GPO PRICE $ ____________

CFSTI PRICE(S) $ ____________

Hard copy (HC) 3.00

Microfiche (MF) .65

ff 653 July 65

REPORT NO DR-5893

PHASE I AND II FINAL REPORT ON THE DEVELOPMENT OF A NET COUCH-RESTRAINT SYSTEM

FACILITY FORM 602

N68-16183 (ACCESSION NUMBER)

(THRU)

185 (PAGES)

1 (CODE)

CR-65941 (NASA CR OR TMX OR AD NUMBER)

05 (CATEGORY)

NASA CR 65941

WEBER AIRCRAFT
DIVISION OF WALTER KIDDE & COMPANY INC
BURBANK, CALIFORNIA

ENGINEERING REPORT

DR 5893
PHASE I & II FINAL REPORT

ON

THE DEVELOPMENT OF A UNI-DIRECTIONAL LIGHTWEIGHT ENERGY ABSORBING NET COUCH-RESTRAINT SYSTEM FOR USE IN THE APOLLO OR FOLLOW-ON PROJECTS

PREPARED FOR

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
MANNED SPACECRAFT CENTER
CREW SYSTEMS DIVISION

Houston, Texas

Contract No. NAS 9-3497

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APPROVED BY L.E. Thompson DATE 19 Aug 1966
L. E. Thompson, Program Manager

APPROVED BY Turner DATE 19 Aug 1966
J. Turner, Director of Engineering

FOREWORD

This report was prepared by Weber Aircraft, Division of Walter Kidde & Company, Inc., 2820 Ontario Street, Burbank, California, on National Aeronautics and Space Administration Contract No. NAS 9-3497 "Unidirectional Lightweight Energy Absorbing Net Couch Restraint System for use in the Apollo or Follow-on Projects". The work was administered under the direction of the Crew Systems Division of the NASA Manned Spacecraft Center with Mr. Douglas J. Geier, Head of the Acceleration Projects Section acting as Technical Monitor.

This document is prepared in accordance with the Contract Schedule, Part VIII - Reports of Work, paragraph 3 - Final Report, and is submitted to fulfill the contractual obligation specified therein. All work on this development program has been conducted by direction of the Engineering Department, under the Weber Aircraft Project Number 537. This document has a Weber Aircraft Report No. DR 5893.

Weber Aircraft wishes to acknowledge the contributions of Mr. D. Johansen, Project Engineer at Weber, and Mr. M. Olson of the United States Rubber Company under subcontract to Weber, who were primarily responsible for the development of the Energy Absorbing Net Couch - Restraint System.

ABSTRACT

The development of the Apollo Energy Absorbing Net Couch - Restraint System was performed by Weber Aircraft between October 1964 through August 1966. The Final Report DR 5893 summarizes the technical tasks performed during this period in the design, development, testing and fabrication of a prototype system which would be interchangeable with the existing hard couch system in the Apollo spacecraft. The program was divided into two phases identified as a development phase and a fabrication phase. The development phase was proportioned to take advantage of the state-of-the-art techniques in the fibre and fabric processing industry. These techniques were utilized to develop a body support insert concept which would attenuate a 50-g impact force to 20-g as felt by an anthropomorphic dummy. Three fabrication techniques, each prepared by a different supplier, were analyzed by Weber and evaluation tests performed. As a result the twisted cord filament wound construction concept, utilizing undrawn nylon fibers, was selected for the prototype couch system.

Phase II - Fabrication and Test of the Couch System - was provided first, to incorporate modifications resulting from the Phase I tests; second, to perform additional tests; and third, to design and fabricate a three man couch system capable of being installed in the Apollo Command Module.

As a direct result of this development program, it may be concluded that the use of undrawn nylon fibers to attenuate impact forces within the

ABSTRACT - Continued

limits of human tolerance is a very practical method to afford crew protection from emergency load conditions. The net couch system weight is less than one half that of the present hard couch system and can be removed, folded, and stored in the vehicle during space flight. All objectives set forth in the initial phases of the program have been met or exceeded. It is believed that a qualified man-rated system employing the concept developed, can be perfected for the Apollo Command Module or other Manned Space Vehicles. It is estimated that an 18 month program would be required to deliver the first operational production Apollo system.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS - Cont.

LIST OF ILLUSTRATIONS - Cont.

LIST OF TABLES

LIST OF TABLES - Cont.

1.0 INTRODUCTION

Weber Aircraft was awarded the National Aeronautics and Space Administration Contract No. NAS 9-3497 to develop an unidirectional netting type crew couch system which would be interchangeable with the existing hard couch system in the Apollo spacecraft.

The system developed by Weber, shown in Figure 1, utilizes undrawn nylon fibers integrated into a body support assembly which is attached to a lightweight monocoque aluminum sheet metal couch frame. During predetermined impact conditions the nylon fibers are subjected to forces which cause molecular realignment of the randomly oriented molecules in the undrawn fibers, producing a plastic hysteretic displacement at a constant force level, resulting in the desired attenuation of the couch occupant.

The individual couches are mounted on a rigid intermediate structure which uses the same attachment locations and fittings as the existing hard couch in the Apollo Command Module.

This final report summarizes the technical task resulting from Phase I and II of the design, development, testing and fabrication of a prototype couch system as required in Part VIII, Item 3 of the Contract.

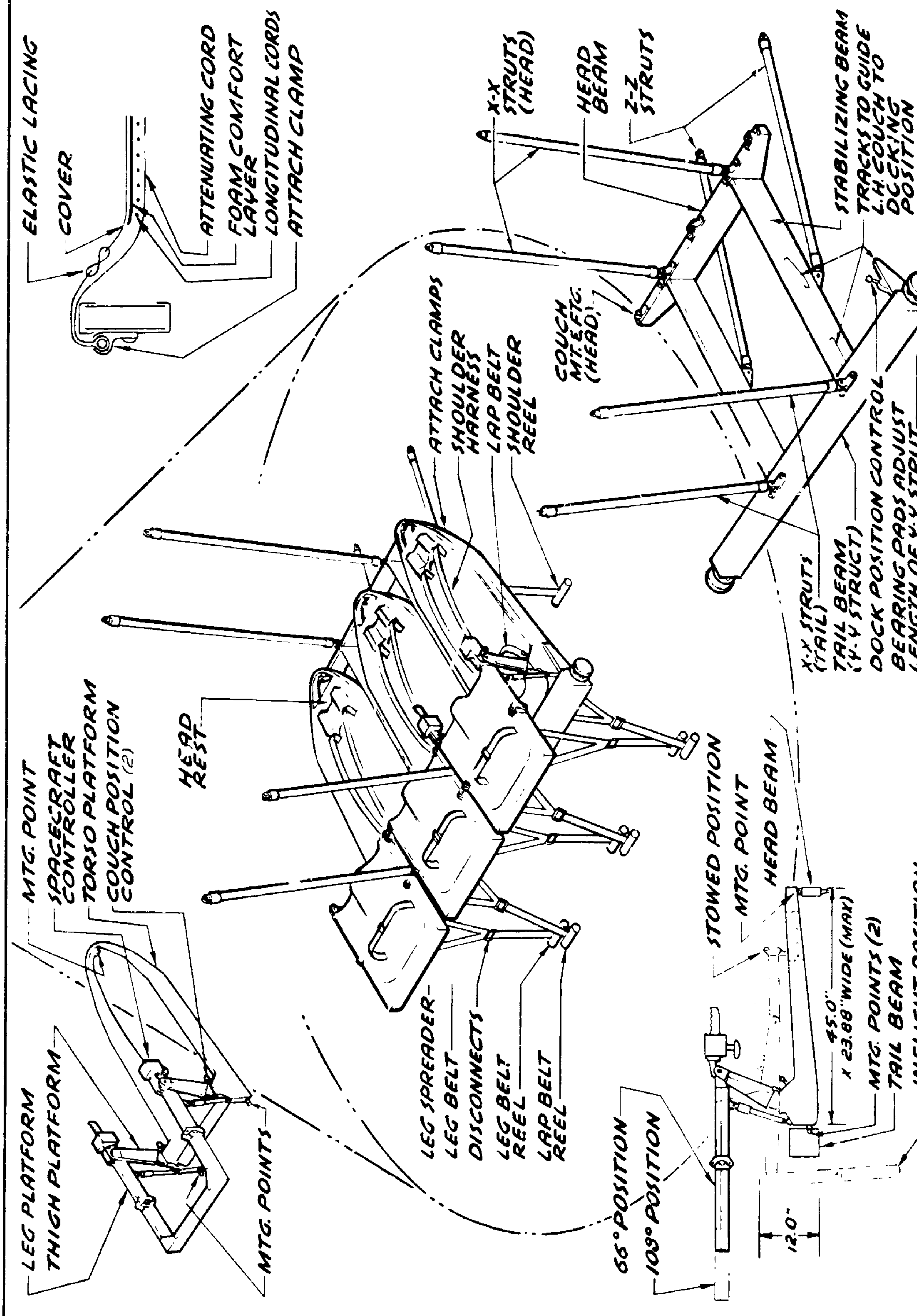


FIGURE 1

SKETCH OF APOLLO NET COUCH SYSTEM

2.0 PROGRAM PLAN

The program was divided into two major phases, a design-development phase and a fabrication phase identified as Phase I and Phase II, respectively. The design-development phase was further defined as having two distinct subtasks; Task A - Development of a Body Support Concept, and Task B - Development of a Couch System.

The phases and tasks were further subdivided, as shown in Figure 2, into the major elements of design, fabrication and testing required to complete the program. The effort related to both Phase I and Phase II of the program is discussed in the following sections.

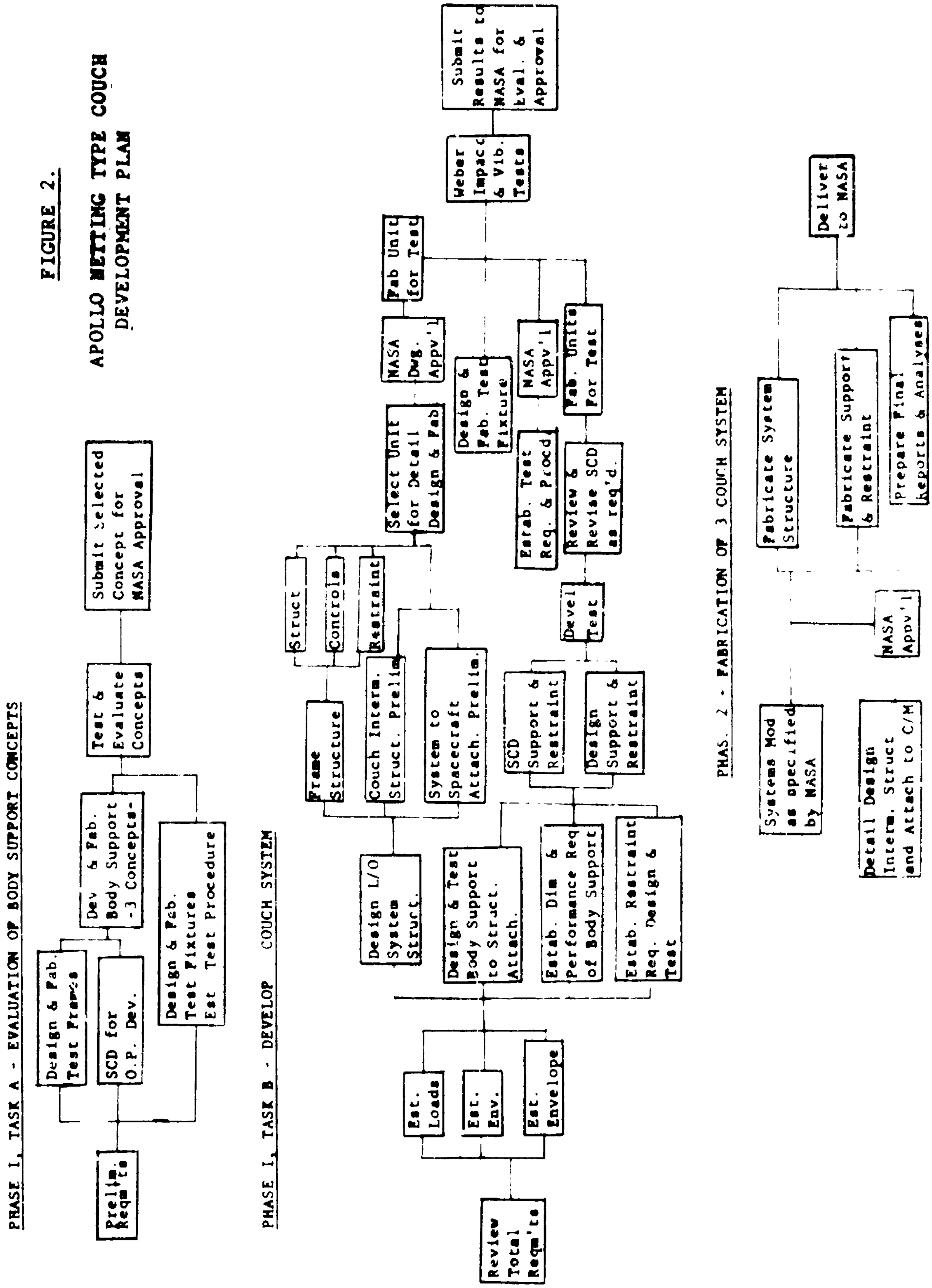


FIGURE 2.

