,210	3.79	1.97	9.25	0	150	RM	RM	
								2										6.50		150			
SPX168B4	1B-4	5,850	3.00	2.00	15.69	52.50	1.75	1	1,920	14	14.50		5,800	4,260	7,530			15.63	05	150	RM	RM	
								2			13.75							15.88		150			

* - 2nd Load Applic

** - RM - Ambient Room Temperature (Approximately 72 F)

Figure 7-36. Tabular Test Data Summary for Phase IA Full Length Test Specimens SPX-168A-1 Through SPX-168B-4

(No.s SPX168B5 Thru SPX168C6)

Specimen Number		Average Load of End Sample	Diameter		Cross Sectional Area	Length	Weight	Test No.	Impact Weight	Impact Velocity		Average Crush Load	Initial Peak Loads			Load Onset Rate		Stroke	Rebound	Vacuum	Temperature		Time
Bendix	Hexcel	(Lbs)	O.D. (In)	I.D. (In)	(In²)	(In)	(Lbs)		(Lbs)	Target (FPS)	Actual (FPS)	(Lbs)	Max (Lbs)	Min (Lbs)	True (Lbs)	(Lbs/Sec)	(G's/Sec)	(In)	(In)	(Equal to 100 Microns or Less)	Target (°F)	Actual (°F)	(Minutes)
SPX168B5	1B-5	5,350	3.00	2.00	15.69	52.50	1.75	1	1,920	20	21.25		6,670	3,720	6,510	4.01	2.69	35.50	0	150	RM	RM	
SPX168B6	1B-6	5,200	3.125	2.00	18.09	52.125	1.94	1	780	10					5,510	5.36	7.05	6.75		100	RM	RM	
								2										7.38		100			
								3										3.13		100			
								4										2.75		100			
SPX168B7	1B-6	5,350	3.00	2.00	15.69	52.50	1.75	1	2,850	10	11.05		7,660	4,600	5,785	4.79	1.68	39.75		150	RM	RM	
SPX168B8	1B-8		3.00	2.00	15.69	52.50	1.75	1	3,750	10	10.87		6,180	4,080	6,560	5.11	1.36	42.00	11	150	RM	RM	
SPX168C1	1C-15		3.00	2.00	15.69	55.50	3.56	1		Static								4		200	RM	RM	
								2		Static								6		200			
								3		Static								10		200			
								4		Static								10.5		200			
								5		Static								10.35		200			
								6		Static										200			
SPX168C2	1C-16	5,175	3.00	2.00	15.69	55.50	3.50	1	1,920	5					6,935	4.36	2.27	1.81	0	100	RM	RM	
								2			4.44				6,770	4.24	2.21	1.75	.11	100			
								3										1.63		100			
								4										1.63		100			
								5								4.20	2.19	1.56	20	80			
								6										1.56		80			
								7												80			
								8								3.48	1.81	1.75	.19	80			
								9										1.75		80			
								10			4.94		7,925	5,350	7,540	3.5	1.64	1.75	25	90			
								11										1.67					
								12								2.96	1.54	1.56	25	100-150			
								13										1.59					
								14										1.56					
								15								2.23	1.18	1.63	.30				
								16										1.56		100-125			
								17										1.93		100-125			
								18								1.85	963	1.63	35	100-125			
								19										1.63		100-123			
								20										[illegible]		100-125			
								21			5.09				6,880	1.61	.837	[illegible]	24	100-125			
								22			4.58				6,789	1.15	597	[illegible]	20	100-125			
SPX168C3	1C-22	5,250	3.00	2.00	15.69	55.94	3.25	1	1,920	10	10.45		9,050	3,500	5,630	5.84	[illegible]	10.00	19	150	RM	RM	
								2			10.41		8,340	3,780	5,885	4.85	[illegible]	10.25	18	[illegible]			
								3			10.51		6,680	4,370	6,030		3.19	9.94	28	120			
								4			10.65		8,330	4,02	6,020			8.94	40	120			
SPX168C4	1C-20	5,625	3.00	2.00	15.69	56.00	3.13	1	1,920	14	14.19		9,250	3,960	6,523	5.98	2.86	14.00	18	150	RM	RM	
								2			14.40		10,300	4,080	6,450			13.81	17	150			
SPX168C5	1C 17	5,625	3.00	2.00	15.69	56.00	3.19	1	1,920	20	[illegible]		6,630	2,620	5,320	5.98	3.12	37.25	1.06	150	RM	RM	
SPX168C6	1C-1	5,625						1	760	10	10.15				6,341	8.25	10.90	3.06		100	RM	RM	
								2										2.31		100			
								3										2.38		100			
								4										2.75		100			
								5										2.63		100			
								6										2.44		100			
								7										2.19		100			
								8										2.38		100			
								9										2.38		100			
								10										2.44		100			
								11										2.50		100			
								12										2.50		100			
								13										2.13		100			
								14										1.88		100			
								15										1.81		100			
								16										2.81		100			

Figure 7-37. Tabular Test Data Summary for Phase IA Full Length Test Specimens SPX-168B-5 Through SPX-168C-6

(No s SPX168C7 Thru SPX167B5)

Specimen Number		Average Load of Test Sample	Diameter		Cross-Sectional Area	Length	Weight	Test No.	Impact Weight	Impact Velocity		Average Crush Load	Initial Peak Loads			Load Onset Rate		Stroke	Rebound	Vacuum Into TORR Rec'd	Temperature		Time
Bendix	Hexcel	(Lbs.)	O.D. (In.)	I.D. (In.)	(In.²)	(In.)	(Lbs.)		(Lbs.)	Target (FPS)	Actual (FPS)	(Lbs.)	Max. (Lbs.)	Min. (Lbs.)	True (Lbs.)	(Lbs/Sec x 10)	(G's/Sec x 10)	(In.)	(In.)	(Equal to 100 Microns or Less)	Target (°F)	Actual (°F)	(Minutes)
SPX168C7	1C-2	5,350	3.125	2.00	18.09	55.75	3.25	1	2,850	10	10.70		9,649	2,618	5,581	6.45	2.26	16.75	17	120	RM	RM	
								2										14.13		120			
SPX168C8	1C-1	5,525	3.125	2.00	18.09	58.00	3.50	1	3,750	10	10.55		10,261	4,441	6,179	6.14	1.64	20.75	0	120	RM	RM	
SPX167A1	1A-1		7.00	5.50	58.90	51.13	3.13	1		Static								4		90	RM	RM	
								2		Static								6		90			
SPX167A2	2A-5	5,400	7.00	5.50	58.90	51.00	3.25	1	1,920	5	4.94		8,518	4,416	6,195	2.70	1.41	2.75	.039	90	RM	RM	
								2								2.92	1.52	4.88		90			
								3								1.57	.819	4.38	.012	90			
								4								1.28	.551	4.58	.010	90			
								5								1.48	.771	3.38	.008	90			
								6								1.66	.873	4.86	.012	90			
								7								1.05	.547	3.25	.078	90			
								8								1.57	.816	1.63	.116	90			
SPX167A2	2A-2	5,400	7.00	5.50	58.90	5.1?	3.25	1	1,320	10	10.55		8,069	5,152	7,739	3.96	2.06	9.00	0	90	RM	RM	
								2										12.00		90			
								3										12.63		90			
								4										3.13		90			
								5										2.50		90			
SPX167A4	2A-1 -1		7.00	5.50	58.90	51.06	3.25	1	1,920	14	14.53		7,380	3,720	6,830	4.96	2.53	28.00			RM	RM	
								2	1,920		10.58		6,583	4,657	6,198	3.30	1.72	9.38	77				
SPX167A5			7.00	5.50	58.90	51.00	3.19	1	1,920	20								35.13		90	RM	RM	
SPX167A6	2A-1	5,775	6.90	5.50	54.30	51.00	3.25	1	760	10	10.20				7,018	7.11	9.36	5.6		100	RM	RM	
								2										6.15		100			
								3										4.38		100			
								4										4.00		100			
								5										3.78		100			
								6										3.88		130			
								7										1.75		100			
								8										1.75		100			
SPX167A7			7.00	5.50	58.90	51.00	3.31	1	1,950	10	10.52					5.78	2.03	37.88		90	RM	RM	
SPX167A8	2A-8	5,460	7.00	5.50	58.90	51.00	3.31	1	3,750	10	10.37					5.71	1.52	36.50		90	RM	RM	
SPX167B1	2B-9		7.13	5.56	54.70	51.06	3.56	1		Static								4			RM	RM	
								2		Static								6					
								3		Static								10					
SPX167B2	2B-8	5,325	7.00	5.50	58.00	51.00	3.25	1	1,920	5	5.01		7,013	4,182	6,305	3.10	1.61	2.63	03		RM	RM	
								2	1,920	5						2.96	1.54	2.50	085				
								3	1,920	5						2.83	1.47	3.13	01				
								4	1,920	5						1.71	89	3.38	07				
								5	1,920	3						1.70	89	3.3	0				
								6	1,920	5						1.29	67	4.13	05				
								7	1,920	5						1.56	81	3.00	02	90			
								8	1,920	5						1.33	69	4.63	01	95			
								9	1,920	5						1.25	.63	3.13	13	90			
								10	1,920	5						1.42	74	1.75	14	90			
								11	1,920	5						1.57	82	1.38	185	90			
SPX167B3	2B-7	5,175	7.00	5.50	58.90	51.00	3.53	1	1,920	10	10.53		8,000	[illegible]	7,220	4.35	2.37	10.00	05	90	RM	RM	
								2	1,920	10								9.50		90			
								3	1,920	10								9.50		90			
								4	1,920	10								9.25		90			
SPX167B4	2B-6		7.00	5.50	58.90	51.00	3.38	1	1,920	14	14.15		8,100	1,950	7,070	7.12	2.08	22.25			RM	RM	
								2	1,920	14								11.50					
SPX167B5	2B-4		7.06	5.55	61.70	51.13	3.38	1	1,920	20						9.82	5.11	35.13		90	RM	RM	

Figure 7-38. Tabular Test Data Summary for Phase IA Full Length Test Specimens SPX-168C-7 Through SPX-167B-5

[illegible] SPX167B6 Thru SPX167C6

Specimen Number		Average Load @ End Sample	[illegible]		Section Area	[illegible]	[illegible]		[illegible]	[illegible]		[illegible]	[illegible] Peak Loads			Load Share Rat		[illegible]	[illegible]	[illegible]	Temperature		Time
[illegible]	Hexcel	(Lbs)	O.D. In	I.D. In					[illegible]	Target	Actual	[illegible] Load	Max	Min	[illegible]	[illegible]	[illegible]			[illegible]	Target (°F)	Actual (°F)	(Minutes)
SPX167B6	2B-10	5 625	7 13	5 50	64 70	51 00	3 50	1	760	10	10 11				8,064	7 59	9 99	4 75		100	RM	RM	
								2	760	10								2 75		100			
								3	760	10								3 00		100			
								4	760	10								2 88		100			
								5	760	10								2 88		100			
								6	760	10								3 38		100			
								7	760	10								3 13		100			
								8	760	10								3 13		100			
								9	760	10								3 88		100			
								10	760	10								3 50		100			
								11	760	10								3 00		100			
								12	760	10								3 00		100			
								13	760	10								3 13		100			
SPX167B7	2B-5		7 13	5 50	64 70	51 00	3 50	1	2,650	10	10 60		8,184	3 575	7,416	5 22	1 83	20 38	12	99	RM	RM	
								2		10								17 00					
SPX167B8	2B-1	5 [illegible]25	7 06	5 50	61 70	51 00	3 4375	1	3,750	10	10 44		8 543	2 755	7,262	6 04	1 61	38 50	48	99	RM	RM	
SPX167C1-1	2C-[illegible]*		7 19	5 50	67 00	50 50	4 25	1		Static								4			RM	RM	
								2		Static								6					
								3		Static								10					
								4		Static								10					
								5		Static								10					
SPX167C2	2C-52	5,250	7 19	5 50	67.00	50 50	3 75	1	1 920	5	5 04		6,866	4,819	5,611	1 47	.766	2 50	093		RM	RM	
								2	1 920		4.95		6,260	4,860	6,260	2 77	08	2 25	098				
								3	1 920									2.25					
								4	1,920									2 13	183				
								5	1 920									2 13					
								6	1 920		5 03		7,320	5,350	7,320	2 90	1 51	2 13	14				
								7	1 920		5 11		7,366	5,066	6 780	2 12	1 [illegible]1	2 00	16				
								8	1 920									2 00					
								9	1 920									1 88	17				
								10	1 920									1 88					
								11	1 920							2 82	1 47	1 88	195				
								12	1 920									1 88					
								13	1 920		4 80		[illegible]	5,386	6 787	2 53	1 32	1 75	20				
								14	1 920									1 75					
								15	1,920		4 87		7,066	5,543	6,741	2 15	1 12	1 75	21				
								16	1,920									1 75					
								17	1 920									1 75					
								18	1,920							1 67	872	1 75	23				
								19	1 920									1.75					
								20	1 920		4 95					1 51	[illegible]	1 75	25				
SPX167C3	2C-50	5,32[illegible]	7 19	5 50	67 00	50 50	3 88	1	1,920	10	10 [illegible]8		7,830	4,781	7,285	4 81	2 50	8 75	05	100	RM	RM	
								2	1 920		10 47		8,102	5,162	7,285	3 92	2 04	8 25	11	100			
								3	1,920											100			
								4	1,920											100			
								5	1 920											100			
SPX167C4	2C-51	5,47[illegible]	7 19	5 50	67 00	50 50	3 [illegible]4	1	[illegible]	14	13 [illegible]		7,649	5,04[illegible]	7 519	[illegible]	3 41	14 38	11	100	RM	RM	
								2	1,920		14 37		[illegible]	5 33[illegible]	8 134	[illegible]	2 36	13 38	17	100			
								3	1 920		14 13		[illegible]	5 380	8 673	[illegible]	3 04	13 00	[illegible]	100			
SPX167C5	2C-64	[illegible]700	7 19	[illegible]	67 00	50	4 50	1	1,920	20	20 [illegible]		7 849	4 38[illegible]	6 968	13 04	[illegible]	[illegible]8 88	10	100	RM	RM	
																				100			
SPX167C6	2C 6[illegible]	5 175	[illegible]	[illegible]	[illegible] 00	50 [illegible]	4 13	1	[illegible]	10	10 34				[illegible]	[illegible]	[illegible]	3 [illegible]		[illegible]	RM	RM	
																		3 13		[illegible]			
																		3 13		[illegible]			
																		[illegible]		[illegible]			
																		3 [illegible]		[illegible]			
																		3 75		[illegible]			
																		3 [illegible]		[illegible]			
																		[illegible]		[illegible]			
																		[illegible]		[illegible]			
																		3 63		[illegible]			
								11										3 50		[illegible]			
																		3 50		[illegible]			
								13										[illegible]50		100			
								14										[illegible]75		100			

Figure 7-39. Tabular Test Data Summary for Phase IA Full Length Test Specimens SPX-167B-6 Through SPX-167C-6

(Nos. SPX167C7 Thru SPX166B6)

Specimen Number		Average Load of End Sample	Diameter		Cross Section Area	Length	[illegible]	Test	Impact [illegible]	Impact Velocity		[illegible]	Initial Peak Loads			Load Onset Rate		Stroke	Retained	Vacuum	Temperature		Time
Bendix	Hercules	(lbs)	O.D.	I.D.			(in²)		(lbs)	Target (FPS)	Actual (FPS)	Crush Load (lbs)	Max. (lbs)	Min. (lbs)	[illegible] (lbs)	(lbs/Sec) ($\times 10^5$)	(G's/Sec) ($\times 10^3$)	(in)	(in)	[illegible] TORR Read (1 psi to 500 Microns or Less)	Target (°F)	Actual (°F)	(Minutes)
SPX167C7	2C-58	5,400	7.19	5.50	67.00	50.50	4.1875	1	2,850	10	10.64		8,433	5,980	7,633	5.03	1.77	14.[illegible]0	[illegible]	100	RM	RM	
								2										13.13		100			
								3										6.75		100			
SPX167C8	2C-56	5,025	7.31	5.50	72.70	50.50	4.00	1	3,750	10					6,300	9.14	2.44			100	RM	RM	
SPX166A1	3A-41		5.63		99.20	50.00	3.39	1		Static								4.5		[illegible]	RM	RM	
								2		Static										[illegible]			
SPX166A1-3	3A-53	5,400	5.62		100.5	50.00	3.25	1		Static										125	RM	RM	
SPX166A1-3	3A-53	5,400	5.62		100.50	30.00	3.25	1		5	4.94		7,574	4,767	6,583	3.192	1.662	2.25	.055	125	RM	RM	
								2										2.63		125			
								3										3.25		125			
								4										4.88		125			
SPX166A2	3A-42	5,325	5.63		100.50	30.00	3.44	1	1,920	5								36.25		125	RM	RM	
SPX166A2-1	3A-50	5,625	5.38		90.40	50.00	3.50	1	1,920									2.25			RM	RM	
								2	1,920									2.25		100			
								3	1,920									4.13					
								4	1,920														
SPX166A6	3A-47	5,400	5.63		100.50	50.00	3.13	1	760	10	10.30				6,156	6.57	8.65	5.06		100	RM	RM	
								2	760														
SPX166B1	3B-44		6.00		113.00	50.00	3.41	1		Static								4		125	RM	RM	
								2		Static								8		125			
								3		Static								10		125			
								4		Static								10		125			
SPX166B2	3B-43	5,475	6.00		113.00	50.00	3.89	1	1,920	5	4.99		8,706	4,424	6,454	2.14	1.11	2.12		125	RM	RM	
								2	1,920									2.12		125			
								3	1,920									2.00		125			
								4	1,920									2.00		125			
								5	1,920									2.75		125			
								6	1,920									2.25		125			
								7	1,920									19.75		125			
SPX166B3	3B-40	5,550	6.00		113.00	50.00	3.88	1	1,920	10	10.50		8,960	4,640	6,920	4.77	2.48	8.87	.157	125	RM	RM	
								2	1,920									9.56		125			
								3	1,920									8.56		125			
								4	1,920									10.63		125			
SPX166B3-1	3B-51	5,325	6.00		113.00	50.00	3.44	1	1,920	10	10.36		7,900	4,680	6,310	3.86	2.01	10.62	.06	100	RM	RM	
								2	1,920		13.25		8,943	3,931	7,003	3.96	2.06	15.37	.14	100			
								3	1,920											100			
SPX166B4	3B-42	5,250	6.00		113.00	50.00	3.88	1	1,920	14	14.14		8,48[illegible]	[illegible]	6,193	8.01	4.17	16.82	0	125	RM	RM	
								2	1,920		10.39		[illegible]	[illegible]	[illegible]	3.46	1.80	9.25	.069	125			
								[illegible]	1,920											125			
								4	1,920											125			
SPX166B5	3B-41	5,625	6.00		113.00	50.00	3.88	1		20								37.25			RM	RM	
SPX166B6	3B-46	5,700	6.00		113.00	50.00	3.88	1	760	10	10.[illegible]3				5,910	[illegible].42	8.44	3.00		100	RM	RM	
									760									2.75		100			
								3	760									2.75		100			
								4	760									3.00		100			
								5	760									2.87		100			
								6	760									3.00		100			
								7	760									2.50		100			
								8	760									2.27		100			
								9	760									2.50		100			
								10	760									2.37		100			
								11	760									2.50		100			
								12	760									2.50		100			
								13	[illegible]									2.50		100			

Figure 7-40. Tabular Test Data Summary for Phase IA Full Length Test Specimens SPX-167C-7 Through SPX-166B-6

(Nos SPX166C1 Thru SPX166C2-2)

Specimen Number Bendix	Specimen Number Hexcel	Average Wt of End Sample (Lbs)	Diameter O.D. (In)	L/D	Cross Sectional Area (In²)	(In)	Weight (Lbs)	T	Impact Weight (Lbs)	Impact Velocity Target (FPS)	Impact Velocity Actual (FPS)	Average Crush Load (Lbs)	Initial Peak Loads Max. (Lbs)	Initial Peak Loads Min. (Lbs)	Initial Peak Loads True (Lbs)	Load Onset Rate (Lbs/Sec x 10⁶)	Load Onset Rate (G's/Sec x 10³)	Stroke (In)	Rebound (In)	Vacuum 3x10⁻¹ TORR Head (Equal to 300 Microns or Less)	Temperature Target (°F)	Temperature Actual (°F)	Time (Minutes)
SPX166C1	3C-9		6 25		122 50	52 43	3 15	1		Static								3		0	RM	RM	
SPX166C1-1	3C-10		6 19		120 00	52 38	3 13	1		Static										0	RM	RM	
SPX166C1-2	3C-4						3 [illegible]			Static								4		0	RM	RM	
										Static								6		0			
										Static								10		0			
										Static								10		0			
										Static								11 5		0			
SPX166C1-3	3C-8		6 25		122 50	52 32	3 13	1		Static								4		150	RM	RM	
								2		Static								6		100			
								3		Static								10		90-100			
								4		Static								10		90 100			
								5		Static								10		90			
SPX166C1-5	3C-20		6 25		122 50	52 38	3 00	1		Static								4		200			
								2		Static								5					
								3		Static								10					
								4		Static								10					
SPX166C2-0	3C-5	5,400	6 19		120 00	52 31	3 12	1	1,920	5	4 56		7,420	4,325	6,100	4 81	2,51	2 12	114	200	RM	RM	
								2	1,920											100-400			
SPX166C2-1	3C-7	5,350	6 25		122 50	52 34	3 00	1	1,920	5	4 55				5 450	7,55	3 79	2 37	169	150	RM	RM	
								2	1,920		4.00				5,450	3 93	1 97	2 00	084	95			
								3	1,920						5,350	6.90	3 46	2 03	076	90			
								4	1,920						5,650	3,09	1 55	2 03	083	80			
								5	1,920						5,250	5 00	2 51	2 03	096	75			
								6	1,920						5,300	2 85	1 43	2 03	093	80			
								7	1,920						5,350	2 90	1 45	2 09	095	75			
								8	1,920						5,625	2 91	1,48	1 87	113	70			
								9	1 920						5,900	2 15	1 28	2 18	149	100			
								10	1,920						5,900	1 15	0 597	2 20	123	100			
								11	1,920		4 30		6,370	4,740	5,850	3 03	1 57	1 62	112	70			
								12	1 920						5,900	2 40	1 21	1 97	114	130			
								13	1,920						5,800	2 27	1 14	2 00	121	150-80			
								14	1,920						5,500	1 91	0 959	1 87	132	70			
								15	1,920						5,340	1 32	1 16	1 83	148	70			
								16	1,920						5,370	1,70	0,893	1 87	153	70			
								17	1,920						5 340	2 22	1,11	1 75	148	70			
								18	1,920						5,500	1 42	0 713	1 75	147	70			
								19	1 920						5,450	1 50	0 753	1 75	175	70			
								20	1,920						5,450	1,68	0 843	1 75	175	70			
								21	1,920		4 38		6,120	4,670	5,430	1 48	0 738	1 81	135	70			
SPX166C2-2	3C-22	5,450	6 25		122 5	52 [illegible]	2 94	1	1,850	5	4 64		7,240	4 250	5,588	4 13	2 23	2 25	02	200	RM	RM	
								2	1,850		4 82		7,600	4,050	6,150	4 05	2 11	2 18	18	200			
								3	1 850							4 18	2 26	2 18	037	200			
								4	1,850									2 12		200			
								5	1 850									2 12		200			
								6	1 850							[illegible] 87	2 63	2 06	12	200			
								7	1 850									2 06		200			
								8	1 850									2 06		200			
								9	1 850							3 39	1 63	2 06	1[illegible]	200			
								10	1 850									2 06		200			
								11	1 850									2 00		200			
								12	1 850							2 24	1 75	1 87	205	[illegible]			
								13	1,850									1 87		200			
								14	1 850									1 87		200			
								15	1 850							2 55	1 38	1 93	227	200			
								16	1 850									1 87		200			
								17	1 850									1 87		200			
								18	1 850							2 12	1 15	1 87	215	[illegible]			
								19	1 850									1 87		200			
								20	1 850									1 87		200			
								21	1 850		3 05		5 890	5 000	5 560	1 26	[illegible]	1 00	1	[illegible]			

Figure 7-41. Tabular Test Data Summary for Phase IA Full Length Test Specimens SPX-166C-1 Through SPX-166C-2-2

(No's SPX166C3 Thru SPX166C8)

Specimen Number Bendix	Specimen Number Hercules	Average [illegible] & End [illegible] (Lbs)	Diameter O.D. (In)	Diameter I.D. (In)	Cross Section Area (In²)	Length (In)	[illegible] (Lbs)		Impact Weight Actual (Lbs)	Impact Velocity Target (FPS)	Impact Velocity Actual (FPS)	Average Crush Load (Lbs)	Actual Peak Loads Max (Lbs)	Actual Peak Loads Min (Lbs)	Actual Peak Loads Final (Lbs)	Load Under Curve (Lbs Sec x 10³)	Load Under Curve ([illegible] Sec x 10³)	Stroke (In)	Rebound (In)	Vacuum 5x10⁻⁴ TORR Head (Equal to 100 Microns or Less)	Temperature Target (°F)	Temperature Actual (°F)	Time (Minutes)
SPX166C3-0	3C-2	5,450	6.3125		124.90	52.375	3.00	1	1,850	10	[illegible]		9,010	3,605	6,170	5.15	2.58	8.125	055	100	RM	RM	
								2	1,850		9.62		7,910	1,605	6,790	2.65	1.38	8.00	170	80	RM	RM	
								3	1,850		9.40		9,010	3,650	6,690	4.83	2.40	7.583	167	[illegible]	RM	RM	
								4	1,850		9.46		8,740	3,620	6,510	4.75	2.47	7.625	111	80	RM	RM	
								5	1,850		9.78		7,030	4,140	6,470	2.95	1.54	8.187	222	80	RM	RM	
SPX166C3-1	3C-9	5,250	6.25		122.50	52.375	3.00	1	1,850	10										100	RM	RM	
								2	1,850	10										100	RM	RM	
								3	1,850	10										100	RM	RM	
								4	1,850	10										100	RM	RM	
								5	1,850	5										100	RM	RM	
								6	1,850	5										100	RM	RM	
								7	1,850	5	4.34		7,325	5,540	6,625	954	0.496	1.750	220	100	RM	RM	
								8	1,850	10										100	RM	RM	
SPX166C3-2	3C-8	5,450	6.25		122.50	52.25	3.00	1	1,850	10										100	RM	RM	
SPX166C3-3	3C-1	5,400	6.25		122.50	52.375	2.9375	1	1,850	5	4.92		7,050	4,131	6,070	7.25	3.78	2.187	177	100	RM	RM	
								2	1,850	5	4.75				5,630	3.33	1.74	2.250	078	125	RM	RM	
								3	1,850	10	9.65				5,680	4.38	2.28	8.625	102		RM	RM	
								4	1,850	10	9.48				5,700	6.38	3.32	8.312	121	100-200	RM	RM	
								5	1,850	10	9.81				5,800	7.20	3.75	8.125	077	125	RM	RM	
								6	1,850	5	4.50				5,470	1.39	0.723	2.00	146	125	RM	RM	
								7	1,850	5	4.83					1.10	0.573	1.375	147	100	RM	RM	
								8	1,850	5								1.813		100	RM	RM	
								9	1,850	5								1.937			RM	RM	
								10	1,850	5	5.59					1.12	0.583	2.750	179				
SPX166C3-4	3C-21	5,375	6.25		122.50	52.00	2.875	1	1,850	10	9.71				6,338	6.12	[illegible]			200	RM	RM	
								2	1,850											250	RM	RM	
								3	1,850											275	RM	RM	
								4	1,850												RM	RM	
								5	1,850												RM	RM	
SPX166C4-1	3C-27		6.25		122.50	52.00	3.00	1	1,920	14	13.66		9,110	3,695	[illegible]	6.59	3.43	16.5	102	200	RM	RM	
								2	1,920									17.625	225	200	RM	RM	
								3	1,920	10	9.15		8,000	4,125	5,720	3.43	1.78	7.625	400	200	RM	RM	
SPX166C5-1	3C-26		6.25		122.50	52.00	3.00	1	1,920	20								32.25		150	RM	RM	
								2	1,920		8.35		8,160	3,670	6,270	4.98	[illegible]	7.13	1	150	RM	RM	
SPX166C5-2	3C-24	5,475	6.25		122.50	52.00	2.94	1	1,920	20	13.05		8,700	3,430	3,800	4.71	2.52	35.06	0	150	RM	RM	
								2	1,920		8.41			4,520	7,450	12.55	6.71	6.13	16	150	RM	RM	
SPX166C6	3C-28		6.50		132.50	52.00	2.8125	1	760	10	9.48							2.38		100	RM	RM	
								2			9.70							2.88		100			
								3			10.40							3.00		100			
								4										2.63		80			
								5			9.80							2.40		80			
								6			9.67							2.63		80			
								7										2.69		80			
								8										2.75		80			
								9										2.75		80			
								10										2.75		60			
								11										2.75		60			
								12										2.50		80			
								13										2.63		80			
								14										2.50		80			
								15										1.25		0			
SPX166C7	3C-29		6.25		122.50	52.00	3.125	1	[illegible]	10								22.75		100	RM	RM	
								2										16.25		100			
								3												100			
SPX166C8	3C-30		6.25		122.50	[illegible]	[illegible]	1	[illegible]	10	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	37.81	0	100	RM	RM	
																				100			

Figure 7-42. Tabular Test Data Summary for Phase IA Full Length Test Specimens SPX-166C-3 Through SPX-166C-8

These plots and other data from the records and tables, after close study, provided confirmation of the original visual observations regarding those configurations which were displaying the most satisfactory crushing characteristics. The four configurations selected for Phase IB tests under the cryogenic temperature (-260°F) and the vacuum of 3 x 10^{-1} TORR were as follows:

⊙ SPX-168B - Internal Annular - 30° cell axis
⊙ SPX-168C - Internal Annular - 0° cell axis
◯ SPX-167C - External Annular - 0° cell axis
● SPX-166C - Circular Solid - 0° cell axis

The data considered of most interest is presented in the graphs and tables Figures 7-43 through 7-53.

Figure 7-43 is a plot of the density versus stroke for the various configurations. You will note there is, as expected, a general linear relationship of increased stroke with decrease in density. The solid circular section, 15° cell axis configuration shows the highest stroke percent but there is not a large percentage difference between those at the upper end of the curve.

Specific energy in terms of ft.lbs./lb. is probably one of the more important factors to be considered for design. Figure 7-44 provides a summary of these values. In Figure 7-45 both the static and dynamic results are plotted versus density, with the heavy lines running more or less on the vertical axis indicating the solid circular, external annular and internal annular when reading from left to right. Note the separation of 0° oriented cell axis lines(which run roughly horizontal across the graph), because of a cell shape difference. The 0° oriented cell in the solid circular configuration is most efficient by

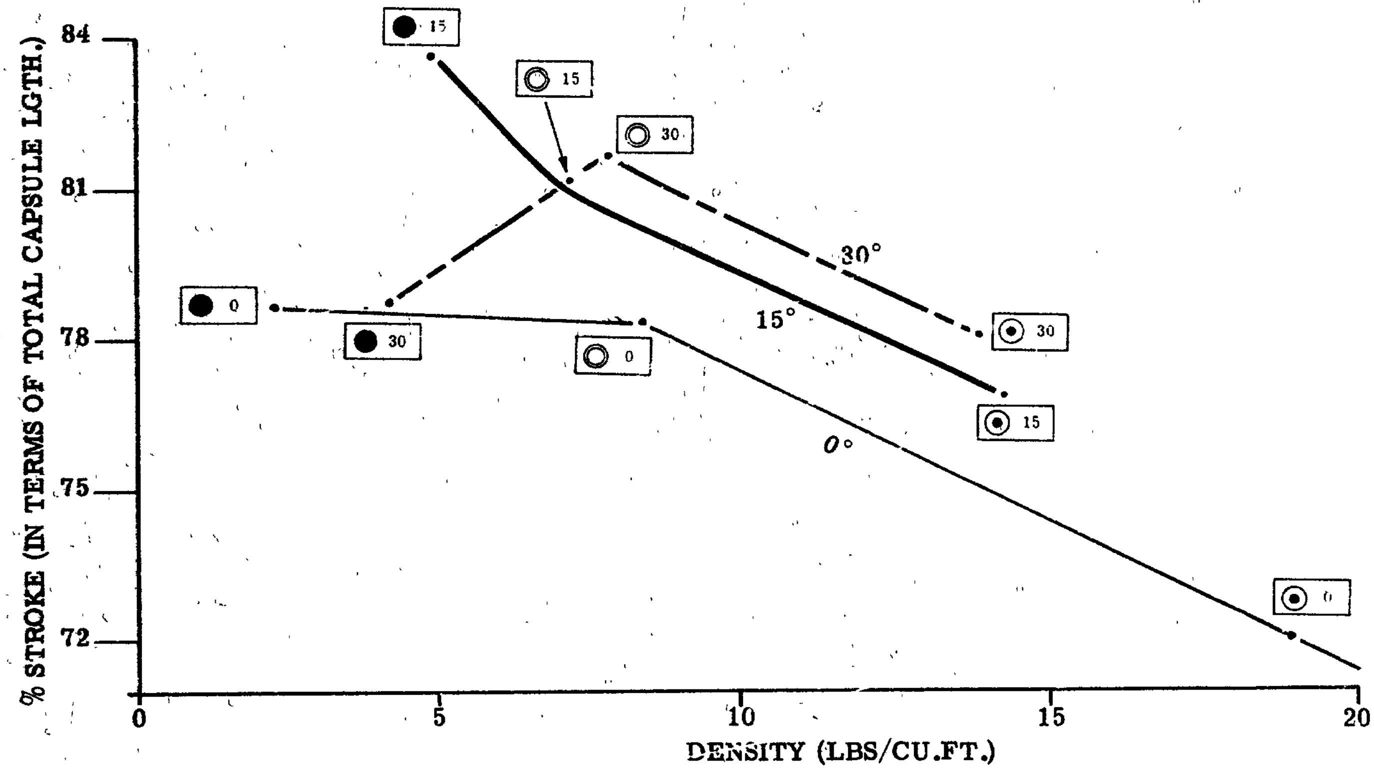


Figure 7-43. Capsule Stroke versus Density

Key	Specimen No	Diameter		Length In.	Cross-Sectional Area In ^{2}	Volume In ^{3}	Weight		Density Lbs Ft^3	Average Crush Load Lbs.	Total Stroke In	Stroke Efficiency	Energy Absorbed In-Lbs.	Specific Energy	
		O.D. In.	I D In.				Grams	Lbs.						In-Lbs Lb	Ft-Lbs Lb.
⊙	SPX-163A-1	5.438	-	6.00	24.301	145.8	176.6	.389	4.61	5400	5.044	84.1	27489	70800	5880
⊙	SPX 163A-2	5.563	-	6.00	23.221	139.3	175.0	336	4.77	5970	5.008	85.4	29685	77000	6400
⊙	SPX-163B-1	6.000	-	6.00	26.275	169.8	198.6	438	4.45	5830	4.723	78.8	29564	67500	5610
⊙	SPX-163B-2	5.938	-	6.00	27.688	166.1	203.0	447	4.65	6140	4.702	73.4	29951	67000	5580
⊙	SPX-163C-2	6.125	-	6.00	29.465	176.9	140.5	310	3.02	5400	4.718	78.6	25565	82400	6860
⊙	SPX-163C-[illegible]	6.125	-	6.00	29.465	176.9	142.5	314	3.07	5650	4.722	78.8	26302	83800	6960
○	SPX-164A-1	6.900	5.50	6.375	13.634	87.0	[illegible]	352	6.98	5380	5.027	80.2	27436	78050	6490
○	SPX-164A-2	7.000	5.50	6.250	14.726	92.0	167.1	.368	6.91	5710	5.164	82.1	28705	78100	6510
○	SPX-164B-1	7.000	5.50	6.00	14.726	88.4	169.5	.374	7.31	5270	4.778	81.7	25745	68900	5720
○	SPX-164B-2	7.000	5.50	6.00	14.726	88.4	164.5	.363	7.10	5960	4.351	81.3	28835	79400	6610
○	SPX-164C-15	7.188	5.50	5.875	16.816	98.8	204.0	.450	7.87	5980	4.534	78.0	27205	6[illegible]00	5020
○	SPX-164C-16	7.187	5.50	6.025	16.811	101.3	210.0	463	8.10	5300	4.559	78.5	25385	54800	4550
●	SPX-165A-1	3.000	2.00	6.00	3.927	23.5	90.0	.199	14.60	5450	4.619	77.0	25042	130900	10900
●	SPX-165A-2	3.000	2.00	6.00	3.927	23.5	90.0	199	14.60	5400	4.320	75.8	25319	127200	10550
●	SPX-165B-5	3.125	2.00	6.00	4.528	27.2	99.0	218	13.83	5500	4.701	78.1	26404	121100	10[illegible]0
●	SPX-165B-6	3.125	2.00	6.00	4.528	27.2	100.0	.221	14.04	5450	4.705	78.5	26017	117700	9810
●	SPX-165C-11	3.125	2.00	6.00	4.528	27.2	152.0	.335	21.25	5600	4.350	72.6	24327	72700	6030
●	SPX-165C-12	3.125	2.00	6.00	4.528	27.2	148.5	.327	20.75	5600	4.293	71.5	27646	84600	7040

Figure 7-44. Summary of Static Test Data From Successful Six-Inch Length Preproduction Control Specimens

KEY

SPEC.	STATIC		DYNAMIC	
	RM. TEMP.	-260°F	RM. TEMP.	-260°F
165	○ A, B, or C	● A, B, or C	⊕ A, B, or C	◐ A, B, or C
167	□ A, B, or C	■ A, B, or C	⊞ A, B, or C	◧ A, B, or C
168	△ A, B, or C	▲ A, B, or C	⟁ A, B, or C	◭ A, B, or C

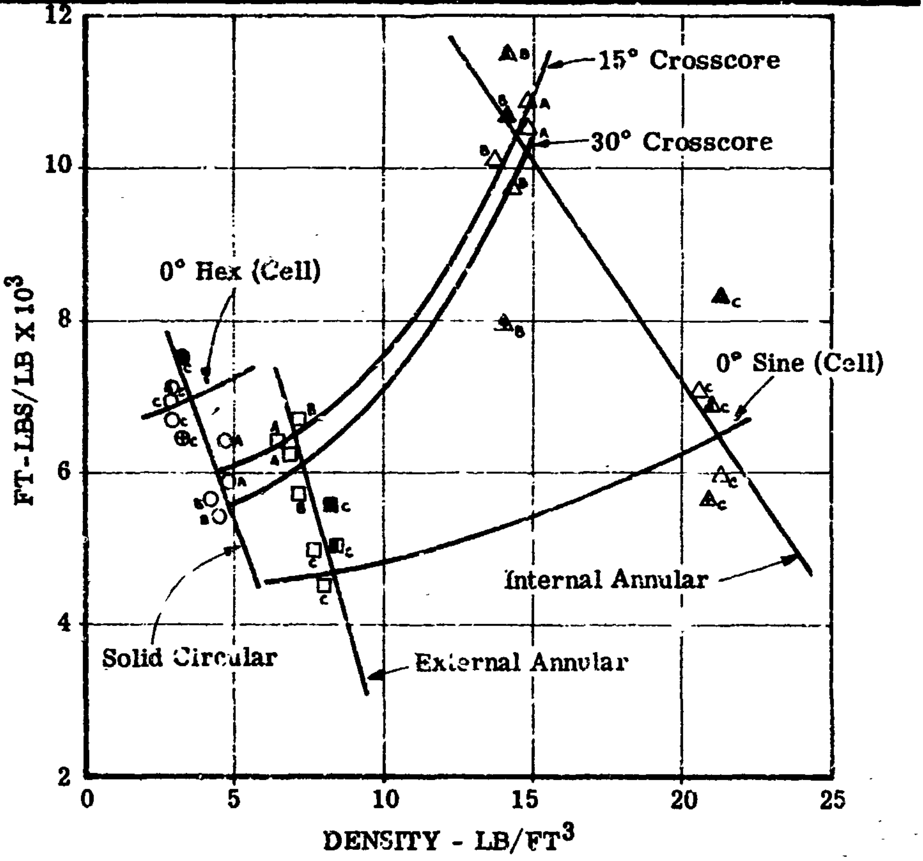


Figure 7-45. Static and Dynamic Specific Energy Under Room Temperature And -260°F Environment

a good margin. A somewhat lesser energy absorption capability is shown for the dynamic values as compared to the static values. This result, which was unexpected has been both supported and disputed by other tests which were run under atmospheric pressure where the cellular entrapped air would have an effect. Figure 7-45A shows a second plot of data regarding the specific energy where comparison is made between specimens tested at 5 and 10 fps impact velocity. This plot denotes significant changes due to temperature but little effect due to the 5 fps change in impact velocity, which is further confirmed by the tabular data shown in Figure 7-46.

The load onset rate obtained under the first impact on a full length specimen (in terms of g's/sec.) when plotted against the impact velocity with a constant mass of 1920 pounds, provides three broad bands for the three cross sectional configurations with the lower end at 1500 to 2000 and the upper end varying from 3000 to 5500. In each case as shown in Figure 7-47, the 0° cell defines the upper edge of the band but the 15° and 30° cell configurations shift. Plotting of the load onset rate versus the weight of the impacting rig mass as shown in Figure 7-48 where the impact velocity remained constant at 10 ft./sec. provides two more bands with the 15° and 30° cell axis configurations forming just one set of curves. These configurations exhibit a moderately declining slope in the area of 2000 to 4000 after rapidly dropping from the value attained with the 760 pound weight. The 0° cell configurations show a somewhat steeper slope in the same area of 2000 to 4000 and roughly the same at the upper and lower ends.

Figures 7-47A and 7-47B illustrate the variations which are evident in comparing the load onset rate versus impact velocity at the second and third impacts on the same specimen. Interpolating the data by drawing approximating curves through the several points for the two configurations subsequently determined in Phase II to be of prime interest (○ 0 and ● 0) indicates, when comparison is made with the first or initial impact as shown in Figure 7-47, a lesser value for both the second and third impacts with the second dropping off more than the third.

Figures 7-48A and 7-48B show the changss which occur in comparison of the load onset rate versus impact weight under the second and third impacts on the same specimen. Again, approximation of a curve through the several points for the external annular and solid circular configurations with 0° cells, reveals in a comparison with the first impact as shown in Figure 7-48 a lower value for both the second and third impacts. In this case, however, the curves for the second and third impacts for each configuration are very close together.

Figure 7-49 indicates a characteristic shape displayed by the various configurations when load-onset rate and rebound are plotted versus the percent of capsule stroke uncrushed. The onset rate shows a roughly linear decline for all types with not must slope in the line.