APOLLO NETTING TYPE COUCH DEVELOPMENT PLAN

3.0 PHASE I - TASK A - DEVELOPMENT AND EVALUATION OF BODY SUPPORT CONCEPTS

The first task was to develop, fabricate and test several body support concepts and select one which most satisfied the requirements of the program. To take advantage of the state-of-the-art techniques in the fiber and fabric processing industry, it was determined that three textile development companies would be selected and awarded contracts to develop prototype assemblies for testing and evaluation by Weber.

To accomplish this, a statement of work (Reference 1) was prepared and an evaluation procedure (Reference 2) was established. The work statement consisted, essentially, of isolating the body support requirements from the couch system performance parameters specified in the contract and were provided to each supplier. This work statement contained the following basic requirements:

The prototype assembly shall be of fabric construction and is required to reduce, by plastic deformation, a 50-g impact (30 fps, eyeballs-in) to a 20-g level as felt by an anthropomorphic dummy. An allowable occupant displacement of 12 inches from a no load (zero-g) position is permissible to attenuate the maximum impact forces.

The prototype assembly also shall elastically support an occupant at a sustained 9-g force level. For static 9-g loads, an occupant displacement of three inches is permitted. From no load to 1-g, a displacement of one and one-half inches is allowed.

3.0 BODY SUPPORT CONCEPT DEVELOPMENT (continued)

The body support shall accommodate occupants in the 15th to 90th percentile size and weight range. Upon dynamic displacement of the body support, the deflection shall be uniform without adjustments to the assembly. Additionally, the fibers used in the system shall be readily available; attachment to the couch framework shall be of a concept which lends itself to a method which could permit a crew member to replace the body support during space flight.

Weber provided each supplier with a boilerplate framework on which the supplier attached the body support assembly. A second body support assembly was provided by the supplier for test and evaluation at Weber.

3.1 Concept Evaluation Procedure

Each supplier was provided with an evaluation procedure to aid in determining which parameters contained the most merit during the tests to be performed at Weber.

The evaluation procedure outlined four major areas to be considered. Each area was broken down further into specific performance parameters. Each parameter was assigned a number from one to three to establish its weighted value in relation to the other parameters.

3.1 Concept Evaluation Procedure (continued)

The performance of the system was evaluated and each parameter was graded. Each parameter grade, based on the actual performance of the supplier's entry, and ranging in value from two to ten, then was multiplied by the weighted value of the particular parameter being graded. The weighted-grades for the individual parameters then were added, thus obtaining a score for the total system. The score was the basis for determining which concept most adequately satisfied the requirements of the program.

The four basic areas evaluated were: General performance, static performance, dynamic performance, technical performance and experience of the supplier. Under general performance, eight parameters were evaluated and included comfort, system weight, material availability, structural integrity, and technical support and analysis of the system by the supplier. Static performance included body support deflection at 1-g and 9-g loads, its elasticity, and conformance to the occupant shape. In all, six parameters were reviewed.

Run-ravel resistance, dynamic displacement and attenuating force levels, and the amount of plastic elongation of the material were major items of the six parameters considered during the dynamic tests.

3.1 Concept Evaluation Procedure (continued)

Reporting methods, equipment and facilities, supplier background and comprehension of the problem were evaluated in the fourth area.

A summary of the evaluation parameters and the weighted value for each area is shown in Table 1.

The body support concepts tested and the associated evaluation are presented in detail in Reference 3. There were twenty-nine (29) individual parameters to be considered, each weighted with values ranging from one (1) to three (3) for a total value of sixty-nine (69). When making the evaluation the evaluator rated each concept as ten (10) points excellent; six (6) points acceptable, two (2) points unsatisfactory. A perfect system would get six hundred and ninety (690) points from each of three evaluation teams for a grand total of two thousand and seventy (2,070) points. The total score for each concept is broken down into the four (4) general parameter classifications and is shown in Table 2.

The close grouping of the three system scores indicates that each concept was given considerable thought by each manufacturer. The time allocated for this portion of the

3.1 Concept Evaluation Procedure - Cont.

TABLE 1

SUMMARY OF SUPPLIER EVALUATION PARAMETERS

GENERAL PERFORMANCE	WEIGHTED VALUE	
Articulation, conformance to body shape and pressure points............	2	
Distribution of material, stress levels...............................	4	
Material availability, system weight and overall comfort level............	4	
Analysis of supplier developed test data by supplier......................	3	
TOTAL		13
STATIC LOAD PERFORMANCE		
Ability to uniformly support various body masses and occupant size.........	4	
Deflection at 1-g and 9-g loads, load distribution and elasticity......	11	
TOTAL		15
DYNAMIC PERFORMANCE		
Attenuation level, body displacement rates, structural integrity, energy absorbing capacity..................	34	
TOTAL		34
TECHNICAL EXPERIENCE AND FACILITIES		
General background and capabilities	7	
TOTAL		7

3.1 Concept Evaluation Procedure (continued)

program precluded extensive research into all of the required parameters and necessitated a certain amount of trade-off as far as the individual parameters are concerned. This trade-off condition is also indicated by the scores being grouped in the mid-range of the maximum possible points.

3.1 Concept Evaluation Procedure - Cont.

TABLE 2

POINT RATING OF EACH SYSTEM CONCEPT

SYSTEM CONCEPT	PERFORMANCE PARAMETER SCORE GENERAL	STATIC	DYNAMIC	TECH	SYSTEM SCORE
Woven Tape Construction	206	206	700	106	1218
Knitted Cord Const.	194	258	512	114	1078
Filament Wound Const.	254	234	752	174	1414

Maximum possible score, any system - 2070 points

The next phase of the body support development will include remeding the areas of weak performance and expanding the concept into an operational system incorporating a restraint system and an easy attachment method onto a prototype couch structure.

3.2 Woven Fabric, Tape Construction Body Support Concept

The woven fabric, tape construction concept was fabricated by Prodesco, Incorporated, Perkasie, Pennsylvania under contract to Weber Aircraft. See Figure 3.

The design concept is based on a composite textile structure. A breakout component in an elastic member permits transfer of the load to a hysteretic member at the 9-g load level, and makes available the excess length in a bight (loop) in the elastic member for subsequent energy absorption. At the 60% elongation level of the hysteretic member, the bight will have been pulled up taut, and the elastic member will again provide support in order to limit the total deflection of the net platform.

The platform construction consists of a series of transverse textile webbing assemblies suspended from the side rails of the couch frame. There are no load bearing textile assemblies extending in the longitudinal (head-to-toe) direction. These load bearing assemblies are approximately 0.75 inches in width and are spaced along the length of the body support platform according to the anthropomorphic weight distribution given in the NASA-MSC statement of work. Each load bearing assembly consists of a nylon tape with a bight sewn near one end.

3.2 Woven Fabric, Tape Construction Body Support Concept - Cont.

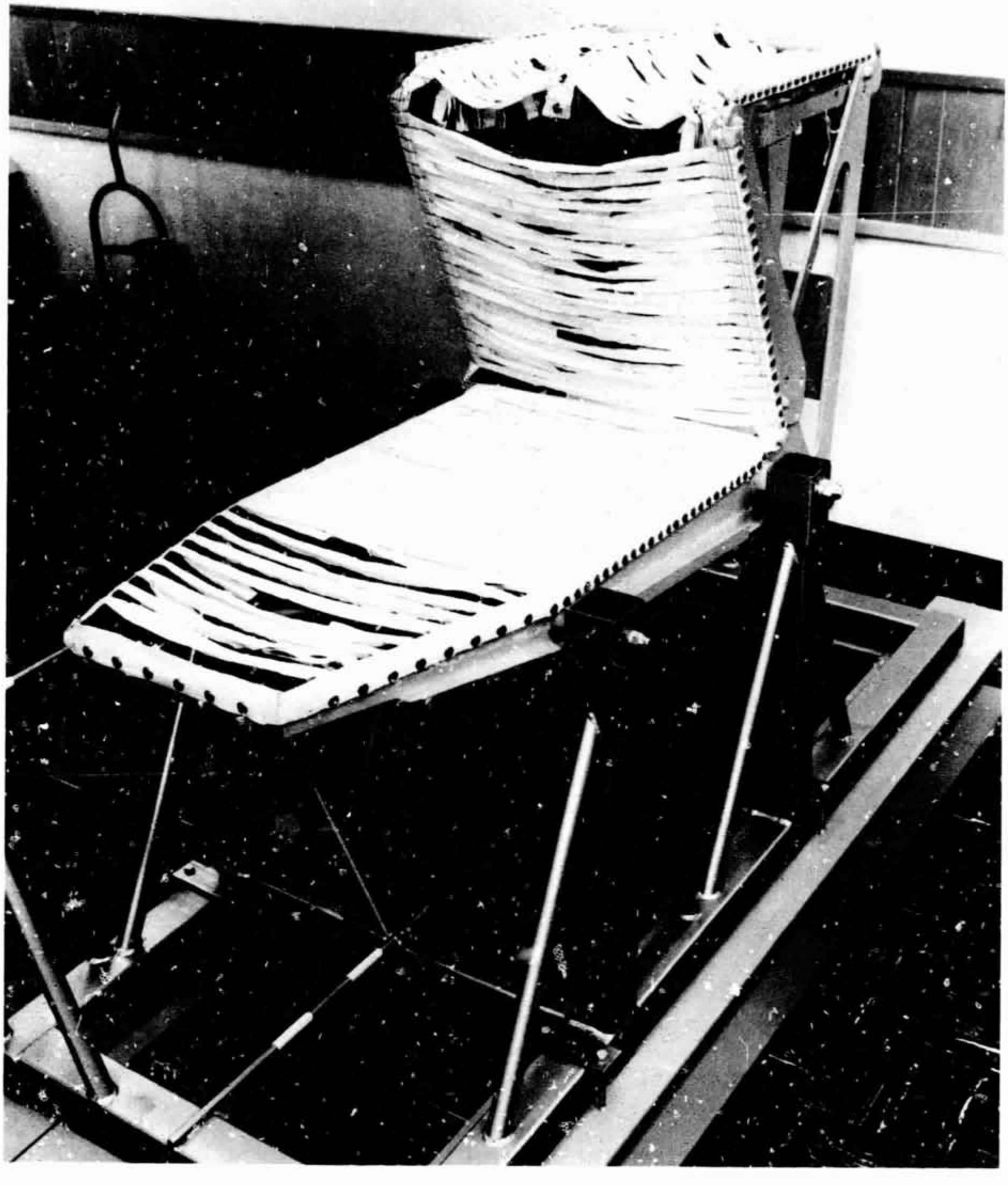


FIGURE 3
WOVEN FABRIC TAPE CONSTRUCTION CONCEPT

3.2 Woven Fabric, Tape Construction Body Support Concept - Cont.

The bight is closed by a short piece of cotton tape acting as the break-out component in the elastic system. Cotton is selected because of its low extensibility. Holes are punched in the middle of each piece of cotton tape to insure that failure will occur in the tape rather than at the sewn seam.

The hysteretic material, in the form of another tape, is sewn lightly to the tape mentioned above. The stitches are located at two ends only; there is no stitching across the transverse free span.

The various load bearing assemblies are sewn to a peripheral frame of heavy nylon webbing. The heavy nylon web is attached to the couch frame by grommets and snaps. The bight in each load bearing assembly is located alternately along the webbing frame to provide symmetrical displacement of the platform.

The distribution of the load bearing assemblies is in accordance with load calculations. Test data indicates that 79 tape assemblies are required.

Legs = 27% x 79 = 21 members
Torso = 54.3% x 79 = 51 members
Head = 8.7% x 79 = 7 members

3.2 Woven Fabric, Tape Construction Body Support Concept - Cont.

These are minimum quantities and assume 100% energy absorption. Because of the tapered platform, the head area requires shorter load bearing assemblies lengths. Since there is less energy-absorbing potential in this area, the number of assemblies was arbitrarily increased to 9.

For this phase of the effort, there is no load on the load bearing assemblies in the thigh area; the assemblies are placed there at an arbitrary one inch spacing, to maintain the integral appearance of the net.

This then results in a net platform with a total of 102 transverse load bearing assemblies: 81 of them are active, and located in the head, torso, and lower leg areas, and 21 inactive members in the thigh areas. The total of 81 assemblies sharing the load is determined through their total energy-absorbing potential. This total number, when checked on a force balance basis, shows that 81 assemblies, each with a break-out strength of 25 lbs., will provide a total break-out load of approximately 2000 lbs. This will be an adequate design level, since the 2000 lbs. combined strength is greater than the 1750-lb total load projected for a 9-g static loading, and less than the 2250-lb total loading at the ultimate 20-g load level. Therefore, if loads are

3.2 Woven Fabric, Tape Construction Body Support Concept - Cont.

adequately distributed, the break-out system will function at a load level above the 9-g static strength requirement, and below the 20-g filter level.

3.2.1 Design Calculations

As a first order approximation, the variously deformed cross sections of the net platform, under the weight of the occupant whether 1-g or 20-g's, are assumed to be segments of circular arcs.

Assume a 225 pound occupant, under a 9-g deceleration in the "eyeballs in" direction, causes the net platform to deflect 3 inches at its center. For a chord length (distance between the supporting rails) of 20 inches, the arc length corresponding to this assumed deflection is 21.2 inches. The total tensile load in the platform is 1750 pounds.

Assuming that the same occupant displaces the platform 12 inches under 20-g's, the calculated platform arc length is now 35.4 inches and the total tensile load 2250 pounds.

Tensile loads are calculated by the equation:

3.2.1 Design Calculations

$$T = \frac{W \times g}{2 \cos \theta}$$

Where:

W = 225 lbs.

0 = the included angle between the body support and side rail structure of the couch frame

g = acceleration factor

After extensive testing of materials, Prodesco style PWC 5-1 twill weave nylon warp webbing, treated with formic acid (HCOOH) was selected for use as the hysteretic material.

This tape has a static breaking strength of 37.0 lbs, an elongation to break of approximately 113% and an estimated yield strength of 3.3 lbs. with a yield point elongation of approximately 12%. At an elongation of 75%, representing the maximum 12-inch vertical deflection of the couch, this material has a projected load bearing capacity of approximately 28.8 lbs.

Since the total load on the couch at 9-g's has been estimated at 1750 lbs. with a maximum total load of 2250 lbs, then the load at break-out should be 1750/2250 = 80% of the maximum total load, and the break-out load of each strip

3.2.1 Design Calculations - Cont.

should be 80% x 28.8 = approximately 23 lbs.

The load just prior to break-out, should be shared by the hysteretic material, loaded within its elastic limit (less than 5% elongation) and by the break-out strip itself.

At 5% elongation the hysteretic members can sustain loads of approximately 2 lbs.

The break-out material selected was a one-half inch wide cotton tape, with a hole punched to provide a notch effect for a controlled localized failure. Tests indicated that a 3/16" diameter hole would afford a 23-lb breaking strength, so that the total break-out load would be approximately 23 plus 2, or 25 lbs per strip.

Back-up material for the couch must provide support of the astronaut during static loading, and again after break-out, to limit the extreme of his deceleration displacement. For the assumed loading conditions and geometry of the couch, the displacement limit at 9-g's corresponds with a material elongation of 5% at the equivalent load level. Nylon tape, MIL-Spec.T-5038-C, Type II, 3/4 inch wide, was selected as having properties generally suitable for this service.

3.2.1 Design Calculations - Cont.

A heavier webbing was required for the peripheral framing member, and for this service, a webbing 1-3/4 inches wide was selected, generally similar in construction to MIL-W-4088B Type VIII, except woven from Nomex (HT-1) yarn instead of nylon yarn to make it easier for sewing. Construction of this webbing required a warp of 198 ends of 8 ply, 200 denier yarn, and a filling of the same yarn of 21 picks per inch. Nominal breaking strength of this material is 3700 lbs.

In the required bent-knee position, the thighs are not directly supported in the vertical direction, hence the weight of the thighs is arbitrarily divided and borne equally by the torso section and the leg section, to support this additional mass.

The mass distribution and required density of support strap spacing can then be tabulated as follows:

3.2.1 Design Calculations - Cont.

	Leg Area	Torso Area	Head Area
Weight of Man and Pressure Suit (lbs)	51.3	163.3	18.2
% of Total	22	70	8
Lbs/inch of Couch Length	2.45	6.8	1.15
Length of Man (inches) *	17.6	24	13.1
Lbs./inch of Man Length	2.87	6.8	1.39
Total Load on Couch, if body load extended to full length of couch(lbs)	75	163.3	22.3
% of Total	28.7	62.7	8.9

* Note: The thigh is not involved in these calculations.

3.2.2 Tensile Testing of Composite Load Bearing Members

Figures 4 and 5 show the performance of an energy-absorbing strip assembly under both static and dynamic load conditions. The static test (Figure 4) was conducted on an Instron tester. The load was increased to approximately 60% of the ultimate strength, and then released to show the hysteretic energy absorption. At the maximum load level reached, the back-up strips had not yet begun to function.

3.2.2 Tensile Testing of Composite Load Bearing Members - Cont.

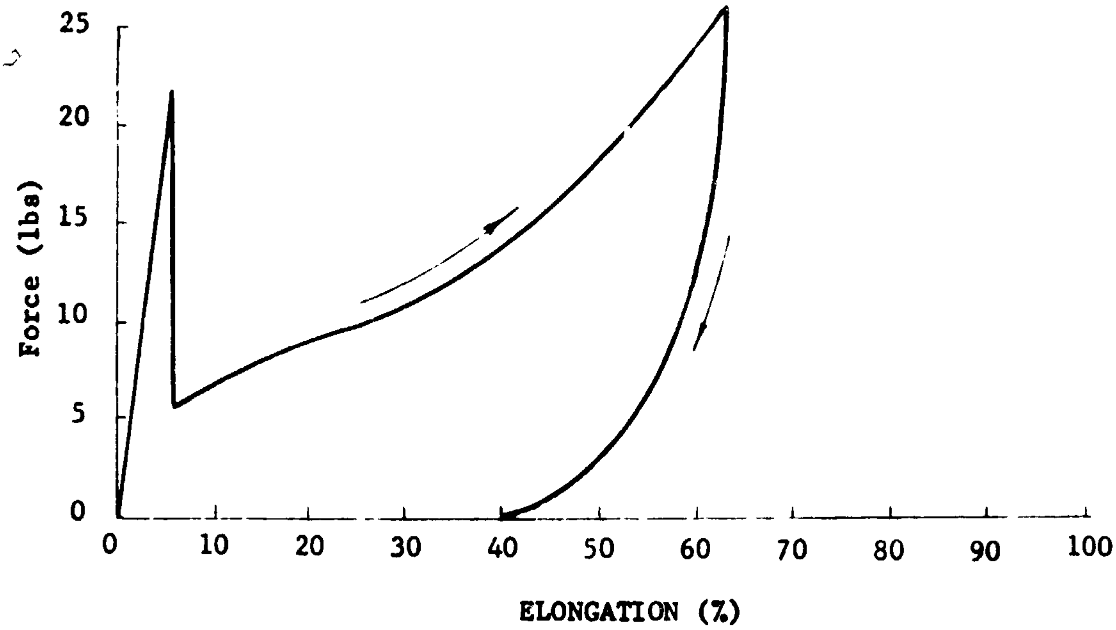


FIGURE 4

STATIC LOAD - ELONGATION OF A
LOAD BEARING ASSEMBLY,
WOVEN TAPE CONCEPT

3.2.2 Tensile Testing of Composite Load Bearing Members - Cont.

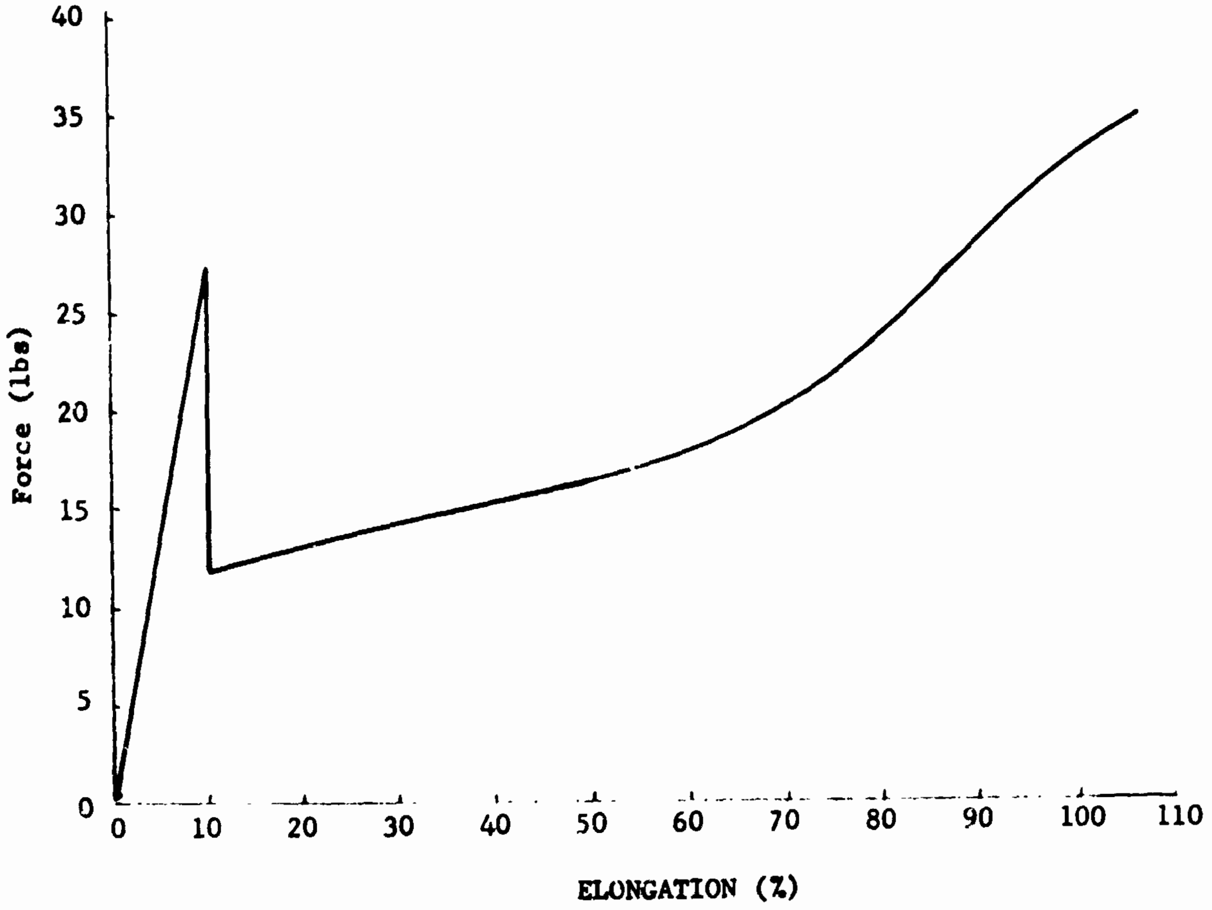


FIGURE 5
DYNAMIC LOAD - ELONGATION OF A
LOAD BEARING ASSEMBLY,
WOVEN TAPE CONCEPT

3.2.2 Tensile Testing of Composite Load Bearing Members - Con

In the dynamic test (Figure 5) performed on a high speed piston tester, it is not possible to interrupt the test at a predetermined load level, so here it is seen that the load continued beyond the point where the nylon back-up members pick up the load, as evidenced by the sharply upturned portion of the load-elongation curve at the end of the loading period.

3.2.3 Materials Research

Three materials were selected for evaluation as possible candidates which would exhibit the high impact hysteretic characteristics required for this system concept. These were undrawn nylon, heat-shrunk Dacron and formic acid treated nylon.

All three materials are known to have relatively high static rupture elongation. In this program they were subjected to both static and high speed dynamic testing so that selection of a material with a predicted sensitivity to rate-of-straining could be made based on test results which simulated the use condition rate of straining.

3.2.3 Materials Research - Cont.

Concurrent studies evaluating the properties of the three candidate materials were conducted in yarn form and actual weaving trials. Weaving trials are of particular importance in regard to the undrawn nylon materials because of their tendency to elongate when placed under tension. In normal textile processing yarns may be placed under tensions during the preparation of warps and again, during weaving. Therefore actual weaving trials of these elongation sensitive materials were made to allow a study of processing effects on yarn evaluation tests.