KEY

SPEC.	IMPACT VELOCITY	
	5 FT/SEC	10 FT/SEC
166	○ A, B, or C	● A, B, or C
167	□ A, B, or C	■ A, B, or C
168	△ A, B, or C	▲ A, B, or C

Specimen Temp. Other Than Room Temp., Indicated

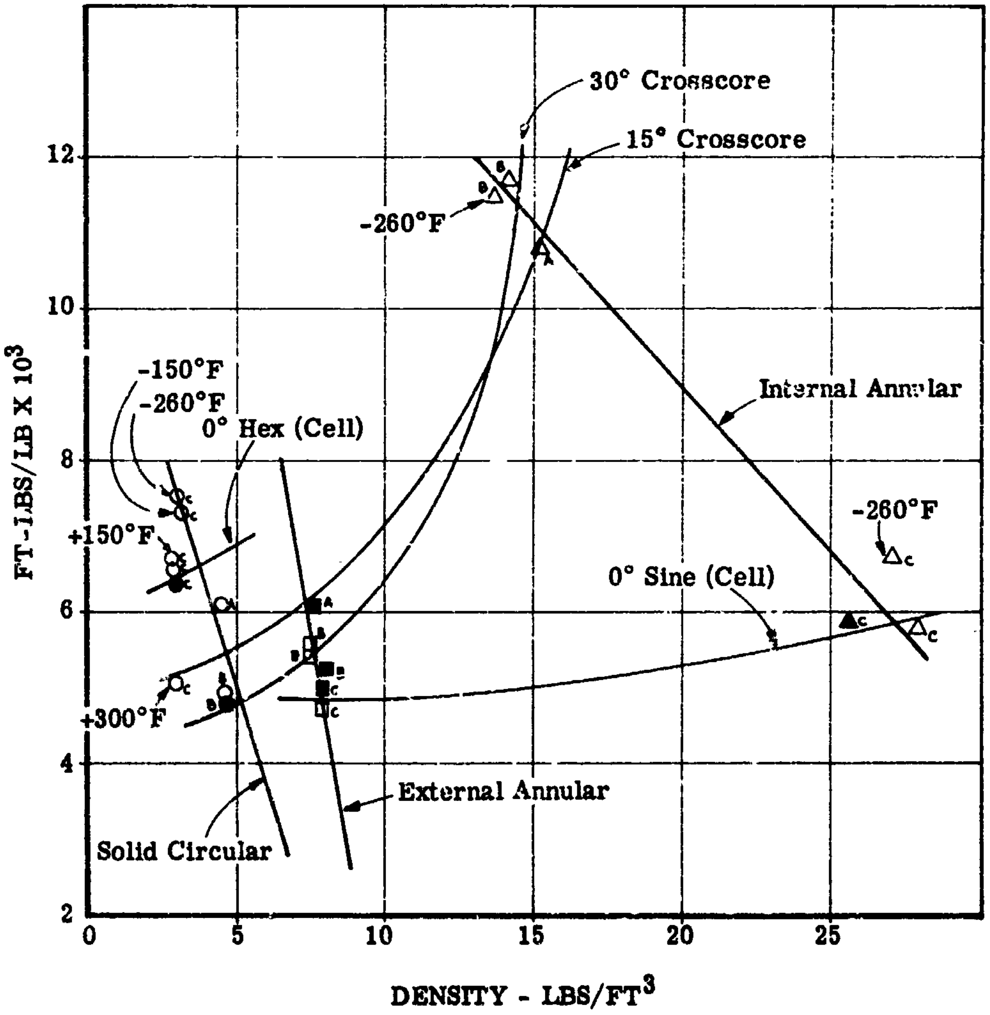


Figure 7-45A. Specific Energy Comparison Using Two Impact Velocities Under a Range of Temperatures

KEY	SPECIMEN NUMBER		DIAMETER		AREA	VOLUME	WEIGHT		DENSITY	STROKE	ASSUMED STROKE*	INPUT ENERGY	ABSORBED ENERGY	SPECIFIC ENERGY	
	BENDIX	HEXCEL	OD IN.	ID IN.	IN.^{2}	IN.^{3}	TOTAL LBS.	INCREMENT LBS.	LBS./FT.^{3}	IN.	%	FT-LBS.	FT-LBS.	FT-LBS./LB.	IN-LBS./LB.
	TEST CONDITIONS: IMPACT VELOCITY 5FPS, IMPACT MASS 1920 LBS.														
● 15	SPX-166 A2	3A-42	5-5/8		24.85	1242.53	3.25	.174	4.52	2.25	83.7	1127	1063	6,088	73,061
● 30	SPX-166 B2	3B-43	6		28.27	1413.72	3.87	.209	4.73	2.12	73.6	1130	1033	4,931	59,167
● C	SPX-166 C2-2	3C-22	6-1/4		30.68	1595.34	2.93	.161	3.18	2.25	78.7	1051	1062	6,580	78,954
○ 15	SPX-167 A2	2A-5	7	5-1/2	14.72	750.72	3.25	.215	7.48	2.75	81.1	1228	1172	5,431	65,176
○ 30	SPX-167 B2	2B-6	7	5-1/2	14.72	750.72	3.25	.205	7.48	2.62	81.5	1127	1143	5,572	65,866
○ C	SPX-167 C2	2C-[illegible]2	7-3/16	5-1/2	16.00	848.40	3.75	.237	7.63	2.50	78.2	1212	1134	4,780	57,357
◉ 15	SPX-168 A2	1A-4	3	2	3.92	205.19	1.81	.112	15.26	2.50	76.8	1128	1223	10,841	130,092
◉ 30	SPX-168 B2	1B-2	3	2	3.92	206.17	1.68	.097	14.14	2.37	78.3	1171	1135	11,649	139,785
◉ C	SPX-168 C2	1C-16-1	3	2	3.92	217.95	3.50	.158	27.75	1.81	72.0	1075	920	5,800	69,598
	TEST CONDITIONS: IMPACT VELOCITY 10FPS, IMPACT MASS 1920 LBS.														
● 15	SPX-156 A	This type not tested under 10FPS condition, due to uncontrolled failures at 5FPS.													
● 30	SPX-166 B3	3B-40	6		28.27	1413.72	3.87	.875	4.73	8.875	78.6	4901	4235	4,840	58,082
● C	SPX-166 C3-4	3C-21	6-1/4		30.68	1595.34	2.87	.605	3.11	8.625	78.7	4270	3951	6,521	78,247
○ 15	SPX-167 A3	2A-2	7	5-1/2	14.72	751.03	3.25	.706	7.47	9.0	81.1	4953	4283	6,061	72,737
○ 30	SPX-167 B3	2B-7	7	5-1/2	14.72	751.03	3.53	.849	8.12	10.0	81.5	5127	4498	5,297	63,565
○ C	SPX-167 C3	2C-50	7-3/16	5-1/2	16.81	849.18	3.87	.870	7.88	8.875	78.2	4929	4325	4,970	59,642
◉ 15	▲SPX-168 A3	1A-3	3	2	3.92	205.18	1.87	1.423	15.79	30.5	76.8	9145	7304	5,483	65,793
◉ 30	▲SPX-168 B3	1B-3	3	2	3.92	206.16	1.68	.738	14.14	18.0	78.3	6548	5788	7,834	94,012
◉ C	SPX-168 C3	1C-22	3	2	3.92	219.66	3.25	.808	25.56	10.0	72.0	5195	4695	5,822	69,867

*Reference Figure 7-43

▲Catastrophic failure of specimen must be taken into account in comparing these test results with those at 5 fps.

Figure 7-46. Comparison of Dynamic Test Data for Various Specimen Types at 5 and 10 fps Impact Velocity

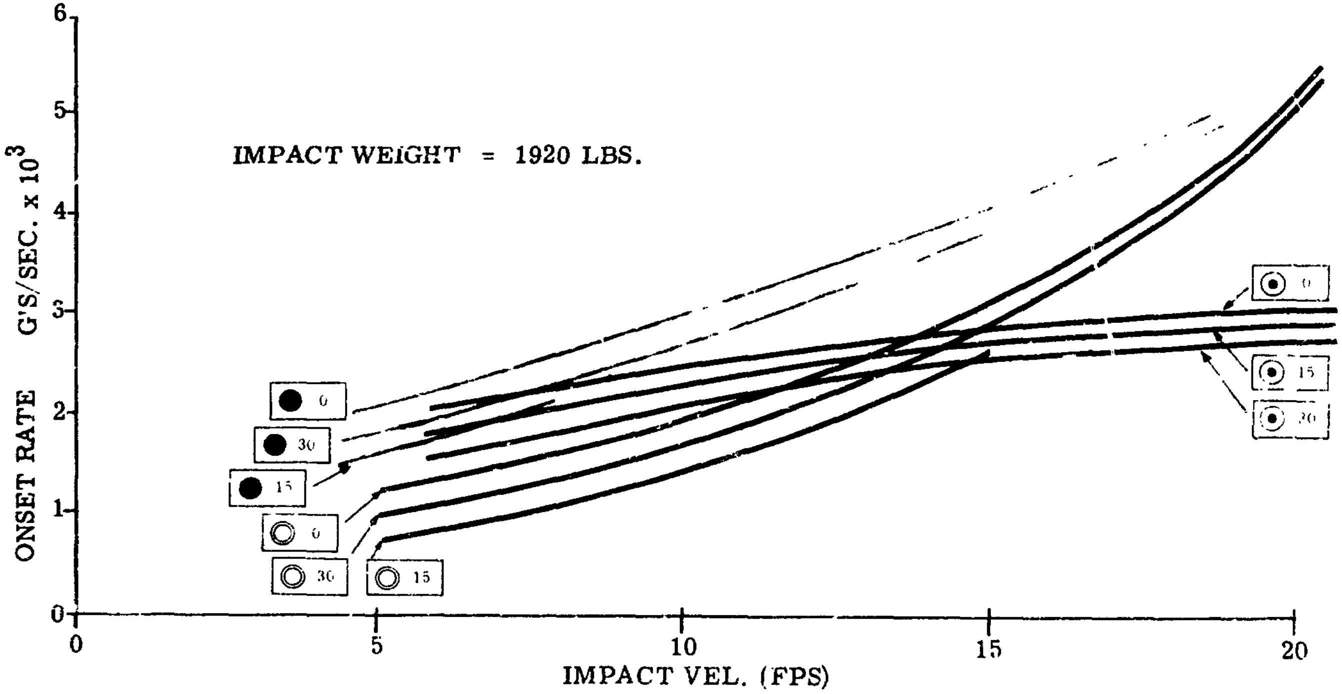


Figure 7-47. Load Onset Rate Versus Impact Velocity
(First Impact on Full Length Specimen)

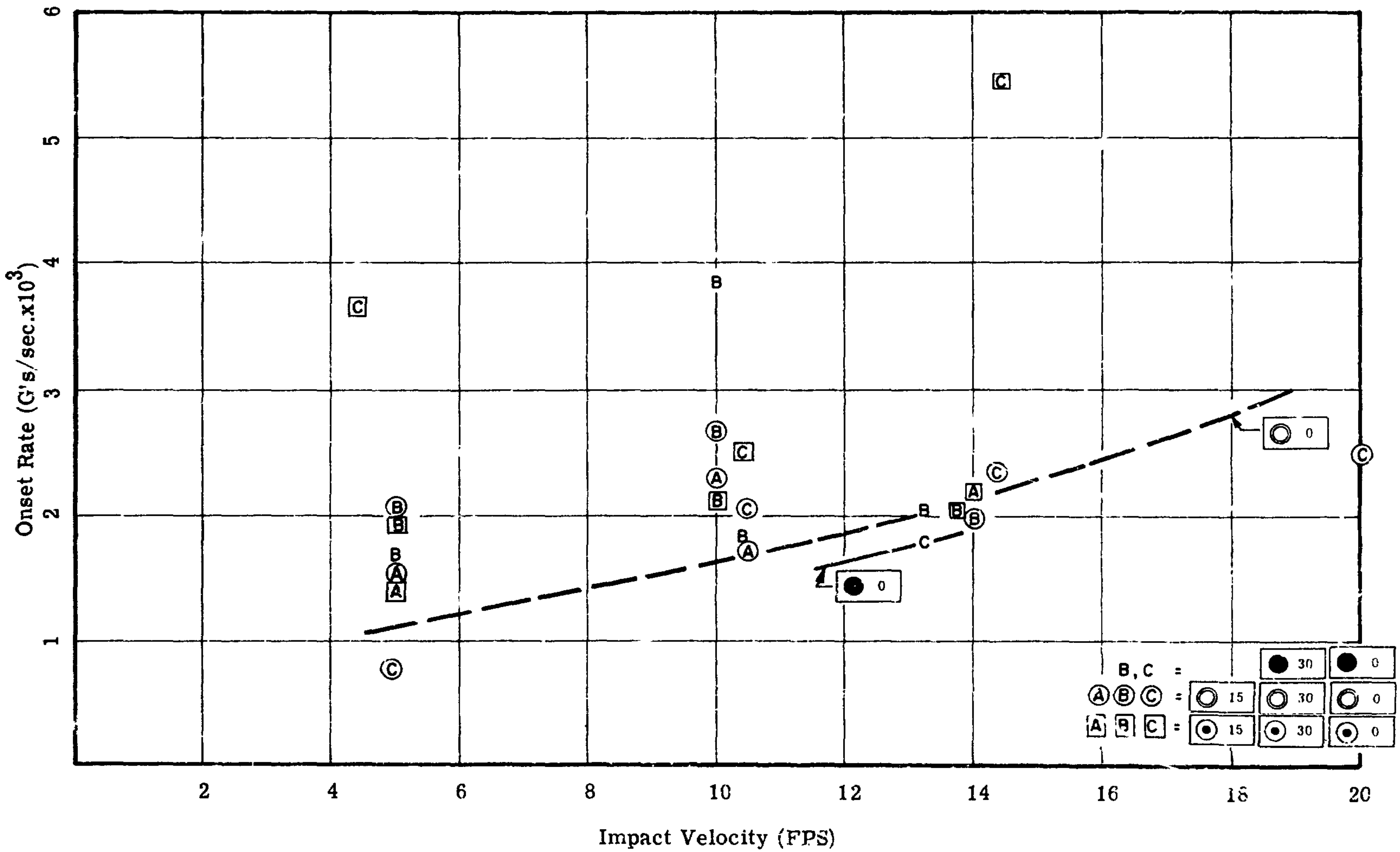


Figure 7-47A. Load Onset Rate vs. Impact Velocity (Second Impact - Test No. 2)

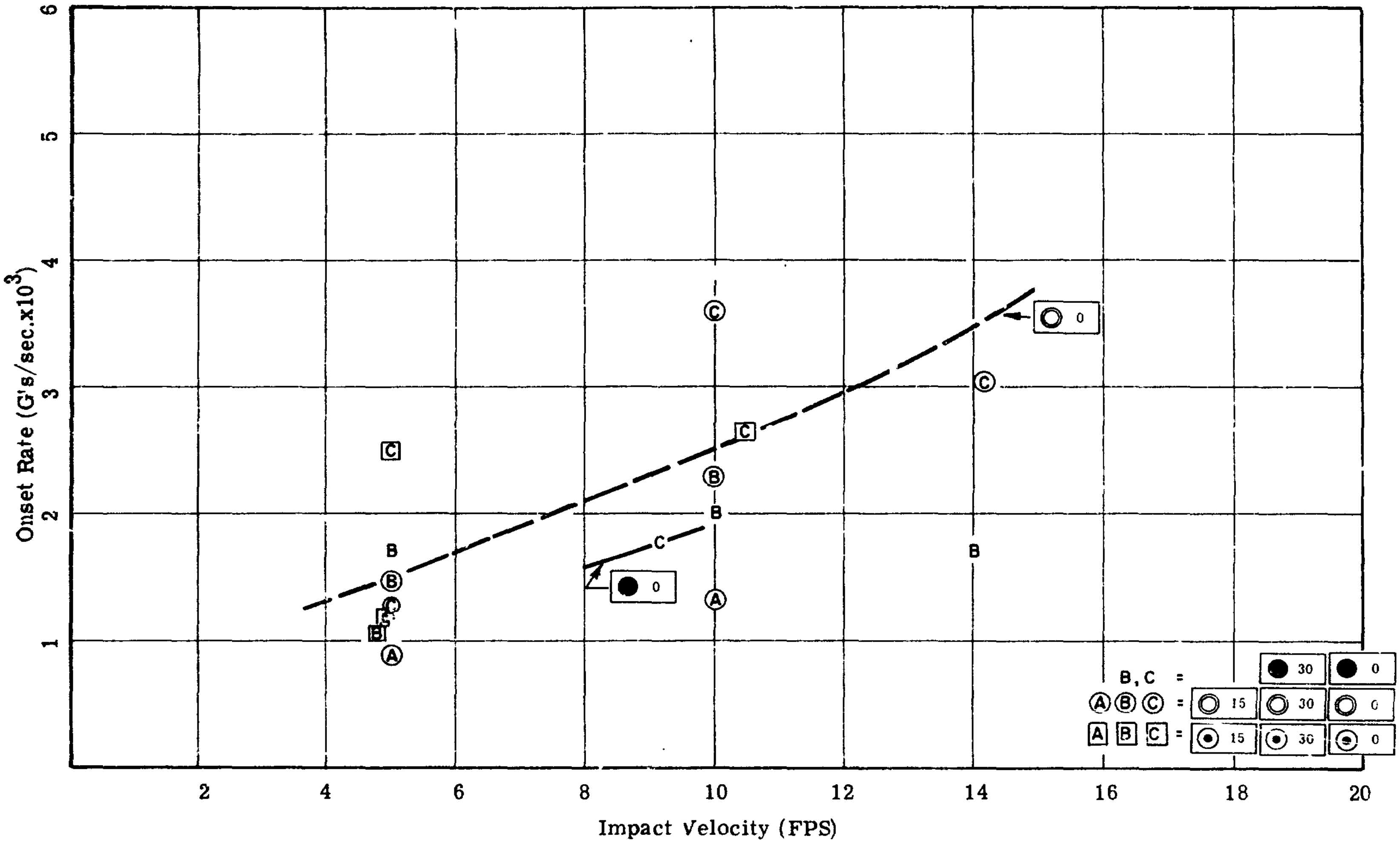


Figure 7-47.3. Load Onset Rate vs. Impact Velocity (Third Impact - Test No. 3)

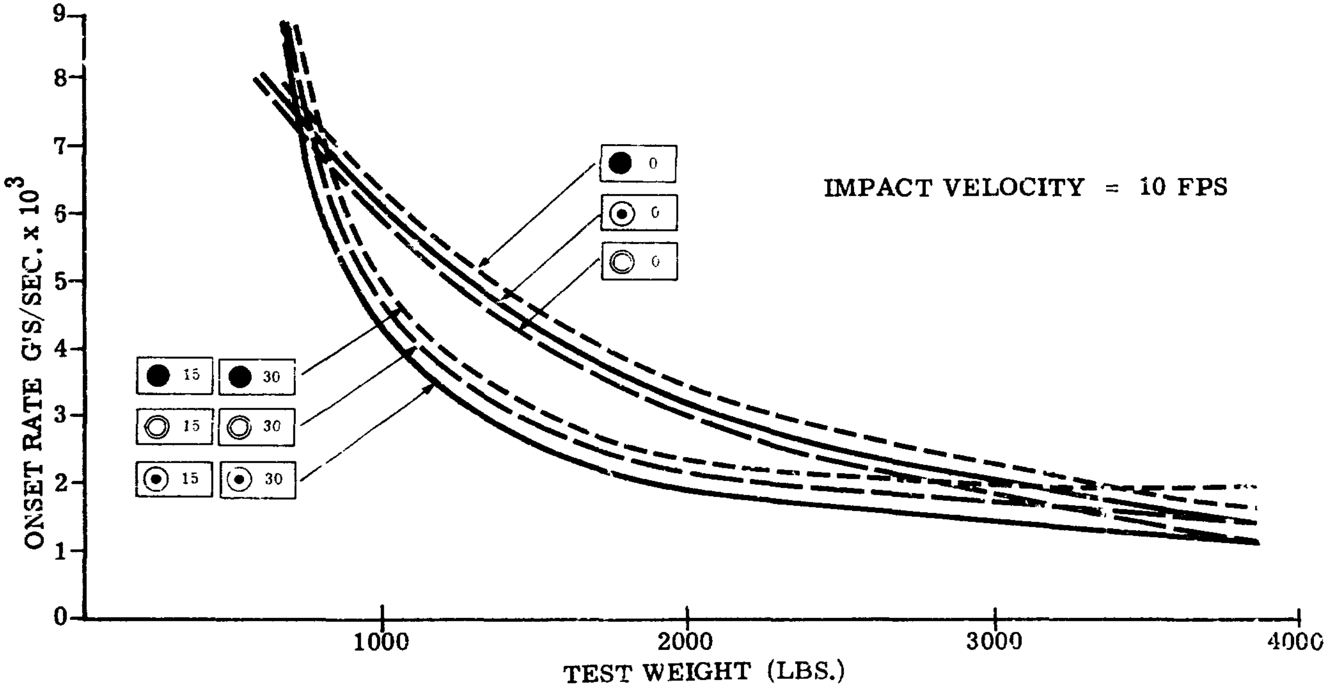


Figure 7-48. Load Onset Rate Versus Weight of Impacting Test Rig

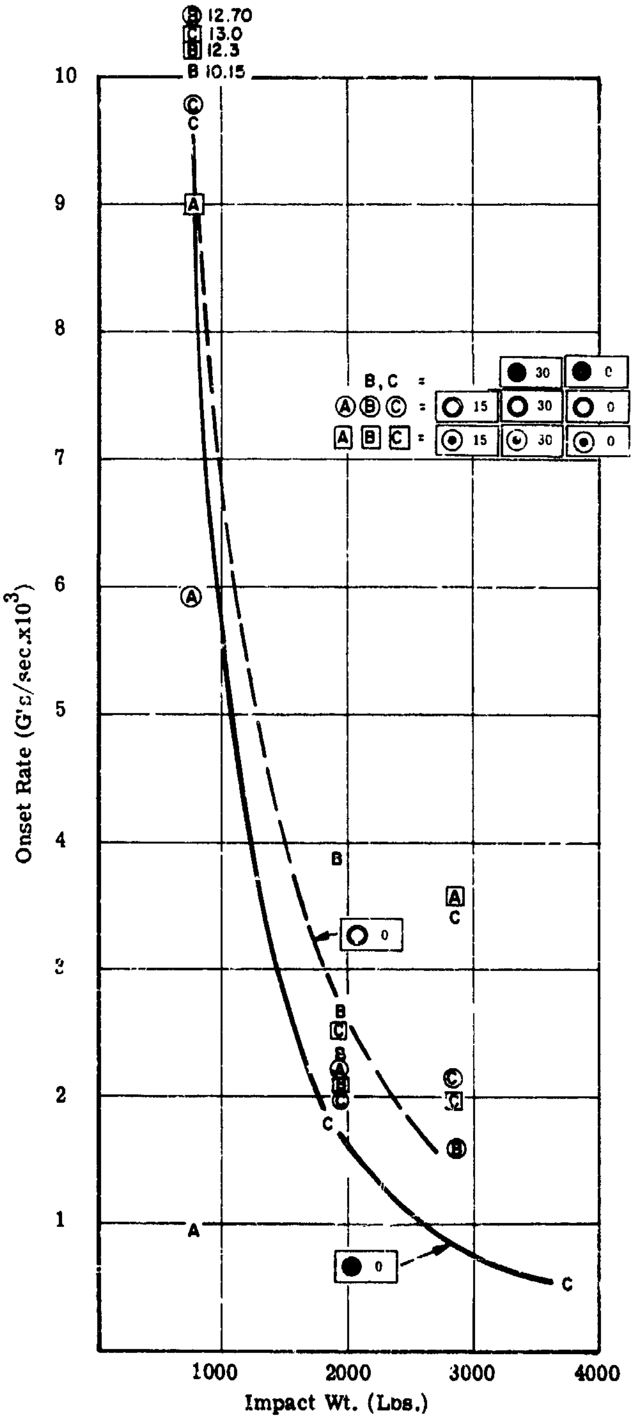


Figure 7-48A. Load Onset Rate vs. Impact Mass (Third Impact - Test No. 2)

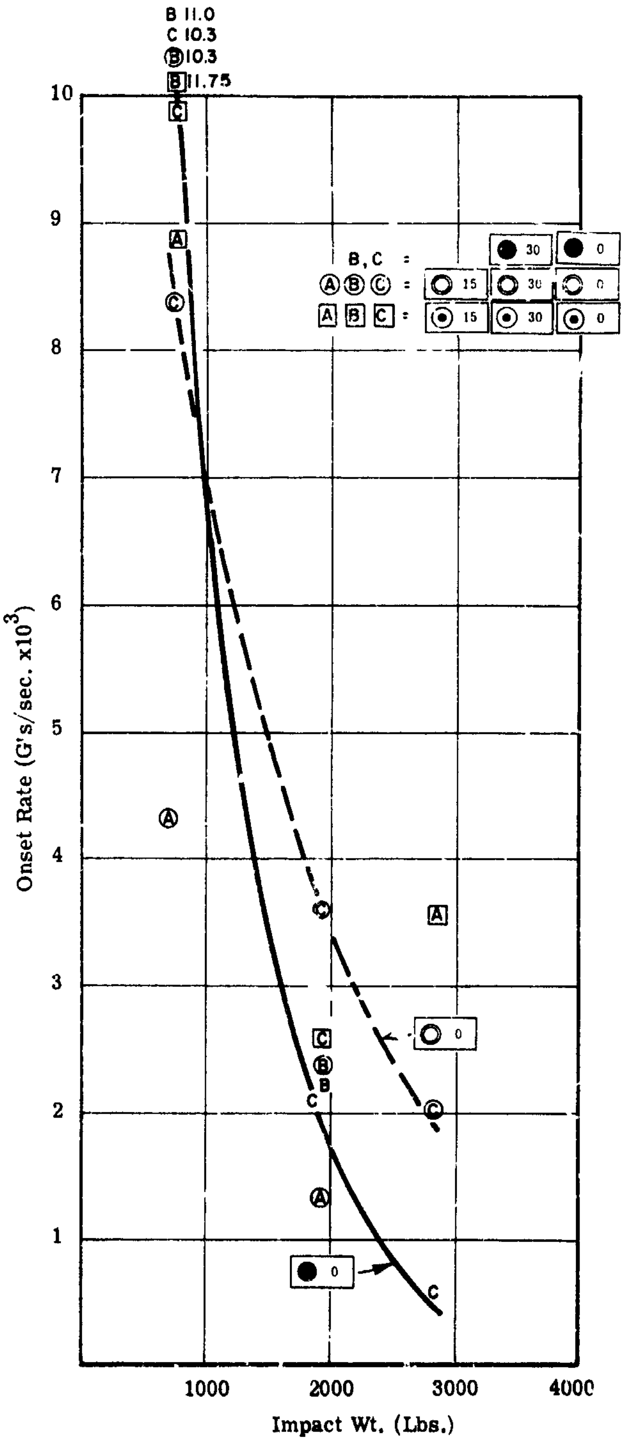


Figure 7-48B. Load Onset Rate vs. Impact Mass (Third Impact - Test No. 3)

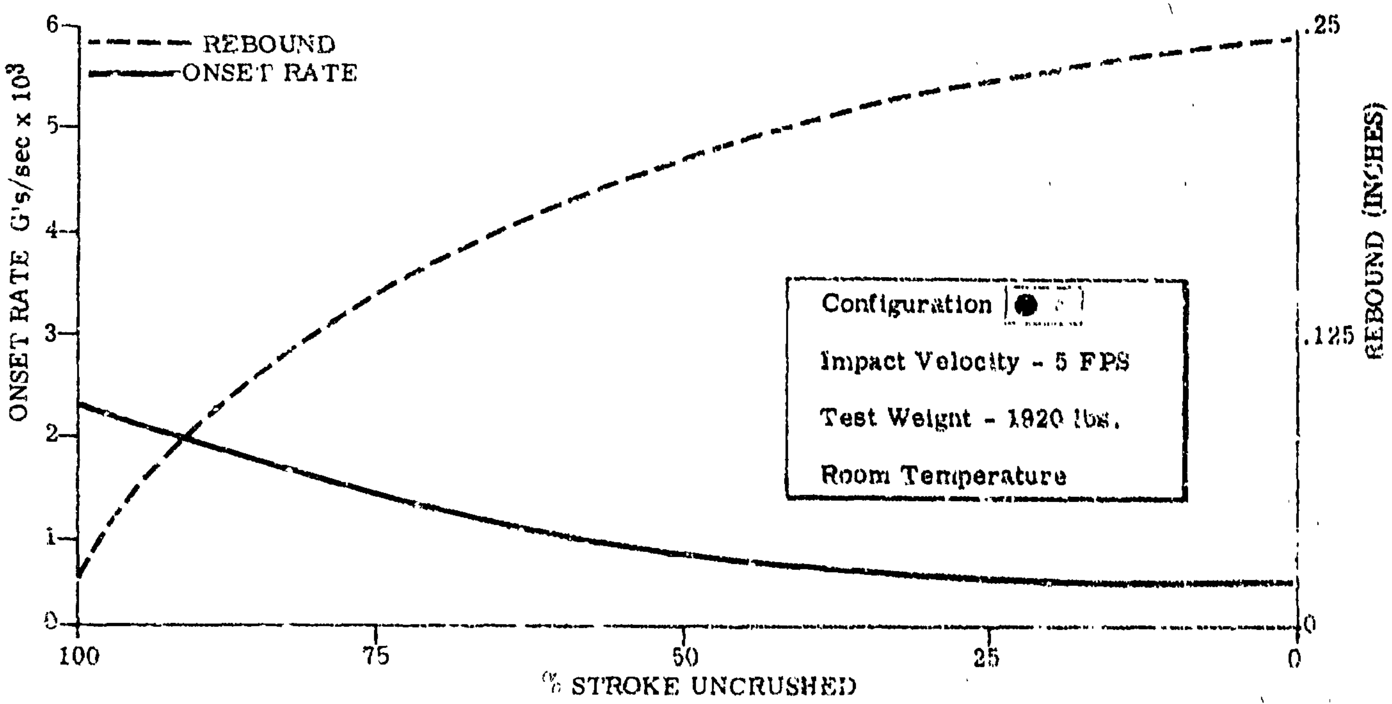


Figure 7-49. Load Onset Rate and Rebound Plotted Versus % of Total Available Stroke Remaining Uncrushed

Contrary to what was expected, however, the rebound increases as the uncrushed portion of the capsule becomes shorter. It had been predicted that the rebound would be primarily a function of the elastic or uncrushed portion of the capsule but all rebound curves (though not showing the same slopes) exhibit this increase, indicating an apparently larger effect by the crushed or plastically deformed section. The 0° cells of the highest strength generally show the largest rebound except in isolated cases of catastrophic specimen failure and those with the 30° cell axis usually provide more rebound than the 15° type.

In regard to spring rates, the values for full length specimens span the range from approximately 75,000 down to 12,000 lbs. in. as the capsule length decreases. The high crush strength 0° cell capsules in the "internal annular" configuration, and the low crush strength 30° cell in the external annular configuration define the upper and lower edges of the broad band described in Figure 7-50 which covers all configurations.

An indication of the repeatability of average crush load for a group of specimens of the same or similar configurations can be seen in Figure 7-51. This data was plotted from the average crush loads of end samples cut from each of the full length test specimens in Phase I and is compared with the target crush load as specified (5,500 lbs.).

Typical examples of the type of load versus time and load versus stroke plots which are provided through analysis of the oscillograph records taken during the dynamic tests are shown in Figures 7-52 and 7-53. Figure 7-52 is taken from one of the tests on a "circular solid" configuration with 0° cell axis and illustrates a uniform type of progressive crush action. Figure 7-53 is taken from a test on an "external annular" configuration with 15° cell and illustrates how the load gradually increases to an excessive value when a specimen such as this develops a secondary folding action resulting in an eventual binding action on the guide tube.

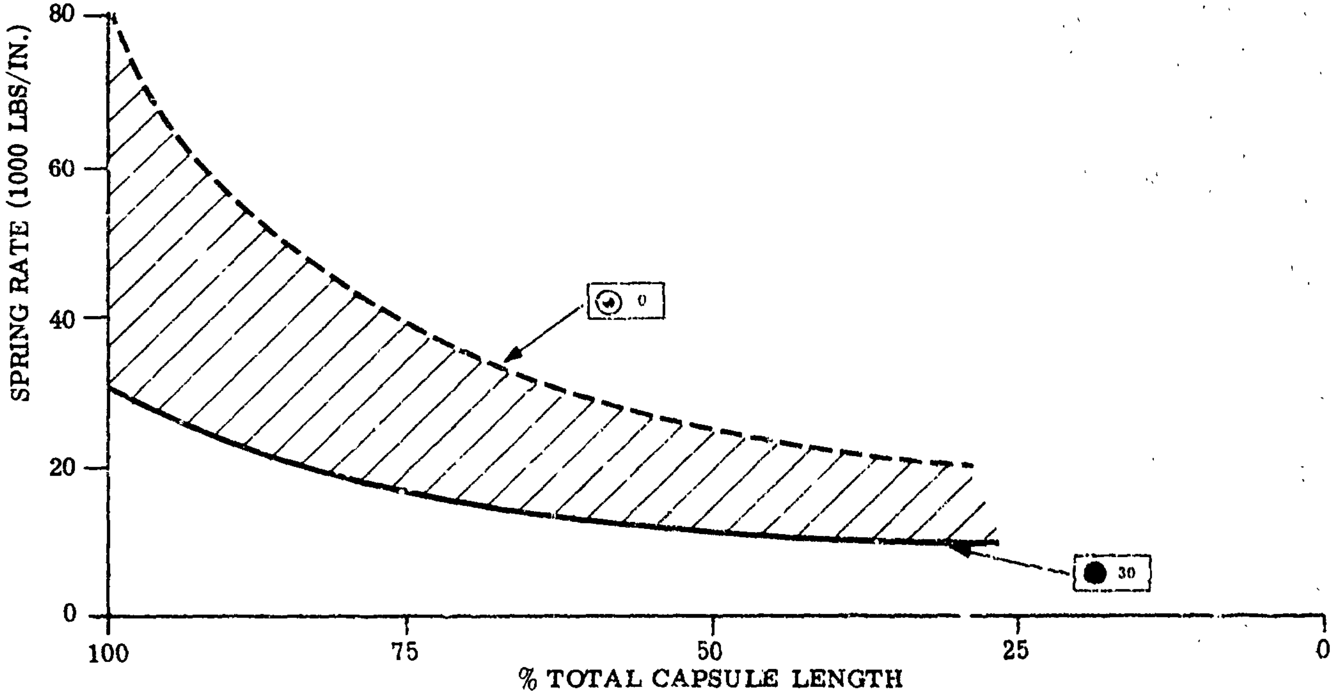


Figure 7-50. Spring Rate Versus % of Total Capsule Length

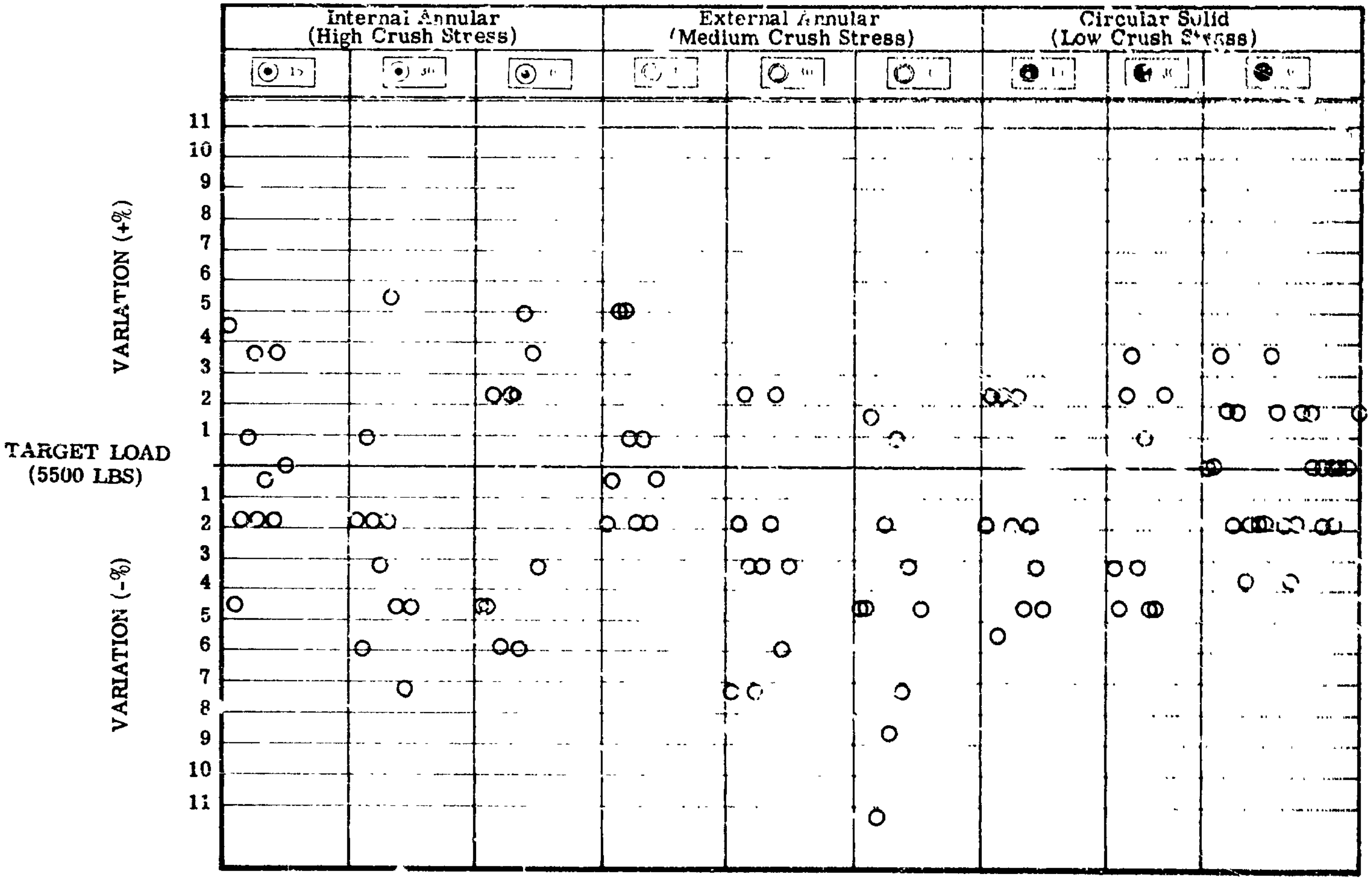


Figure 7-51. Percentage Variation From Target Crush Load (5,500 lbs.) for the Various Configurations

Other examples of load versus stroke plots may be seen in the Phase IB and Phase II Tests Results.

7.4 PHASE IB TESTS ON FULL LENGTH TEST SPECIMENS

7.4.1 General

Conclusion of Phase IA tests as previously pointed out in paragraph 7.3 resulted in the selection of the four configurations exhibiting the most satisfactory characteristics. Those configurations selected are listed under paragraph 7.4.2

Two specimens of each configuration were subjected to the test conditions as outlined in Section VI and Figure 6-1 and included static testing of one specimen and dynamic testing of the second; both under cryogenic temperature.

7.4.2 Phase IB Test Specimen Configurations

⊙ 30 SPX-168B - Internal Annular - 30° cell axis
⊙ 0 SPX-168C - Internal Annular - 0° cell axis
◎ 0 SPX-167C - External Annular - 0° cell axis
● 0 SPX-166C - Circular Solid - 0° cell axis

Photos of the crushed specimens as well as a full length uncrushed specimen and a cross-sectional example are shown for the above configurations in Figures 7-53A through 7-56. The specimen numbering system (detailed in paragraph 6.7 and Figure 6-2) has been used in identifying the specimens in regard to the impact velocity, test weight and temperature. General comments regarding the information obtained and data plotted is included in the Analysis of Test Results in paragraph 7.4.3.

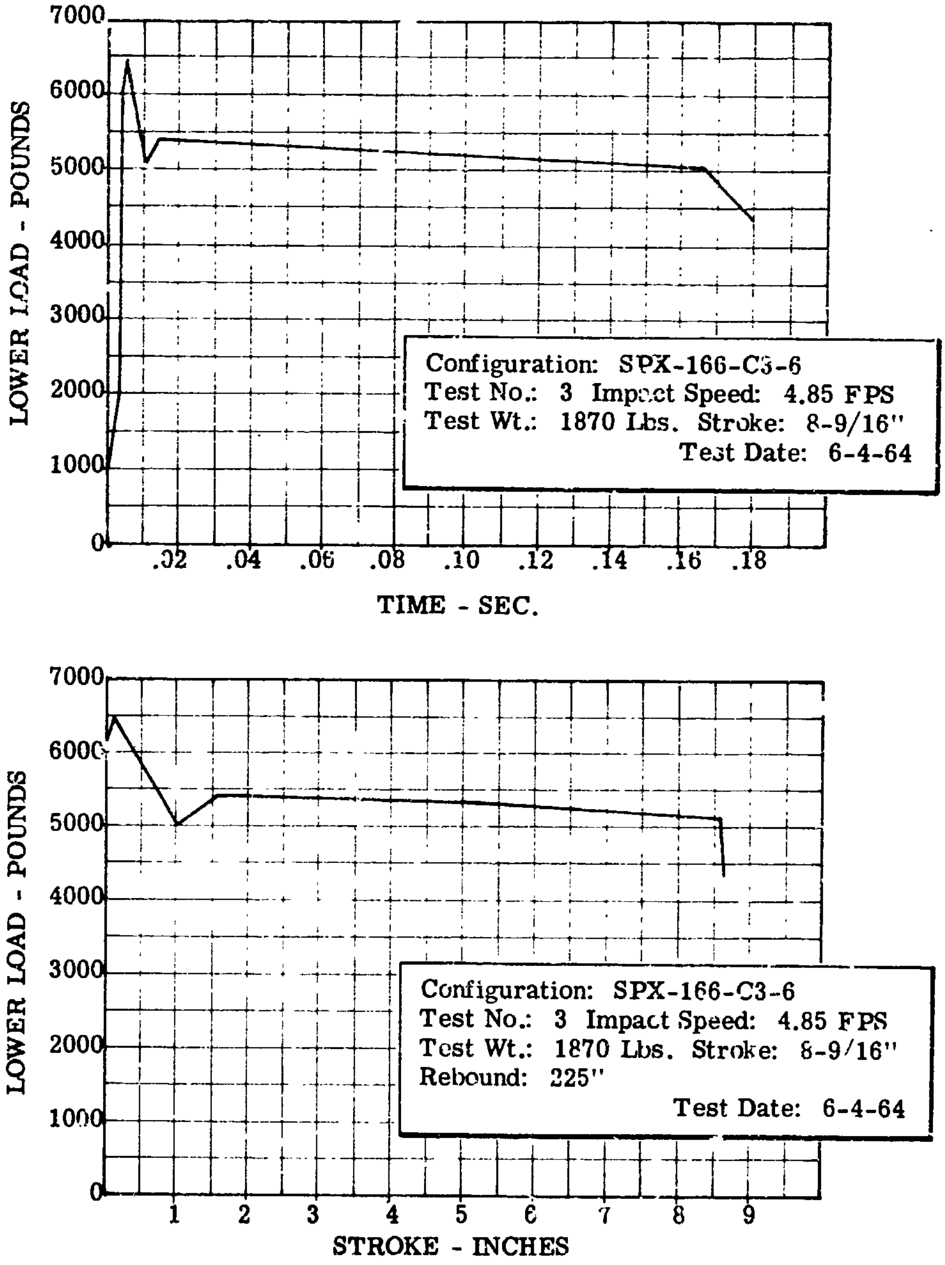


Figure 7-52. Typical Dynamic Crush Plots from Test Data on Circular Solid Specimens With 0° Cell

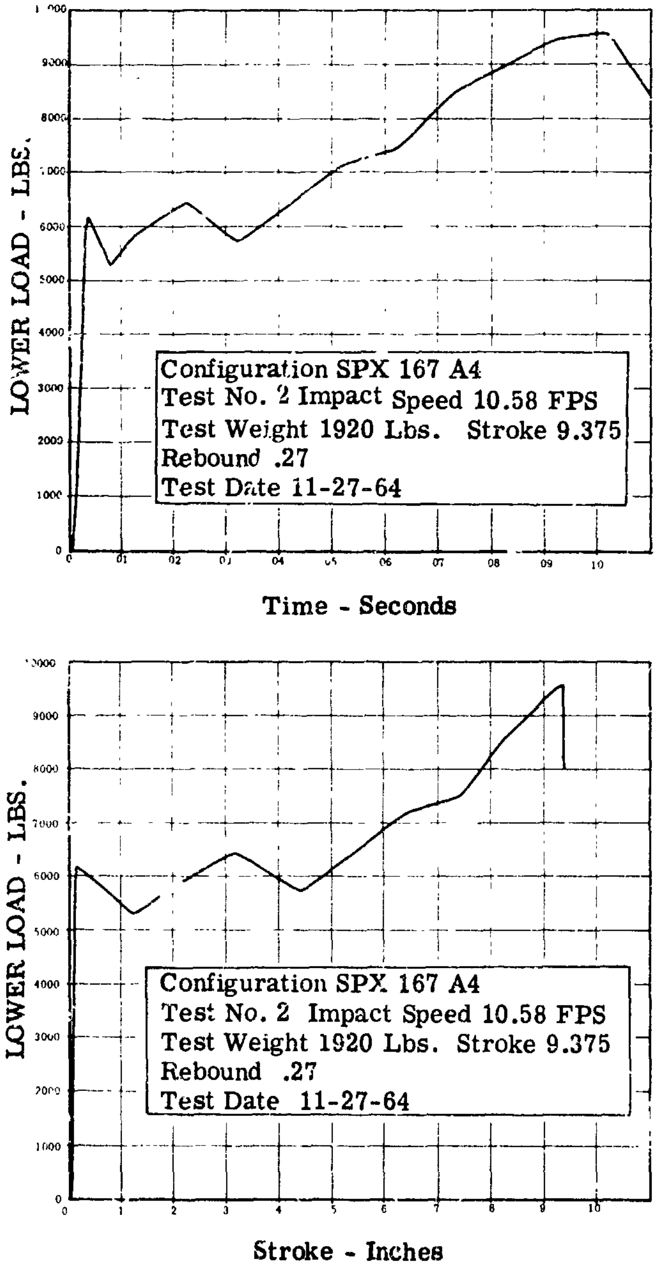


Figure 7-53. Typical Dynamic Crush Plots from Test Data on External Annular Specimens With 15° Cell

TYPE SPX-168-8

Figure 7-53A. Pictorial Summary of Specimens (◉ 30) Tested in Phase IB For Number Identification With Test Conditions, See Figure 6-2

Figure 7-54. Pictorial Summary of Specimens (◉ 0) Tested in Phase IB For Number Identification With Test Conditions, See Figure 6-2

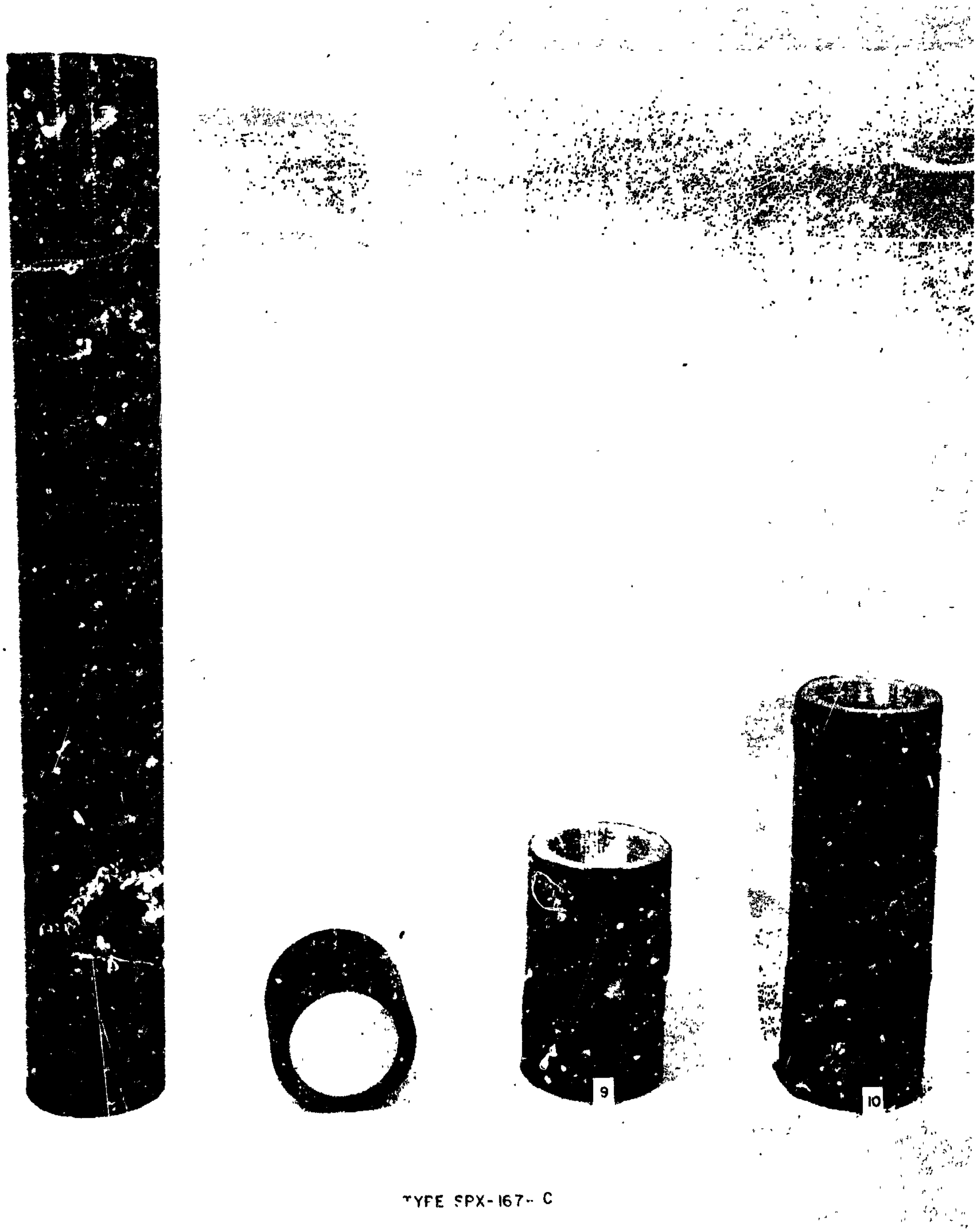


Figure 7-55. Pictorial Summary of Specimens (◎ 0) Tested in Phase IB For Number Identification With Test Conditions, See Figure 6-2

Figure 7-56. Pictorial Summary of Specimens (●) Tested in Phase IB
For Number Identification With Test Conditions, See Figure 6-2

7.4.3 Analysis of Phase IB Test Results

The test data was acquired in the same manner as described in Phase IA with both static and dynamic results of the tests being recorded. Figures 7-57 through 7-60 show the static crush loads obtained and Figures 7-61 and 7-62 are typical examples of the dynamic test results obtained at -260°F. The data reduced from the records is tabulated in Figure 7-63.