A description of tapes and braids fabricated from undrawn nylon fibers follows:

Type	Warp	Filling
PWC 2 (2" wide) Sateen weave	36 ends 965 denier Dupont N-13 nylon	25 picks 965 denier Dupont N-13 nylon
PWC 3-2 (braid)	4 ends per supply package/16 carriers 60 denier/13 filament Chemstrand high elongation nylon	
PWC 3-1 (braid)	1 end per carrier/8 carriers 965 denier N-13 Dupont nylon	
PWC 4-1 (2" wide) Sateen weave	112 ends 965 denier Dupont N-13 nylon	30 picks 965 denier Dupont N-13 nylon
PWC 4-2 (2" wide) Sateen weave	112 ends 965 denier Dupont N-13 nylon	35 picks 965 denier Dupont N-13 nylon

3.2.3 Materials Research - Cont.

Undrawn and Partially Drawn Nylon

Undrawn and partially drawn nylon exhibit unrecovered extension, hence hysteretic energy absorption, when subjected to tensile loading. Samples of duPont Type N-13 undrawn nylon yarn were obtained and tested to determine suitability as an energy-absorbing material.

Samples of this material were subjected to tensile tests, using a standard Instron tester for conventional slow speed static tests, and a dynamic tensile tester to obtain test data for high speed loading conditions. Static tests were performed at jaw speeds of 20 inches per minute. Dynamic tests were performed at draw rates of 30 feet per second.

Additional samples of the undrawn nylon yarn were then subjected to varying degrees of drawing, using both hot and cold drawing techniques. These samples were then subjected to both static and dynamic tensile testing.

A summary of the tensile test data for all of these materials is tabulated in Table 3.

3.2.3 Materials Research - Cont.

TABLE 3

TENSILE TEST DATA OF N-13 NYLON YARN
(965 denier, 34 filaments)

	Static		Dynamic	
	Instron at 20"/min 2 inch gage length		30'/sec 3 inch gage length	
	Breaking Load gms	Elongation %	Breaking Load gms	Elongation %
Control	998	466	620	280
Drawn 50% at 70°F	1098	366	640	280
at 370°F	1140	317	-	-
Drawn 100% at 70°F	1223	206	745	220
at 365°F	1083	154	645	180
Drawn 200% at 70°F	1304	81	1294	13
at 380°F	1159	56	-	-
Drawn 400% at 70°F	1524	35	953	16
at 370°F	1588	18	-	-

3.2.3 Materials Research - Cont.

Heat-Shrunk Dacron

Certain types of Dacron yarns when exposed to elevated temperatures shrink considerably, resulting in materials which possess greater energy-absorbing capability through higher elongations to break. Samples of Type 52 (110 denier) Dacron yarn, and Type 5100 (220 denier) yarn were subjected to thermal treatments, and then tested both statically and dynamically to determine strength and elongation properties. Results of these tests are summarized in Table 4.

3.2.3 Materials Research - Cont.

TABLE 4

TENSILE TEST DATA OF DACRON YARNS

	Static		Dynamic	
	Instron at 5"/min 5 inch gage length		30'/sec 3 inch gage length	
	Breaking Load gms	Elongation %	Breaking Load gms	Elongation %
Type 52 (1100 d)				
Treated at 350°F for 2 min	7850	33	5992	26
Treated at 400°F for 1 min	8172	50	5600	33
Type 5100 (220 d)				
Treated at 350°F for 2 min	1362	36	1378	25
Treated at 400°F for 1 min	1285	47	1200	41

3.2.3 Materials Research - Cont.

Formic Acid Treated Nylon

Earlier work has shown that drawn nylon yarn shrunk in formic acid solution exhibited high elongation properties. For the present work, additional experiments were performed using a 59% concentration throughout, with varying temperature and reaction time to determine a treatment formula which would provide a shrunk nylon with optimum properties.

Results of this series of tests are given in Table 5.

3.2.3 Materials Research - Cont.

TABLE 5

TENSILE TEST DATA OF FORMIC ACID TREATED NYLON YARNS

	Static		Dynamic	
	Instron at 5"/min 5 inch gage length		30'/sec 3 inch gage length	
	Breaking Load gms	Elongation %	Breaking Load gms	Elongation %
Control (Type 300 Nylon 55, 210-34-1-2)	1669	18.9	1700	13.3
Treated 59% HCOOH at 31°C for 15 min	1397	45.4	1580	40
Treated 59% HCOOH at 66°C for 7-1/2 min	1050	112.4	603	101
Treated 59% HCOOH at 50°C for 2 min	1373	64	1135	52
Treated 59% HCOOH at 60°C for 2 min	1202	79	1135	72

3.2.3 Materials Research - Cont.

From these experiments one sample appeared superior to all others with regard to the desired impact tensile behavior. This was the formic acid-treated Type 300 nylon yarn treated at 66°C for 7½ minutes. Another potential candidate was the Type 5100 Dacron, heat-relaxed at 400°F. However, the rupture extensibility of the Dacron was rather low and its general stress-strain curve shape was not as good as the formic acid-treated nylon. The drawn N-13 yarns were extremely variable and were eliminated from further consideration. Figure 6 shows the stress strain curves for these three materials when tested at 30 feet-per-second draw rates.

As seen in Figure 6 the formic acid-treated nylon is more desirable because its stress-strain curve shows a more nearly flat post-yield slope at a reasonably high sustained load level. This promises a large potential for hysteretic energy absorption over the long elongation range required by the geometry of the couch cross-section.

3.2.3 Materials Research - Cont.

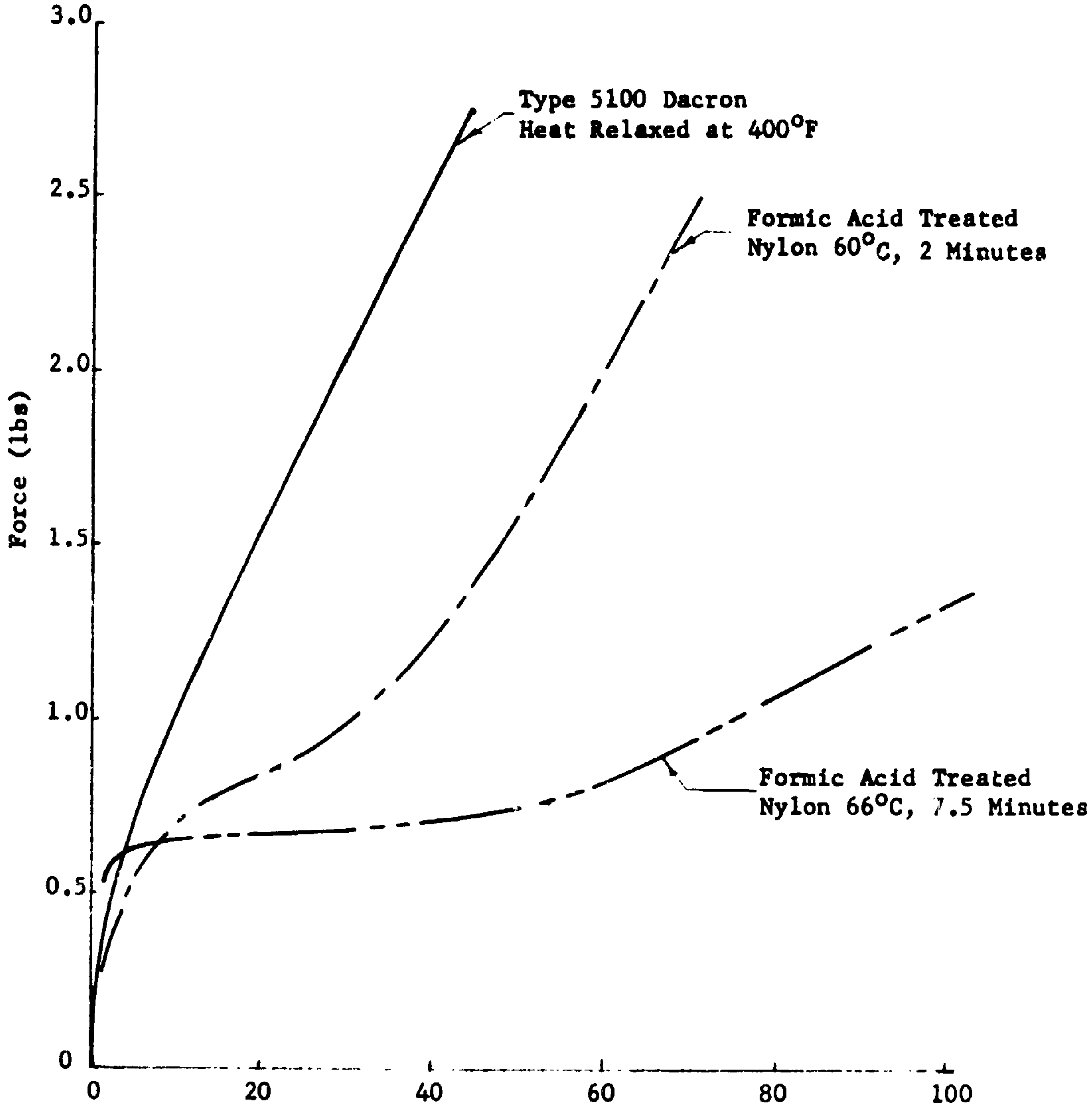


FIGURE 6

LOAD ELONGATION CURVES FOR TREATED NYLON AND DACRON YARNS TESTED AT 30 FEET PER SECOND

3.2.3 Materials Research - Cont.

Based on the test results of formic acid treated yarns this treatment technique was extended into woven material. Two tapes had been woven concurrently with yarn studies that were constructed of nylon warp and filling materials that would be unaffected by the acid treatment. Construction of these tapes required warp yarns to be of a nature that would react to the formic acid shrinkage and filling yarns to be relatively inert to the formic acid. In addition, the mechanical appearance of texture of these tapes had to be so designed to allow for shrinkage in the longitudinal direction. A relatively open design was utilized for this purpose. For initial testing, two tapes were woven.

Tapes	Warp	Filling
PWC 4-3(9/16" wide) Sateen Weave	50 ends 100 denier/34 fil Type 300 nylon	30/1 65/35% Dacron/cotton yarn, 40 picks/inch
PWC 4-4 (9/16" wide) Sateen Weave	50 ends 100 denier/34 fil Type 300 nylon	30/1 65/35% Dacron/cotton yarn, 88 picks/inch

3.2.3 Material Research - Cont.

Formic acid treatment of these two woven tapes produced results somewhat different from treatment of the yarn, which was expected due to differences of shrinkage restraint imposed by the geometry of the woven structure. Evaluation of these treated tapes suggested a design modification which would be more stable during the acid treatment. The added stability of [illegible] tape was achieved through the use of a balanced weave construction which is a 4 over 4 twill weave as opposed to the 7 over 1 sateen weave used on the prior type. In addition, this tape had a selvage woven using edge wires which produce a longer length of filling yarn resulting in reduced restraint during warp shrinkage. Tensile test results on the tapes are given in Table 6.

3.2.3 Materials Research - Cont.

TABLE 6

TENSILE TEST DATA OF FORMIC ACID TREATED NYLON TAPES

	Static		Dynamic	
	Instron at 2"/min 2 inch gage length		30'/min 3 inch gage length	
	Breaking Load lbs.	Elongation %	Breaking Load lbs.	Elongation %
Sample PWC 4-3				
Untreated	65	23.8		
Treated (2 min)				
60°C	37.9	145		
66°C	28.9	186		
72°C	14.5	241		
78°C	Brittle	-		
Sample PWC 4-4				
Untreated	67.2	21.9		
Treated (2 min)				
60°C	46.7	116	34.4	112
66°C	36.6	138		
72°C	21.5	179		
78°C	Brittle	-		
Sample PWC 5-1				
2 min - 60°C	37.0	113.3		

Based on this developed data PWC 5-1 webbing was selected for use as the energy absorbing material in the body support.

3.3 Braided Cord, Knitted Construction Concept

This concept was fabricated by Somyk, Incorporated, Lincoln, Rhode Island under contract to Weber Aircraft.

Based upon prior experience in the development of net type body supports for the Mercury spacecraft, work proceeded directly into the construction of the body support utilizing "Somykord" in a knitted construction.

The general characteristics of the nylon cords and the fabrics, in physical appearance, are the same as reported in References 4 and 5. The cords are braided from six yarns in such a fashion as to eliminate the center hole which is characteristic in most cord constructions. The fabric was knitted in a loop pattern designed to distribute the non-uniform load of the human body elements such that equal displacement for the body members occurs at all load levels.

The net was fabricated to the internal size of the framework with a 3/32 diameter aircraft cable encased all around the total periphery of the net. The net was assembled on the framework by hand lacing around the aircraft cable and through lacing holes in the couch frame. The lacing holes are

3.3 Braided Cord, Knitted Construction Concept - Cont.

spaced about 1.0 inch apart all around the couch frame. A skirt arrangement with cable, located at the apex of the thigh-torso platform intersection, was used to assist in pulling the net to the required shape.

After stretching the net to "drum-head" tightness by lacing to the couch frame, a sateen woven fabric was attached to the frame by elastic rubber tie downs. The purpose of the sateen fabric was to produce a known friction condition between the couch occupant and net.

Construction

The net was knitted from braided cords made from yarns of several deniers as shown in Figures 7 & 8.

3.3 Braided Cord, Knitted Construction Concept - Cont.

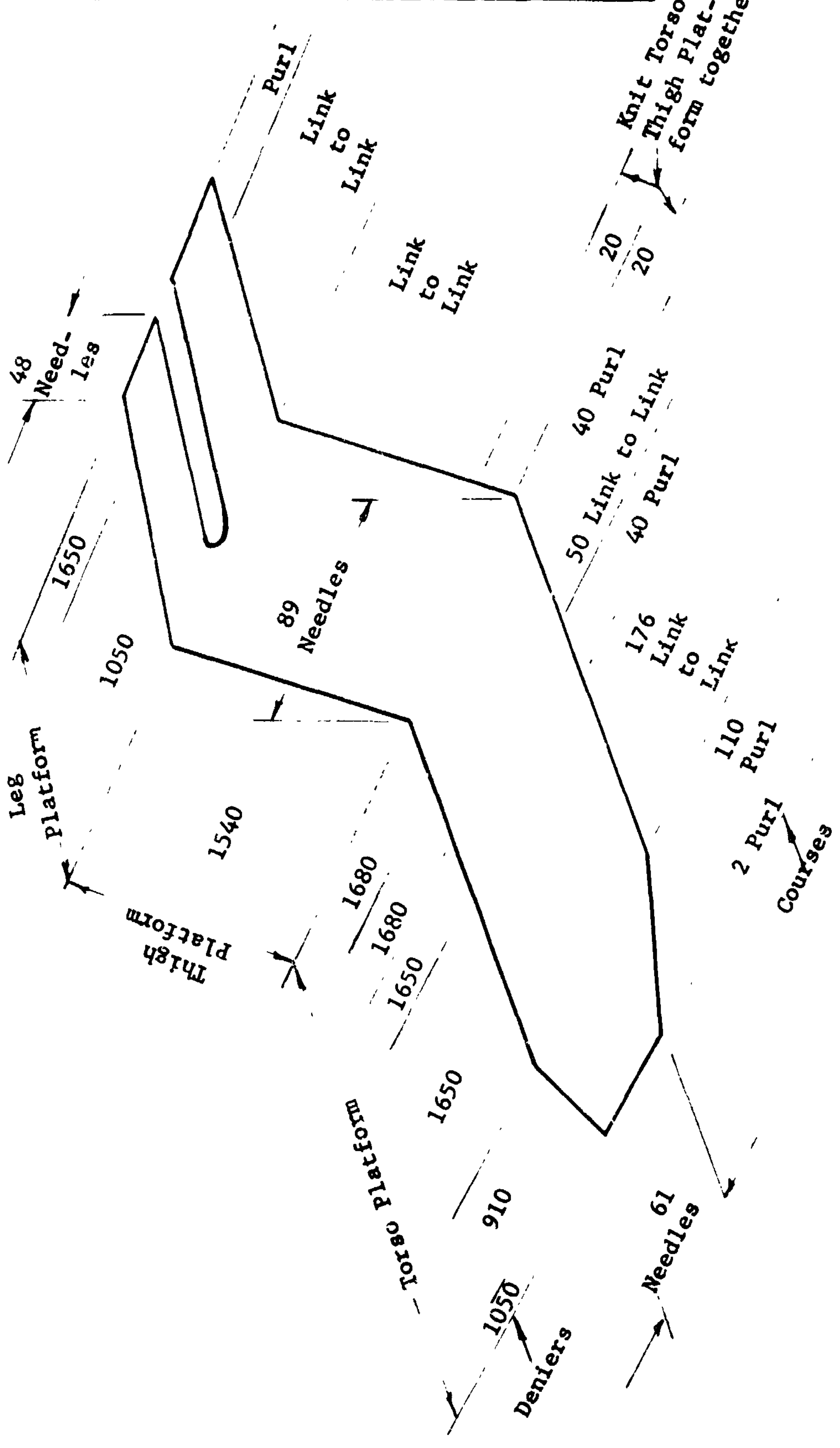


FIGURE 7
CONSTRUCTION DETAIL
KNITTED CORD CONCEPT

3.3 Braided Cord, Knitted Construction Concept - Cont.

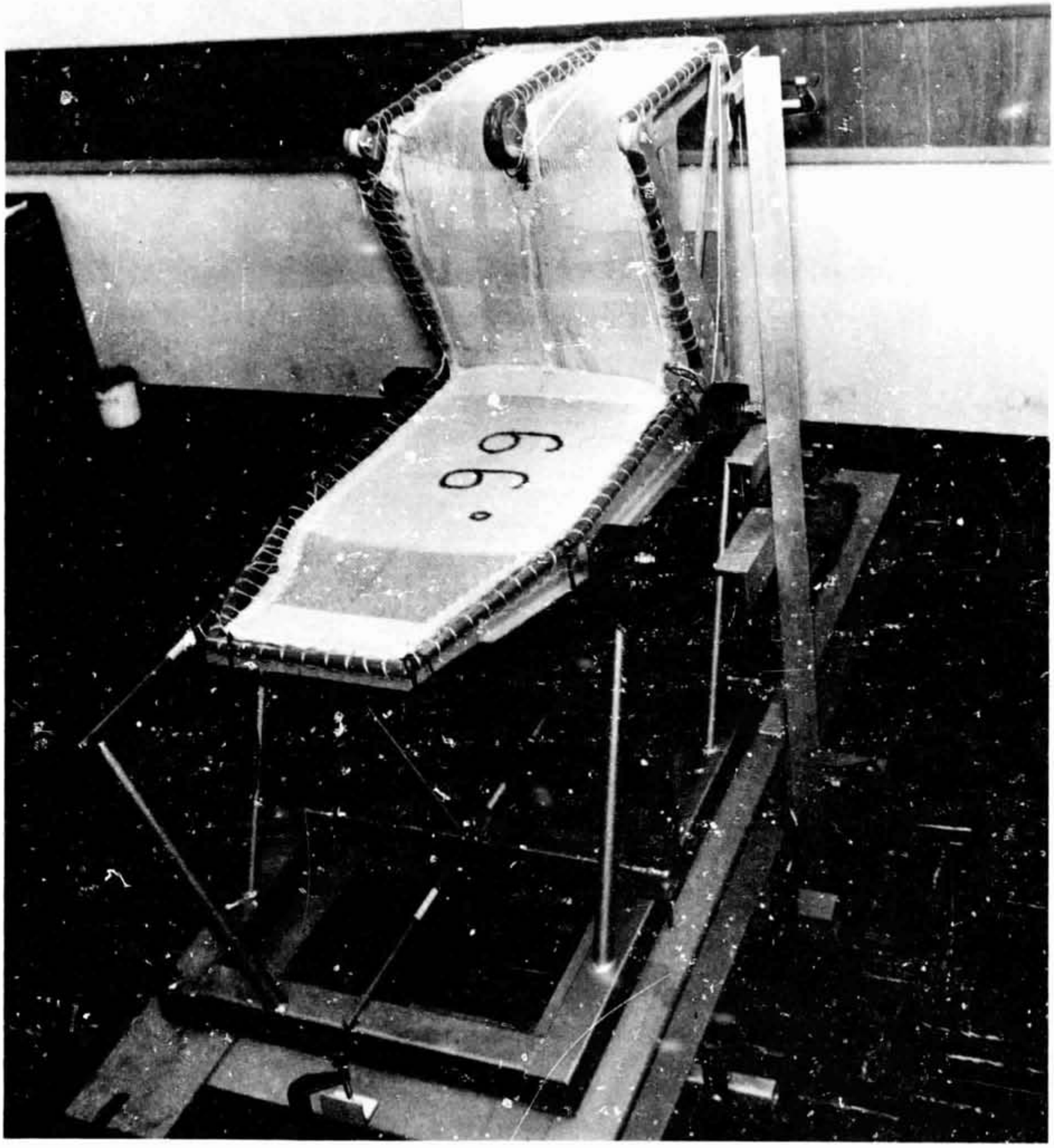


FIGURE 8

BRAIDED CORD KNITTED CONSTRUCTION

3.4 Twisted Cord, Filament Wound Construction Concept

This concept was fabricated by the United States Rubber Company Research Center, Wayne, New Jersey, under contract to Weber Aircraft and has been selected as the concept which will be used for the remainder of the Couch Development Program.

Based on prior experience, it was decided early in the program to use an available 750 denier, 16 filament, zero twist, Nylon 6 undrawn yarn for constructing the couch platform. The material was supplied by Allied Chemical Company and is coded BWS 13.

Consideration was given for its use in the following four ways:

a. As received
b. Predrawn 100% to 375 denier (yarn)
c. As 3 ply 13/13, S/Z cord twisted to 2668 denier
d. Cord (c) predrawn 100% to 1350 denier

As a result of experiments, it was found that the predrawn yarn (consideration "b" above) could not be twisted to make a satisfactory cord (consideration "d").

Instron stress-strain curves for constructions a, c and d above are shown in Figure 9. The single ply untwisted yarn exhibits the highest ultimate strength while the 3

3.4 Twisted Cord, Filament Wound Construction Concept - Cont.

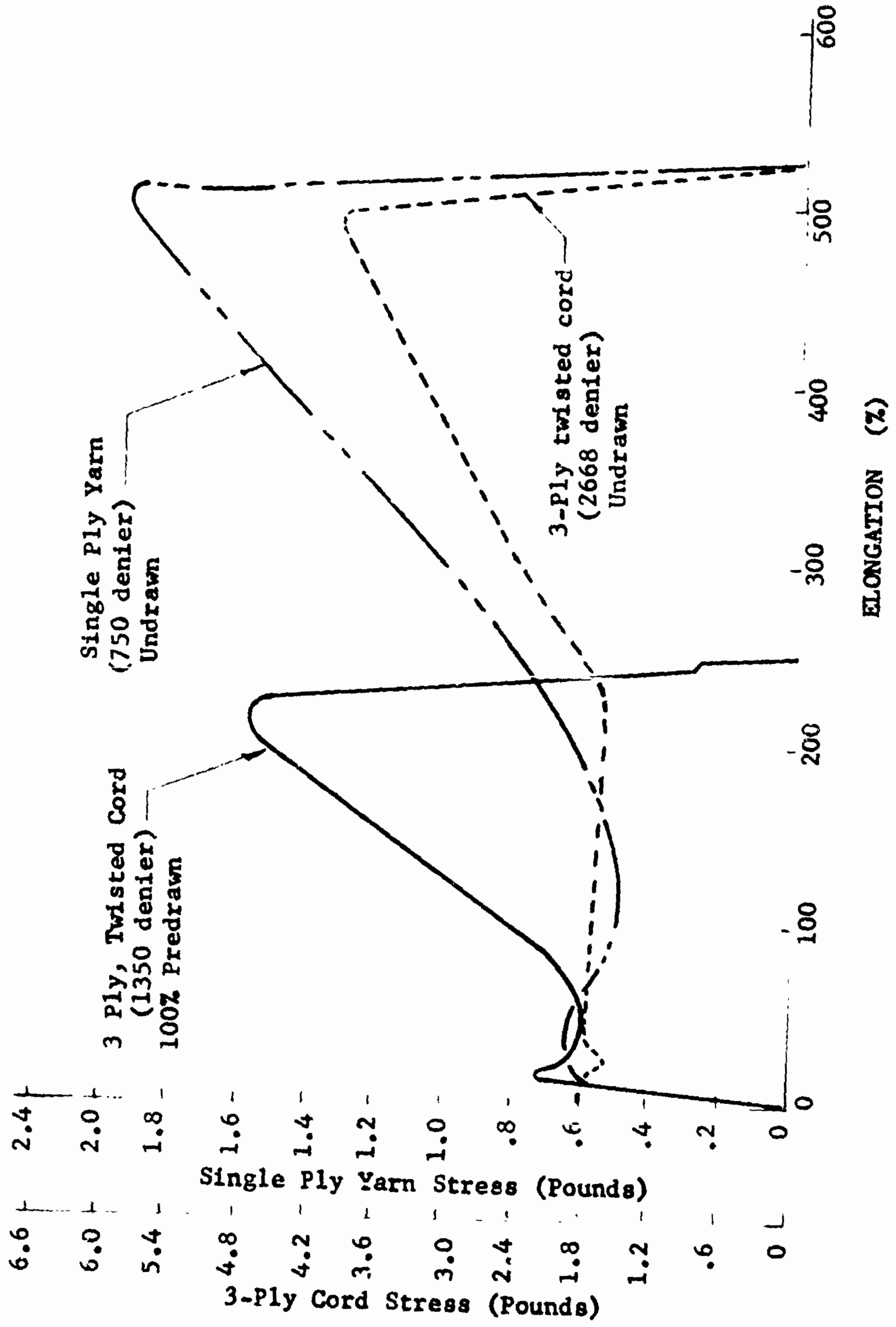


FIGURE 9
STRESS-STRAIN CURVES
OF VARIOUS NYLON 6 FILAMENT
CONSTRUCTIONS

3.4 Filament Wound Concept (continued)

ply twisted cord exhibits the longest and most stable draw characteristics. The ultimate elongation of predrawn cord is closely related to the percent to which it is predrawn. All constructions exhibit a considerable inherent safety factor in ultimate breaking stress above their basic draw stress.