Certain data was plotted from the various test records to assist in determining the two configurations which were to be used for the final Phase II evaluation under the full range of temperatures.

Some of this data, although plotted before the initiation of the Phase II program is included in that section (VIII) where comparison is made over the full range of the (4) temperatures.

Study of these plots and the tabular data from Phase IB (Figure 7-63) resulted in the selection of the two configurations listed for use in Phase II.

◯ SPX-167C - External Annular - 0° cell axis

● SPX-168C - Circular Solid - 0° cell axis

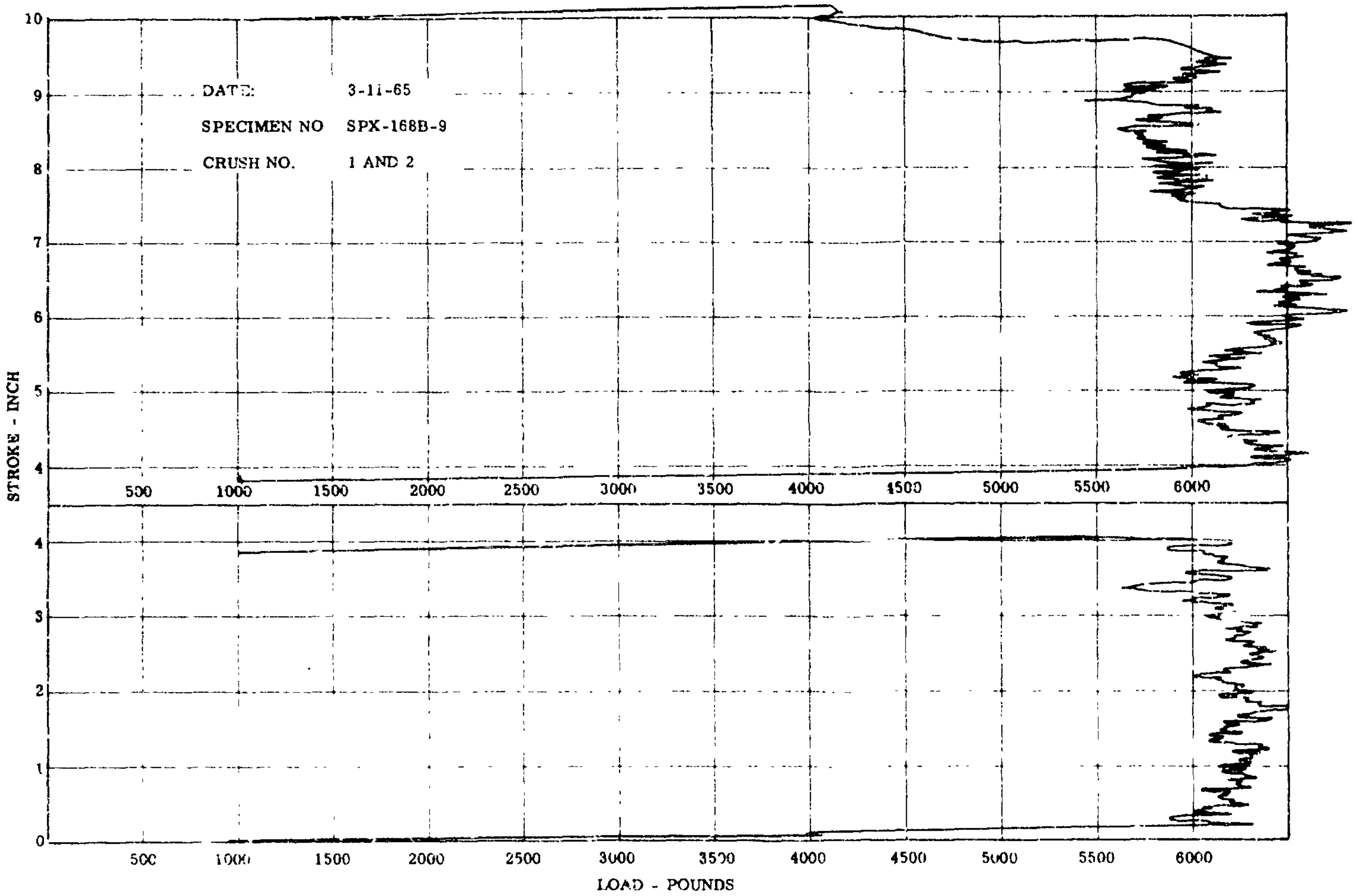


Figure 7-57. Static Crush Record for Phase IB Test Specimen ($\boxed{\odot\ 30}$) -260°F For Number Identification With Test Conditions, See Figure 6-2

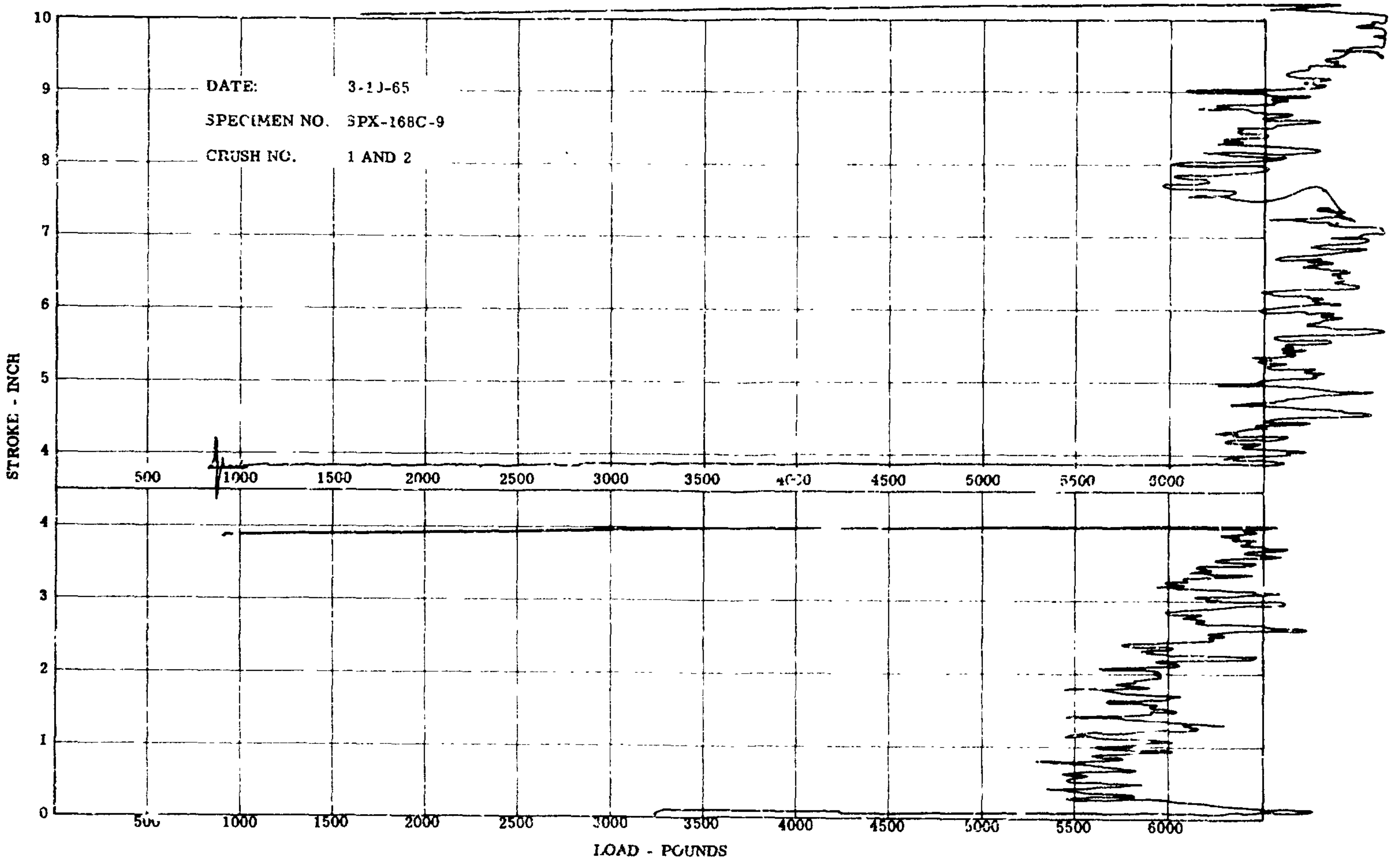


Figure 7-58. Static Crush Record for Phase IB Test Specimen (☉) -260°F
For Number Identification With Test Conditions, See Figure 6-2

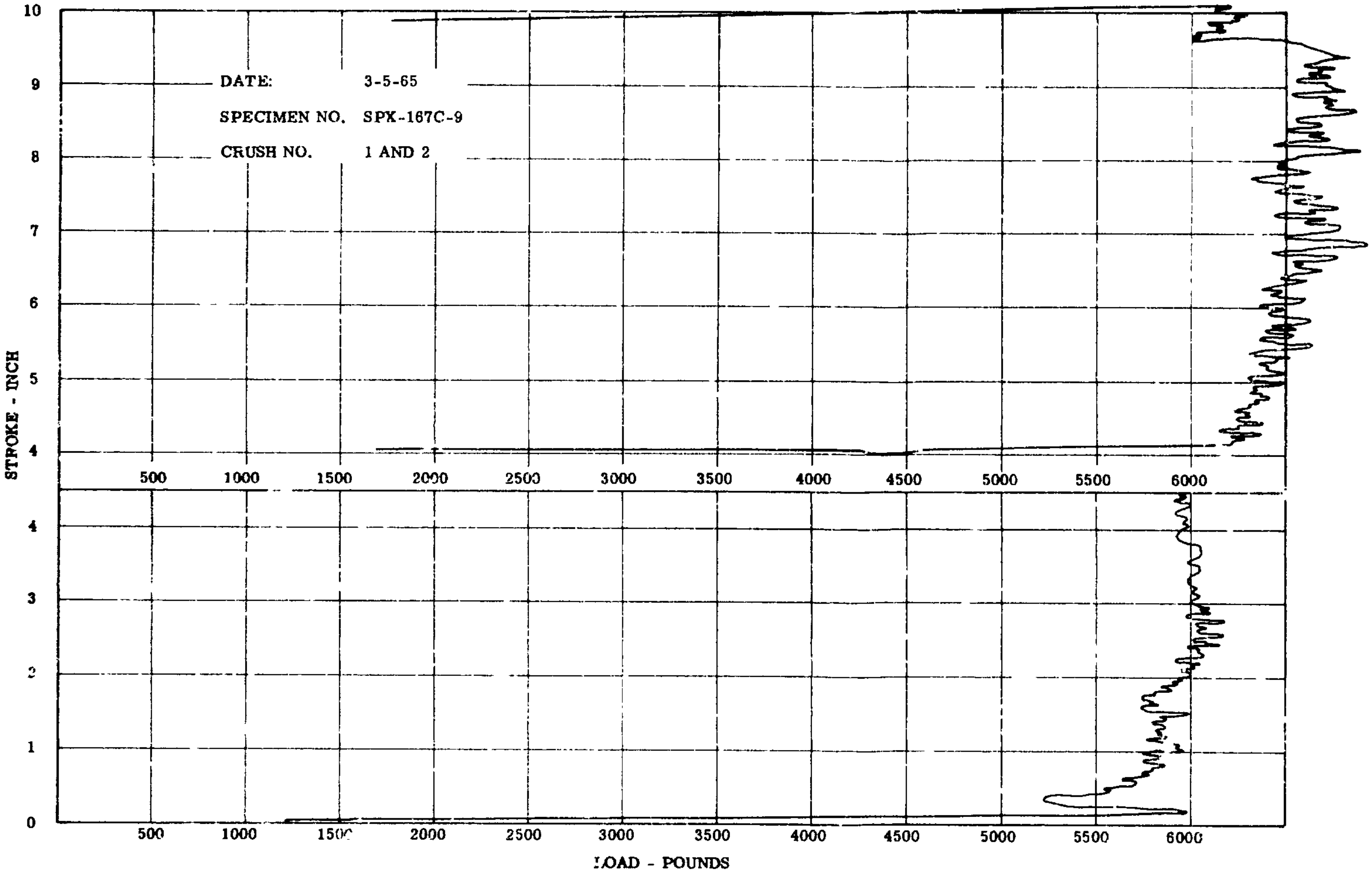
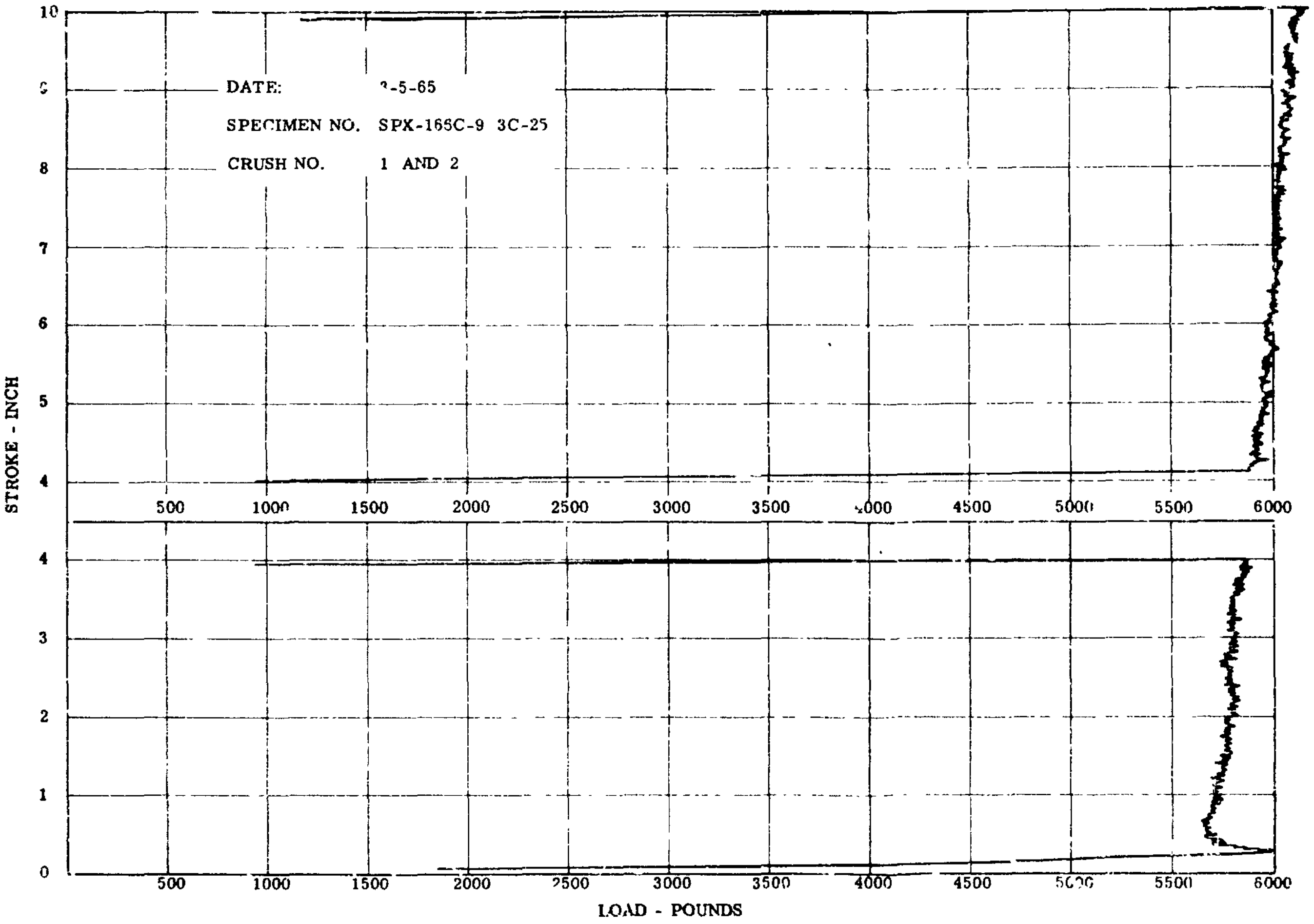


Figure 7-59. Static Crush Record for Phase IB Test Specimen (◎) -260°F
For Number Identification With Test Conditions. See Figure 6-2



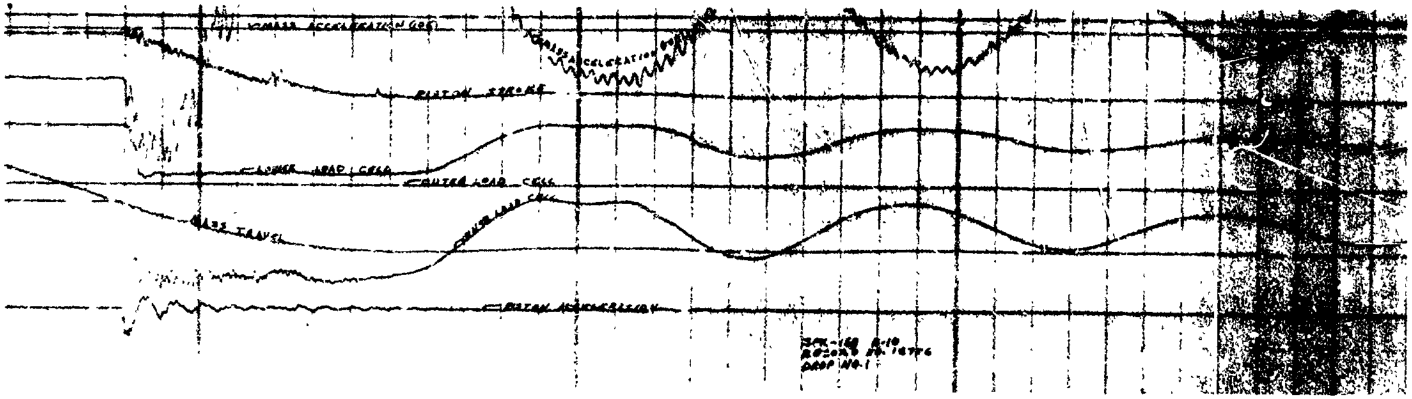
DATE: 3-5-65

SPECIMEN NO. SPX-165C-9 3C-25

CRUSH NO. 1 AND 2

Figure 7-60. Static Crush Record for Phase IB Test Specimen (● ") -260°F
For Number Identification With Test Conditions, See Figure 6-2

SPX-168-B10



SPX-168-C10

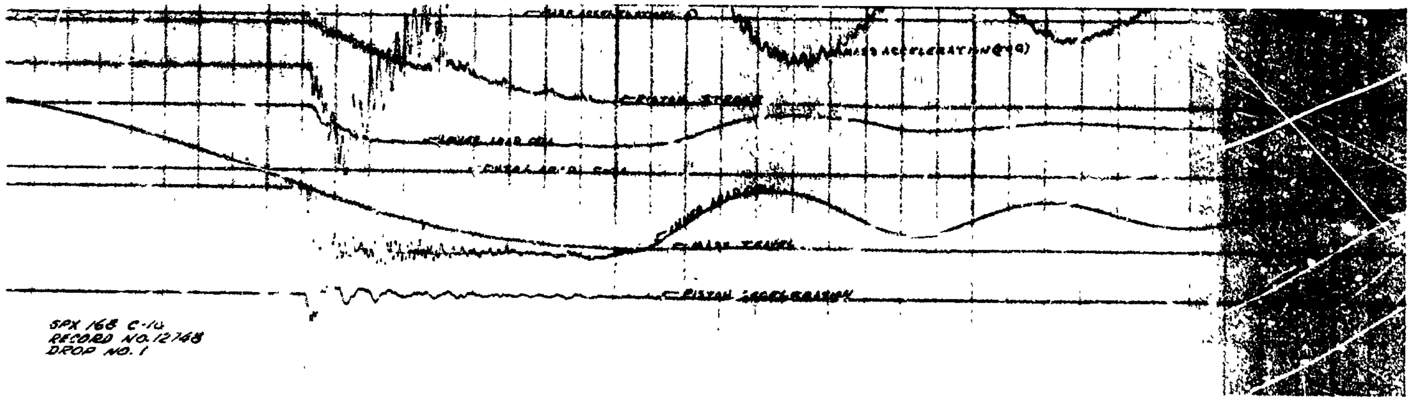
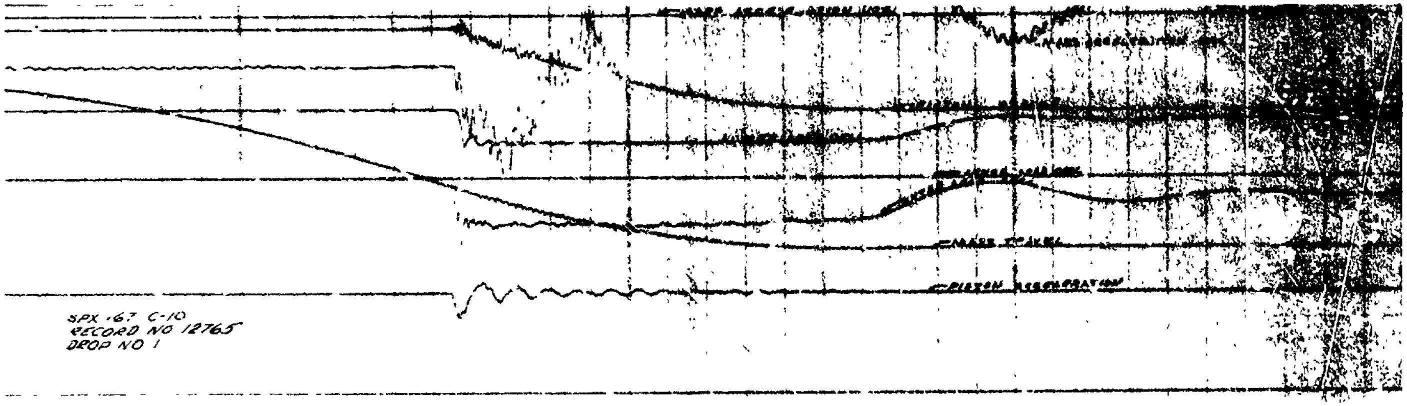


Figure 7-61. Oscillograph Records of Dynamic Tests on Phase IB Specimens for Number Identification With Test Conditions, See Figure 6-2; Upper: ⊙ 30 -260°F , Lower: ⊙ -260°F

SPX-167-C10



SPX-166-C10

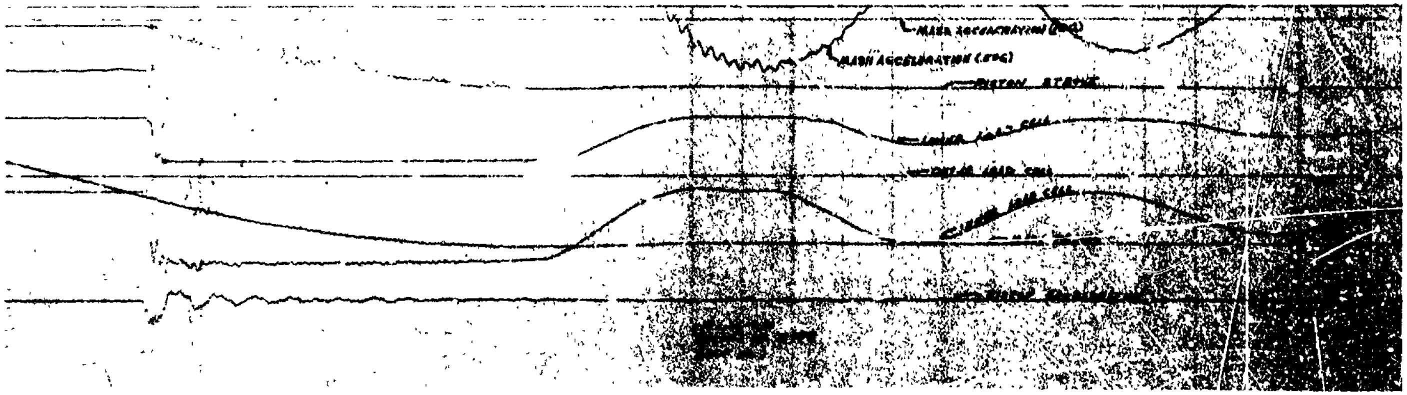


Figure 7-62. Oscillograph Records of Dynamic Tests on Phase IB Specimens for Number Identification With Test Conditions, See Figure 6-2; Upper: ◯ -260°F , Lower: ● -260°F

(No's SPX168B9 Thru SPX166C10)

Specimen Number		Average Load of End Sample	Diameter		Cross-Sectional Area	Length	Weight	Test No.	Impact Weight	Impact Velocity		Average Crush Load	Initial Peak Loads			Load Onset Rate		Stroke	Rebound	Vacuum 3x10^{-1} TORR Req'd	Temperature		Time
Bendix	Hexcel	(Lbs.)	O.D. (In.)	I.D. (In.)	(In^2)	(In.)	(Lbs.)		(Lbs.)	Target (FPS)	Actual (FPS)	(Lbs.)	Max. (Lbs.)	Min. (Lbs.)	**True (Lbs.)	(Lbs./Sec x 10^6)	(G's/Sec x 10^3)	(In.)	(In.)	(Equal to 300 Microns or Less)	Target (°F)	Actual (°F)	(Minutes)
SPX168B9	1B-7	5550	3.00	2.00	15.69	52.50	1.81	1		Static								4		300	-260	-260	
								2		Static								6		300	-260	-277	
								3		Static								8			-260	[illegible]	
SPX168B10	1B-10	5365	3.00	2.00	15.69	52.50	1.94	1	1920	5	5.04		6973	6436	6900	2.788	1.45	2.13	18	200	-260	-215	
								2		10	10.65		7377	6436	6900	6.32	3.29	9.00	11	250	-260	-255	
								3		14	14.83			5092	5495	4.02	2.09	19.06	46	300	-260	-273	
SPX168C9	1C-21	5250	3.00	2.00	15.69	56.00	3.13	1		Static								4		200	-260	-235	
								2		Static								6		200	-260	-255	
								3		Static								10		250	-260	-254	
								4		Static								10		300	-260	-279	
								5		Static										300	-260	-286	
SPX168C10	1C-16	5175	3.00	2.00	15.69	56.00	2.63	1	1920	5	5.05		2224	2089		7.8	395	2.75	.07	90	-260	-202	
								2		10	10.61		6420	5320	6400	1.094	570	11.00	.06	200	-260	-254	
								3		14	14.58		6590	5369	6101	3.364	1.752	16.88	.19	300	260	-252	
SPX167C9	2C-35		7.38	5.50	75.80	50.50	4.13	1		Static								4		150	-260	-272	
								2		Static								6		200	-260	-279	
								3		Static								10		250	-260	-282	
								4		Static								10		300	-260	-271	
								5		Static								10		300	-260	276	
SPX167C10	2C-39	4875	7.38	5.50	75.80	50.50	4.32	1	1920	5			5375	4200	5375	3.188	1.66	3.06	.02	150	260	-288	
								2		10	10.57		7270	5077	6640			10.88	.08	200	-260	-285	
								3		14			8460	4951	7320			16.38	10	300	-260	-272	
SPX166C9	3C-25	5550	6.25		122.50	52.00	2.81	1	1920	Static								4		200	-260	-213	
								2		Static								6		250	-260	-269	
								3		Static								10		300	-260	-270	
								4		Static								10		300	-260	-272	
SPX166C10	3C-31		6.25		122.50	52.00	2.88	1	1920	5			5635	5237	5635	4.28	2.23	2.38	.10	80	-260	-254	
								2		10	11.08		6420	6120	6100	5.56	2.90	9.50	115	100	-260	-266	
								3		14			7987	5916	7740			15.50	.10	190	-260	-276	

Figure 7-63. Tabular Test Data Summary for Phase IB Full Length Test Specimens SPX-168B-9 Through SPX-166C-10

SECTION VIII

PHASE II TESTS

8.1 GENERAL

Phase II of the project was initiated immediately upon the successful conclusion of the Phase IB test program which had resulted in selection of the two configuration exhibiting the most satisfactory combination of performance characteristics. The first step following the selection of these two configurations as identified in paragraph 8.2, involved procurement of a quantity of each configuration for testing under the varied environmental conditions. Test conditions included both static and dynamic loadings with variations in impact velocities and test weights, and with the further added temperature variations of +300°F, +150°F, -150°F and -260°F in combination with the vacuum of 3×10^{-1} TORR. Section VI and Figure 6-1 are again referred to for Test Procedures.

8.2 PHASE II - TEST SPECIMEN CONFIGURATIONS


SPX-167C - External Annular - 0° Cell Axis


SPX-166C - Circular Solid - 0° Cell Axis

Thirty-one specimens of each of the above configurations were evaluated under the several environmental conditions. Photos of these crushed specimens as well as a full length uncrushed specimen and a cross sectional example are shown for these configurations in Figures 8-1 thru 8-8. The specimen numbering system (detailed in paragraph 6.7 and Figure 6-2) has been used in identifying the specimens regarding the

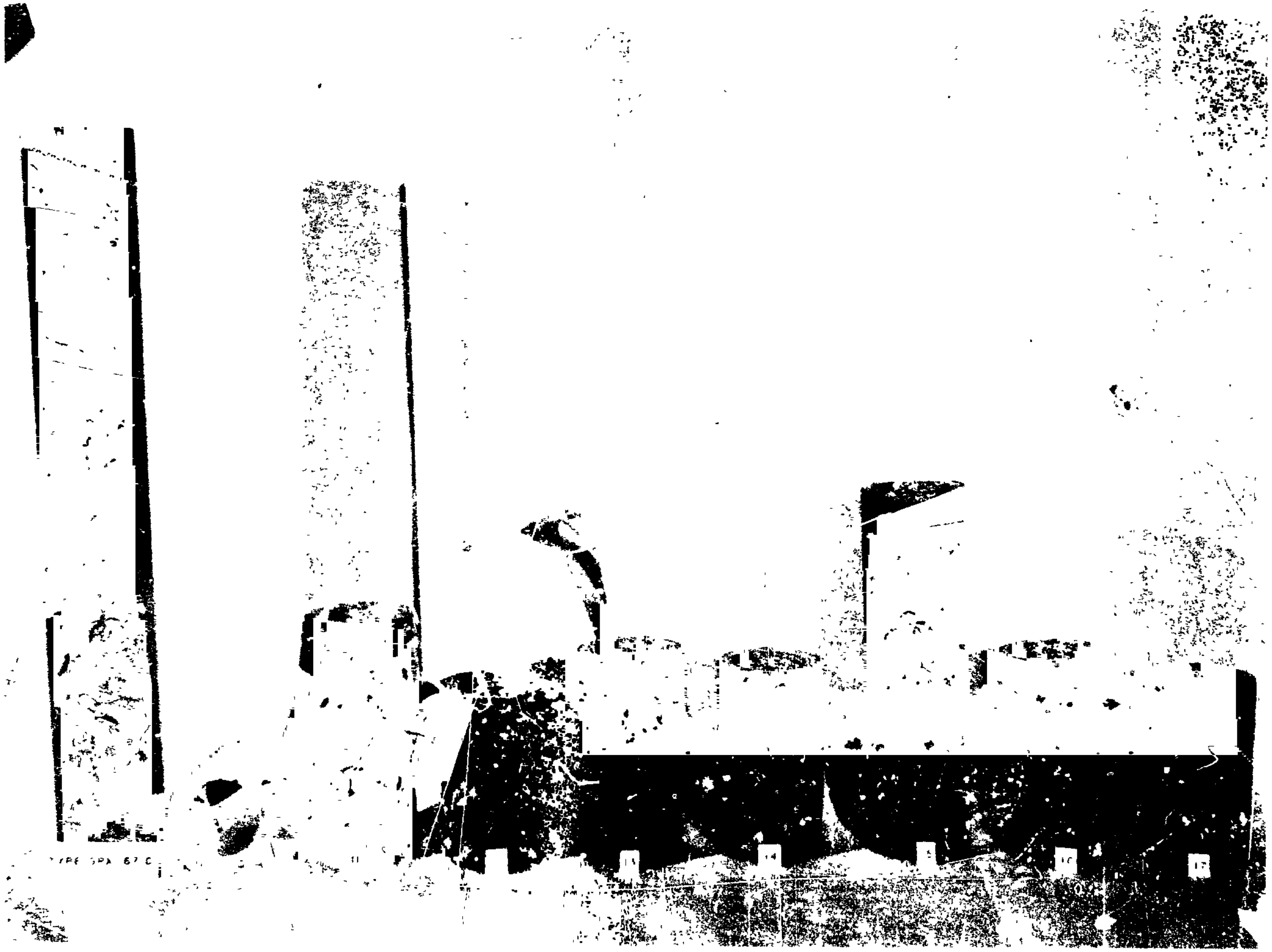


Figure 8-1 Pictorial Summary of Specimens (◎ 6) Tested in Phase II; Temperature -260°F
For Number Identification With Test Conditions, See Figure 6-2

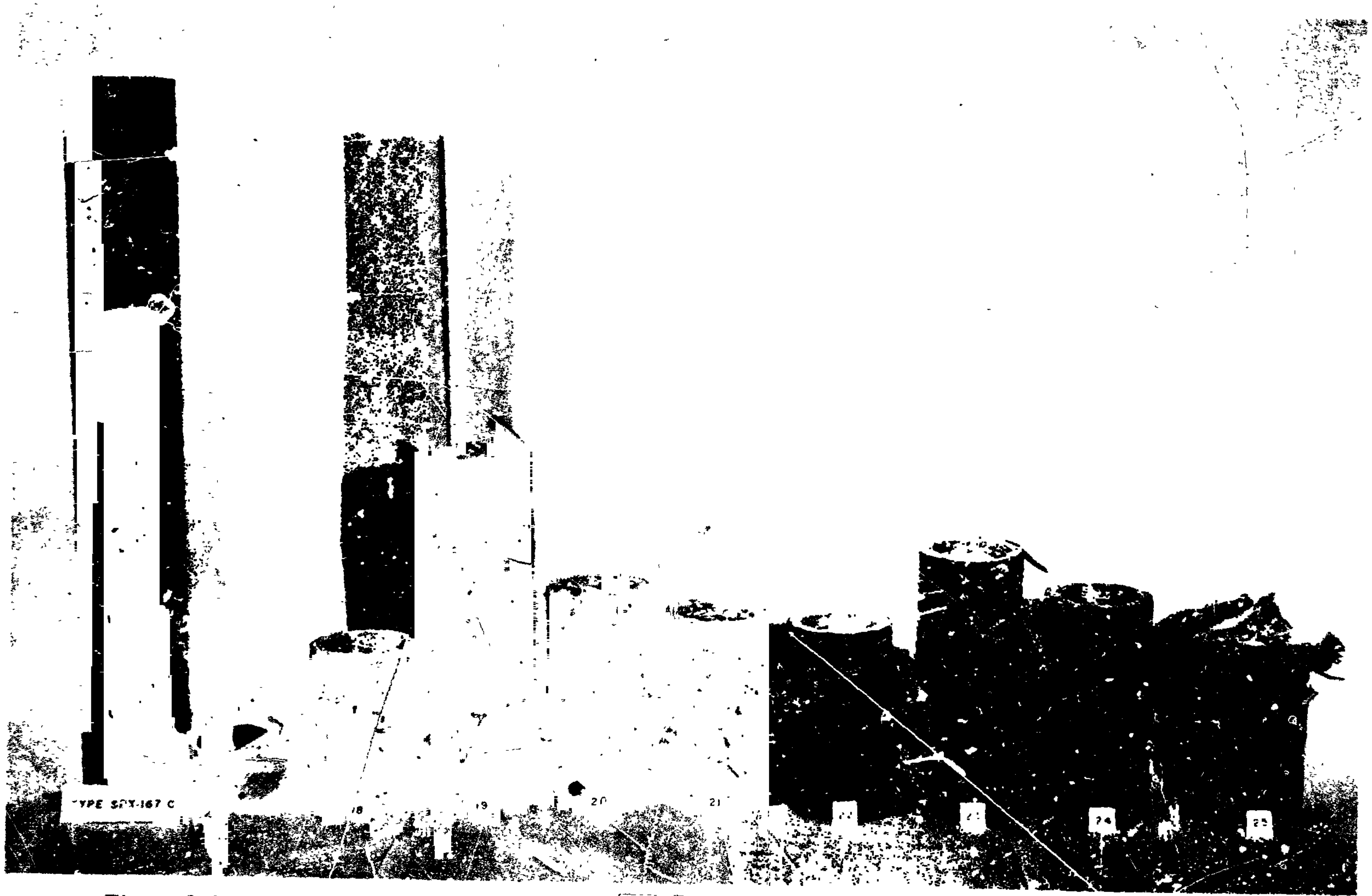


Figure 8-2. Pictorial Summary of Specimens (©) Tested in Phase II; Temperature -150°F For Number Identification With Test Conditions, See Figure 6-2

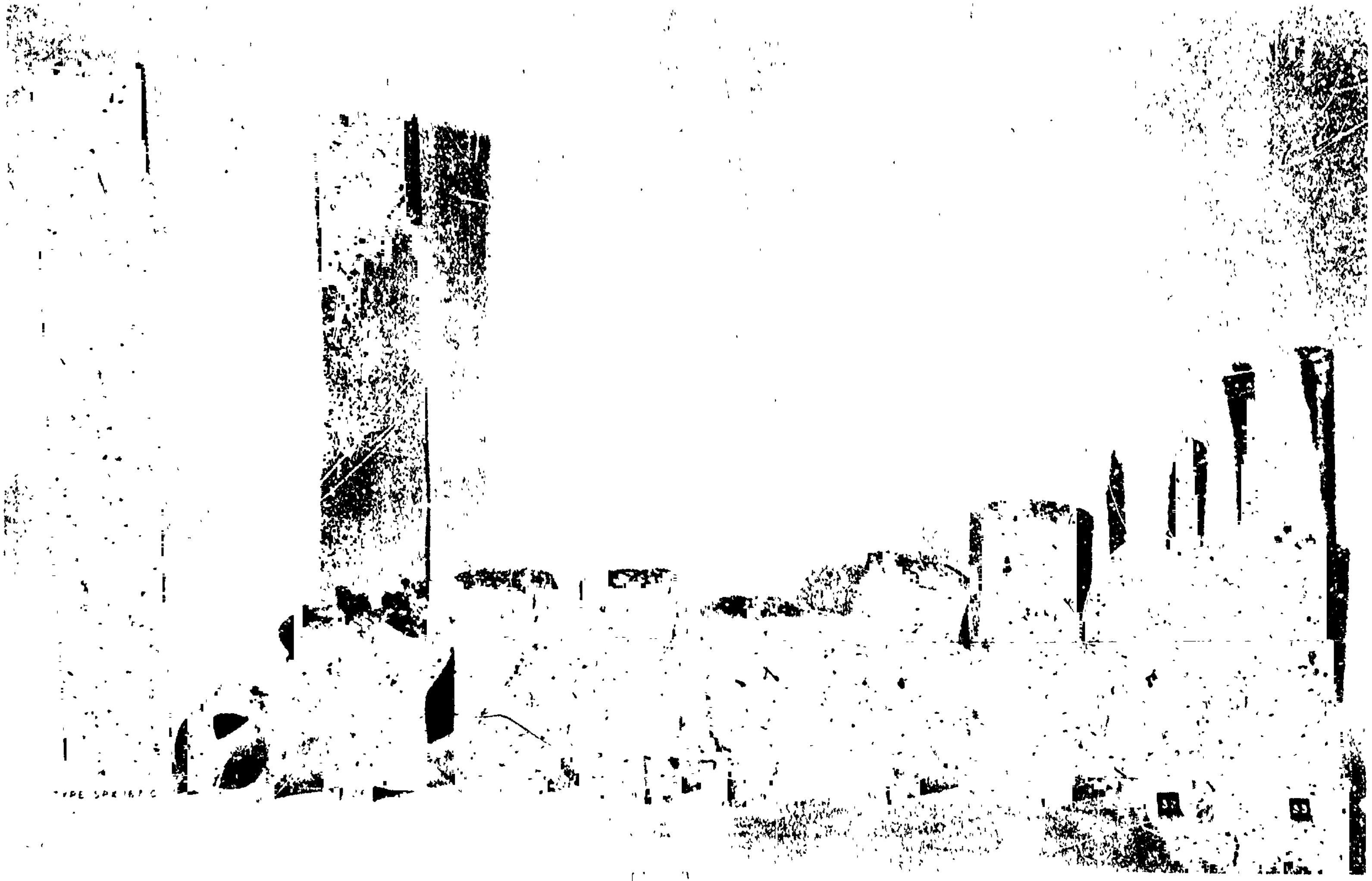


Figure 8-3. Pictorial Summary of Specimens ([illegible]) Tested in Phase II; Temperature +150°
For Number Identification With Test Conditions, See Figure 6-2

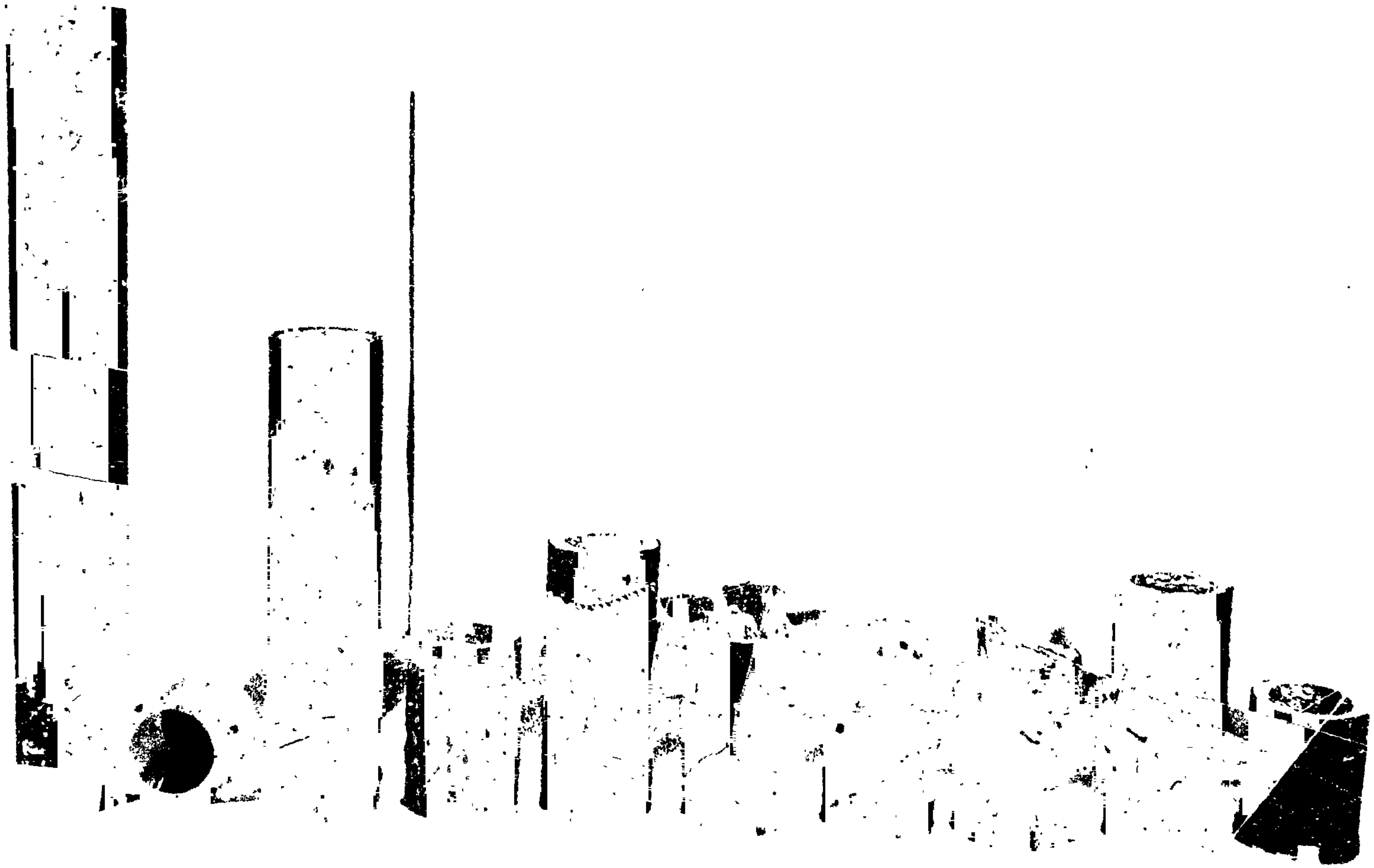


Figure 8-4. Pictorial Summary of Specimens ([illegible]) Tested in Phase II; Temperature +300°F For Number Identification With Test Conditions, See Figure 6-2

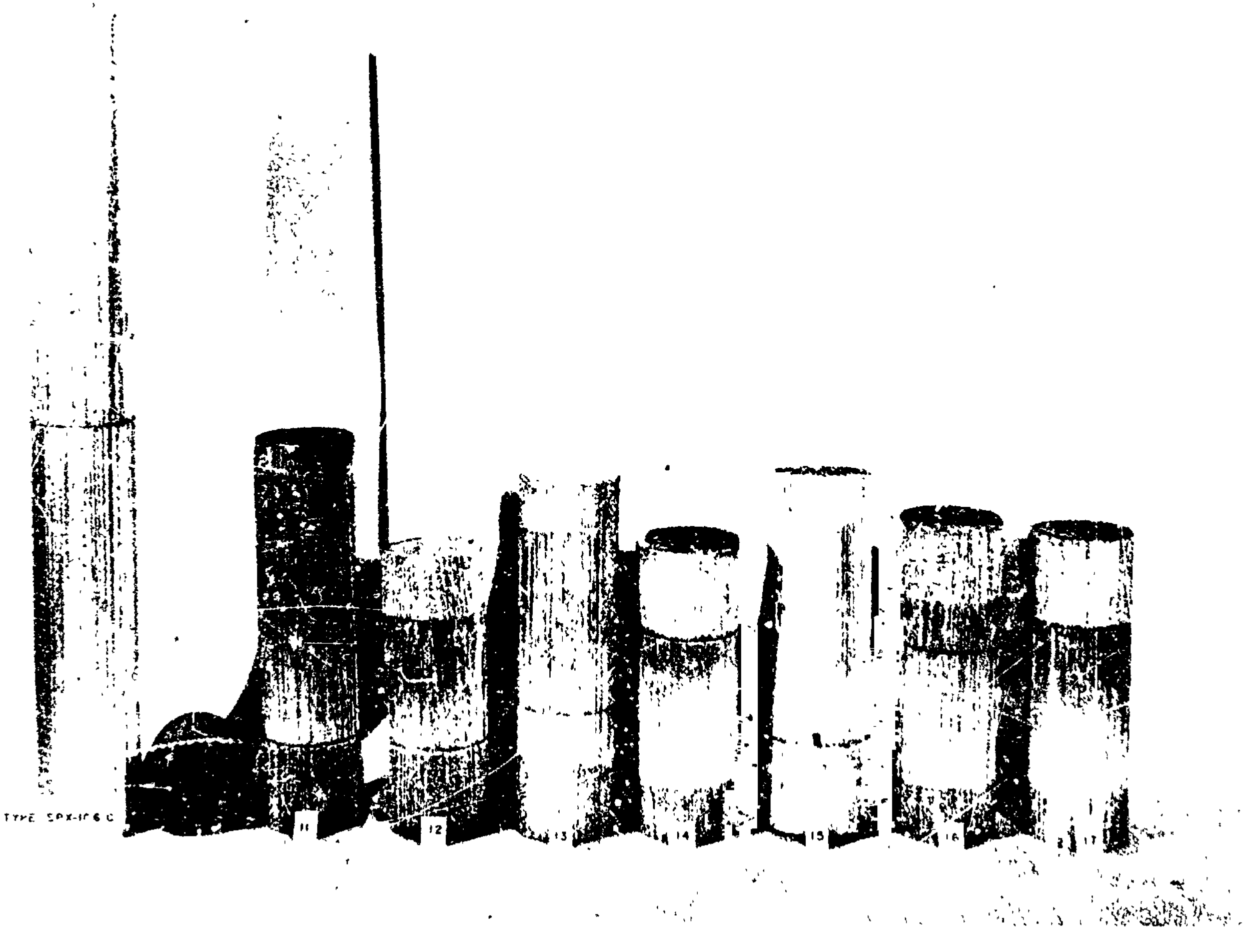


Figure 8-5. Pictorial Summary of Specimens (● ○) Tested in Phase II; Temperature -260°F For Number Identification With Test Conditions, See Figure 6-2

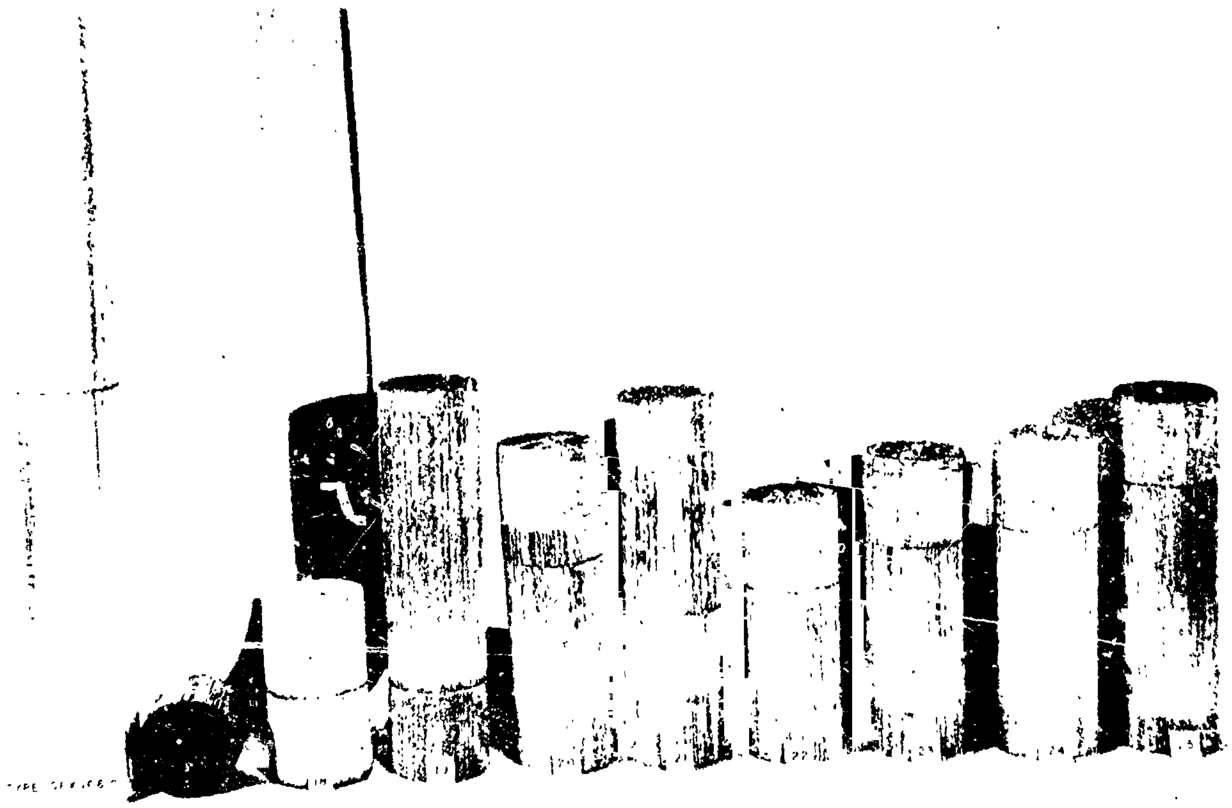


Figure 8-6. Pictorial Summary of Specimens (●) Tested in Phase II: Temperature -150°F For Number Identification With Test Conditions, See Figure 6-2

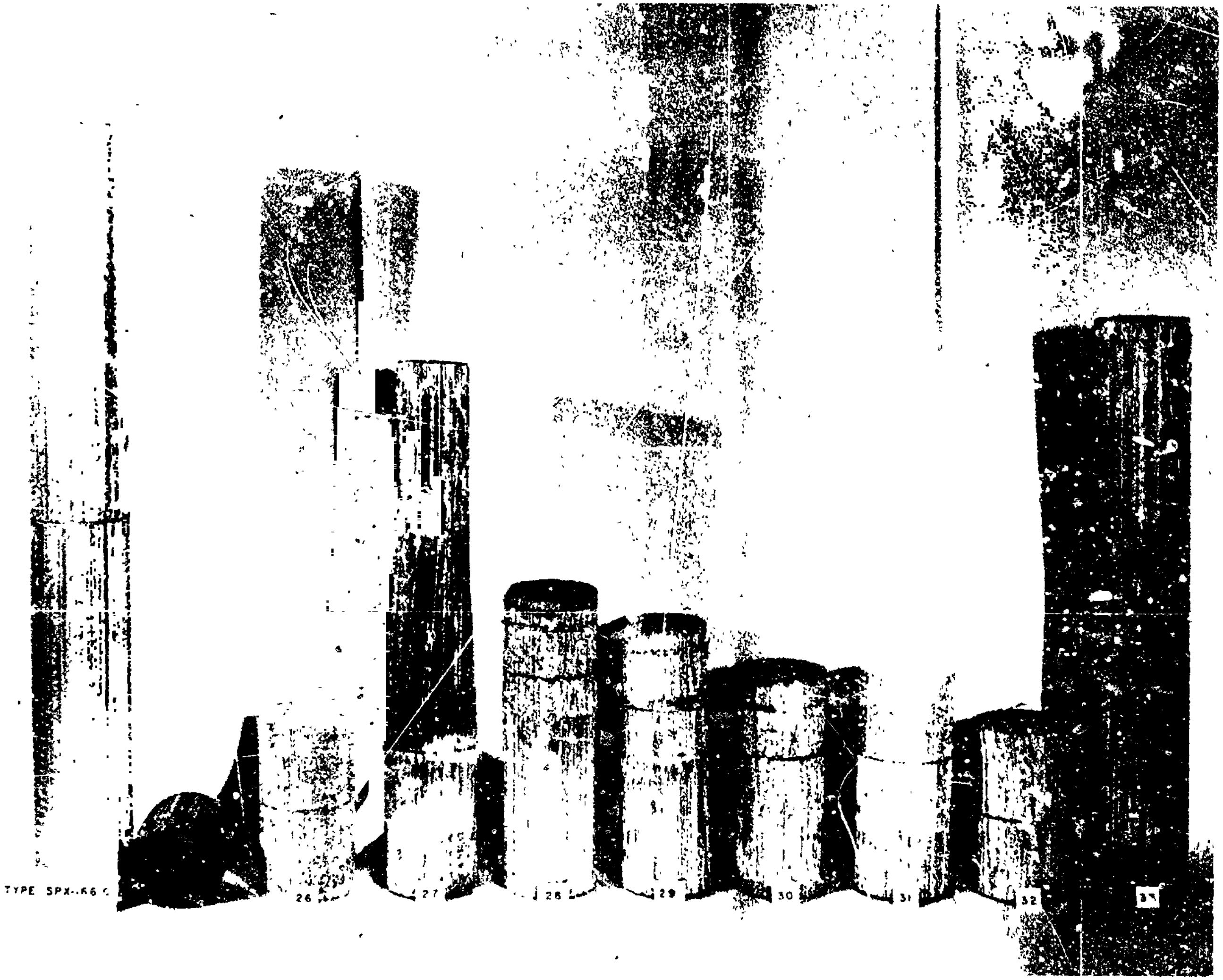


Figure 8-7. Pictorial Summary of Specimens (●) Tested in Phase II; Temperature + 150°F For Number Identification With Test Conditions, See Figure 6-2

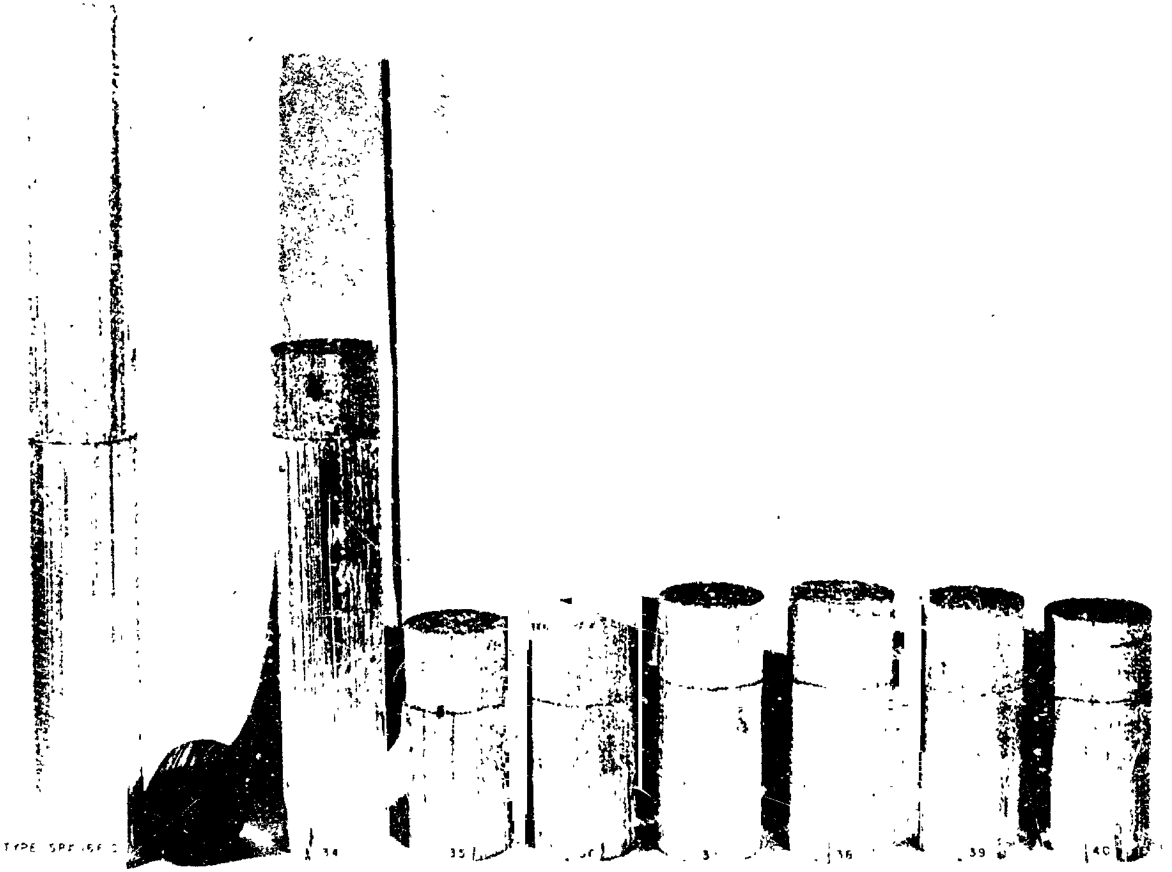


Figure 8-8. Pictorial Summary of Specimens (●) Tested in Phase II; Temperature +300°F
For Number Identification With Test Conditions, See Figure 6-2

impact velocities, test weights, and temperatures. General comments regarding the information obtained and data plotted is included in the Analysis of Test Results in paragraph 8.3.

8.3 ANALYSIS OF PHASE II TEST RESULTS

The recorded data from Phase II specimens included (as did the Phase IA and Phase IB sections of the program) both static and dynamic records. Phase II specimens however were tested under the various high and low temperature environments. Figures 8-9 thru 8-14 illustrate the static crush loads obtained at the various temperatures of +300°F, +150°F and -150°F. The static crush record for these configurations under -260°F may be seen in Figures 7-59 and 7-60. Typical examples of the dynamic test results obtained under these variations in temperature are illustrated as follows:

-260°F	Figures 8-15 and 8-16
-150° and +150°F	Figures 8-17 and 8-18
+300°F	Figures 8-19 and 8-20

The data which was reduced from both static and dynamic records is tabulated at the end of this section. A portion of this data has been plotted as described below.

1. Figures 8-21 and 8-22 illustrate the variations in load onset rate, rebound and average crush load which occur on the two configurations as multiple 5 FPS impacts are made on the test specimens under a temperature of +300°F. As noted the plot is made against the percent of uncrushed stroke remaining at the time of impact.

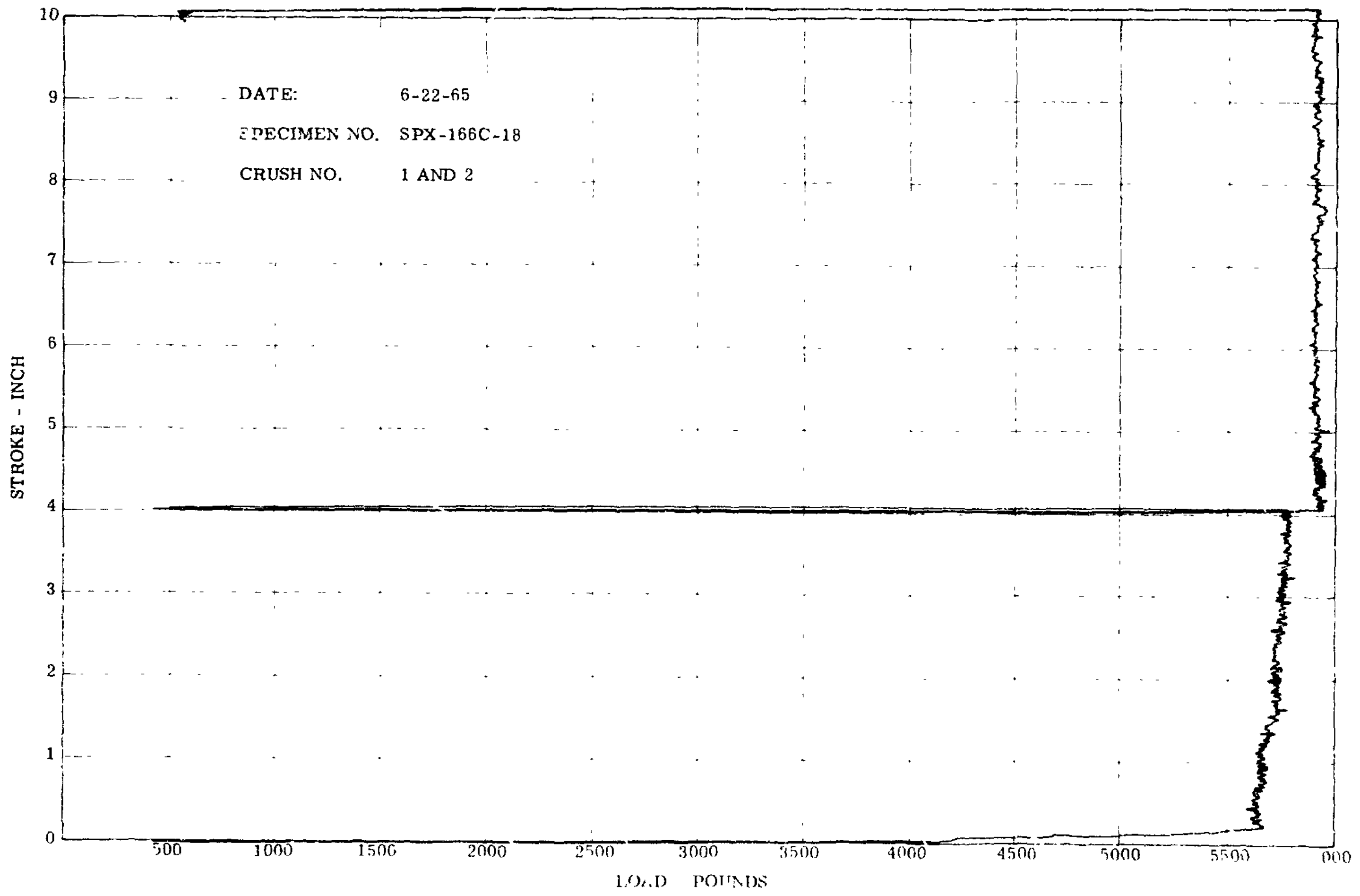


Figure 8-9. Static Crush Record for Phase II Test Specimen (●) -150 F
For Number Identification With Test Conditions, See Figure 6-2

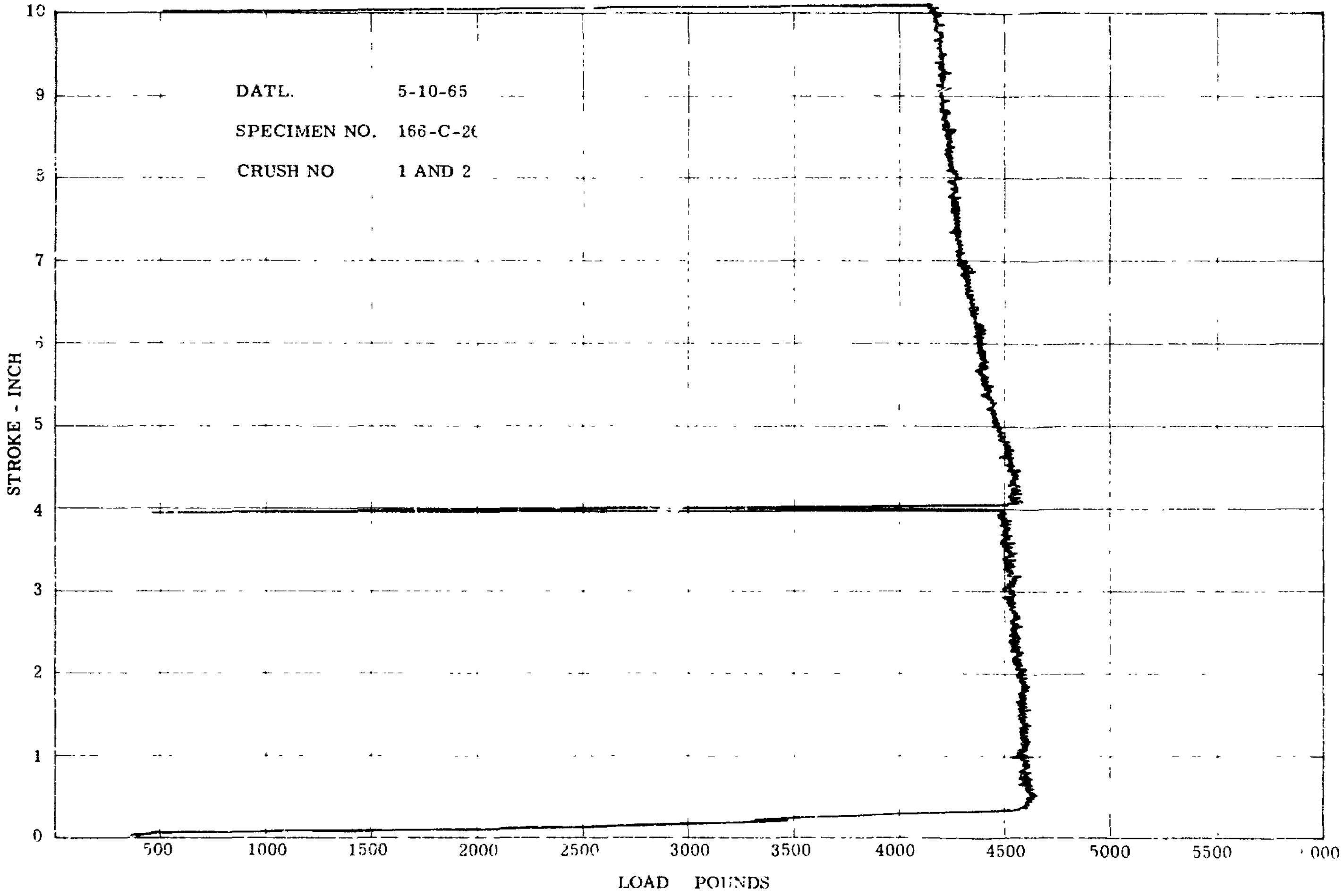


Figure 8-10. Static Crush Record for Phase II Test Specimen (●) +150°F
For Number Identification With Test Conditions, See Figure 6-2

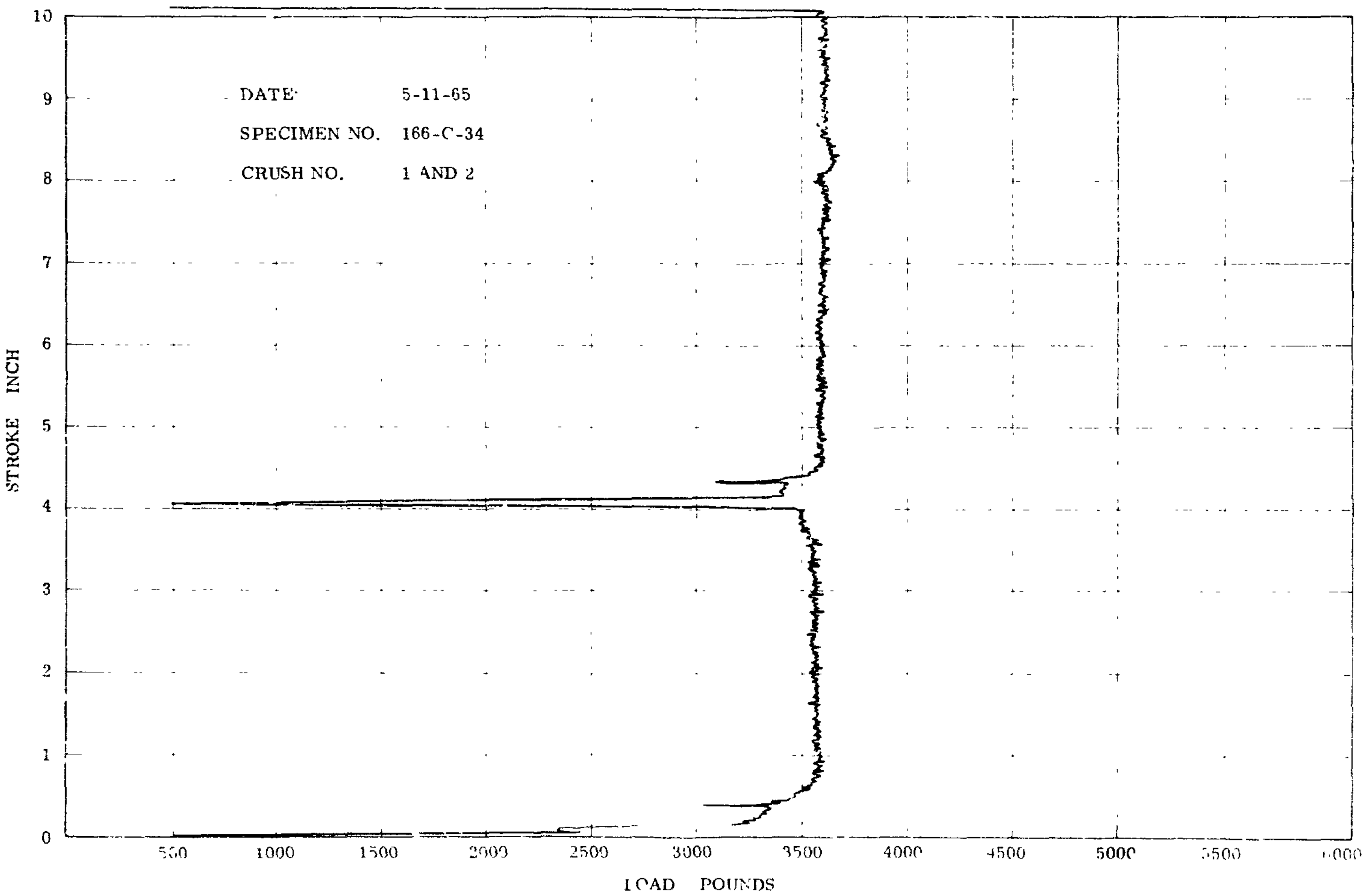


Figure 8-11. Static Crush Record for Phase II Test Specimen (●) +300 F
For Number Identification With Test Conditions, See Figure 6-2

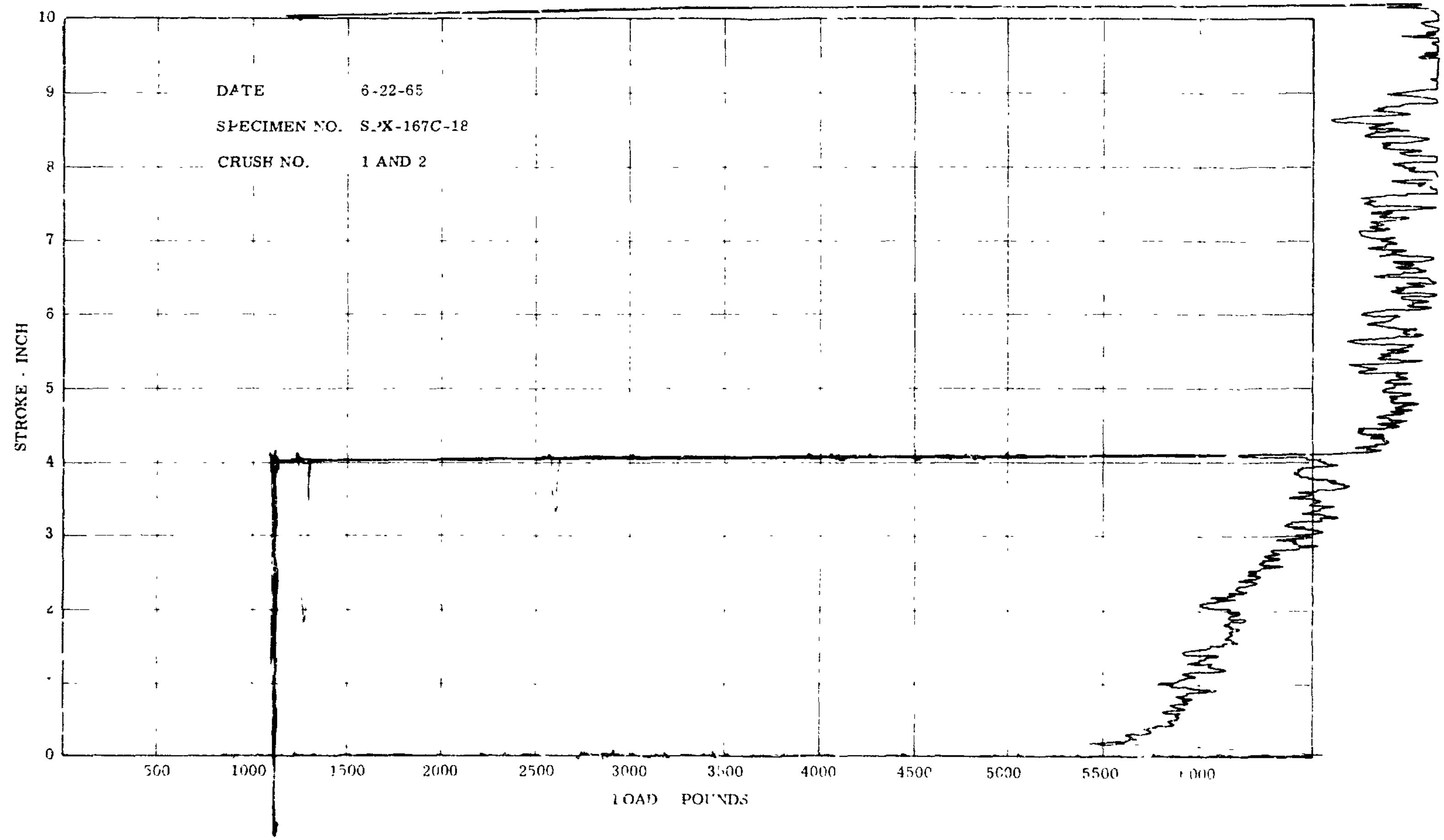


Figure 8-12. Static Crush Record for Phase II Test Specimen (◎) -150°F For Number Identification With Test Conditions. See Figure 6-2

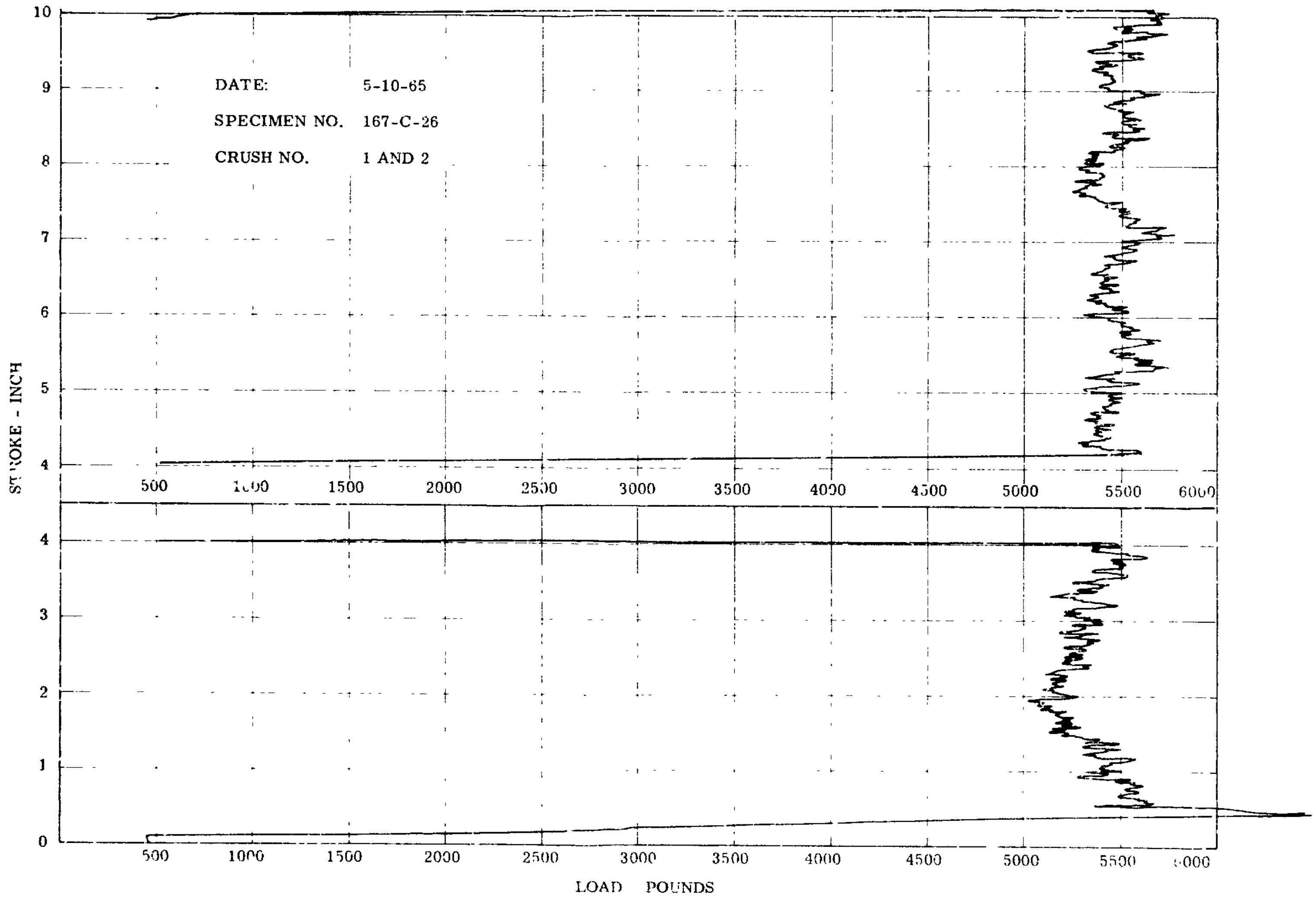


Figure 8 13. Static Crush Record for Phase II Test Specimen ( ) +150°F
For Number Identification With Test Conditions, See Figure 3-2

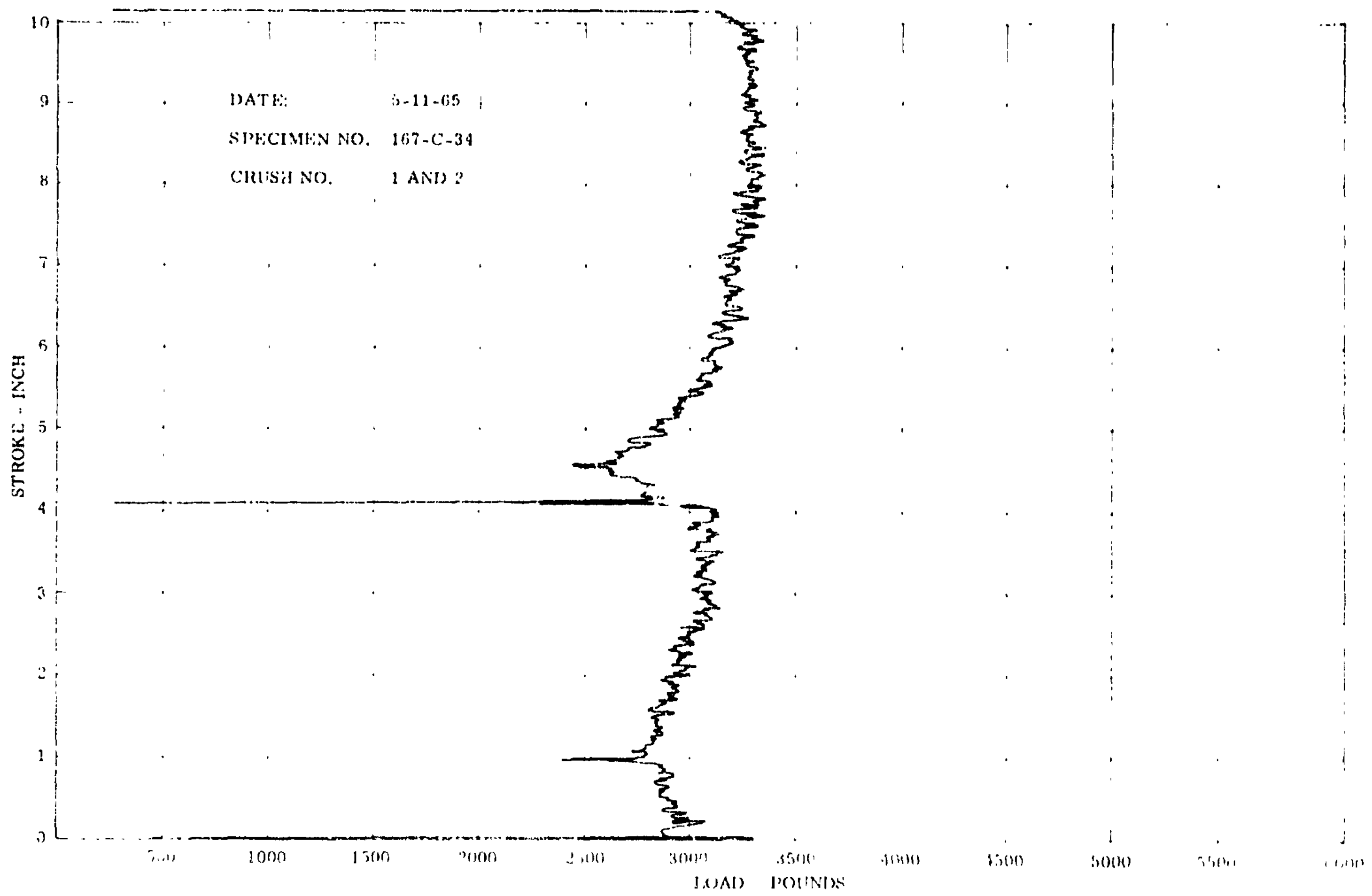
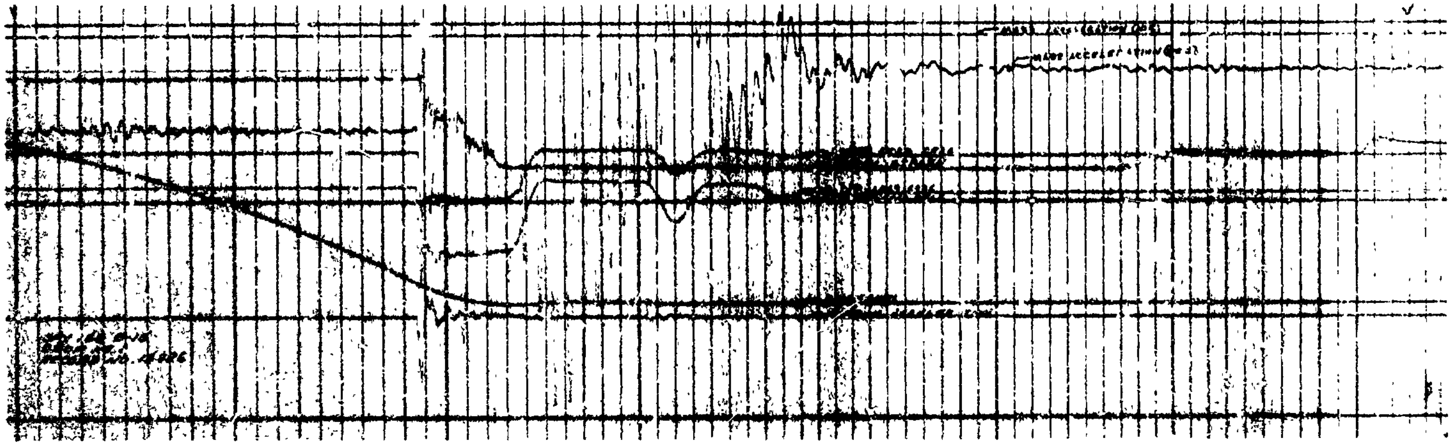