Various attempts were made to establish the stress-strain characteristics of the above filament constructions at high rates of elongation. While no formal documentary evidence of the relationship was obtained, all of the fragmentary results suggested that the stress-strain properties of the yarn are essentially rate independent. The Instron developed stress-strain relationship was used, therefore, for designing drop test samples and, ultimately, the couch platform.

As will be described in greater detail later, the drop test samples were constructed initially of the 750 denier, untwisted and undrawn nylon yarn as received. The Instron stress-strain curve on which the calculations for these samples was based is shown as curve (1) on Figure 10. It was later learned, however, that the drop test results related more closely to curve (2) on the Figure 10 and

3.4 Filament Wound Concept - Cont.

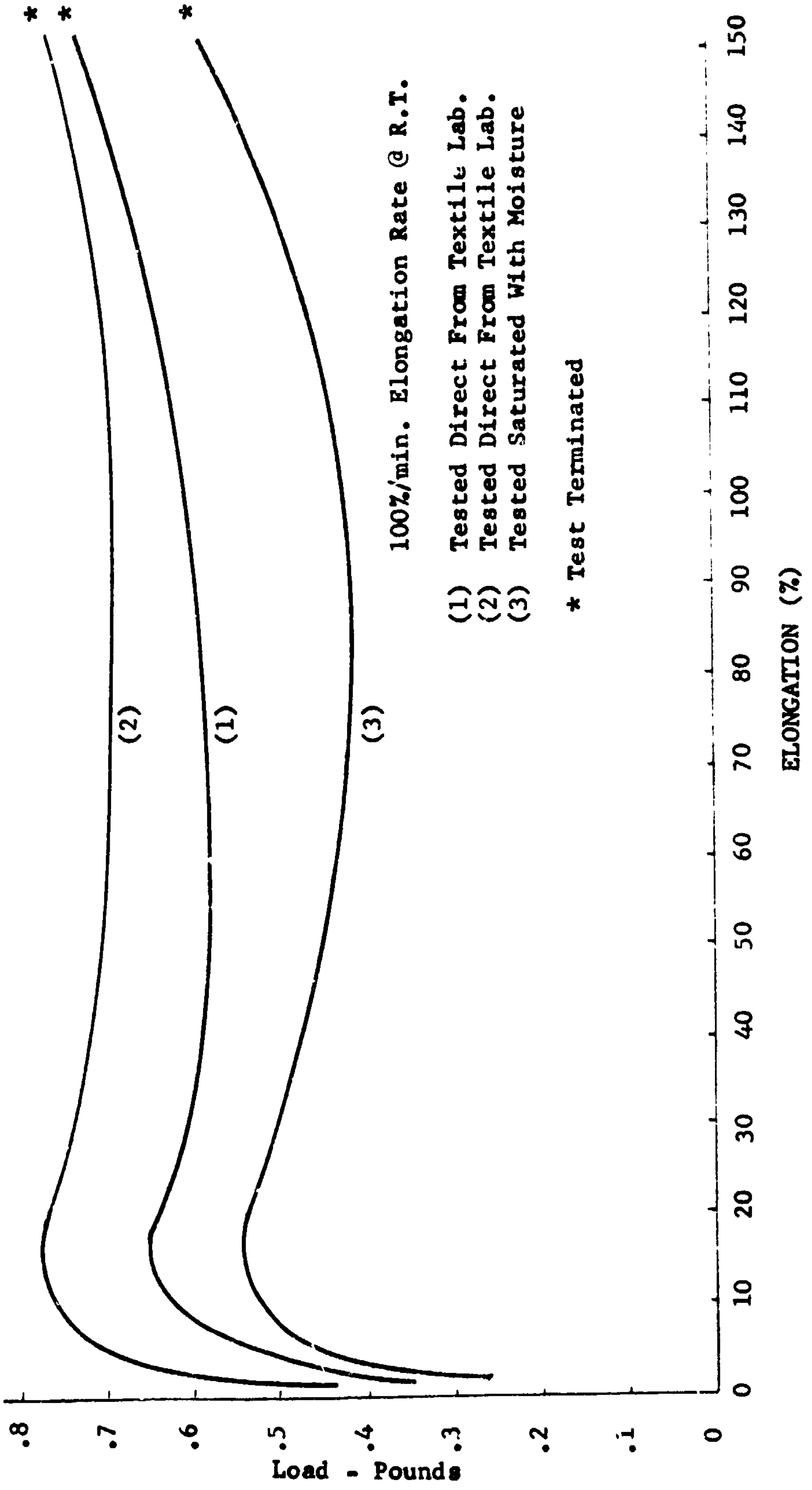


FIGURE 10
STRESS-STRAIN VARIATIONS
ON 750 DENIER UNDRAWN
NYLON 6 YARN

3.4 Filament Wound Concept - Cont.

this latter curve was used to design the couch platform. The draw stress exhibited by curve (2) of approximately .690 lbs/yarn end is 118% of the draw stress of .585 lbs. exhibited by curve (1). Curve (3) on this same figure gave the first clue as to the cause of the stress-strain inconsistencies encountered.

A controlled series of tests were run to establish the qualitative effect of atmospheric moisture content on the stress-strain relationship of Nylon 6 undrawn yarn. The results are plotted on Figure 11. Another series - establishing the effect of temperature - is plotted on Figure 12.

The particular stress-strain data on the 2668 denier 3 ply twisted cord, which is shown as curve (1) on Figure 13, was obtained at the same time curve (2) of the single end yarn was established. The 3 ply cord (curve 1) exhibits a more idealistic stress strain curve which was the primary reason for its selection over a single yarn attenuating member. Curve (2) is the same as was initially shown on Figure 10.