Figure 8-14. Static Crush Record for Phase II Test Specimen ([illegible]) +300 F For Number Identification With Test Conditions, See Figure 6-2

SPX-166C-15



SPX-166C-17

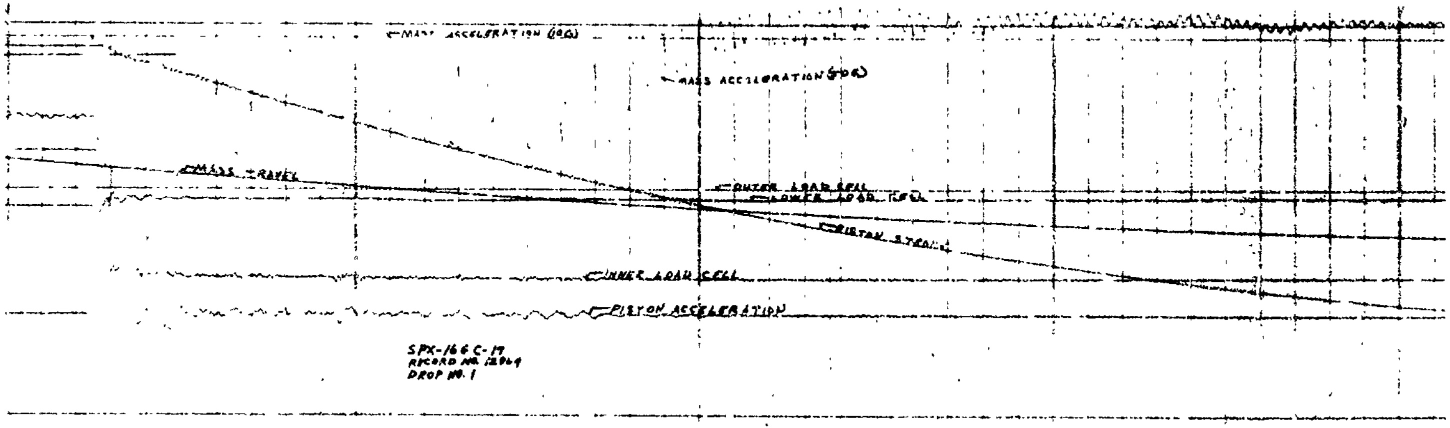
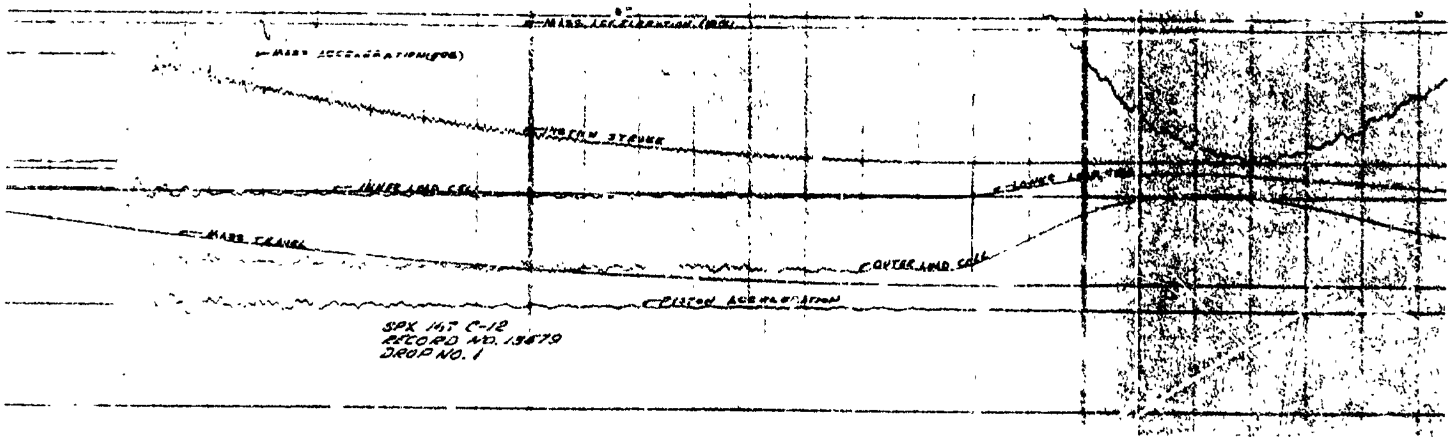


Figure 8-15. Oscillograph Records of Dynamic Tests on Phase II Specimens For Number Identification With Test Conditions, See Figure 6-2; Upper: ● -260 °F Lower: ● -260 F

SPX-167C-12



SPX-167C-15

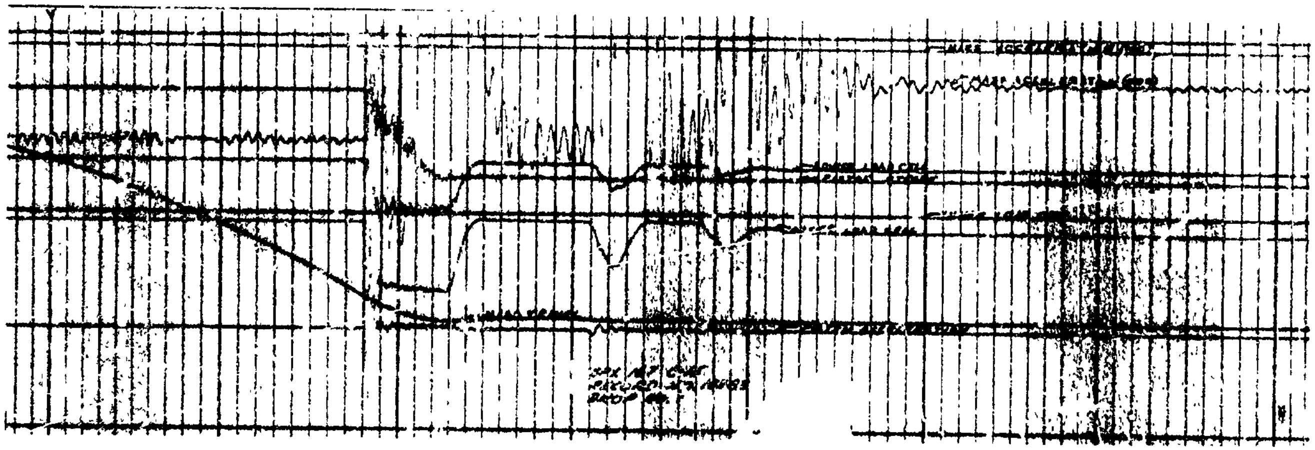
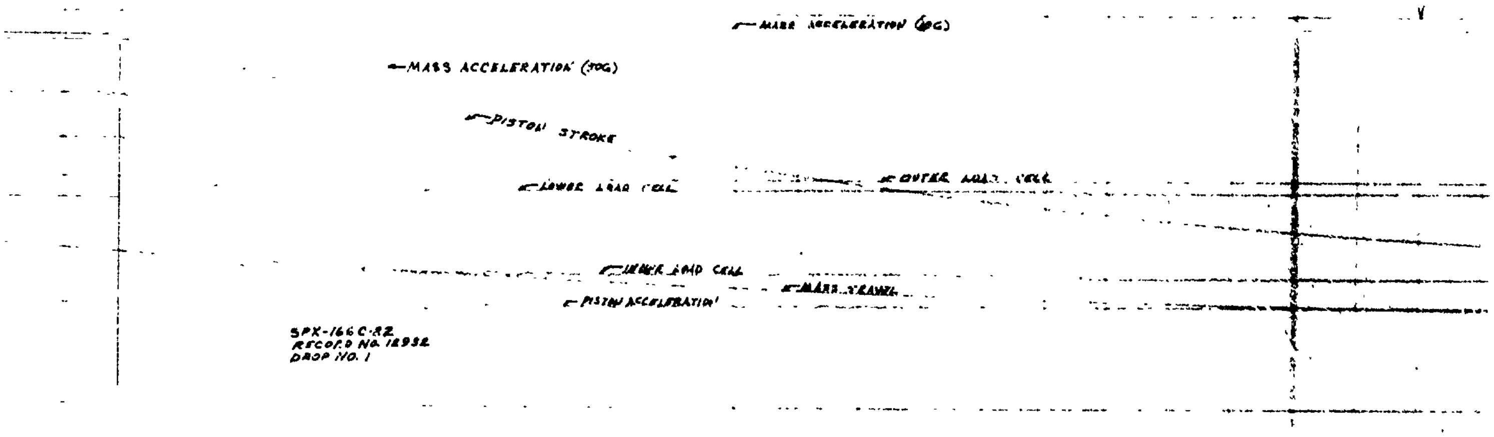


Figure 8-16. Oscillograph Records of Dynamic Tests on Ph imens; For Number Identification
With Test Conditions, See Figure 6-2; Upper: ○ F Lower: ○ -260 F

SPX-166C-22



SPX-166C-27

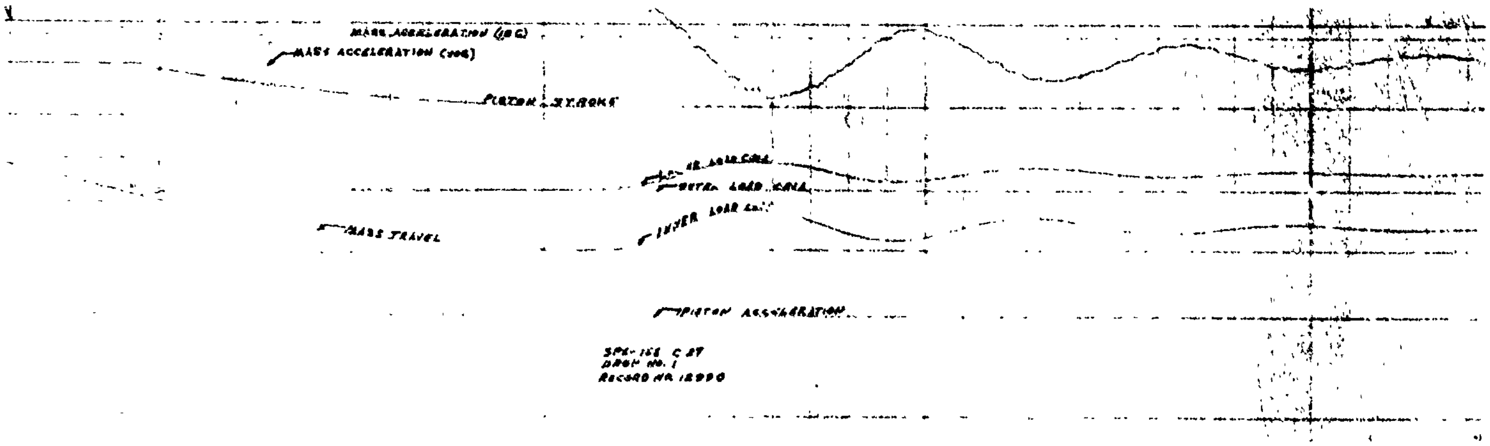
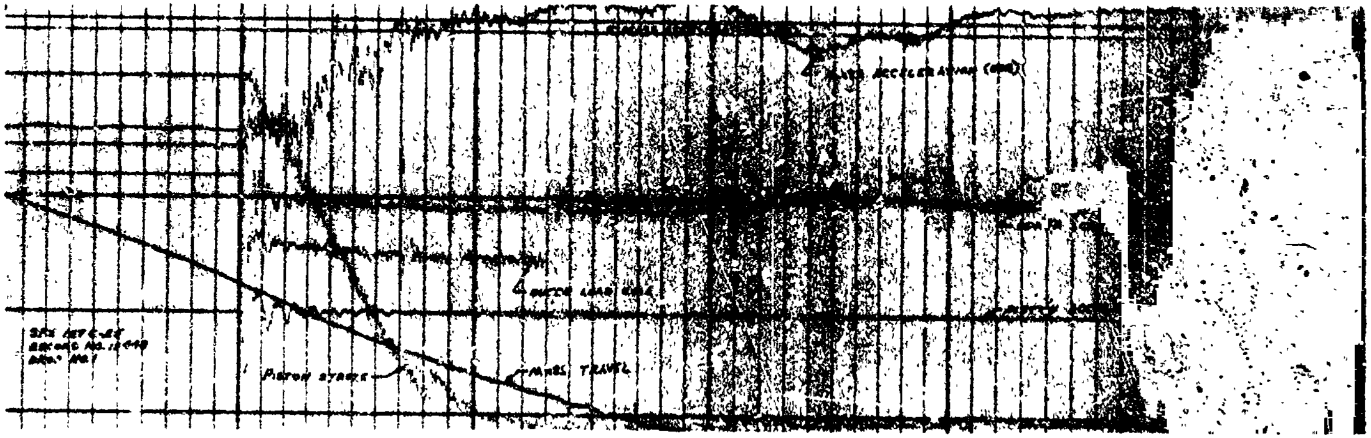


Figure 8-17. Oscillograph Records of Dynamic Tests on Phase II Specimens; for Number Identification With Test Conditions, See Figure 6-2; Upper: ● -150°F Lower: ● +150 F

SPX-167C-25



SPX-167C-28

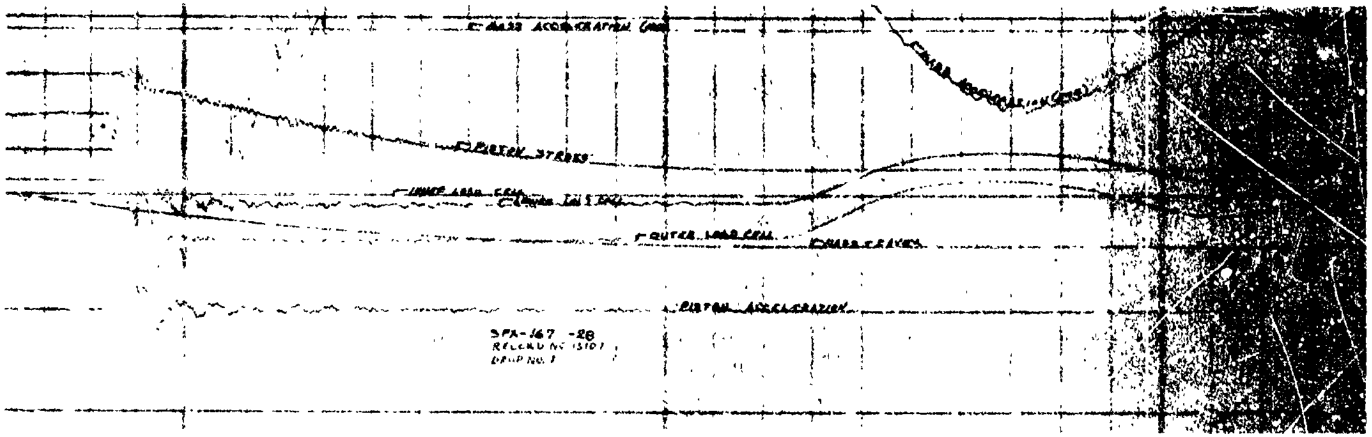
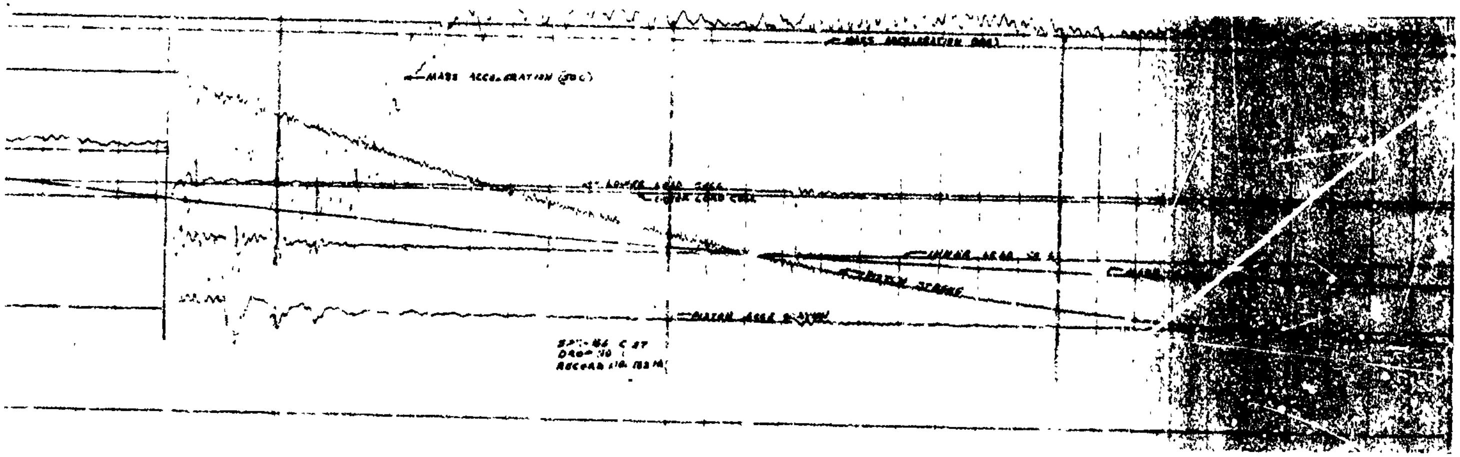


Figure 8-18. Oscillograph Records of Dynamic Tests on Phase II Specimens; for Number Identification With Test Conditions, See Figure 6-2; Upper: [◎] -150 °F Lower: [◎] +150 °F

SPX-166C-37



SPX-166C-40

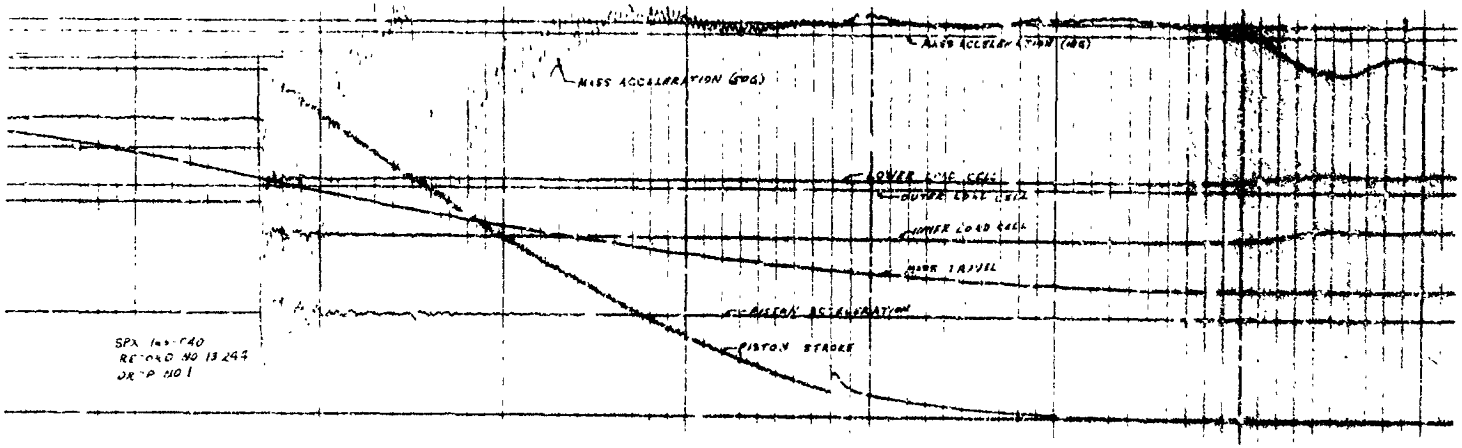
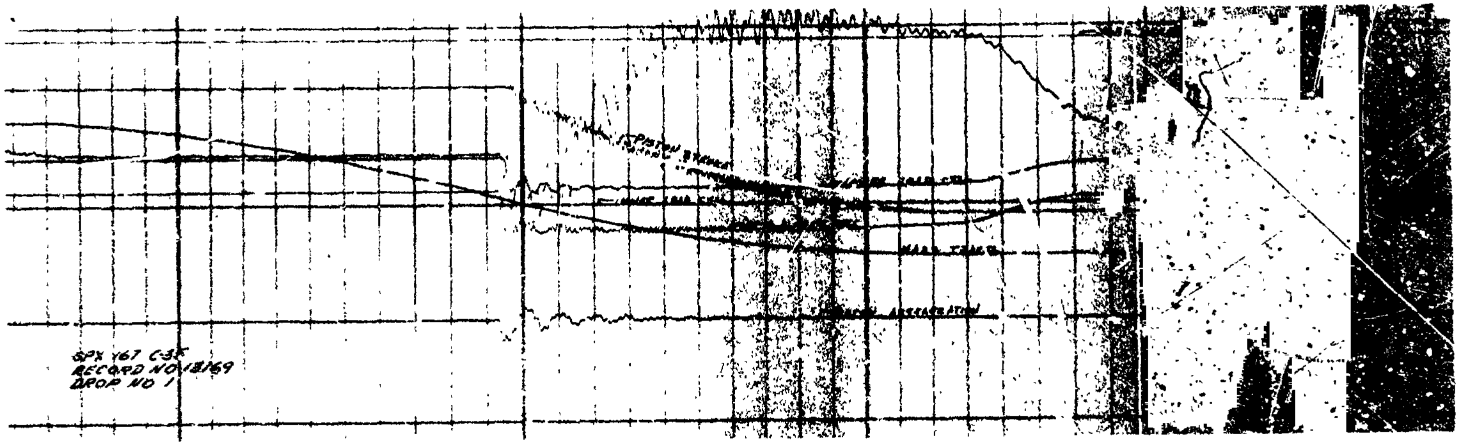


Figure 8-19. Oscillograph Records of Dynamic Tests on Phase II Specimens; for Number Identification With Test Conditions, See Figure 6-2; Upper: ● +300°F Lower: ● +300°F

SPX-167C-35



SPX-167C-41

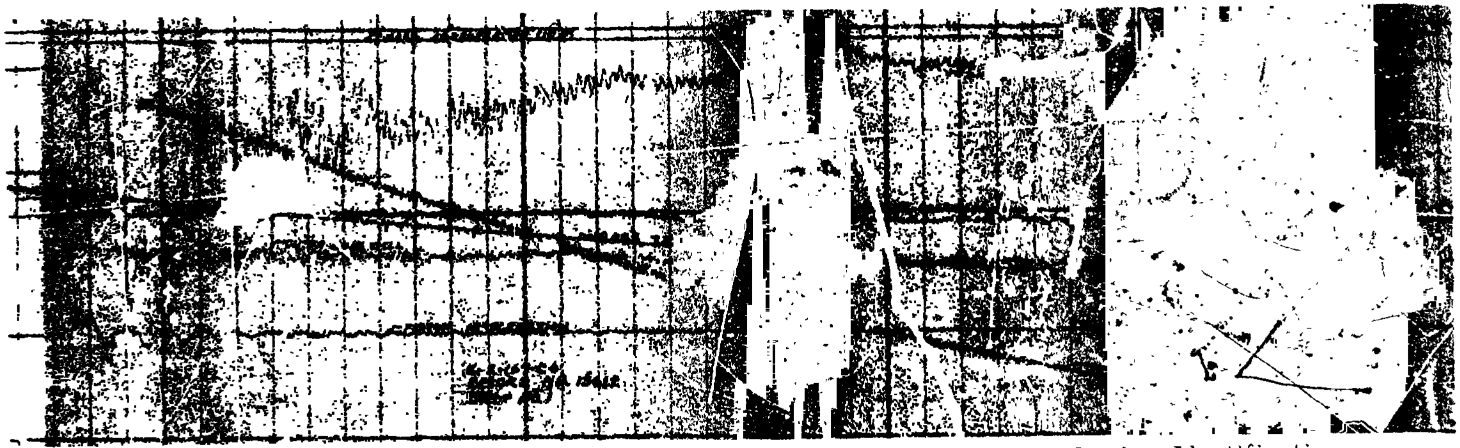


Figure 8-20. Oscillograph Records of Dynamic Tests on Phase II Specimens; for Number Identification With Test Conditions, See Figure 6-2; Upper: +300°F Lower: +300°F

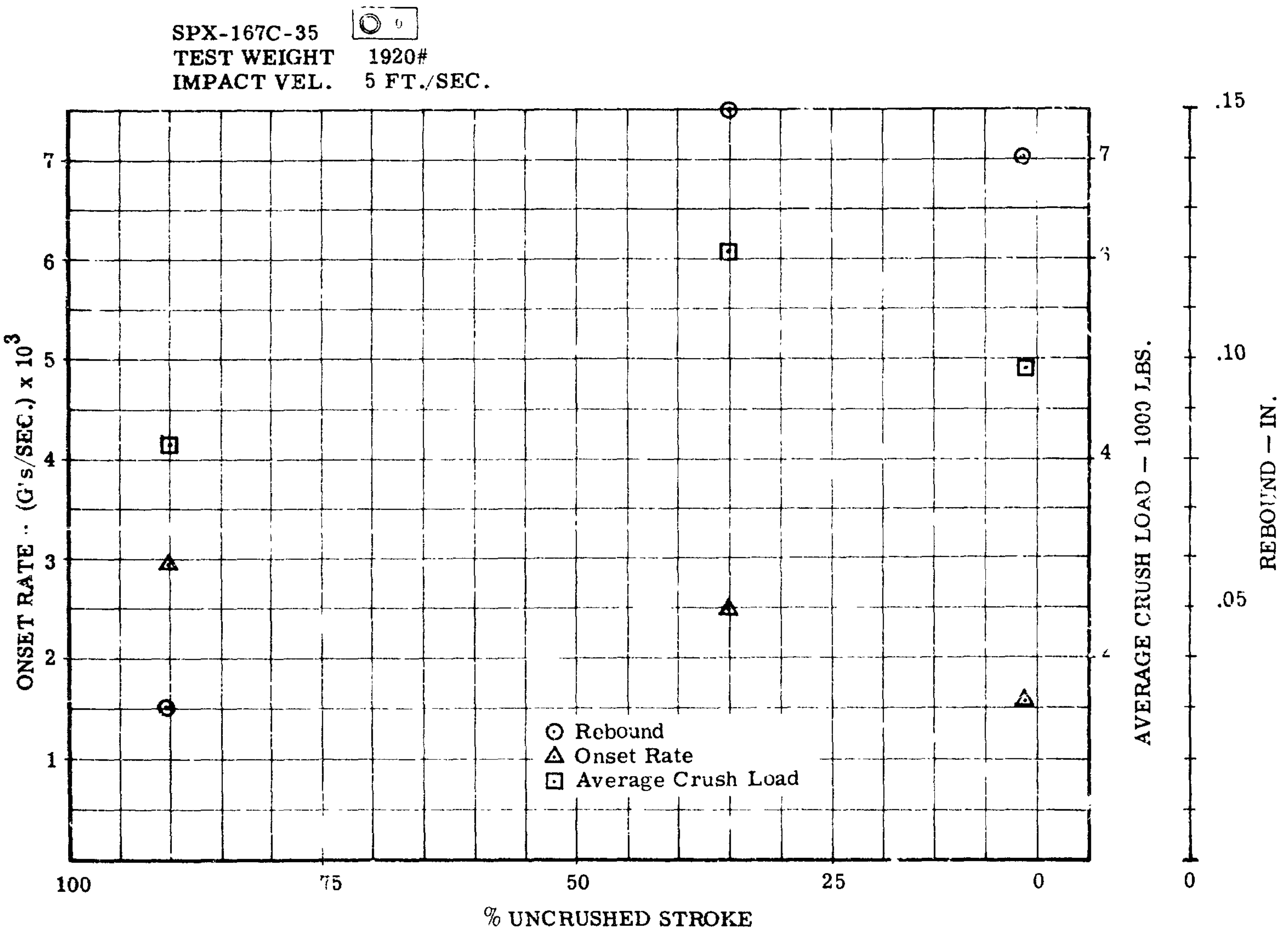


Figure 8-21. Plotted Data from External Annular Configuration at +300°F

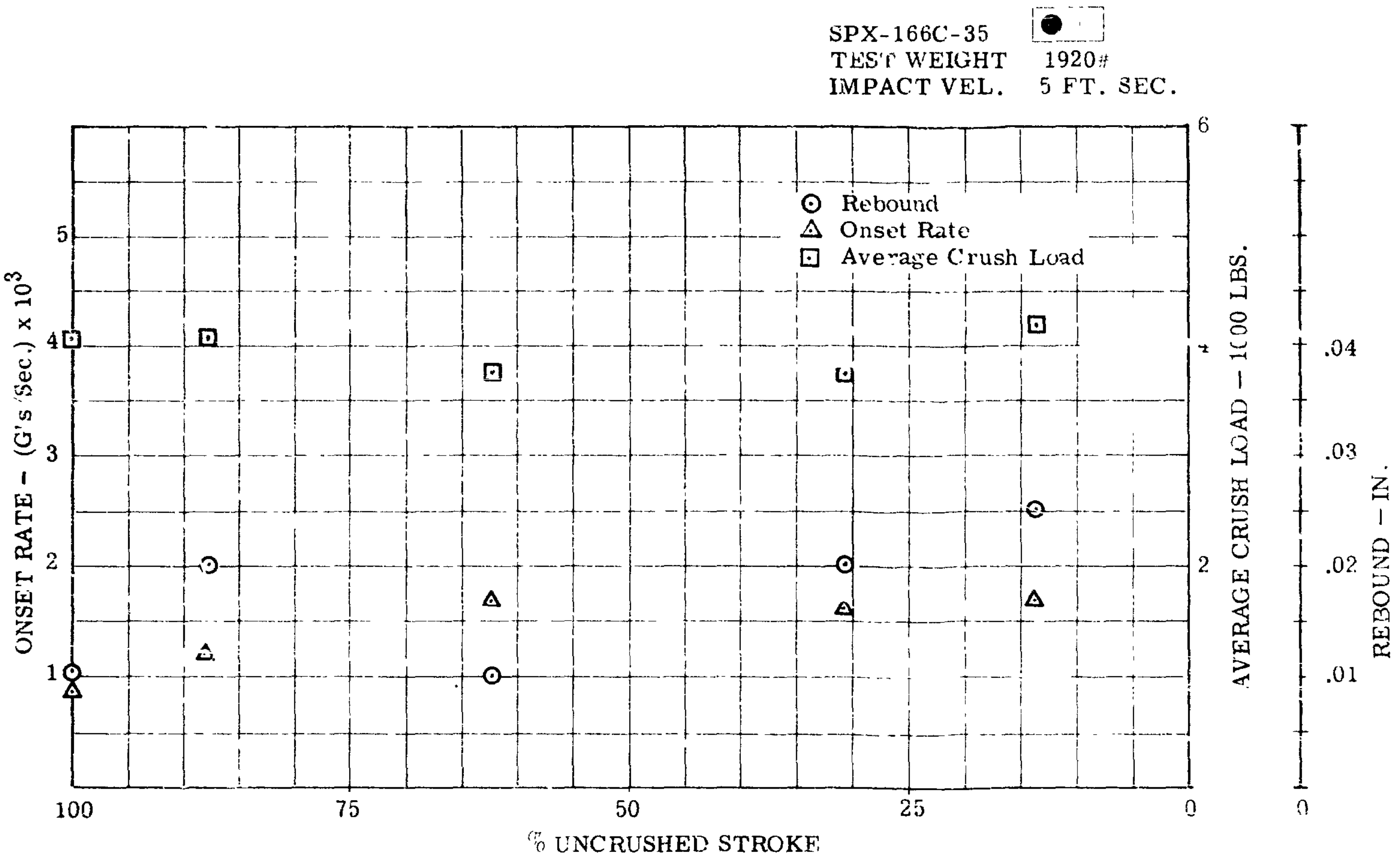


Figure 8-22. Plotted Data from Solid Circular Configuration at +300°F

2. Figures 8-23 and 8-24 provide a comparison; same parameters as noted in (1) above, with Figure 8-22 over the temperature range of +150°F, -150°F and +300°F for the same configuration (● ∘).

3. In Figure 8-25 a plot is provided to indicate how the rebound varies during subsequent 5 FPS impacts on a particular configuration (● ∘), as a result of being exposed to different temperatures during testing.

4. Figures 8-26 thru 8-39 are dynamic load vs. stroke plots of the two configurations under the various temperature conditions with figures 8-26 thru 8-32 being the plots for configuration (◎ ∘) and 8-33 thru 8-39 being plots for configuration (● ∘).

Configuration (◎ ∘)

Figures 8-26 and 8-27	Comparison of -260°F with +300°F
Figures 8-27 thru 8-32	Comparison of various impact velocities and test weights at +300°F

Configuration (● ∘)

Figures 8-33 thru 8-36	Comparison of various impact velocities and test weights at -260°F
Figures 8-33 and 8-37 thru 8-39	Comparison of various temperatures (-260°F, -150°F, + 150°F and +300°F) at same impact velocity (10 FPS) and same test weight (1920 lbs.)

5. Figures 8-40 and 8-41 have been provided to illustrate the effect of impact velocities and test weights on the average crush load under the several temperature conditions. It will be noted that the spread in the average crush load is only the normal expected for a group of specimens under a

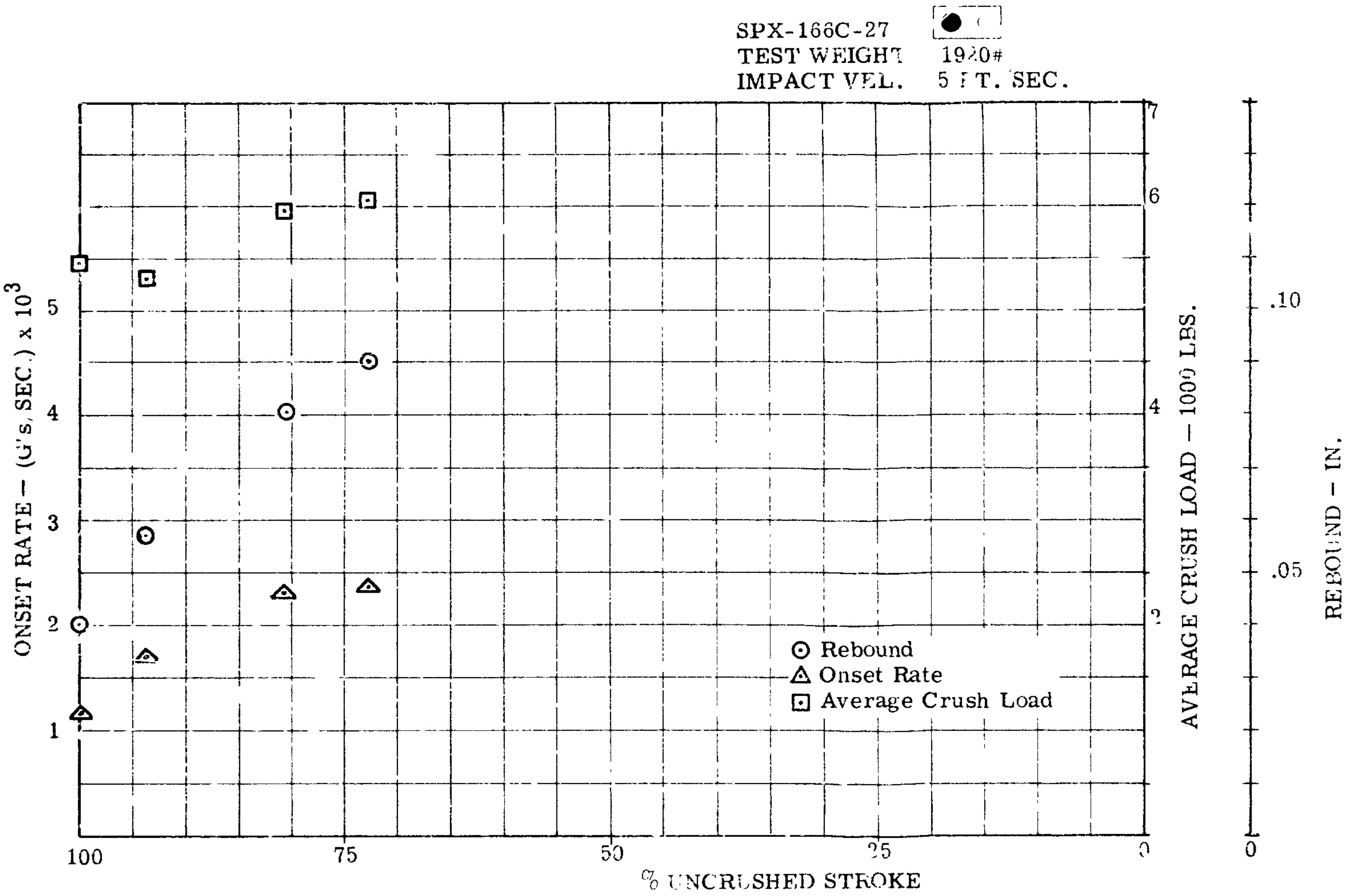


Figure 8-23. Plotted Data from Solid Circular Configuration at +150°F

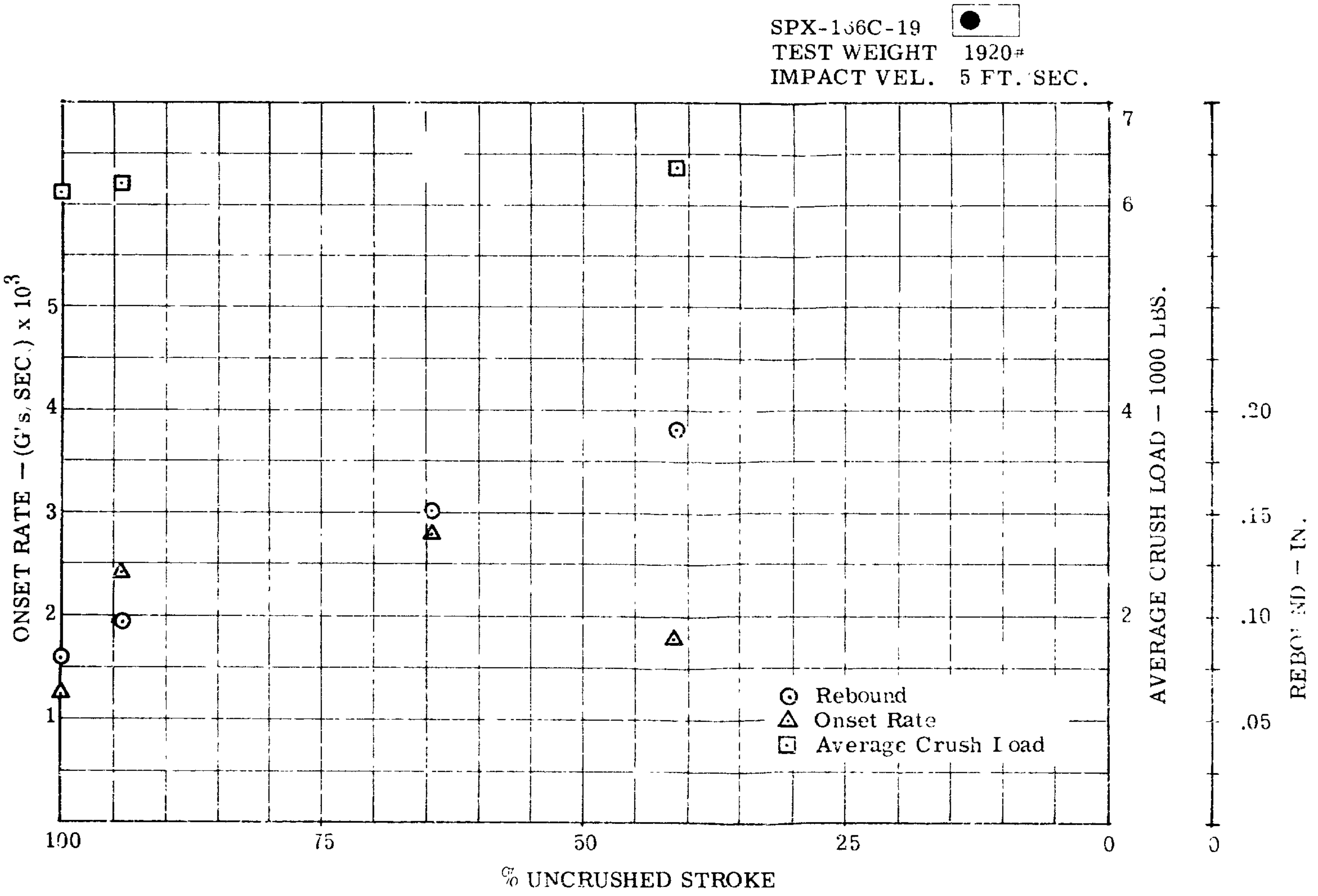


Figure 8-24. Plotted Data from Circular Solid Configuration at -150°F

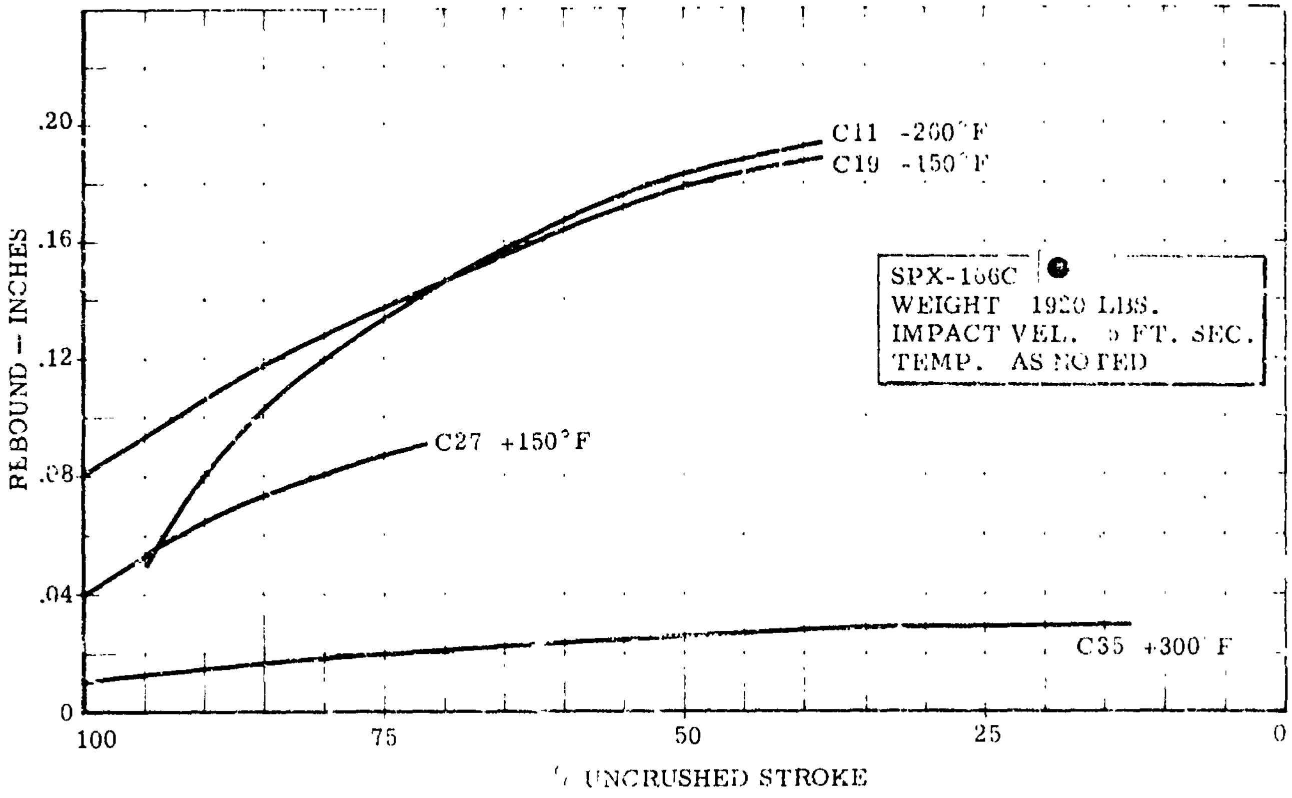


Figure 8-25. Rebound Percent Uncrushed Stroke at Various Temperatures for Solid Circular Configuration

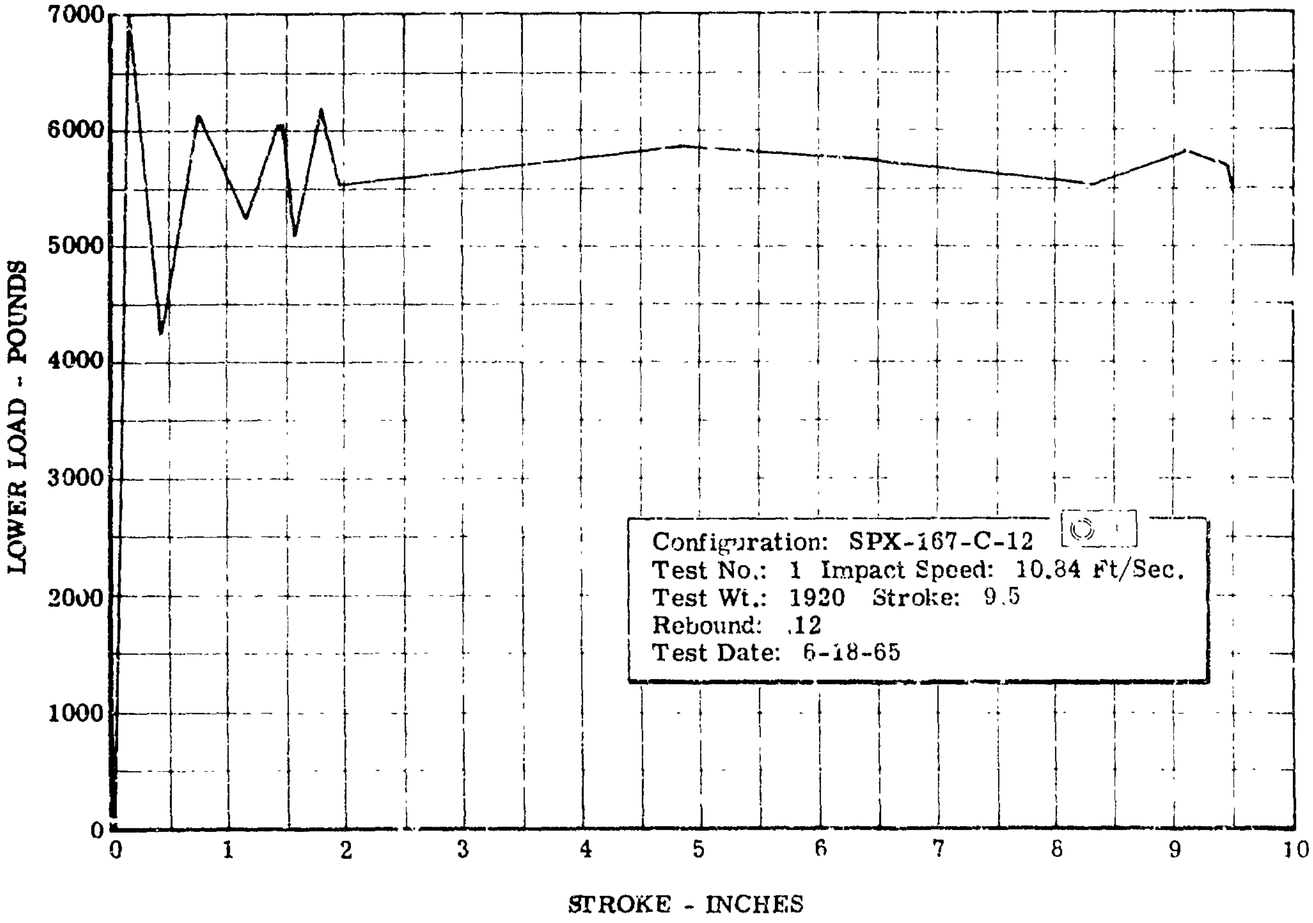


Figure 8-26. Load Vs. Stroke for External Annular Configuration at -260°F

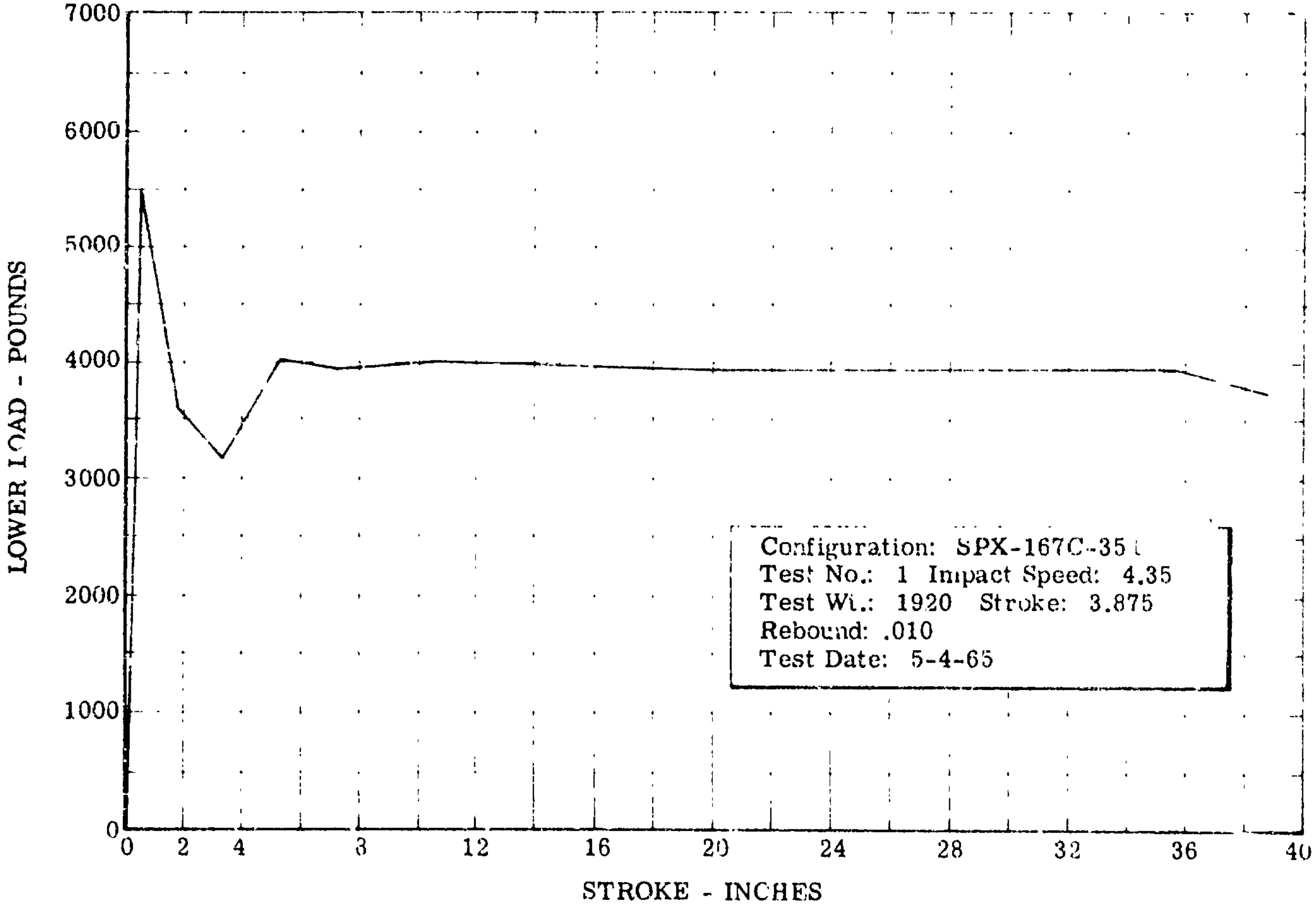


Figure 8-27. Load Vs. Stroke for External Annular Configuration at +300°F

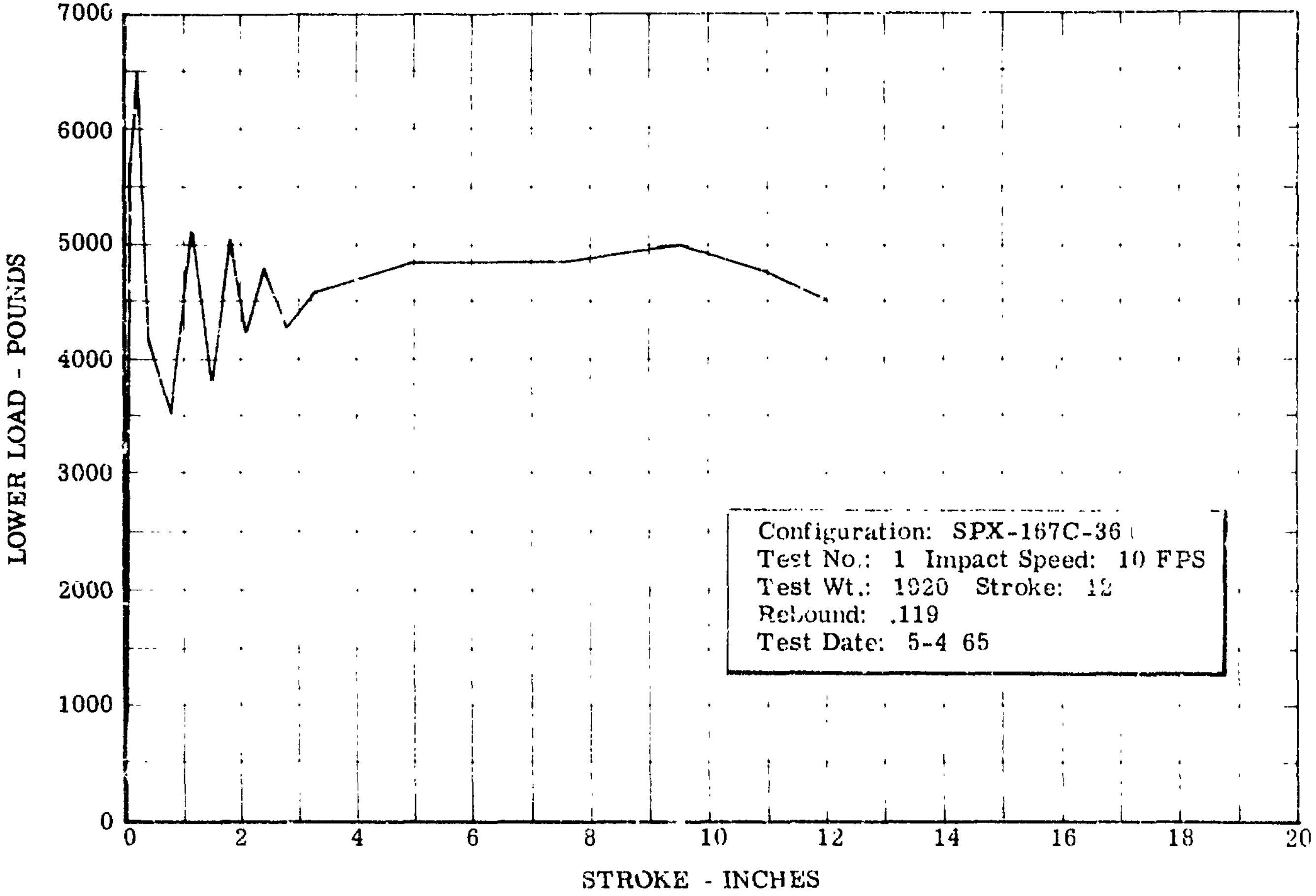


Figure 8-28. Load Vs. Stroke for External Annular Configuration at +300°F

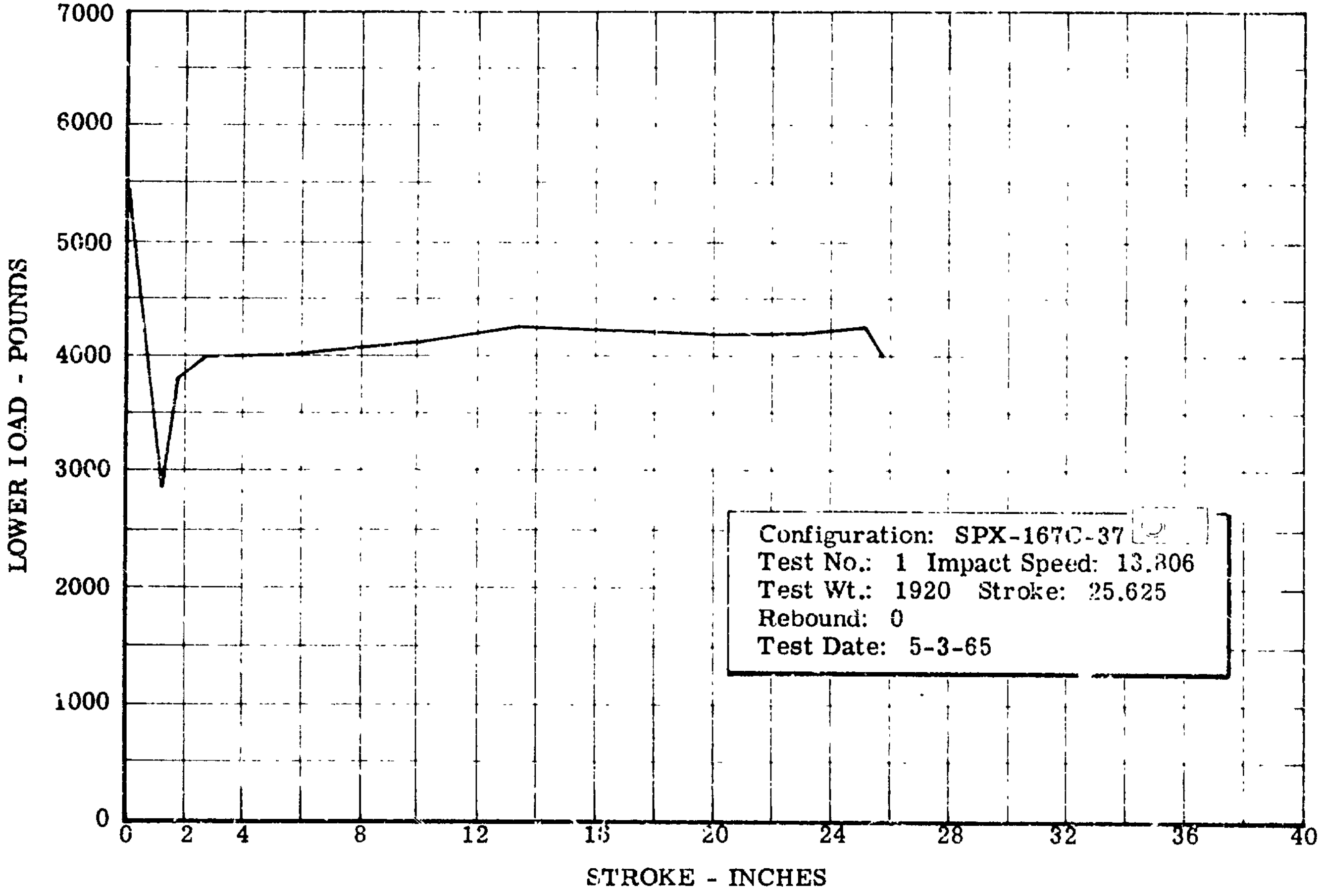


Figure 8-29. Load Vs. Stroke for External Annular Configuration at +300°F

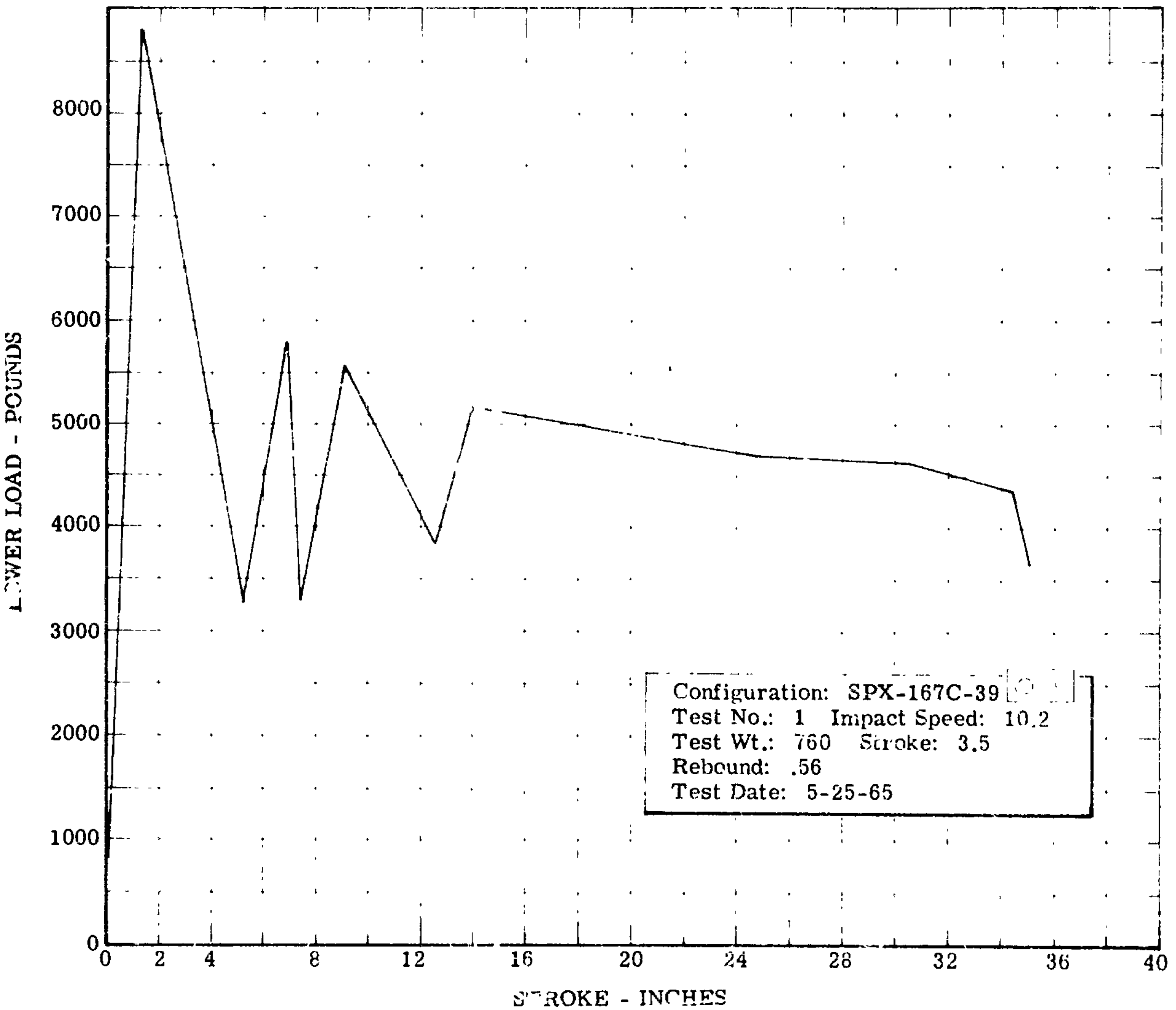
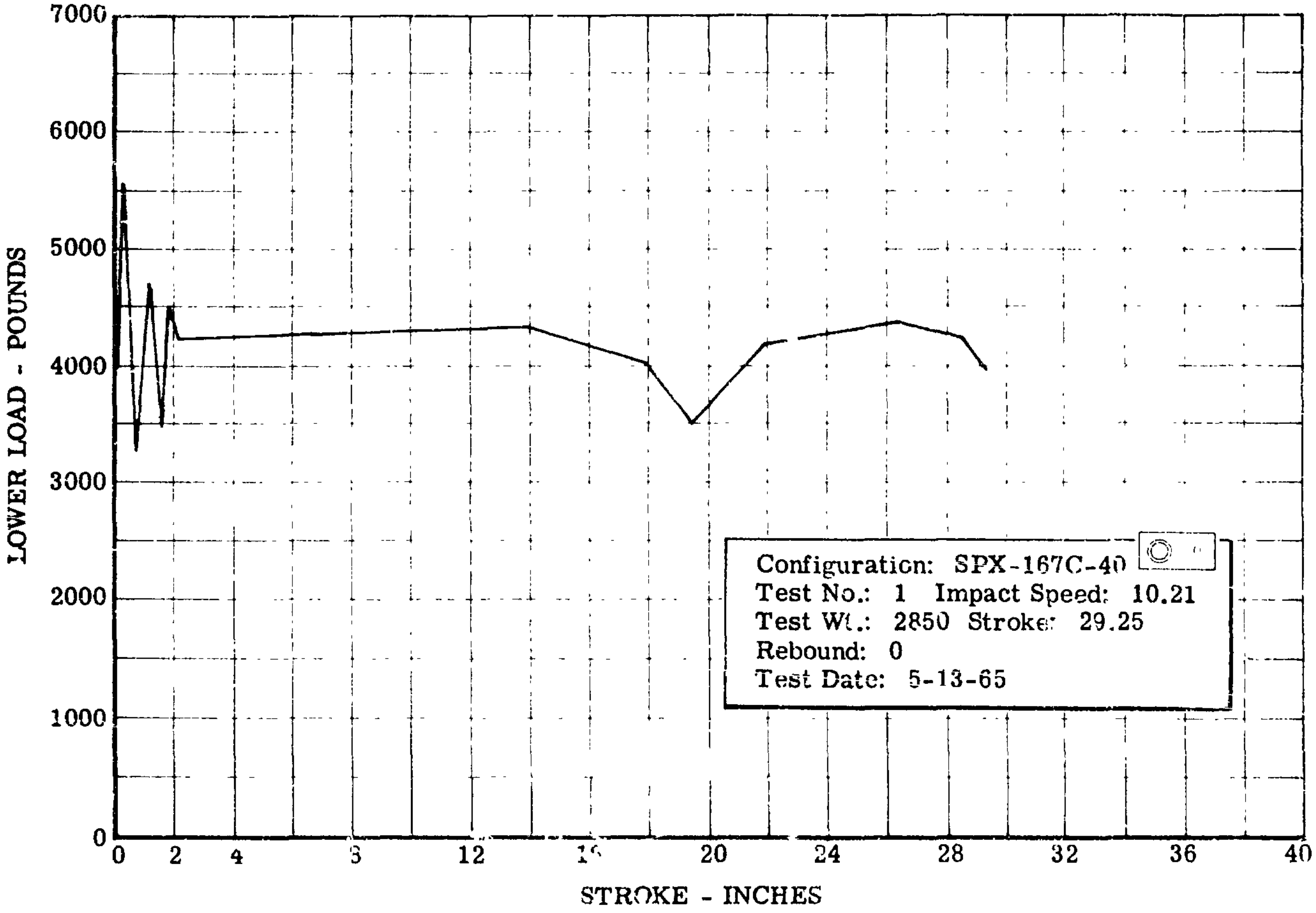


Figure 8-30. Load Vs. Stroke for External Annular Configuration at +300°F



Configuration: SPX-167C-40
Test No.: 1 Impact Speed: 10.21
Test Wt.: 2850 Stroke: 29.25
Rebound: 0
Test Date: 5-13-65

Figure 8-31. Load Vs. Stroke for External Annular Configuration at +300°F

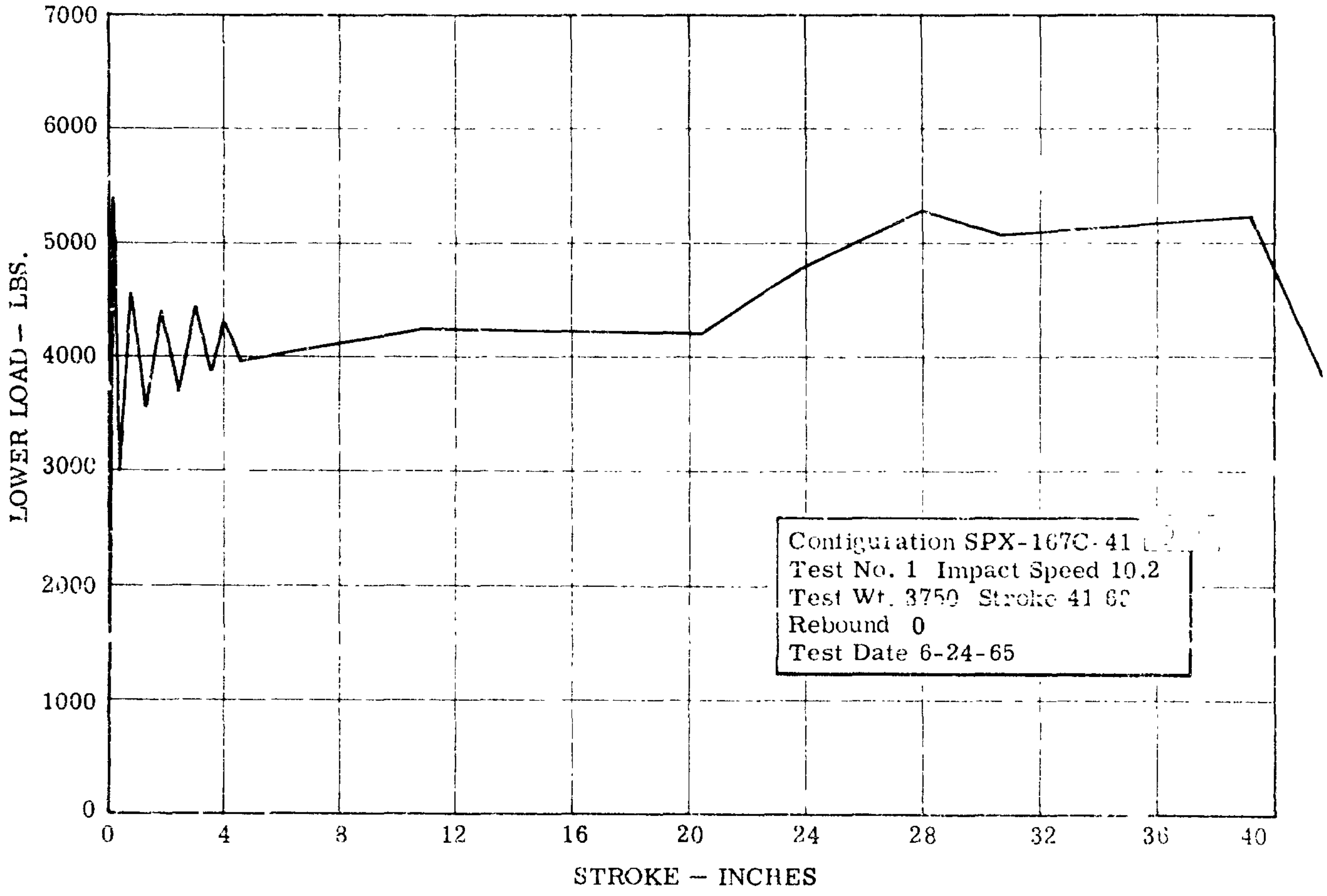


Figure 8-32 Load Vs. Stroke for External Annular Configuration at +300°F

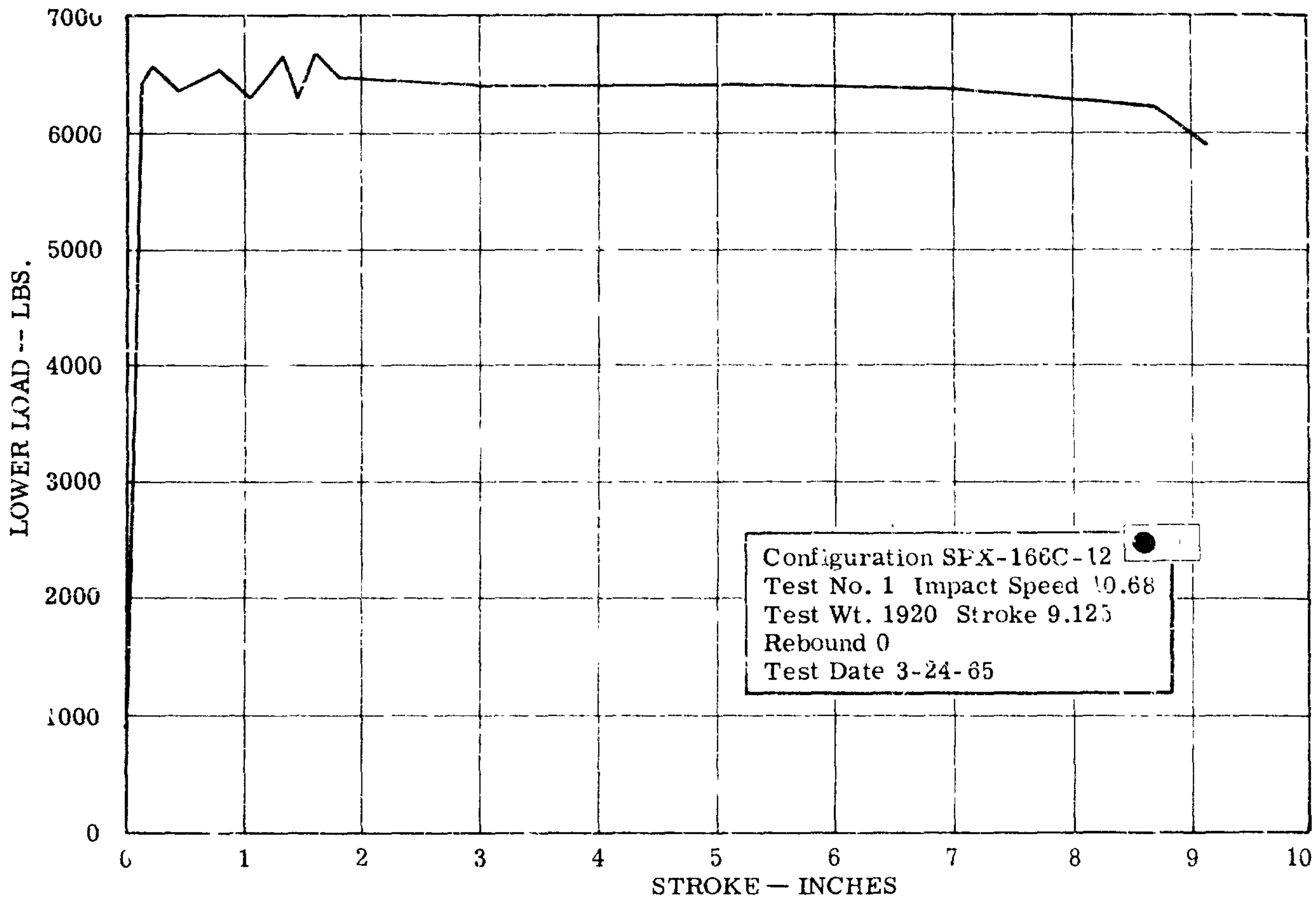


Figure 8-33. Load Vs. Stroke for Solid Circular Configuration at -260°F

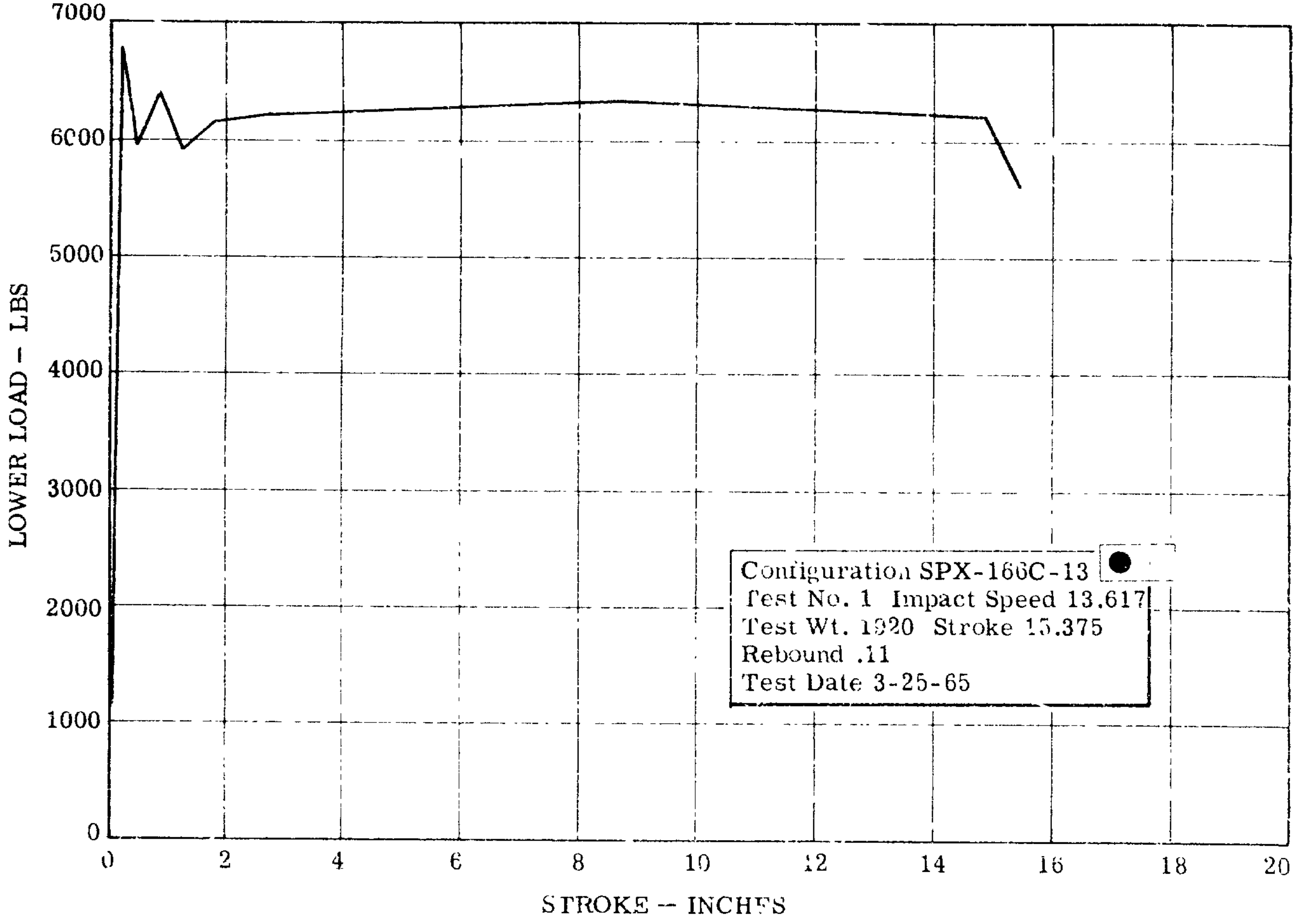
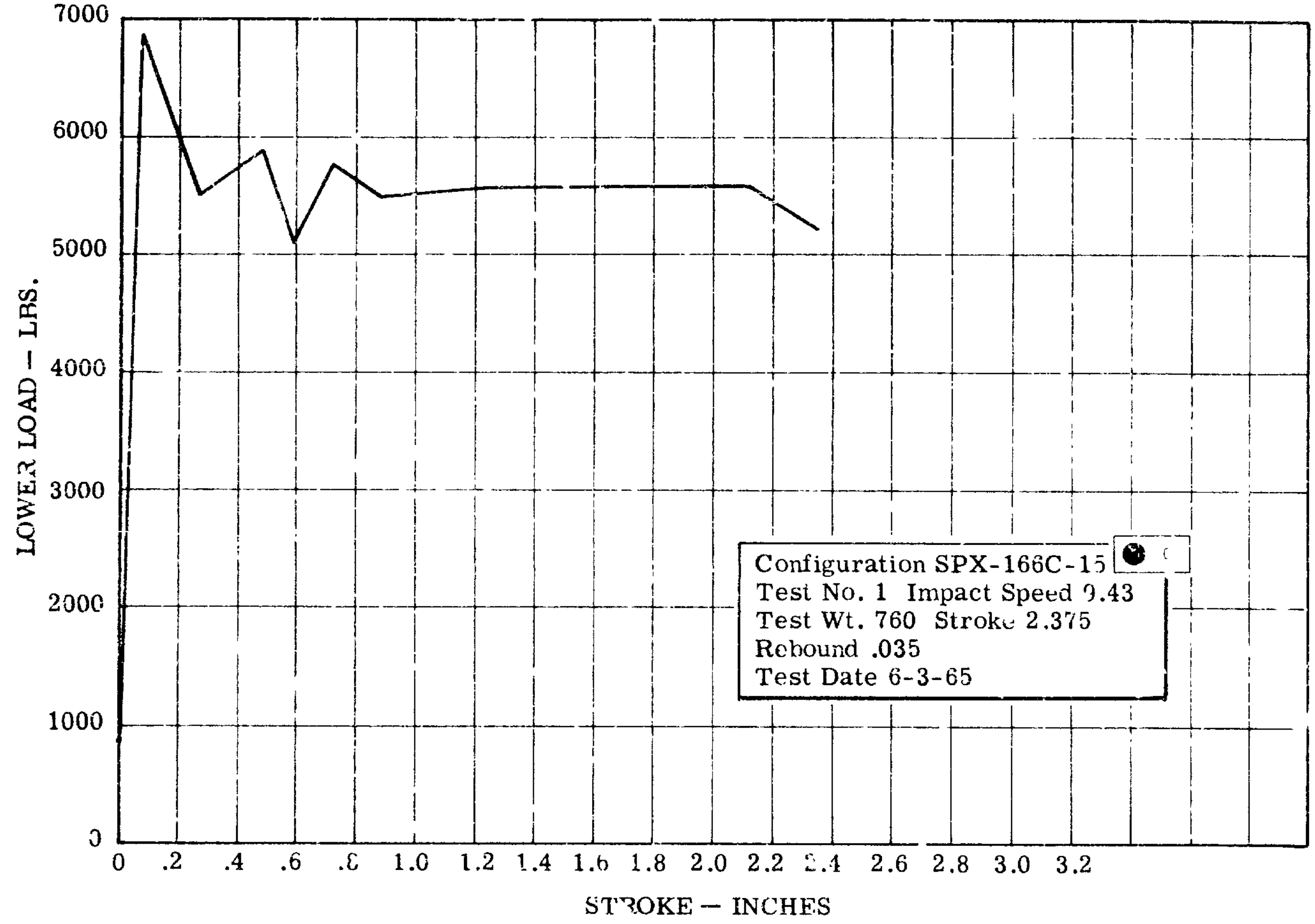


Figure 8-34. Load Vs. Stroke for Solid Circular Configuration at -260°F



Configuration SPX-166C-15
Test No. 1 Impact Speed 9.43
Test Wt. 760 Stroke 2.375
Rebound .035
Test Date 6-3-65