3.4 Filament Wound Concept - Cont.

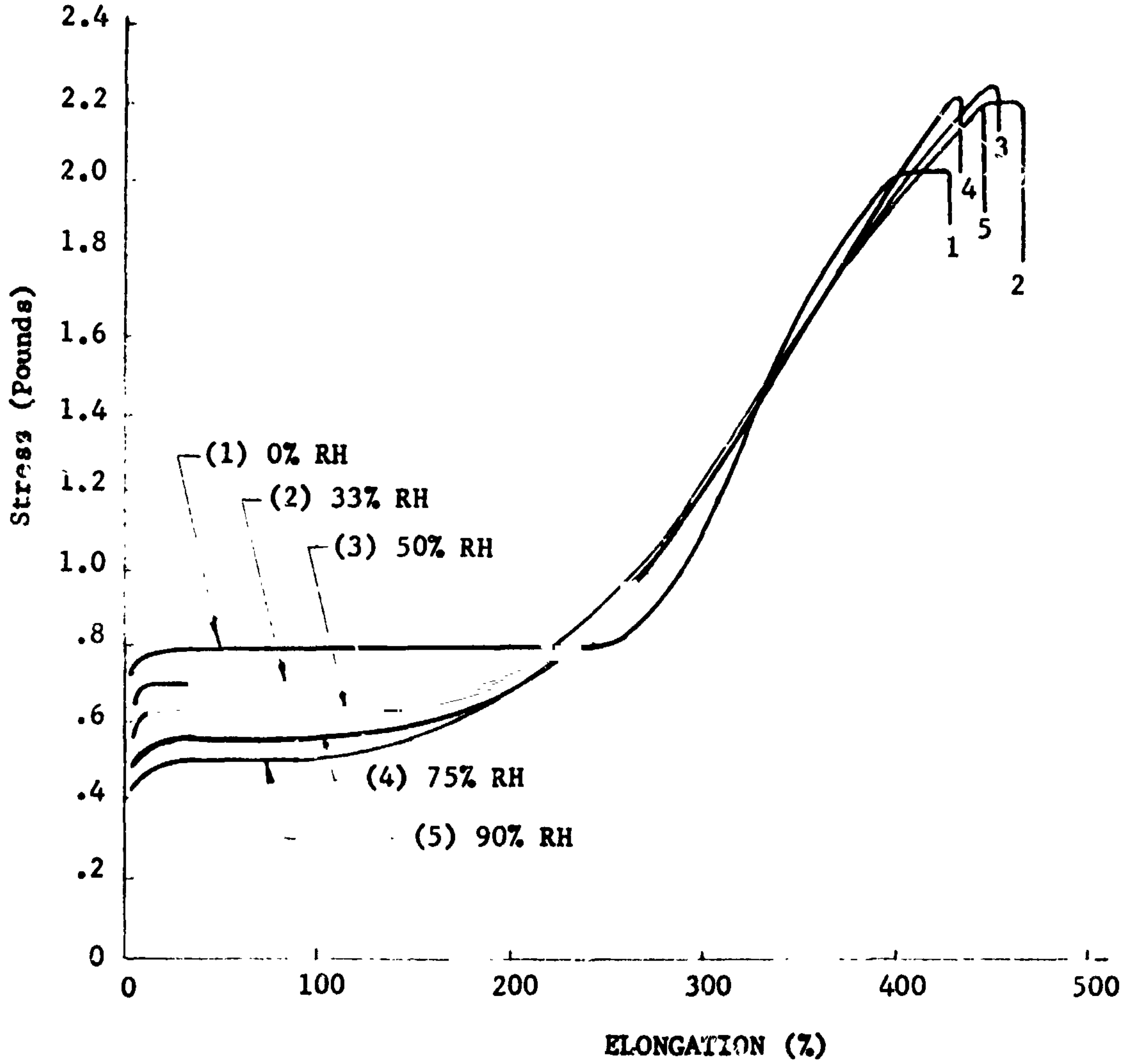


FIGURE 11
EFFECT OF MOISTURE ON STRESS-STRAIN
OF 750 DENIER UNDRAWN NYLON 6 YARN

3.4 Filament Wound Concept - Cont.

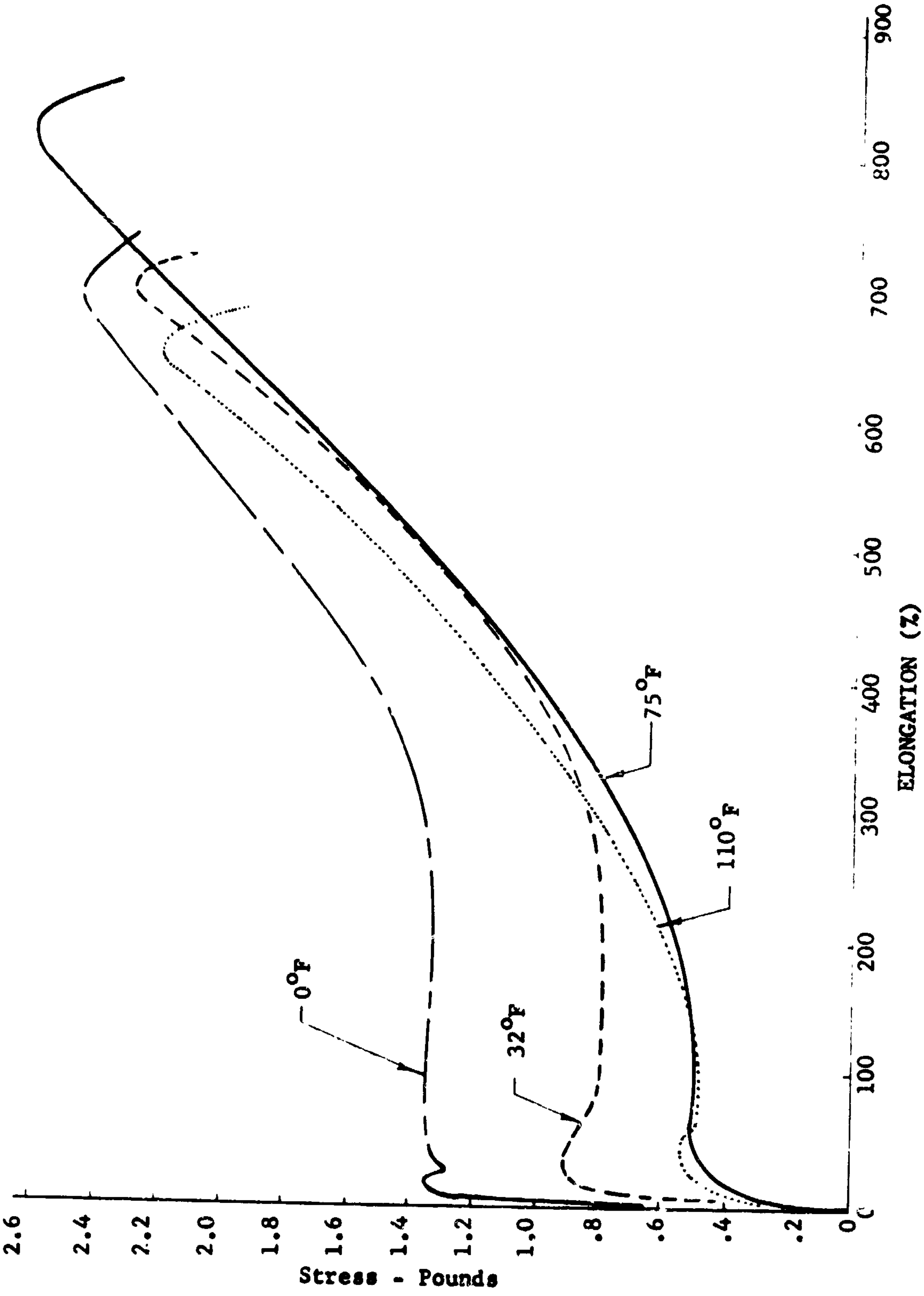


FIGURE 12
EFFECT OF TEMPERATURE ON STRESS STRAIN OF
750 DENIER UNDRAWN NYLON 6 YARN

3.4 Filament Wound Concept - Cont.

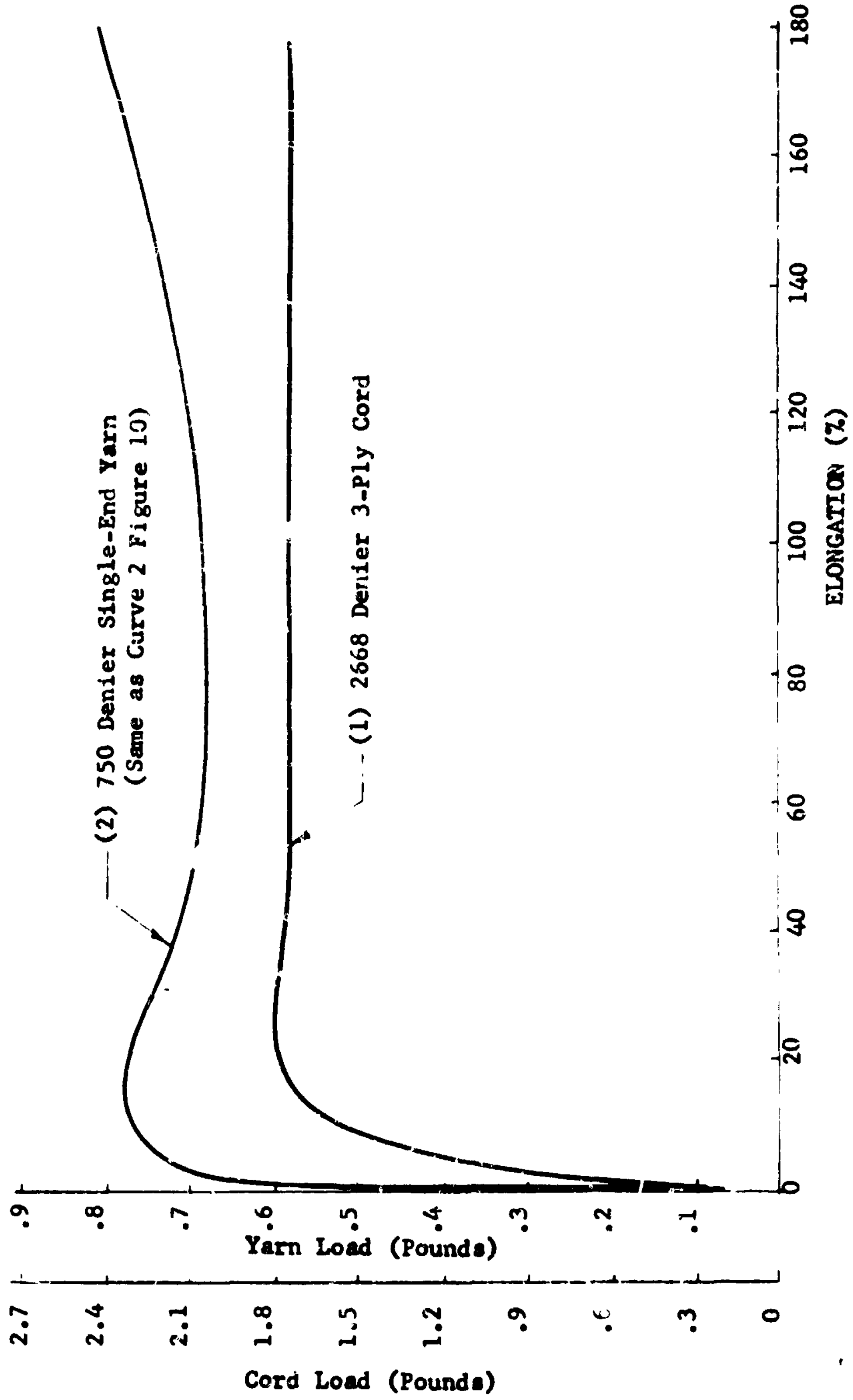


FIGURE 13
STRESS-STRAIN CHARACTERISTICS
OF UNTWISTED UNDRAWN YARN VS 3-PLY TWISTED CORD

3.4.1 Drop Tests

In filament wound construction each attenuating cord is fastened at two diametrically opposite points and the loading is balanced at the center. Formulae were developed for this specific design configuration to express cord attenuation and g's developed in dissipating the energy released in an impact.

To verify experimentally the mathematical treatment of this problem, a 1/2 scale drop test was selected. This apparatus was designed to test short lengths of filament wound fabrics which are suspended across a frame 1/2 the width of the astronaut's couch frame. The load is applied through a form simulating the body torso. A comparison of the full scale couch specifications versus two proposed 1/2 scale test specifications is summarized in Table 7.

3.4.1 Drop Tests - Cont.

TABLE 7

PROPOSED TEST SPECIFICATIONS

Test Equipment	Full Scale Specifications	1/2 Scale Test Specification	
		Proposal A	Proposal B
Suspension Width	20 1/2"	1/2 scale	1/2 scale
Drop form length	body length	6"	6"
Drop form weight	4 1/4 # inch in torso section	25 1/2 #	47 1/2 #
Drop height	14'	7'	3.5'
Impacting velocity	30'/sec.	21.2'/sec.	15'/sec.
Cord strain rate	variable	> full scale	full scale
Approx. max. deflection	12"	6"	6"
Approx. max. -g	20	20	10

3.4.1 Drop Tests - Cont.

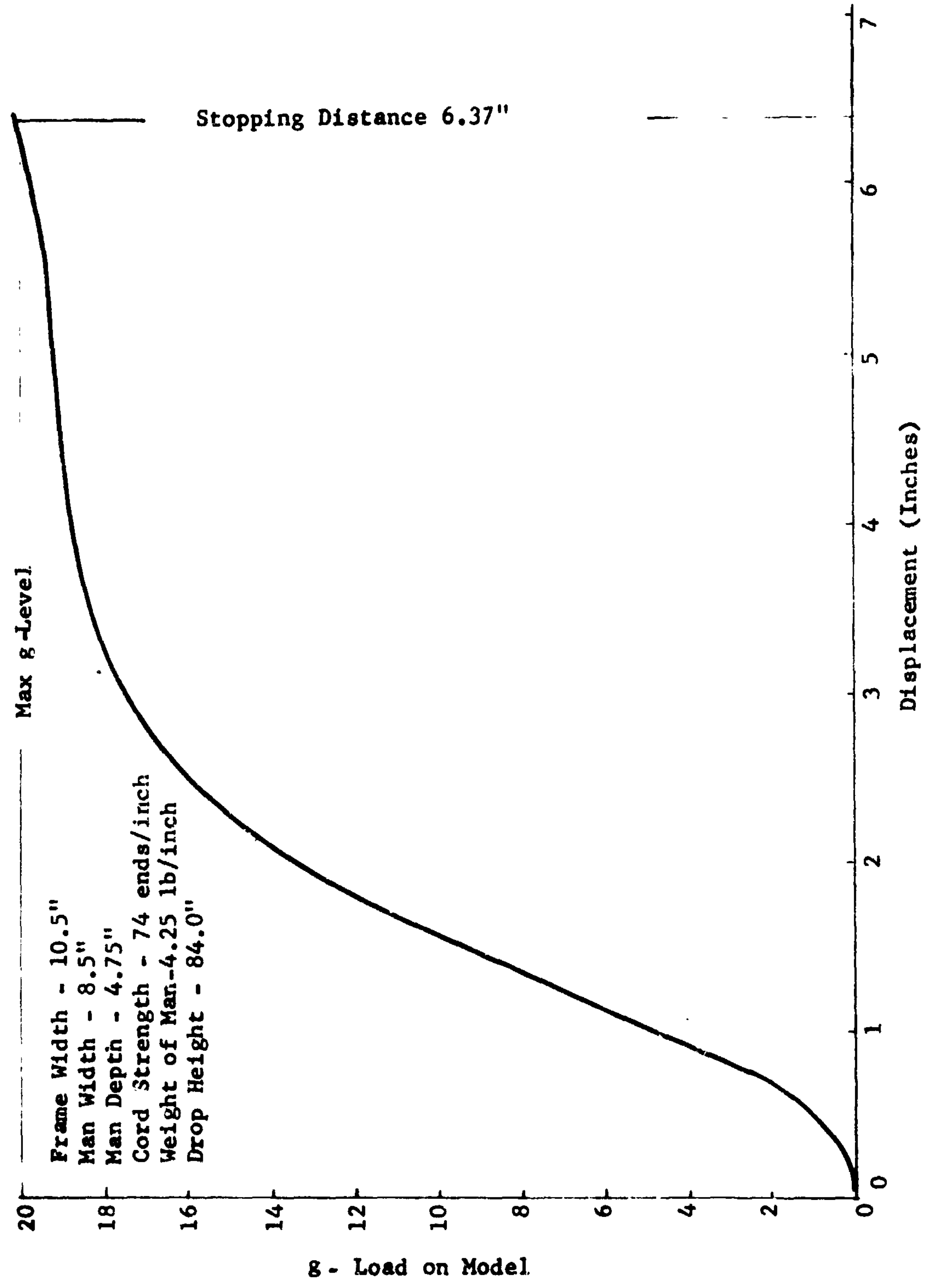
Using curve (1) on Figure 10 as the basis for the design, a test fabric consisting of 74 single yarn ends per inch was established as the design best suited to meet the proposed test conditions. The g-loads and attenuation anticipated for each of the two proposed test conditions are shown on Figures 14 and 15 as calculated.

Figure 16 shows the results of two Instron compression tests made on the 74 end elastomer impregnated filament wound fabric which were obtained for making a direct comparison to the calculated attenuation curve shown on Figure 14. The weight configuration and sample suspension frame which was designed for the drop test was used in conjunction with the Instron tester to develop the experimental curves. Again the effect of wetting was detected.

A total of nine 1/2 scale drop tests were conducted. Several fabrics, including the 74 end/inch design, were tested with results as summarized in Table 8.

The tabulation below highlights the correlation between mathematical prediction and test data which was actually achieved.