Figure 8-35. Load Vs. Stroke for Solid Circular Configuration at -260°F

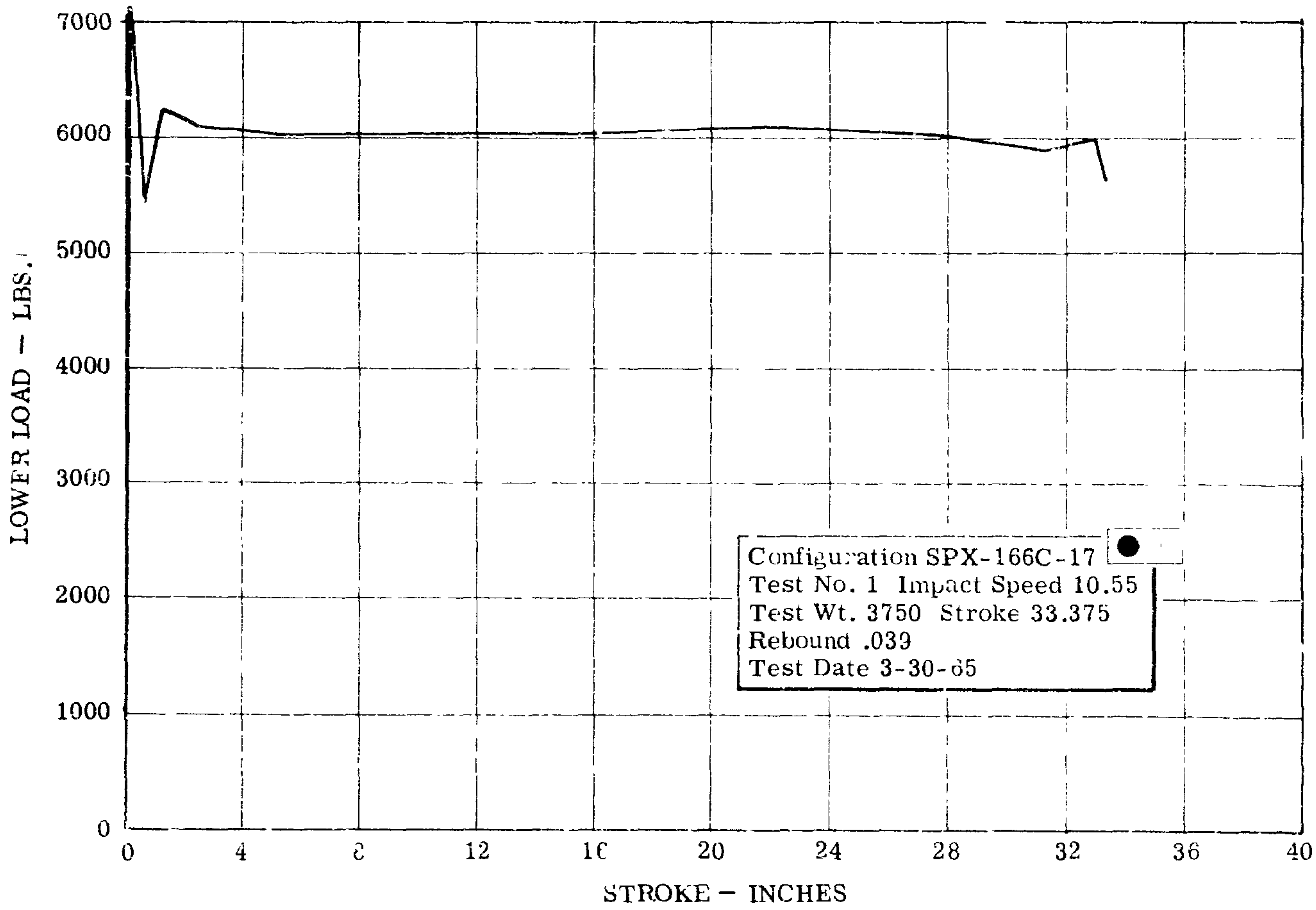


Figure 8-36. Load Vs. Stroke for Solid Circular Configuration at -260°F

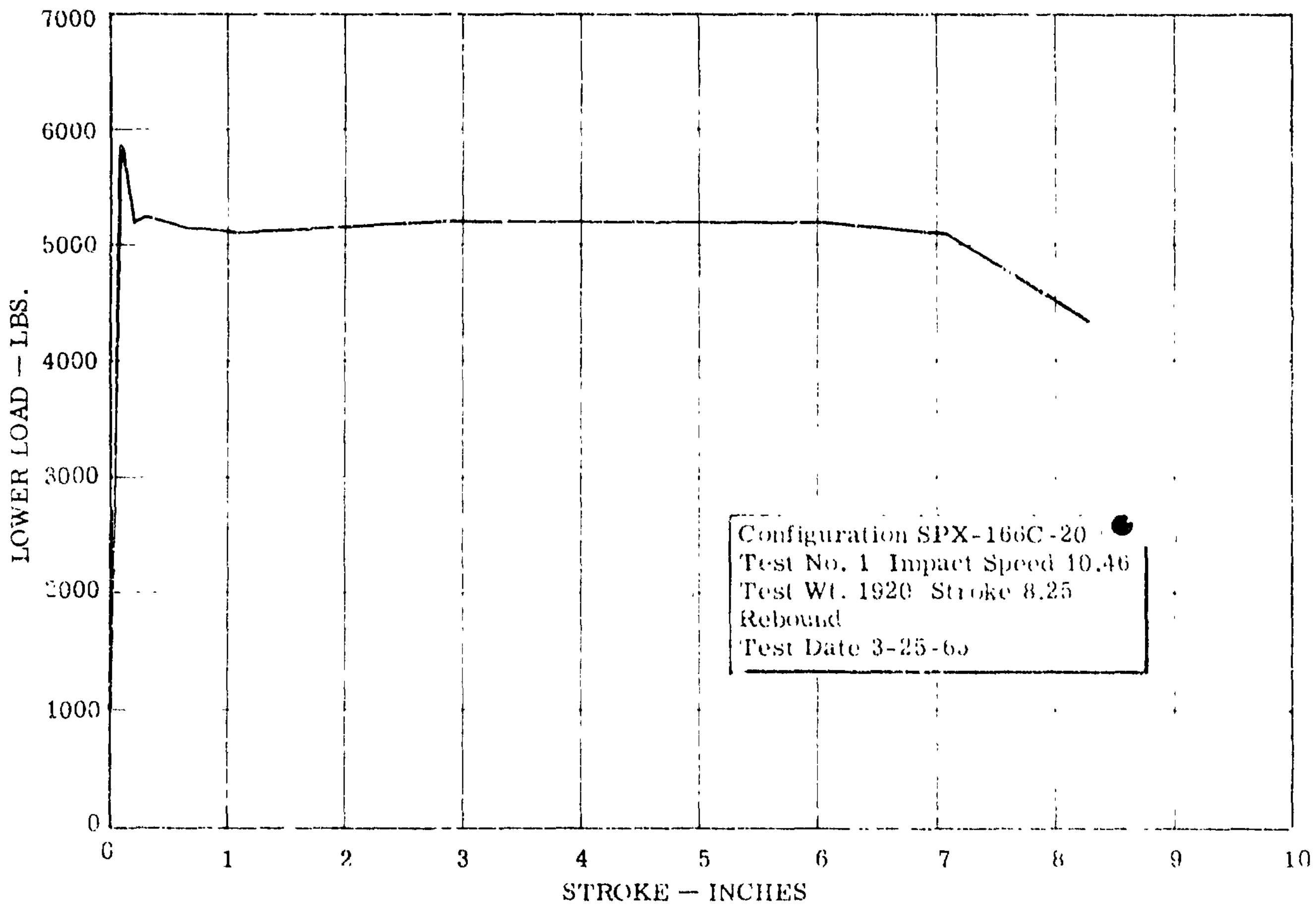


Figure 8-37. Load Vs. Stroke for Solid Circular Configuration at -150°F

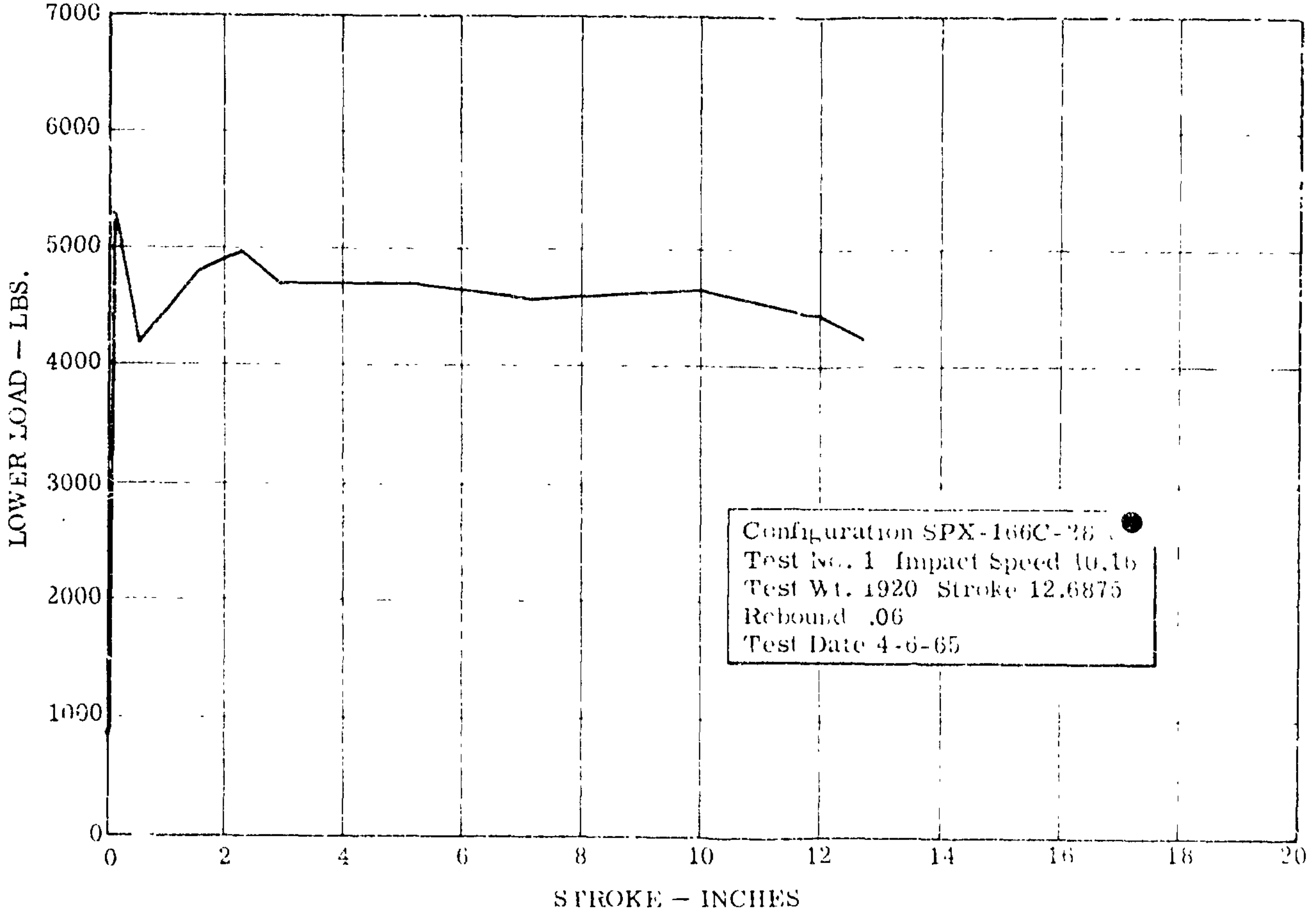


Figure 8-38. Load Vs. Stroke for Solid Circular Configuration at +150 F

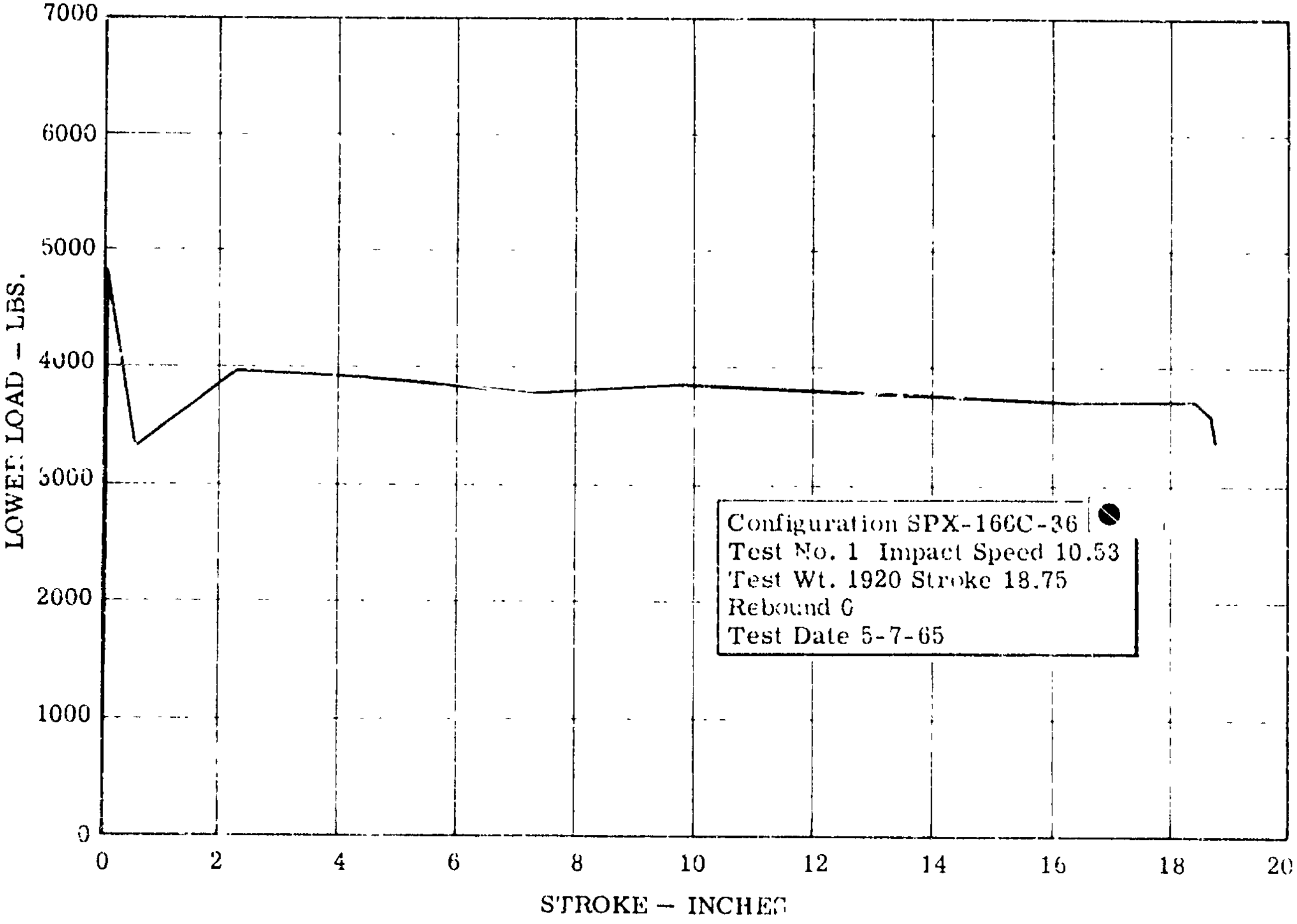


Figure 8-39. Load Vs. Stroke for Solid Circular Configuration at +300° F

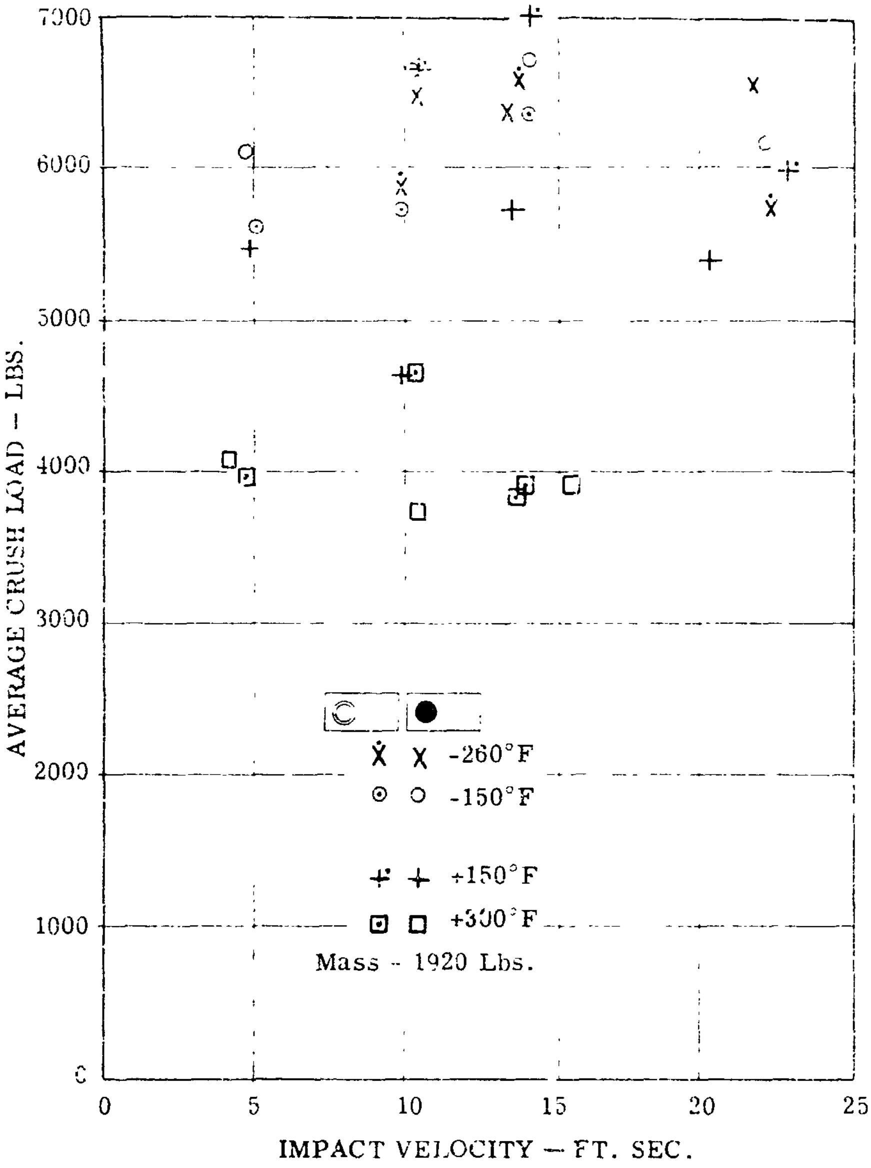


Figure 8-40. Average Crush Load Vs Impact Velocity (Under Various Temperatures)

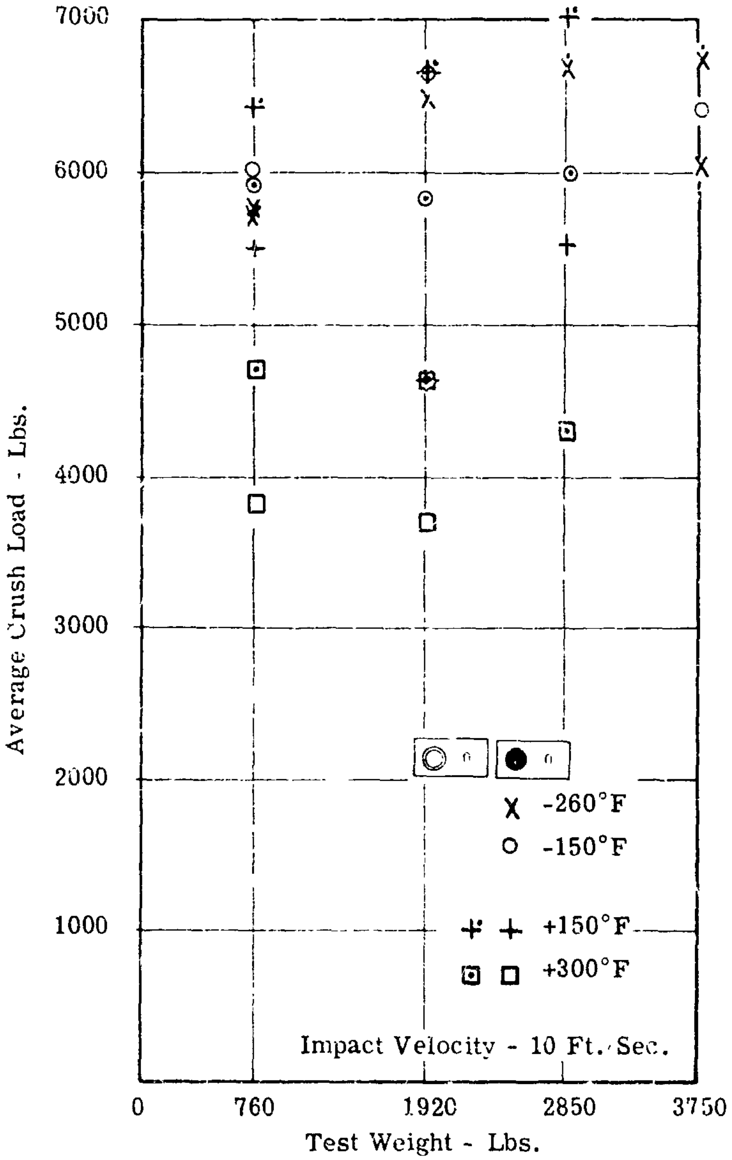


Figure 8-41. Average Crush Load Vs Impact Weight (Under Various Temperatures)

particular temperature. Those with very high loads should be judged on the basis of experiencing an unusual type of crushing action with binding, etc. Although the maximum changes in average crush load are higher, the average of these changes with temperature has been estimated from these points as listed here.

◎	+300	. . . . down approximately	27%
	-260	. . . . up approximately	17%
●	+300	. . . . down approximately	22%
	-260	. . . . up approximately	11%

The differences in percentages between the two configurations are very likely due to the different adhesives used.

6. Figures 8-42 and 8-43 are presented to show the temperature effect on the load onset rate when plotted against the various impact velocities and test weights. A general decline with increase in temperature is evident in Figure 8-42 although the -150°F temperature for the solid circular configuration and the + 150°F temperature for the external annular do not quite fit this pattern. The same comment holds true for Figure 8-43 where the plot is against test weight,however all do fall within a broad band. Here also several room temperature points are indicated which fall in the approximate center of the band.

7. Figures 8-44 thru 8-49 illustrate the effect on spring rate (load per per unit deflection) under temperatures of -150°F, +150°F and +300°F. Four loadings are listed for each specimen with the total stroke (specimen length

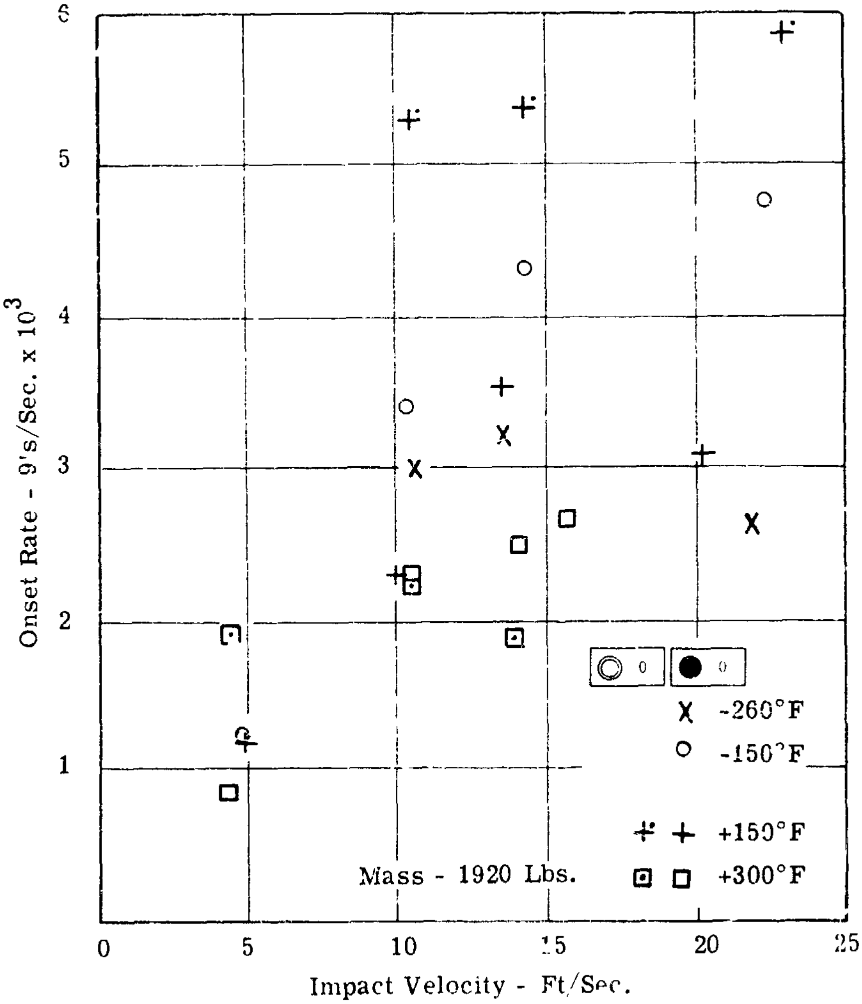


Figure 8-42. Load Onset Rate vs. Impact Velocity (Under Various Temperatures)

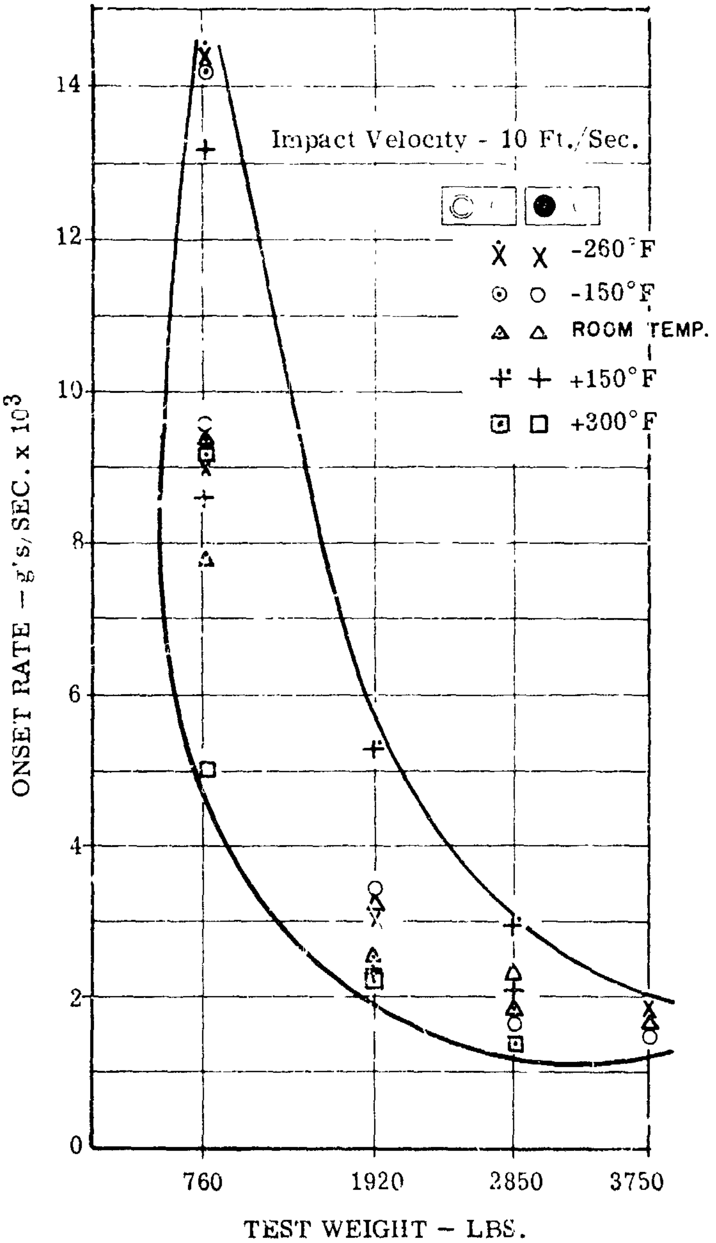


Figure 8-43. Load Onset Rate vs. Test Weight (Under Various Temperatures)

crushed following the spring rate readings) shown under each group of deflection vs. load figures. For the effect of the -260°F temperature Figure 8-50 is referenced, where the change in spring rate with total specimen length is plotted.

All other data reduced from the various test records may be found in the Tabular Test Data Summaries found in Figures 8-51 thru 8-56.

NOTE: Specimen No. SPX-166C41 (Test Weight 3,750 pounds, Impact Velocity 10 FPS, Temperature +300°F) was not tested due to probability of damage to test fixture. This decision was made on the basis of observing Specimen No. SPX-166C33 which crushed under a lower temperature (+150°F) with only the static test weight applied.

SPX-167-C18 ©

Deflection (In.)	Load (Lbs.)	Temperature (°F)
0	840	-150°F
.007	1000	-150°F
.019	1500	-150°F
.029	2000	-150°F
.037	2500	-150°F
.048	3000	-150°F
.055	3500	-150°F
.064	4000	-150°F
First Loading (Total Stroke = 4 In.)		
0	840	-150°F
0	1000	-150°F
.003	1500	-150°F
.012	2000	-150°F
.021	2500	-150°F
.029	3000	-150°F
.034	3500	-150°F
.042	4000	-150°F
Second Loading (Total Stroke = 6 In.)		
0	840	-150°F
0	1000	-150°F
.004	1500	-150°F
.030	2000	-150°F
.052	2500	-150°F
.068	3000	-150°F
.080	3500	-150°F
.095	4000	-150°F
Third Loading (Total Stroke = 10 In.)		
0	1400	-150°F
.020	2000	-150°F
.075	2500	-150°F
.120	3000	-150°F
.150	3500	-150°F
.182	4000	-150°F
Fourth Loading (Total Stroke = 10 In.)		

Figure 8-44. Spring Rate of External Annular Configuration at -150°F

SPX-167-C26

Deflection (In.)	Load (Lbs.)	Temperature (°F)
0	460	+150°F
.015	1000	+150°F
.023	1500	+150°F
.030	2000	+150°F
.038	2500	+150°F
.045	3000	+150°F
.055	3500	+150°F
.065	4000	+150°F
First Loading (Total Stroke = 4 In.)		
0	525	+150°F
.015	1000	+150°F
.035	1500	+150°F
.045	2000	+150°F
.055	2500	+150°F
.066	3000	+150°F
.075	3500	+150°F
.084	4000	+150°F
Second Loading (Total Stroke = 6 In.)		
0	430	+150°F
.034	1000	+150°F
.055	1500	+150°F
.075	2000	+150°F
.100	2500	+150°F
.118	3000	+150°F
.130	3500	+150°F
.144	4000	+150°F
Third Loading (Total Stroke = 10 In.)		
0	210	+150°F
.060	1000	+150°F
.095	1500	+150°F
.124	2000	+150°F
.155	2500	+150°F
.176	3000	+150°F
.200	3500	+150°F
.220	4000	+150°F
Fourth Loading (Total Stroke = 10 In.)		

Figure 8-45. Spring Rate of External Annular Configuration at +150°F

SPX-167-C34

Deflection (In.)	Load (Lbs.)	Temperature (°F)
0	480	+300°F
.008	1000	+300°F
.015	1500	+300°F
.025	2000	+300°F
.035	2500	+300°F

First Load (Total Stroke = 4 In.)

0	380	+300°F
.020	1000	+300°F
.035	1500	+300°F
.050	2000	+300°F
.070	2500	+300°F

Second Loading (Total Stroke = 6 In.)

0	250	+300°F
	1000	+300°F
.065	1500	+300°F
.095	2000	+300°F
.120	2500	+300°F

Third Loading (Total Stroke = 10 In.)

Figure 8-46. Spring Rate of External Annular Configuration at +300°F

SPX-166-C18 ●

Deflection (In.)	Load (Lbs.)	Temperature (°F)
0	600	-150°F
.011	1000	-150°F
.016	1500	-150°F
.024	2000	-150°F
.030	2500	-150°F
.040	3000	-150°F
.050	3500	-150°F
.055	4000	-150°F

First Loading (Total Stroke = 4 In.)

0	560	-150°F
.011	1000	-150°F
.020	1500	-150°F
.026	2000	-150°F
.036	2500	-150°F
.043	3000	-150°F
.050	3500	-150°F
.058	4000	-150°F

Second Loading (Total Stroke = 6 In.)

0	560	-150°F
.028	1000	-150°F
.043	1500	-150°F
.065	2000	-150°F
.078	2500	-150°F
.092	3000	-150°F
.105	3500	-150°F
.110	4000	-150°F

Third Loading (Total Stroke = 10 In.)

0	760	-150°F
.020	1000	-150°F
.055	1500	-150°F
.080	2000	-150°F
.105	2500	-150°F
.125	3000	-150°F
.137	3500	-150°F
.144	4000	-150°F

Fourth Loading (Total Stroke = 10 In.)

Figure 8-47. Spring Rate of Circular Solid Configuration at -150°F

SPX-166-C26 ●

Deflection (In.)	Load (Lbs.)	Temperature (°F)
0	380	+150°F
.015	1000	+150°F
.029	1500	+150°F
.035	2000	+150°F
.049	2500	+150°F
.062	3000	+150°F
.079	3500	+150°F
.170	4000	+150°F
First Loading (Total Stroke = 4 In.)		
0	510	+150°F
.010	1000	+150°F
.025	1500	+150°F
.040	2000	+150°F
.048	2500	+150°F
.059	3000	+150°F
.071	3500	+150°F
.082	4000	+150°F
Second Loading (Total Stroke = 6 In.)		
0	520	+150°F
.019	1000	+150°F
.040	1500	+150°F
.063	2000	+150°F
.078	2500	+150°F
.095	3000	+150°F
.115	3500	+150°F
.120	4000	+150°F
Third Loading (Total Stroke = 10 In.)		
0	480	+150°F
.035	1000	+150°F
.070	1500	+150°F
.098	2000	+150°F
.120	2500	+150°F
.140	3000	+150°F
.160	3500	+150°F
.180	4000	+150°F
Fourth Loading (Total Stroke = 10 In.)		

Figure 8-48. Spring Rate of Circular Solid Configuration at +150°F

SPX-166-C34 ●

Deflection (In.)	Load (Lbs.)	Temperature (°F)
0	520	+300°F
.010	1000	+300°F
.017	1500	+300°F
.030	2000	+300°F
.055	2500	+300°F
.070	3000	+300°F

First Loading (Total Stroke = 4 In.)

Deflection (In.)	Load (Lbs.)	Temperature (°F)
0	520	+300°F
.009	1000	+300°F
.020	1500	+300°F
.035	2000	+300°F
.055	2500	+300°F
.070	3000	+300°F

Second Loading (Total Stroke = 6 In.)

Deflection (In.)	Load (Lbs.)	Temperature (°F)
0	520	+300°F
.015	1000	+300°F
.026	1500	+300°F
.047	2000	+300°F
.075	2500	+300°F
.095	3000	+300°F
.130	3500	+300°F

Third Loading (Total Stroke = 10 In.)

Figure 8-49. Spring Rate of Circular Solid Configuration at +300°F

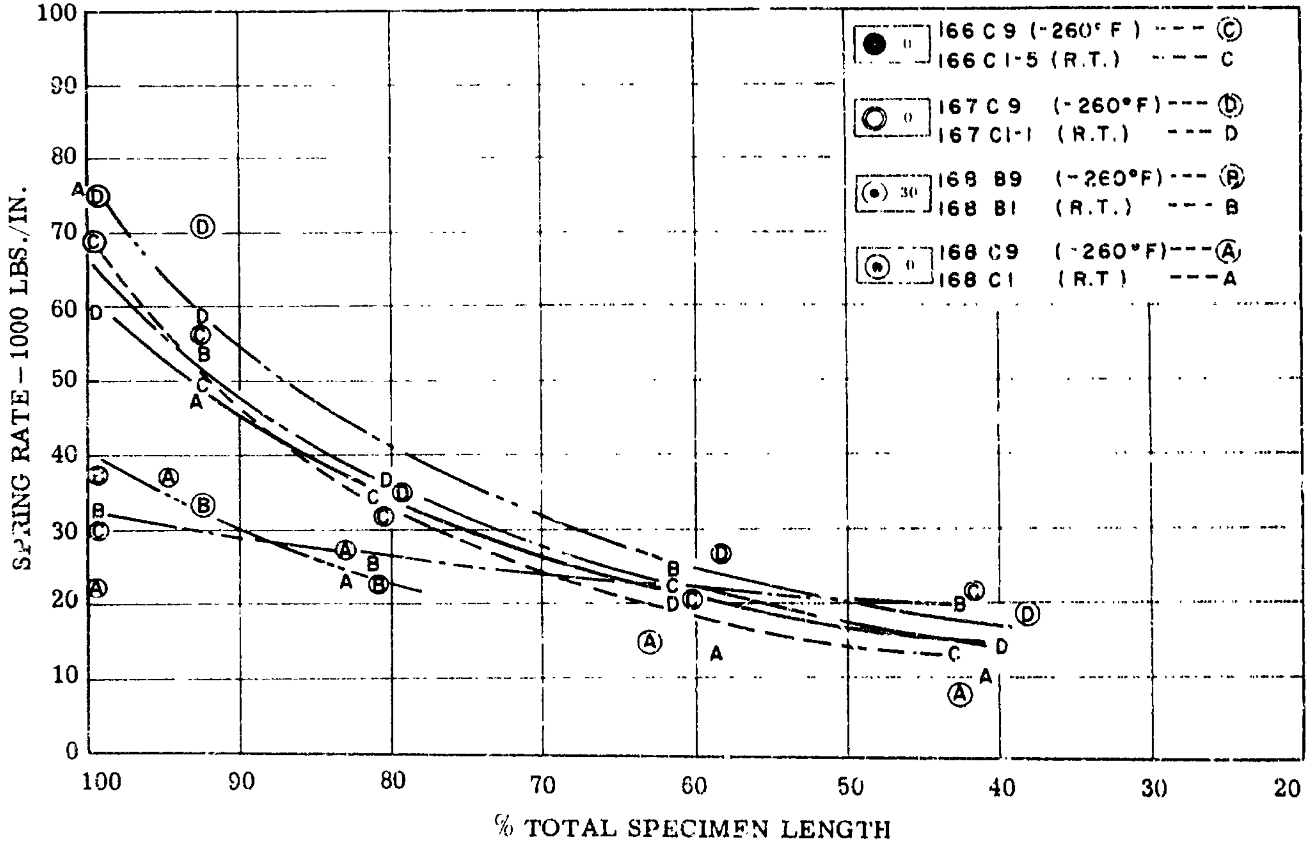


Figure 8-50. Spring Rate Vs. Specimen Length (Room Temperature and -260°F)

(Nos. SPX167C11 Thru SPX167C19)

Specimen Number		Average Load of End Sample	Diameter		Cross-Sectional Area	Length	Weight		Impact Weight	Impact Velocity		Average Crush Load	Initial Peak Loads			Load Onset Rate		Stroke	Rebound	Vacuum 3×10^{-1} TORR Req'd	Temperature		Time
Bendix	Hexcel	(Lbs)	O.D. (In.)	I.D. (In.)	(In.²)	(In.)	(Lbs)		(Lbs)	Target (FPS)	Actual (FPS)	(Lbs)	Max. (Lbs)	Min. (Lbs)	[illegible] (Lbs)	(Lbs/Sec $\times 10^6$)	(G's/Sec $\times 10^3$)	(In.)	(In.)	(Equal to 300 Microns or Less)	Target (°F)	Actual (°F)	(Minutes)
SPX167C11	SNG-24	5,600	7.00	5.50	14.726	50.50	4.13	1	1,920	5	4.98	5,245						?.63	086	190	-260	-245	
								2		5	4.94	5,650						2.38	09	200	-260		
								3		5								2.13		200	-240		
								4		5			Lower Load Cell Inoperative					2.06		200	-260		
								5		5			Use Liner or Outer Cell					2.00		200	-260	-349	
								6		5			Readings For Average Crush					1.88		200	-260		
								7		5			Loads					1.25		250	-260		
								8		5	4.86	6,145						2.00	.30	300	-260		
								9		5								1.75		300	-260		
								10		5								1.88		300	-260	-247	
								11		5								1.94		300	-260		
								12		5								1.75		300	-260		
								13		5	4.08	6,325						1.75		300	-260		
								14		5								8.38	22	300	-260	-252	
SPX167C12	SNG-7	5,500	7.06	5.50	15.417	50.50	4.25	1	1,920	10	10.64	5,905	7,585	4,225	7,060	4.22	2.20	9.50		170	-240	-252	
								2		10		6,525						8.56		200	-260		
								3		10	10.52	6,345	Lower Load Cell Inoperative.					8.25		200	-260		
								4		10	9.06	6,925	Use Inner or Outer Cell					7.00		250	-260		
								5		10	10.3	7,680	Readings For Average Crush Load					5.88		250	-260	-252	
SPX167C13	SNG-14	5,650	7.06	5.50	15.417	50.50	4.25	1	1,920	14	14.30	6,640	Lower Load Cell Inoperative					14.50	.26	200	-260	-243	
								2		14	14.61	5,725	at Impact					14.88	.35	200	-260		
								3		14								7.25		190	-260	-248	
SPX167C14	SNG-35	5,650	7.00	5.50	14.726	50.50	4.25	1	1,920	20	22.51	5,740	Lower Load Cell Inoperative at Impact					37.75	0	300	-260	-243	
SPX167C15	SNG-32	5,650	7.00	5.50	14.726	50.63	4.00	1	760	10	10.20	5,740	10,890	3,600	7,545	10.9	14.4	2.50	.075	300	-260	-300	
								2		10	10.32	6,075	9,950	3,670	8,215	8.33	11.0	2.50	.10	300	-260		
								3		10								2.00		300	-260		
								4		10								2.25		300	-260		
								5		10								2.00		300	-260	-292	
								6		10								2.00		300	-240		
								7		10								1.83		300	-260		
								8		10	10.07	7,620	10,970	6,085	8,895	5.77	7.59	1.38	20	300	-260		
								9		10								1.75		300	-260		
								10		10								1.75		300	-260	-303	
								11		10								1.75		300	-260		
								12		10	10.19	5,415	7,085	4,810	7,085	3.74	4.92	2.38	.24	300	-260	-305	
SPX167C16	SNG-23	5,650	7.22	5.50	17.160	50.50	4.19	1	2,850	10	10.64	6,725	Lower Load Cell Inoperative at Impact					16.63	.124	160	-260	-263	
								2		10	10.45	6,725						17.13	.183	200	-200		
								3		10								3.50		200	-260	-252	
SPX167C17	SNG-29	5,350	7.13	5.50	15.113	50.38	4.25	1	3,750	10		6,745	Lower Load Cell Inoperative at Impact					28.00		300	-280	-294	
								2		10								12.75		300	-280	-300	
SPX167C18	SNG-34	5,650	7.00	5.50	15.417	50.50	4.13	1	1,920	Static								4		200	-150	-148	
								2		Static								6		250	-150		
								3		Static								10		300	-150	-158	
								4		Static								10		300	-150		
								5		Static								10		300	-150	-102	
SPX167C19	SNG-16	5,300	7.06	5.50	15.417	50.50	4.13	1	1,920	5	5.03	5,530						2.38	.066	110	-150	-144	
								2		5	4.99	5,800						2.25	.105	180	-150		
								3		5								2.00		150	-150		
								4		5			Lower Load Cell Inoperative					2.00		160	-150		
								5		5			Use Outer or Inner Cell					2.00		160	-150	-157	
								6		5			Readings For Average Crush					1.75		160	-150		
								7		5			Load					1.75		180	-150		
								8		5	4.80	7,115						1.50	21	200	-150		
								9		5								1.63		200	-150		
								10		5								1.75		150	-150	-153	
								11		5								1.63		200	-150		
								12		5								1.75		200	-150		
								13		5	4.63	7,340						1.50	.33	200	-150		
								14		5								1.25		200	-150		
								15		5								1.25		200	-150	-153	

Figure 8-51. Tabular Test Data Summary for Phase II Full Length Test Specimens SPX-167-C11 Through SPX-167-C19

(Nos SPX167C20 Thru SPX167C29)

Specimen Number Bendix	Specimen Number Nemco	Average Load of End Sample (Lbs)	Diameter O.D. (In)	Diameter I.D. (In)	Cross Sectional Area (In²)	Length (In)	Weight (Lbs)	[illegible]	Impact Weight Actual (Lbs)	Impact Velocity Target (FPS)	Impact Velocity Actual (FPS)	Average Crush Load (Lbs)	Initial Peak Loads Max. (Lbs)	Initial Peak Loads Min. (Lbs)	Initial Peak Loads [illegible] (Lbs)	Load Onset Rate Lbs/Sec x 10	Load Onset Rate [illegible] x 10	Stroke (In)	Rebound (In)	Vacuum 1x10^{-1} TORR Req'd (Equal to 100 Microns or Less)	Temperature Target (°F)	Temperature Actual (°F)	Time (Minutes)
SPX167C20	SNG-22	5,350	7.06	5 50	15 417	50 50	4 19	1	1,920	10	10 59	5,605						10 25	093	150	-150	-148	
								2		10	10 35	5,875	Lower Load Cell Inoperative [illegible]					9 75	.18	200	-150		
								3		10	10 [illegible]5	6,415	Outer or Inner Cell Readings For					8.50	24	200	-150		
								4		10	10 15	6,725	Average Crush Load					7.38	.40	200	-150	-146	
SPX167C21	SNG-31	5,250	7 13	5 50	16 113	50 50	4 19	1	1,920	14	13 53	6,200	Lower Load Cell Inoperative					16 00	17	180	-150	-163	
								2		14	14 01	6,255	At Impact					15 75	.43	180	-150		
								3		14								6.00		250	-150	-163	
SPX167C22	SNG-33	5,600	7 00	5 50	14 726	50.50	4 13	1	1,920	20	23 20		Lower and Outer Load Cells Inoperative At Impact					38	.44	300	-150	-147	
SPX167C23	SNG-18		7.00	5.50	14.726	50 50	4 00	1	760	10	10 20	5,900	10,475	3,910	7,690	10 8	14.2	2.50	0	270	-150	-143	
								2		10	10 38	6,165	10,010	4,240	8,155	9 39	12.4	2.25	.091	150	-150		
								3		10								2.50		180	-150		
								4		10								2.25		[illegible]	-150		
								5		10								2.00		2[illegible]0	-150	-154	
								6		10								2.00		200	-150		
								7		10								2.00		250	-150		
								8		10	10.10	7,030	9,680	5,700	8,355	5.69	7.49	2.00	.29	250	-150		
								9		10								2 00		240	-150		
								10		10								2 00		200	-150	-152	
								11		10								2.00		200	-150		
								12		10								2.00		200	-150		
								13		10	10.53	6,495	7,430	5,835	7,490	3.58	4 71	2.00	.36	300	-150		
								14		10								2.00		350	-150		
								15		10								1.63		300	-150	-141	
SPX167C24	SNG-17	5,650	7 00	5.50	14.726	50 44	4 30	1	2,350	10	10 43	5,930	Lower Load Cell Inoperative					19.63	.09	120	-150	157	
								2		10	10 10	6 750	At Impact					16.13	.18	160	-150	-155	
SPX167C25	SNG-[illegible]	5,650	7.06	5 50	15 417	50 56	4 25	1	3,750	10	10 85	7,410	13,040	3,805	8,065	10 7	2 84	25.2			-150	-149	
								2		10								7 50			-150		
								3		10								2.50			-150	-158	
SPX167C26	SNG-2	5,350	7 13	5 50	16 113	50 63	4 13	1	1 920	Static								4		300	+150	+158	
								2		Static								6		300	+150		
								3		Static								10		[illegible]	+150		
								4		Static								10		300	+150		
								5		Static								10		300	+150	[illegible]	
SPX167C27	SNG-5	5,350	7.00	5 50	14.726	50 50	4 [illegible]	1	1,920	5	4 94		Lower Load Cell Inoperative At Impact					2.13	.016	300	+150	+163	
								2		5	4 97		Lower Load Cell Inoperative At Impact					1.88	019	300	+150		
								3		5								1.75		300	+150		
								4		5								1 75		300	+150		
								5		5								1.75		300	+150		
								6		5								1.63		300	+150	+169	
								7		5								1 63		300	+150	+174	
								8		5	4.76	7,005	9,805	6,135	8,270	4 59	2.89	1 50	.11	300	+150		
								9		5								1 50		300	+150		
								10		5								1.50		300	+150		
								11		5								1.50		300	+150		
								12		5								1.50		300	+150		
								13		5	4 75	7,135	9 475	6,400	8,340	3 47	1.81	1 50	14	300	+150		
								14		5								1.50		300	+150		
								15		5								1 50		300	+150	+174	
SPX167C28	SNG-2	5, 50	7.00	5 50	14 726	50 63	4 13	1	1,920	10	10.53	6,620	12,040	3,640	8,445	10 2	5 31	8 50	12	300	+150	+172	
								2		10	10 51	6,890	11,295	4,345	7,975	8 70	4 53	7 75	15	300	+150		
								3		10	10 18	6,820	11 560	5,330	8,785	7 67	3 99	7 38	24	300	+150		
								4		10	10 29	7,230	10,480	5 6	8,[illegible]85	6 93	3 61	6 75	29	300	+150		
								5		10	10 08	7 635	11 293	6,415	9,125	5 65	2 9	5 [illegible]8	35	300	+150	+144	
SPX167C29	SNG-4	5,450	7 00	5 50	14 725	50 88	4 25	1	1,920	14	14 3	6,990	12 435	4 510	8 7[illegible]	10 3	5 39	14.50		300	+150	+149	
								2		14	14 59	7 200	11 335	4 855	8,785	10 2	5 30	13 00	26	300	+150		
								3		14	14 70	7 735	12 345	5 260	9 800	8 86	5 61	10 15	33	300	+150	+149	

Figure 8-52. Tabular Test Data Summary for Phase II Full Length Test Specimens SPX-167-C20 Through SPX-167-C29

(Nos SPX167C30 Thru SPX167C41)

Specimen Number		Average Load of End Sample	Diameter		Cross Sectional Area	Length	Weight	Test No.	Impact Weight	Impact Velocity		Average Crush Load	Initial Peak Loads			Load Onset Rate		Stroke	Rebound	Vacuum 1x10⁻¹ TORR Req'd	Temperature		Time
Bendix	Hexcel		O.D.	I.D.						Target	Actual		Max.	Min.	Trim	(Lbs/Sec	(G's/Sec				Target	Actual	
		(Lbs)	In	(In	In²	In	Lbs		(Lbs)	(FPS)	(FPS)	(Lbs)	(Lbs)	(Lbs)	(Lbs)	x 10⁶)	x 10³)	(In)	(In)	(Equal to 100 Microns or Less)	(°F)	(°F)	(Minutes)
SPX167C30	SNG-6	5,700	7.00	5.50	14 726	50 63	4 50	1	1,920	20	23 02	5,955	12,290	3,870	6,320	11 3	5.68	30.38	33	300	+150	-187	
								2		20								6.00		300	+150	-175	
SPX1 7C31	SNG-36	5,500	7 00	5.50	14 726	50 50	4 00	1	760	10	10.24	6,420	11,715	3,270	8,030	10 0	13.2	2.38	.089	210	+150	+156	
								2		10	9 33	6,555	11,110	4,545	8,230	8.60	11.4	2.25	.13	250	+150		
								3		10								2 13		250	+150		
								4		10								2.13		250	+150		
								5		10								2.29		300	+150	+151	
								6		10								2.35		250	+150		
								7		10								2.19		250	+150		
								8		10	10.29	6,070	9,140	4,600	7,535	6 13	8.07	2.25	.21	250	+150		
								9		10								2.38		200	+150		
								10		10								2.25		250	+150	+151	
								11		10								2.38		250	+150		
								12		10								2.50		200	+150		
								13		10	10.50	8,200	8,740	4,795	7,270	4 33	5.69	2 00	33	250	+150	+153	
SPX167C32	SNG-3	5,800	7.06	5.50	15.417	50.56	4.13	1	2,850	10	10.62	7,010	11,225	4,940	8,550	8.42	2.96	13.75	0	260	+150	+158	
								2		10	10.72	7,480	11,625	5,940	9,085	7.09	2.49	11.75	0	260	+150		
								3		10	9 92	8,015	11,025	6,075	9,085	6.35	2.23	11.75	.12	260	+150	+151	
SPX167C33	SNG-21	5,600	7.13	5 50	16 113	50.50	4.25	1	3,750	10	10.74	6,536	10,635	4,230	7,715	8.78	2.34	28.25	0	300	+150	+153	
								2		10	4 85							5.25		300	+150	+150	
SPX167C34	SNG-11	5,650	7.00	5 50	14.726	50.44	4.13	1	1,97	Static								4		300	+300	+306	
								2		Static								6		300	+300		
								3		Static								10		300	+300	+296	12
SPX167C35	SNG-13	5,475	7.06	5.50	15.417	50.50	4.00	1	1,920	5	4 48	3,965	6,015	3,105	5,485	3.69	1.92	3.88	0	300	+300	+300	
								2		5	4.53	4,165	5,355	3,505	5,151	2.96	1.55	3.50	.029	300	+300		
								3		5								3.25		300	+300		
								4		5								4.50		300	+300	+309	
								5		5								2.88		300	+300		
								6		5								3.75		300	+300		
								7		5								2.75		300	+300		
								8		5	4 74	6,070	7,135	5,465	7,135	2.47	1 28	2.00	.15	200	+300		
								9		5								1.75		300	+300		
								10		5								2 75		240	+300	+315	
								11		5								2.25		240	+300		
								12		5								2.75		240	+300		
								13		5	4.65	4,900	5,170	4,230	5,170	1.58	821	2.25	14	340	+300	+290	
SPX167C36	SNG-10	5,400	7.00	5.50	14 726	50 50	4.38	1	1 920	10	10 42	4,645	6,505	3,475	6,506	4.34	2.26	12.00	12	300	+300	+301	
								2		10	10.09	4 130	6,230	4,165	5,820	3.60	1.56	11.25	12	300	+300		
								3		10	10.60	4,990	6,645	3,750	6,505	3.99	2.08	10.25	.23	300	+300	+288	
SPX167C37	SNG-9	5,500	7.00	5.50	14.726	50.50	4 00	1	1,920	14	13 81	3,830	5,250	2,670	5,180	3.65	1.90	25.63	0	300	+300	+305	
								2		14	10 32	4,180	5,360	3,210	5,360	3.10	1 61	13 00	.12	300	+300	+289	
SPX167C38	SNG-15	5,550	7.00	5.50	14.726	50.50	4.13	1	1,920	20	19 27							37.13	0	300	+300	+295	
SPX167C39	SNG-19	5,650	7 00	5 50	14.726	50.50	4.13	1	760	10	10 20	4,710	8,865	3,180	7,160	6.94	9 13	3 50	.056	300	+300	+301	3
								2		10	9 84	4,510	5,970	3,780	5,970	4.18	5.50	3 25	.11	250	+300		
								3		10								3.38		250	+300		
								4		10								2.00		250	+300		
								5		10								3 13		250	+300	+298	
								6		10								2 75		250	+300	+300	7
								7		10								2.75		300	+300		
								8		10	9 79	5,040	5,835	4,110	5,835	5 64	4.79	2 75	.26	275	+300	300	8
								9		10								2.50		250	+300	300	9
								10		10								2 50		275	+300	292	10
SPX167C40	SNG-8	5,350	7.00	5 50	14 726	50 50	4 13	1	2,850	10	10 21	4,305	5,535	3,745	5,235	4 14	1 15	34 50	0	260	+300	293	
SPX167C41	SNG-20	5,550	7 06	5 50	15 417	50 50	4 25	1	3 750	10	10 20	5,030	5,680	3,730	5,680	4 90	1 31	41 63		300	+300	+301	

Figure 8-53. Tabular Test Data Summary for Phase II Full Length Test Specimens SPX-167-C30 Through SPX-167-C41

(No's SPX166C11 Thru SPX166C19)

Specimen Number Bendix	Specimen Number Hercules	Average Load of End Sample (Lbs)	Diameter O.D. (In)	Diameter I.D. (In)	Cross Section Area (In 2)	Length (In)	Weight (Lbs)		Impact Weight (Lbs)	Impact Velocity Target (FPS)	Impact Velocity Actual (FPS)	Average Crush Load (Lbs)	Initial Peak Loads Max (Lbs)	Initial Peak Loads Min (Lbs)	Initial Peak Loads Crush (Lbs)	Load Onset Rate (Lbs/Sec x 10^6)	Load Onset Rate (G's/Sec x 10^3)	Stroke (In)	Rebound (In)	Vacuum 5x10^{-1} TORR Req'd (Equal to 500 Microns or Less)	Temperature Target (°F)	Temperature Actual (°F)	Time (Minutes)
SPX166C11	36350B 4A 2A		6.13		117.8	51.88	2.94	1	1,920	5								2.00		250	-260	-274	
								2		5								2.00		260	-260	-269	
								3		5			Lower Load Cell Inoperative Inner or Outer Load Cell Readings for Average Crush Load					2.00		280	-260	-273	
								4		5								1.88		300	-260		
								5		5								1.88		400	-260		
								6		5								1.75		150	-260	-244	
								7		5								1.88		150	-260		
								8		5								1.75		200	-260		
								9		5								1.75		300	-260	-299	
								10		5								1.63		200	-260		
								11		5								1.75		200	-260	-313	
								12		5								2.00		200	-260	-313	
								13		5								2.00		200	-260		
								14		5								1.75		200	-260		
								15		5								1.75		200	-260	-313	
SPX166C12	36350B-1A 36350C-3A		6.25		122.5	51.88	2.88	1	1,920	10	10.63	6,490	6,755	6,165	6,755	5.81	3.02	8.25		100	-260	-233	
								2		10	10.7[illegible]		8,520	5,640	6,950	7.01	3.65	8.13		150	-260		
								3		10	10.826		8,850	5,115	7,015	7.38	3.84	7.88		175	-260	-258	
								4		10	10.567		8,160	5,330	6,910	5.61	2.92	7.50	.21	200	-260		
SPX166C13	36350B 8A-5A		6.19		120	51.94	2.42	1	1,920	14	13.617	6,360	7,345	5,900	6,820	6.21	3.24	15.38	.11	200	-260	-282	
								2		14	13.42	6,425	8,650	6,100	7,475	6.69	3.48	14.39	16	300	-260	-276	
SPX166C14	36360B 11A/7A		6.13			51.88	2.81	1	1,920	20	21.92	6,525	LWR Load Cell Inoperative At Impact			5.12	2.67	34.00		200	-260	-272	
SPX166C15	36690 25/2	5500/5500	6.25		122.5	51.75	3.00	1	760	10	9.43	5,770	8,980	5,180	7,015	6.82	8.98	2.38	.035	300	-260	-268	
								2		10	9.33	5,770	10,355	3,480	7,410	7.60	10.00	2.25	.072	300	-260		
								3		10								2.00		300	-260		
								4		10								2.38		300	-260		
								5		10								2.50		300	-260	-294	
								6		10								2.25		300	-260		
								7		10								2.00		300	-260		
								8		10	9.40	6,035	9,700	4,265	7,080	6.20	8.18	2.25	20	300	-260		
								9		10								2.00		300	-260		
								10		10								2.38		300	-260	-268	
								11		10								2.13		300	-260		
								12		10								2.00		300	-260		
								13		10	9.35	6,100	8,650	5,115	6,755	5.92	7.78	2.00	29	300	-260	-264	
SPX166C16	36349 3A, 4A		6.19		120	51.86	3.00	1	2,850	10	10.86	7,510	LWR. Load Cell Inoperative At Impact					16.63	13	250	-260	-272	
								2		10	10.35	6,525	8,695	5,615	7,505	6.35	2.23	16.00	15	300	-260	-272	
SPX166C17	36349 6A/5A		6.19		120	51.88	3.00	1	3,750	10	10.55	6,035	7,550	5,410	7,070	6.86	1.83	33.38	04		-260	-272	
SPX166C18	36690 17/1	5650/5625	6.25		122.5	51.63	[illegible]	1	1,920	Static								4		200	-150	-156	
								2		Static								6		180	-150		
								3		Static								10		260	-150	-169	
								4		Static								10		300	-150		
								5		Static								10		300	-150	-158	
SPX166C-19	36360C 5A/7A		6.13		117.6	51.88	2.88	1	1,920	5	4.84	6,100	6,585	5,825	6,585	2.40	1.25	2.38	.08	100	-150	-15[illegible]	
								2		5	4.99	6,195	7,855	5,845	7,300	4.66	2.43	2.25	.097	150	-150		
								3		5								2.19		150	-150		
								4		5								1.50		150	-150		
								5		5								2.00		150	150		
								6		5								2.06		150	-150		
								7		5								2.06			-150		
								8		5	4.95	6,525	8,095	6,175	7,505	5.37	2.80	2.00	15	150	-150	-171	
								9		5								1.94		175	-150		
								10		5								1.94		200	-150	-153	
								11		5								1.88		200	-150		
								12		5								1.88		200	-150		
								13		5	4.79	6,340	6,970	6,270	6,970	3.37	1.76	1.75	19	200	-150		
								14		5								1.75		200	-150	-156	

Figure 8-54. Tabular Test Data Summary for Phase II Full Length Test Specimens SPX-166-C11 Through SPX-166-C19

(Nos. SPX166C20 Thru SPX166C31)

Specimen Number		Average Load of End Sample	Diameter		Cross-Sectional Area	Length	Weight	Test No.	Impact Weight	Impact Velocity		Average Crush Load	Initial Peak Loads			Load Onset Rate		Stroke	Rebound	Vacuum 3x10⁻¹ TORR Req'd	Temperature		Time
			O.D.	I.D.						Target	Actual		Max.	Min.	True	Lbs/Sec	G's/Sec				Target	Actual	
Bendix	Hexcel	(Lbs)	(In)	(In)	(In²)	(In)	(Lbs)		(Lbs)	(FPS)	(FPS)	(Lbs)	(Lbs)	(Lbs)	(Lbs)	x 10⁶	x 10	(In)	(In)	(Equal to 300 Microns or Less)	(°F)	(°F)	(Minutes)
SPX166C20	36350C 4A-6A		6.13		117.8	51 88	2 94	1	1,920	10	10.46	6,640	7,415	5,535	7,160	6 55	3.41	8.25		150	-150	-150	
								2		10	10.42		10,000	4,690	7,805	8 34	4 34	8.13		125	-150	-167	
								3		10	10 21		7,805	5,795	7,030	5 13	2.67	7 88		125	-150	-174	
								4		10	10 31		8,390	5,535	6,835	6 77	3 52	7 50	2.	125	-150		
SPX166C21	36340 8A-9A		6 13		117 8	51 88	2 68	1	1,920	14	14.41	6,695	7,920	6,045	7,055	8 32	4.33	15 0	1	300	-150	-151	
								2		14	14 273		10,150	5,255	7,700	8 94	4 65	14 0	.11	250	-150	-162	
SPX166C22	36350C 2A/10A		5.13		117.8	51 88	2 81	1	1,920	20	22 35	6,135	8,875	4,835	7,440	9.09	4.73	36.0	.11	300	-150	-176	
SPX166C23	35690 3/4	5700/5750	6.25		122.5	51 75	3.0	1	760	10	10.25	6,000	6,570	4,750	7,120	7 24	9.53	2 75	0	150	-150	-160	
								2		10	10 19	6,000	8,305	1,880	7,355	6.87	9.03	2 38	.087	150	-150		
								3		10								2.38		130	-150		
								4		10								2 25		150	-150		
								5		10								2 25		170	-150	-153	
								6		10								2 50		150	-150		
								7		10								2 50		150	-150		
								8		10		6,000	8,570	4,880	7,12	6.15	8 09	2.38	.180	180	-150		
								9		10								2.38		300	-150		
								10		10								2 25		180	-150	-159	
								11		10								2.38		130	-150		
								12		10								2 38		180	-150		
								13		10	10 33	6,135	8,270	5,330	7,135	5.56	7.32	2 50	.29	150	-150	-162	
SPX166C24	36348 2A/3A		6.25		122.5	52.00	3.00	1	2,850	10	9 49	6,310	Lower Load Cell Binding At Impact			4 63	1.62	17.50	.02	200	-150	-161	
								2		10	9.28	6,310	8,930	5,620	7,410	7.10	2.49	15.88	.09	250	-150	-154	
SPX166C25	36340 7A/8A		6.19		120	51.88	2 88	1	5,750	10	10.595	6,380	7,480	5,895	7,205	5.50	1.47	29 88	.04	100	-150	-167	
SPX166C26	36090 11/12	5600/5650	6.25		122.5	51.63	3 00	1	1,920	Static								4		300	+150	+148	
								2		Static								8		300	+150		
								3		Static								10		300	+150		
								4		Static								10		300	+150		
								5		Static								10		300	+150	+148	
SPX166C27	36344 4A/5A		6.25		122 50	51.88	2 81	1	1,920	5	5.02	5,480	6,065	5,235	6,065	2.24	1.17	2.63	.04	200	+150		
								2		5	4.88	5,310	7,045	4,785	6,370	3.30	1.72	2 50	.057		+150	+150	5
								3		5											+150	+150	6
								4		5	4.83	5,990	7,575	5,180	7,270	4.46	2 32	3.00	.38		+150	+150	7
								5		5		6,065				4.55	2 37	2.94	.09		+150	+150	9
SPX166C28	36343 11A/12A		6.25		122.50	51 88	2 81	1	1,920	10	10.16	4,640	5,395	4,080	5,260	7.41	2.30	12.69	.06	250	+150		
								2		10	10 19		6,705	3,955	5,810	4 40	2.29	11.63	.09	250	+150	+150	4
								3		10	10 18		7,600	5,125	6,430	5.95	3.10	9.81	.12	200	+150	+150	8
SPX166C29	36340 9A/10A		6 25		122.50	51 94	2.81	1	1,920	14	13.72	5,710	6,835	4,725	6,410	6.79	3.54	21.00	11	200	+150	+150	8
								2										10.75		200	+150	+150	10
SPX166C30	36343 6A/7A		6.19		120 00	51.88	3.00	1	1,920	20	20.37	5,375	6,400	4,005	5,855	5.96	3 10	37 44	28	200	+150		
SPX166C31	36620 29/30	5500/5500	6.25		122 5	51.88	3.00	1	760	10	10 640	5,490	6,550	4,500	6,020	6 33	8.33	2 75	054	250	+150	+166	
								2		10	10 492	5,555	8,270	3,970	6,880	7 89	10 39	2 75	061	200	+150		
								3		10								2 88		195	+150		
								4		10								2 75		180	+150		
								5		10								2 75		195	+150	+149	
								6		10								2.75		180	+150		
								7		10								2.63		190	+150		
								6		10	10 37	5,215	7 790	4 160	6,670	6.03	7.94	2 83		180	+150		
								9		10								2 63		200	+150	+149	
								10		10								2 50		190	+150		
								11		10								2 38		190	+150		
								12		10	10 215	5,480	7,460	4 360	6,340	4 51	5 94	1 50	31	180	+150	+150	

Figure 8-55. Tabular Test Data Summary for Phase II Full Length Test Specimens SPX-166-C20 Through SPX-166-C31

(No's SPX166C32 Thru SPX166C40)

Specimen Number		Average Load of End Sample	Diameter		Cross Sectional Area	Length	Weight	Test No.	Impact Weight	Impact Velocity		Average Crush Load	Initial Peak Loads			Load Onset Rate		Stroke	Rebound	Vacuum $1x10^{-1}$ TORR Req'd	Temperature		Time
			O.D.	I.D.						Target	Actual		Max.	Min.	True	(Lbs/Sec	(G's/Sec.				Target	Actual	
Bendix	Hexcel	(Lbs)	(In)	(In)	(In²)	(In)	(Lbs)		(Lbs)	(FPS)	(FPS)	(Lbs)	(Lbs)	(Lbs)	(Lbs)	$x\ 10^6$)	$x\ 10^3$)	(In)	(In)	(Equal to 300 Microns or Less)	(°F)	(°F)	(Minutes)
SPX166C32	36690	5500/5500	6.25		122.50	51.63	[illegible].00	1	2,850	10	10.78	5,550	6,755	4,960	6,285	5.90	2.07	21.00	.037	270	+150	+151	
	23/24							2			10.84	5,250	8,150	3,835	6,745	6.52	2.29	19.75	.037	270	+150	+150	9
SPX166C33	36349		6.19		120.00	51.88	2.75	1	3,750	10			Sample Crushed Under Test Rig Weight					13.38			+150		
	2A/1B												Yielded Under Static Load										
SPX166C34	36690		6.25		122.50	51.88	3.00	1		Static								4		220	+300	+312	
	15/16							2		Static								6		220	+300		
								3		Static								10		220	+300	+303	12
SPX166C35	36349		6.19		120.00	51.88	2.75	1	1,920	5	4.35	4,070	4,410	3,520	4,410	1.67	.869	5	.01	300	+300	+308	10
	6A/5A							2		5	4.28	4,070	5,020	3,660	4,820	2.32	1.21	4.38	.02	300	+300	+300	11
								3		5								4.13		300	+300	+300	12
								4		5								3.68		300	+300	+305	4
								5		5		3,765				3.24	1.69	3.75	.01	250	+300		
								6		5								3.63		250	+300		
								7		5								3.50		240	+300		
								8		5	4.77	3,765	5,290	3,490	5,080	3.10	1.61	3.38	.02	240	+300		
								9		5								3.50		240	+300		
								10		5		4,180				3.24	1.69	3.75	.03	230	+300	+271	
SPX166C36	36690	5630/5480	6.25		122.50	51.88	3.00	1	1,920	10	10.53	3,710	5,230	3,180	4,835	4.41	2.31	18.25	0	300	+300	+315	
	1/2							2		10	10.28		5,430	3,310	4,900	3.44	1.79	15.63	.06	300	+300		
								3		10								3.36		300	+300	+316	
SPX166C37	36690	5660/5620	6.25		122.50	51.88	3.00	1	1,920	14	14.13	3,890	5,575	3,085	4,900	4.78	2.49	28.75	.04	300	+300	+316	
	7/8							2		14								3.75		300	+300		
								3		14								3.50		300	+300	+277	
SPX166C38	36690	5650/5680	6.25		122.50	51.88	3.00	1	1,920	10	15.72	3,910	5,705	3,115	4,710	5.12	2.66	35.00	0	260	+300		
	9/10																						
SPX166C39	36690	5670/5680	6.25		122.50	51.63	3.00	1	760	10	10.08	3,800	4,540	3,335	4,405	3.79	4.98	4.38	.02	240	+300	311	4
	13/14							2		10	9.96	4,005	5,005	3,265	4,740	3.74	4.92	4	.027	180	+300	+300	6
								3		10								4		180	+300	+300	7
								4		10								3.88		160	+300	+300	3
								5		10								4		150	+300	+300	9
								6		10								3.63		150	+300	+300	9 1/2
								7		10								3.63		150	+300	+300	10
								8		10	10.06	4,335	6,075	3,600	5,275	3.53	4.65	3.50	.13	150	+290	+297	10 1/2
SPX166C40	36690	5500/5590	6.25		122.50	51.94	3.00	1	2,850	10	14.68	3,795	5,165	3,210	4,385	3.66	1.28	34.50	0	260	+300	+303	10
	27/28																						

Figure 8-56. Tabular Test Data Summary for Phase II Full Length Test Specimens SPX-166-C32 Through SPX-166-C40

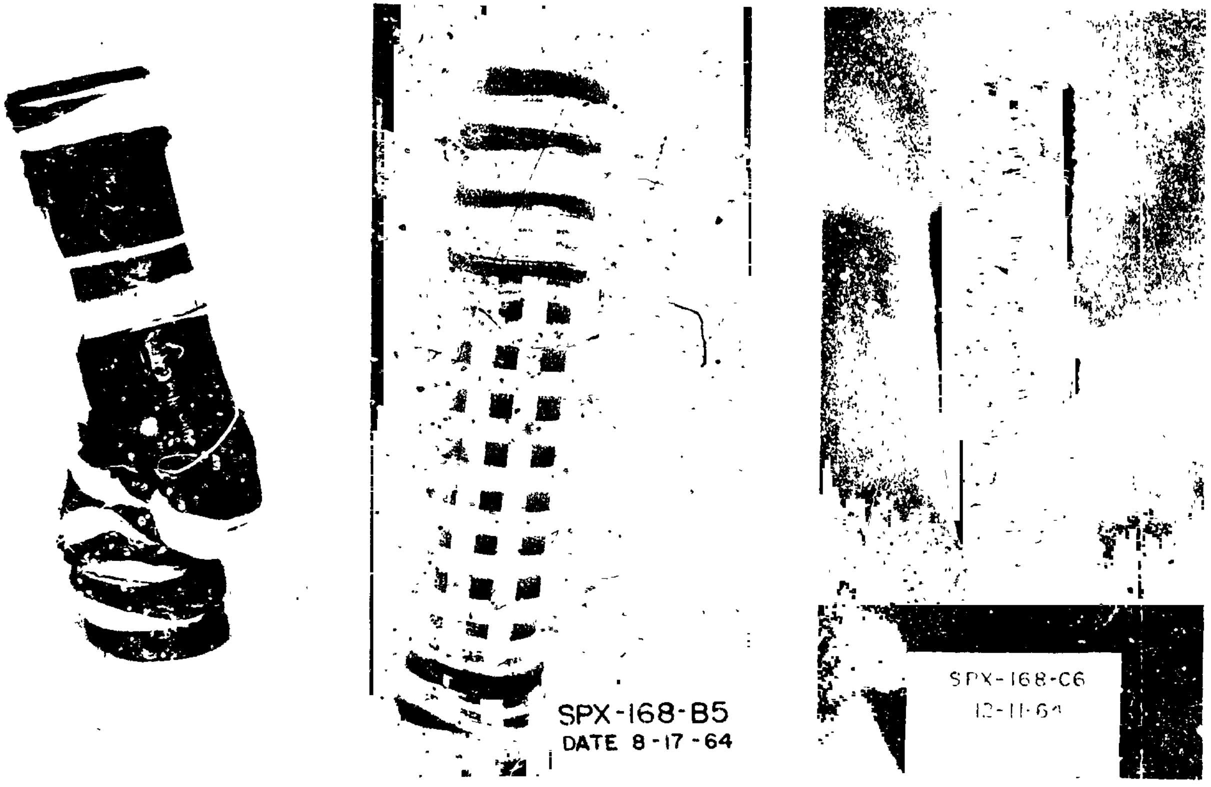
SECTION IX

SUMMARY

The basic objective of this research effort was to obtain quantitative design data concerning the characteristics of selected materials when used in high (L/D) ratio crushable energy absorbing capsules. This effort has resulted in the accumulation of a substantial amount of information and data which will be useful to the designers of shock attenuators for use in the space environment.

Optimized combinations of the desired characteristics such as specific energy, load onset rate, and rebound as defined under the Objective (paragraph 1.2) were embodied in the two configurations tested in Phase II. The external annular ◯ 0 and particularly the solid circular ● 0 (each with 0° cell axis) configurations give ample visual evidence of their satisfactory crushing characteristics when compared with typical examples of the other configurations in Figures 9-1, 9-2, and 9-3.

The solid circular section with the 0° cell axis ● 0 , which is fabricated with an expanded hexagonal cell, provides a regular cell buckling action which results in a very flat average crush load with a minimum of fluctuation. Specific energy is also highest for this configuration although it does not have quite the thickness efficiency (crush stroke in terms of total capsule length) of the solid circular section with the 15° cell axis. Specific energy values, measured during dynamic and static load applications, exhibit very small variation under these test conditions in which the specimens were tested in a vacuum.



15

30

0

Figure 9-1. Typical Crushed Specimens of the Internal Annular Configuration

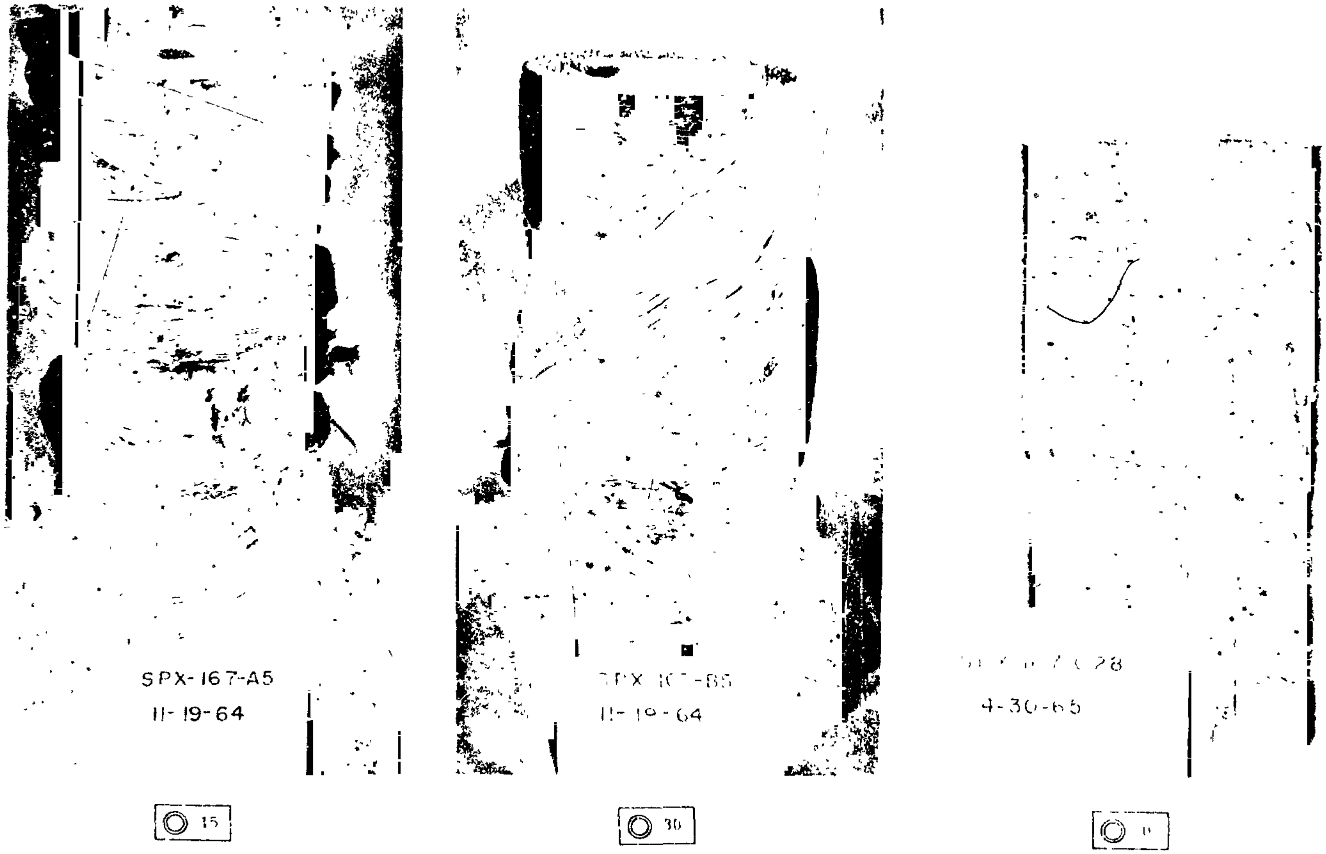


Figure 9-2. Typical Crushed Specimens of the External Annular Configuration

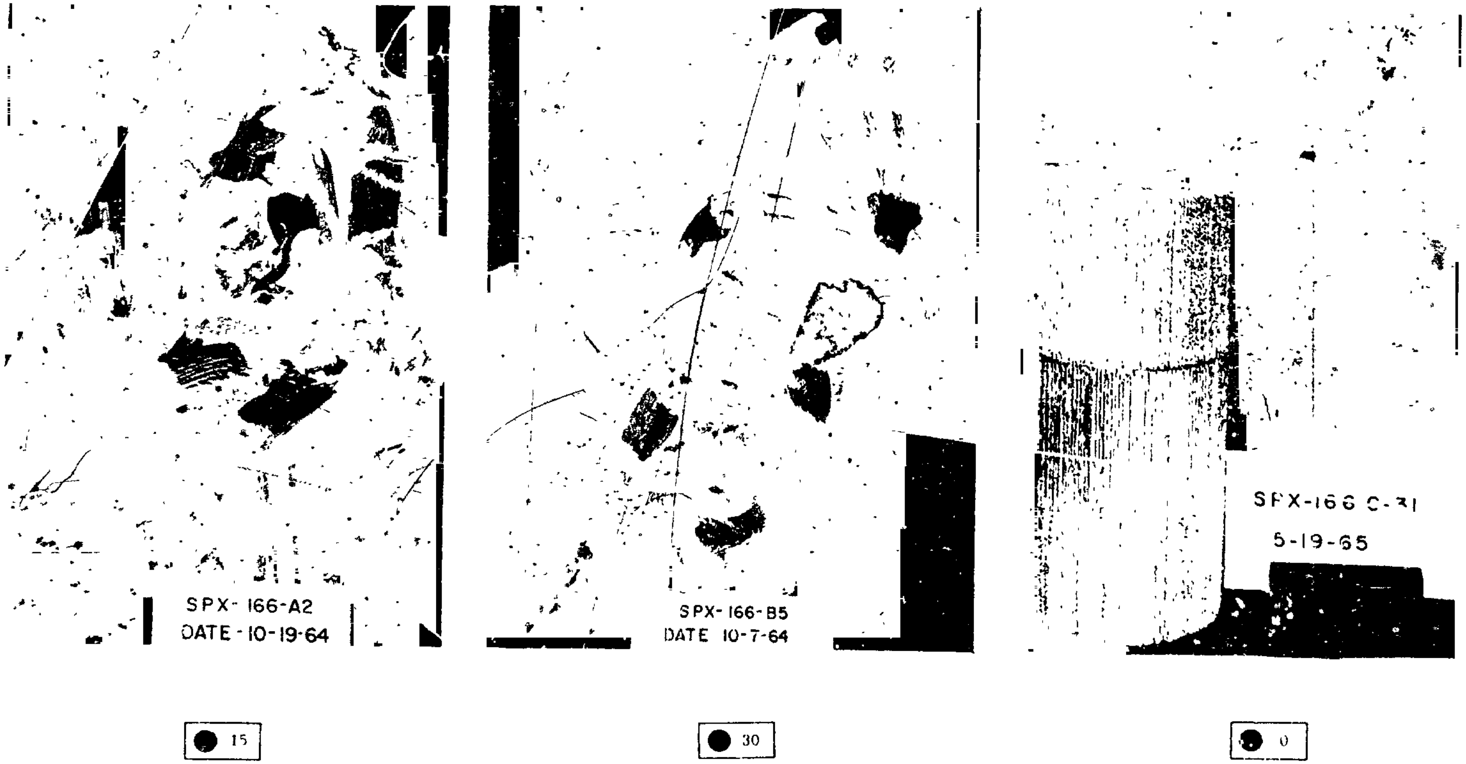


Figure 9-3. Typical Crushed Specimens of the Solid Circular Configuration

Rebound, which is of particular interest to the designer, was not large for any of the specimens. A rebound distance of .56 inch was the maximum recorded. Most specimens did not exceed .25 inch rebound. However, subsequent impacts on partially crushed capsules display an increase in the rebound value as the crushed length of the capsule increases.

Variation of the average crush loads under the extreme temperatures is greater than expected at the initiation of the program. These maximum values varied from room temperature test readings; being 30% higher for -260°F and 35% lower for the +300°F tests.

For a more thorough analysis of the data obtained, reference is made to Sections VII & VIII. Additional discussion may be found in the Conclusions and Recommendations (Section X), Addendum No. 1 containing the specimen suppliers Final Materials Report, Addendum No. II containing additional test records, and the Monthly Progress Reports as listed in the References, (Section XI).

SECTION X

CONCLUSIONS AND RECOMMENDATIONS

10.1 CONCLUSIONS

A broader and more advanced understanding of the many variables involved in the design of crushable aluminum structures for energy absorption is one of the important results of this project. Also, the "state-of-the-art" in the design, fabrication, and testing of energy absorbing capsules has been significantly advanced through the study of these various specimen configurations. These capsules were fabricated only after vigorous development efforts of the specimen supplier (Hexcel), monitored by Bendix Products Aerospace Division, fell short of the original goal. Negotiations were then conducted with NASA-MSC to adjust the requirements as outlined in the specifications. The minor revisions involved still permitted the attainment of the basic objectives of the program and did not detract in any great degree from the information to be obtained. Completion of the test program with its stringent requirements has provided a valuable source of data regarding crushable aluminum structures in a space environment. From this data, the following conclusions have been drawn.

10.1.1 The severe temperature extremes of the space environment have a substantial effect on the crush characteristics of capsules constructed of the materials used in this program.

10.1.2 Only minor differences in the dynamic and static specific energy values are evident when the specimens are tested under a medium vacuum environment.

10.1.3 Minimum rebound is obtained with crushable structures of these configurations. The rebound values increase as capsule length decreases.

10.1.4 Splicing short sections together to obtain a long capsule should be avoided due to the inherent buckling tendency at the splice, although this technique was successfully used on one configuration.

10.1.5 Annular type capsules crush more satisfactorily when using a vertically oriented cell. Capsules with angular cell orientation are prone to a secondary folding and bucking pattern, which is somewhat relieved as the ratio of wall thickness to diameter (D/t) is reduced.

10.1.6 The solid circular configurations of low density with the 15° or 30° cell axes are to be avoided by the designer since they are subject to random shear failures as illustrated in Figure 10-1. This failure mode subsequently results in the capsule buckling and folding with a severe drop off in crush load capacity.

10.1.7 The solid circular configuration with the 0° cell axis, which was fabricated with an expanded hexagonal cell, displayed the optimum combination of crush characteristics. A typical example of this is seen in Figure 10-2, where the smooth regular cell buckling pattern is readily evident.

10.2 RECOMMENDATIONS

Recommendations arising from observation of the tests and study of the information obtained therefrom include the following:

10.2.1 Although the solid circular configuration with the 0° cell axis utilizing two sections bonded together to form a long capsule produced satisfactory results, it is recommended that the inherent problems of such a design be surmounted through development of fabricating and processing equipment which would permit the capsule to be made in one full length section.

10.2.2 As previously noted in this document, the program originally was conceived with the thought of using 2024 aluminum alloy. Alloy 5056 was settled upon as a compromise. Continued development of the higher temperature capability 2024 foil in thicknesses and widths which will permit the fabrication of capsules similar in size to those used in this program is recommended.

10.2.3 The catastrophic failure pattern of the solid circular configuration with the 15° or 30° cell axis, which was initiated with a shearing action and resulted in buckling and folding of the specimens, requires further investigation. A 'failure mechanism" analysis and confirming test program to establish methods of avoiding this type of failure is recommended.

10.2.4 The full range of environmental conditions to which a crushable energy absorbing capsule may be exposed has not been completely investigated. An extension of this test program, which would involve the exposure of the specimens to a temperature cycling condition between high and low limits in combination with a much harder vacuum, is recommended. Important areas for further study would also include other materials and cell shapes.

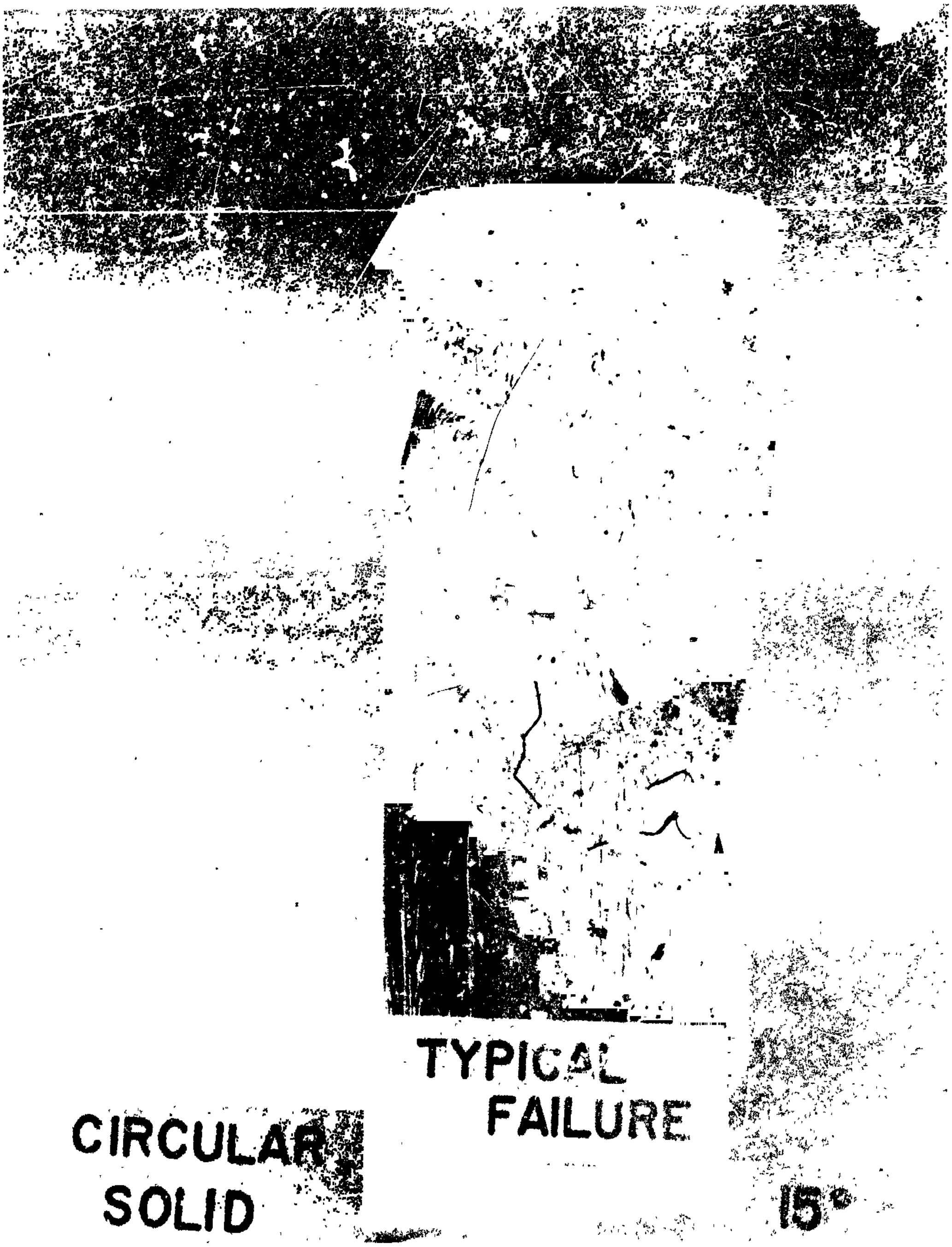


Figure 10-1. Typical Shear Failure Pattern Produced Under Both Static and Dynamic Load Applications on Circular Solid, 15° Cell Axis Configuration

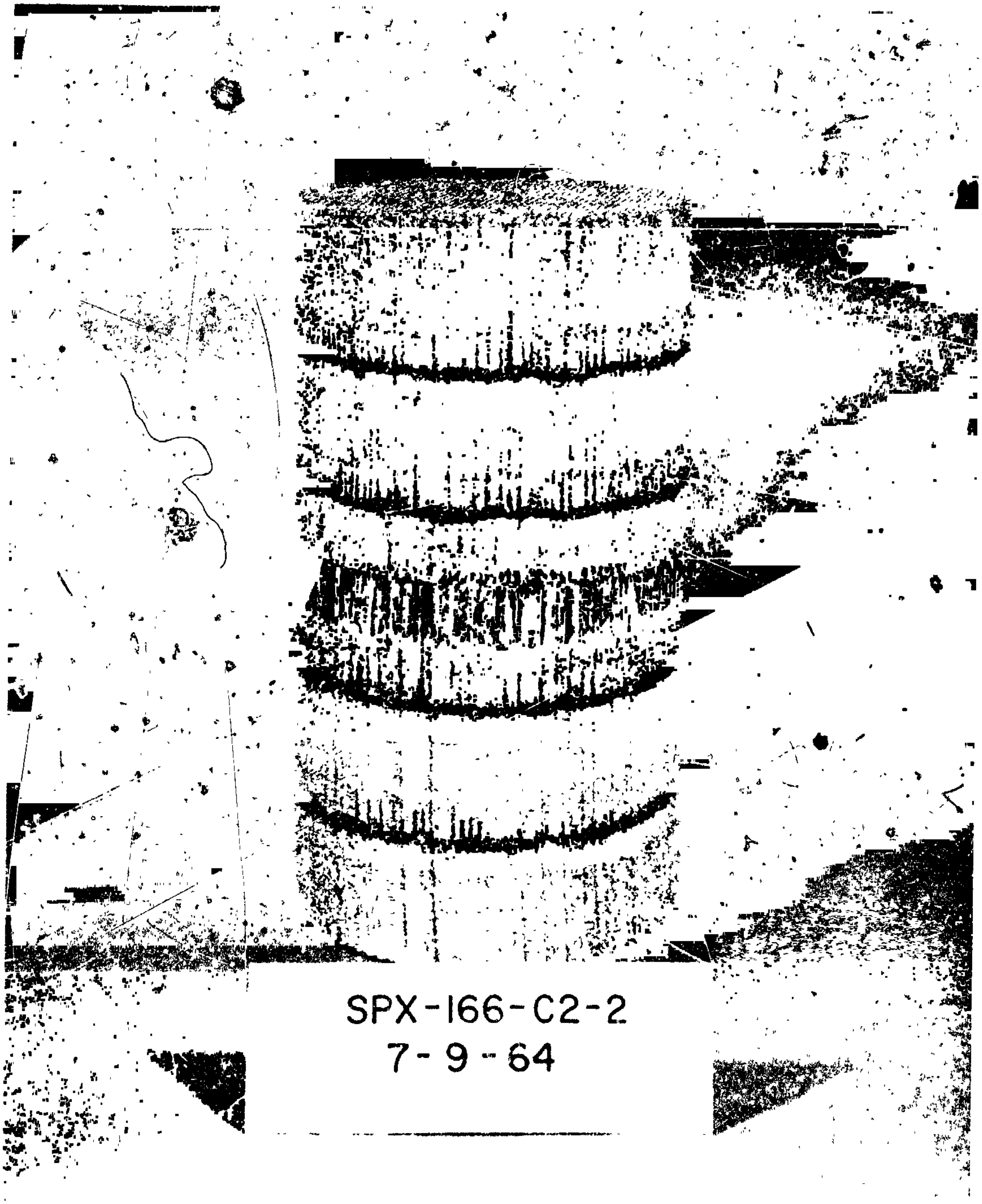


Figure 10-2. Typical Uniform Crush Pattern Exhibited by Circular Solid, 0° Cell Axis Configuration

SECTION XI

REFERENCES

1. Bendix Products Aerospace Division's Addendum No. I to Report SPP-65-107 dated July 24, 1965; containing Hexcel Products Inc. final report covering development and fabrication of Bendix Energy Absorption Capsules.

2. Bendix Products Aerospace Division's Addendum No. II to Report SPP-65-107 dated July 24, 1965; containing complete logs of all tests conducted, summary of data interpretation and pertinent copies of static and dynamic test records not included in the Final Engineering Report.

3. Bendix Products Aerospace Division's Monthly Progress Reports dated from November 4, 1963 thru June 1, 1965 and covering the entire progress of the "Study of Energy Absorbing Characteristics of Crushable Aluminum Structures in a Space Environment." (Ref. NASA Contract No. NAS 9-2074)

4. Jet Propulsion Laboratory's Technical Report No. 32-639, "The Development of Metal Honeycomb Energy-Absorbing Elements" dated July 24, 1964 by R. K. McFarland, Jr.