3.4.1 Drop Tests - Cont.



Frame Width - 10.5"
Man Width - 8.5"
Man Depth - 4.75"
Cord Strength - 74 ends/inch
Weight of Man-4.25 lb/inch
Drop Height - 84.0"

FIGURE 14
LOAD ATTENUATION CURVE FOR TEST SPECIFICATION, PROPOSAL "A", FILAMENT WOUND CONCEPT

3.4.1 Drop Tests - Cont.

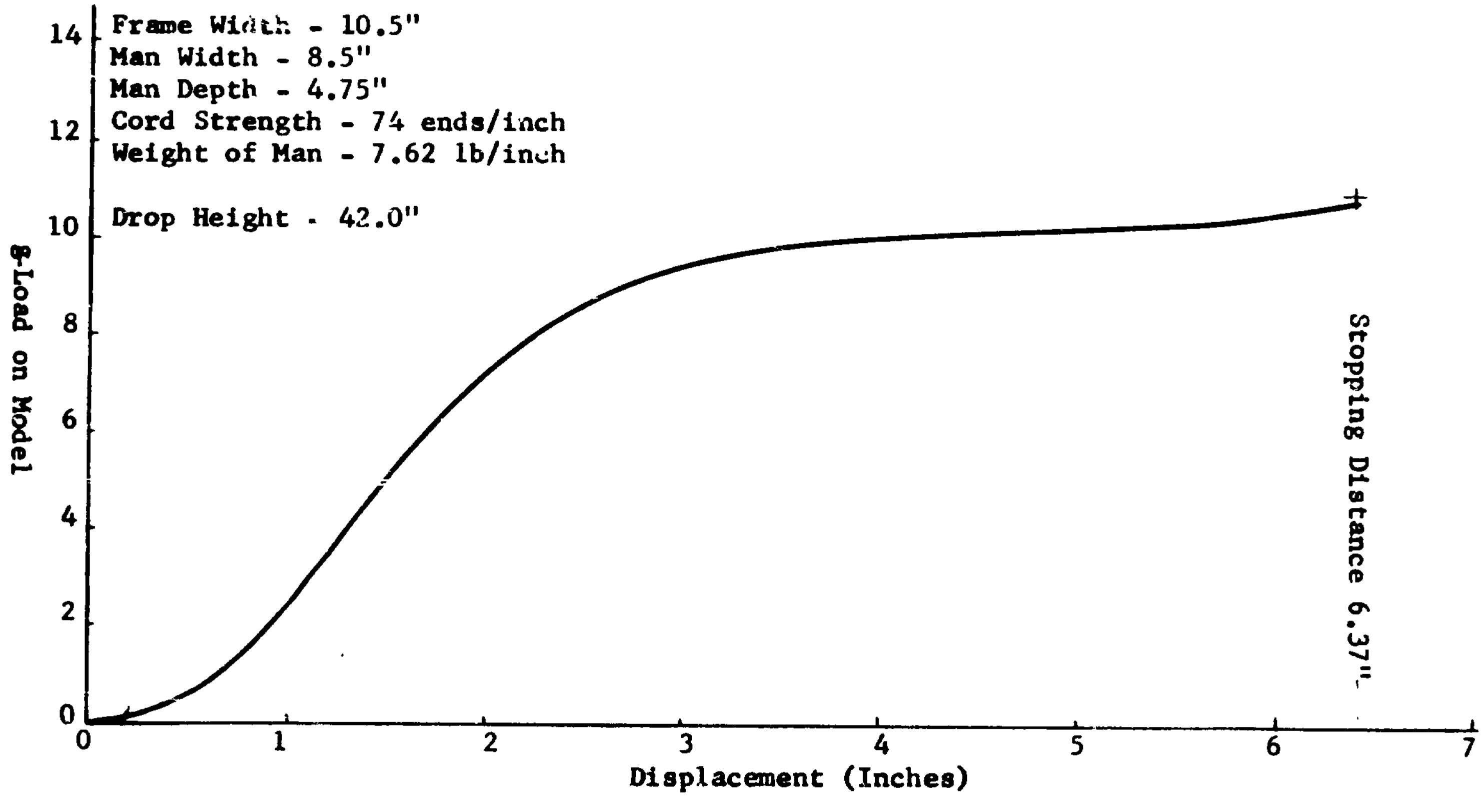
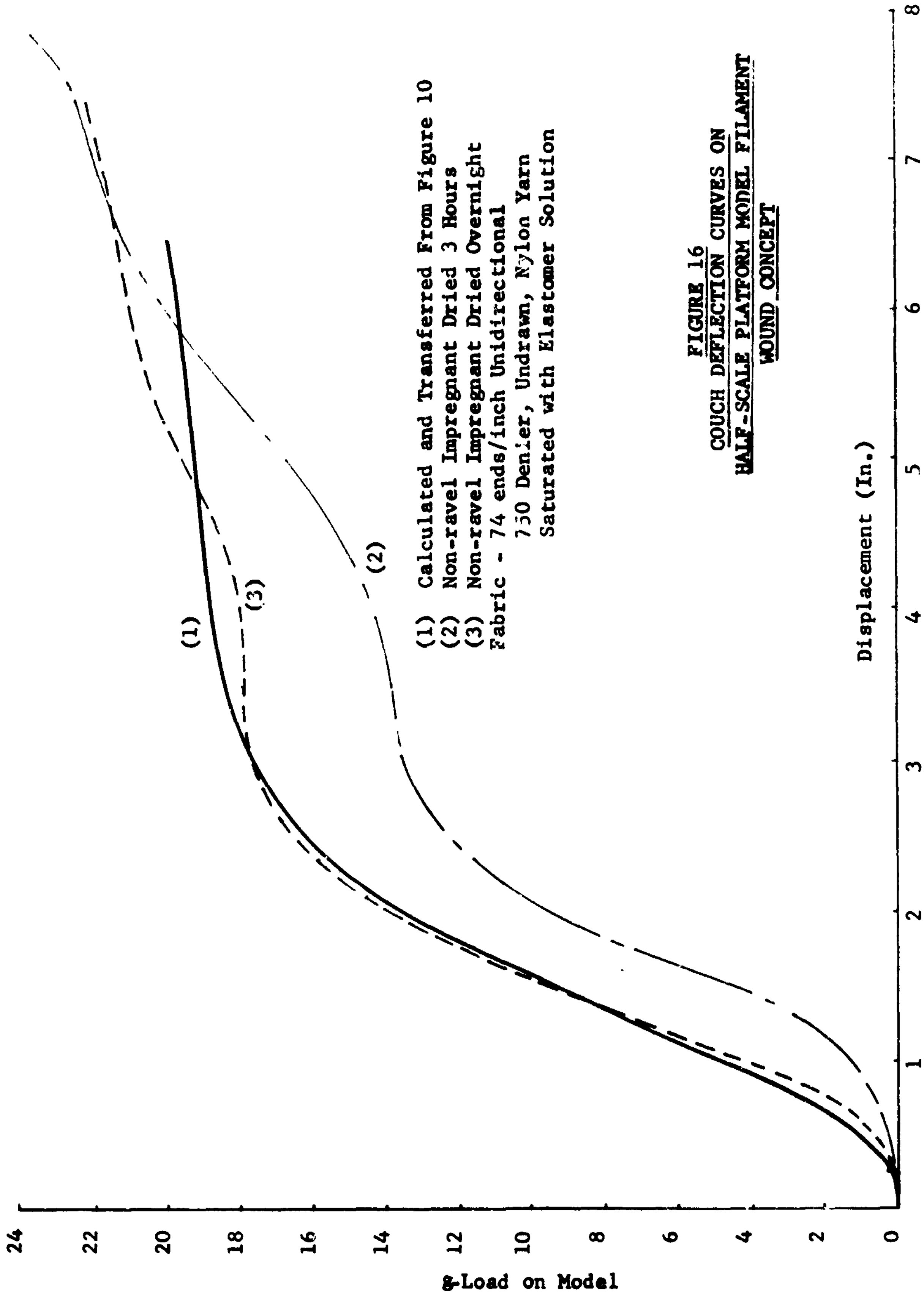


FIGURE 15
LOAD ATTENUATION CURVE
FOR TEST SPECIFICATION, PROPOSAL "B"
FILAMENT WOUND CONCEPT

3.4.1 <u>Drop Tests</u> - Cont.



<u>FIGURE 16</u>
<u>COUCH DEFLECTION CURVES ON</u>
<u>HALF-SCALE PLATFORM MODEL FILAMENT</u>
<u>WOUND CONCEPT</u>

3.4.1 Drop Tests (continued)

TABLE 8

SUMMARY DROP TEST RESULTS

FILAMENT WOUND CONCEPT

Test No.		1	2	3	4	5	6	7	8	9
Yarn ends/inch in sample		74	74	74	54		54			
Cord ends/inch in sample						15.33		22.33	28	27.33
Arresting* deflection in inches		4	4.5	4	5.12	7.25	5.06	5.5	4.34	4.34
G_D ** for arresting deflection		18.7	10.2	10.0	10.3	11.0	10.25	10.4	10.17	10.17
		Figure 10	(Figure 11)							
G_T recorded on test		23.5	12.6	14.6	10.0	7.43	13.1	10.27	14.15	14.35
Fabric *** Adjustment Indicated	Yarn ends/in.	55.0	58.5	48.4	55.6	**** 57.5		**** 57.5	**** 50.8	**** 48.7
	Cord ends/in.	**** 21.6	**** 23.0	**** 19.0	**** 21.9	22.6		22.6	19.9	19.1

*Total of elastic and permanent deflections

**Read from calculated load-attenuation curve on Figures 10 or 11

***Sample yarn or cord ends X G_T/G_D

****One yarn end = .392 cord ends

NOTES CONTINUED ON NEXT PAGE

TABLE 8 (continued)

General Notes on Test Fabrics

Test 1 - Yarns were impregnated with elastomer solution which appeared to have no effect on stress-strain characteristics of fibers.

Test 2 - Same as 1.

Test 3 - Same as 1.

Test 4 - Yarn ends adjust. Impregnated like Test 1.

Test 5 - Twisted cord substituted for yarn. Unimpregnated.

Test 6 - Similar to Test 4 except with cemented in place knit cover. The cover partially sustained the load.

Test 7 - Similar to Test 5 with increased number of cord ends.

Test 8 - Stabilizing cord cemented to center section of test fabric causing all ends to draw effectively. Attenuating cords impregnated with elastomer which subsequent tests indicated could increase the cord draw stress up to 6%. Knit cover pleated and tacked to platform and broke free during drop test.

Test 9 - Same as 8 without cover.

3.4.1 Drop Tests - Cont.

	Yarn Ends in Test Fabric	Yarn Ends in Test Fabric
Predicted using stress-strain relationship shown by Figure 10	74	29
Predicted using stress-strain relationship shown by Figure 11	62.6	24.6
Suggested by test results	48.4 to 58.5	19.1 to 22.6

The discrepancies between the experimental and predicted or design fabrics could be explained in several ways but verification testing would have to be conducted to pin it down precisely. In the meantime, a decision to base the couch platform design on Figure 15 is at least shown to be a conservative action.

Figure 17 is included to show a typical loading trace obtained during a 1/2 scale drop test. This particular trace was obtained from Drop Test Number 3.

3.4.1 Drop Tests - Cont.

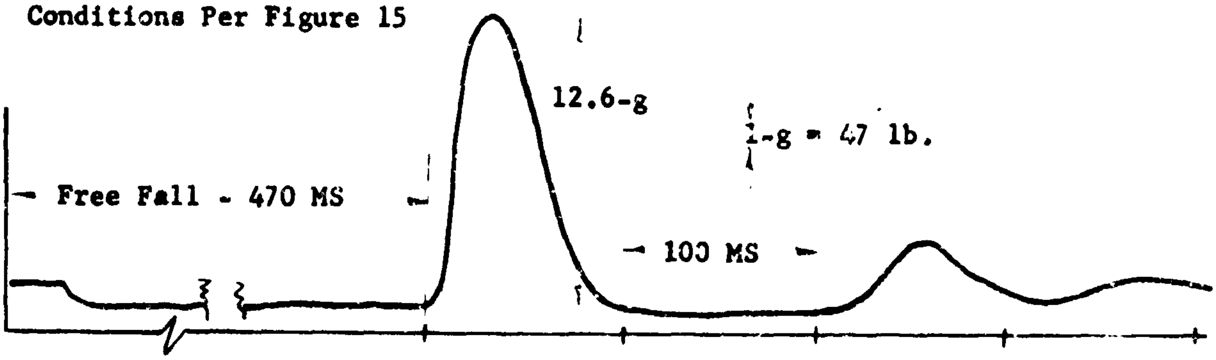


FIGURE 17
LOAD TRACE ON HALF-SCALE DROP TEST
FILAMENT WOUND CONCEPT

3.4.2 Platform Design

The purpose of the first prototype couch platform design was aimed primarily at proving out a design concept. Specifically, it was desired to design a platform which would support a 90 percentile occupant in the eyeballs-in direction:

a. Without appreciable permanent strain when subjected to a 9-g loading condition, and

b. Without exceeding a 20-g loading condition and a total attenuation of 12" on decelerating from an impacting velocity of 30 ft./min.

Calculations showed, however, that the best compromise possible would result in the following:

Body	Cords Ends/inch In Attenuating Fabric	g-Load Anticipated With 12" Attenuation*
Upper head	9.3	19.7
Lower head	10.0	20.4
Neck	15.0	21.2
Upper torso	29.2	17.8
Middle torso	34.7	20.1
Lower torso (including ½ thigh)	54.5	20.0
Upper shank (including ½ thigh)	11.8	20.8
Middle shank	4.0	20.9
Foot	8.4	20.9

* Beyond 1-g loading condition. Total deflection from taut horizontal net position was calculated to be 13-1/2".

3.4.2 Platform Design (continued)

Cords were chosen in preference to yarn because the twisted construction tends to protect and certainly make the individual filaments involved less vulnerable to damage.

Figure 18 shows the overall design as actually assembled for full scale testing. The attenuating cords are fastened to the sides of the couch frame by a clamping arrangement. The stabilizing cords are cemented onto the attenuating cords. Polymeric elastic sheeting is inserted between the attenuating cord sections to achieve a one-piece construction. A two-piece knit cover is lightly tacked to the backing to provide a degree of comfort and damage protection.

To avoid end damage it was decided to suspend the attenuating cord from nylon rods which in turn could be fastened to the frame.

3.4.2 **Platform Design** - Cont.

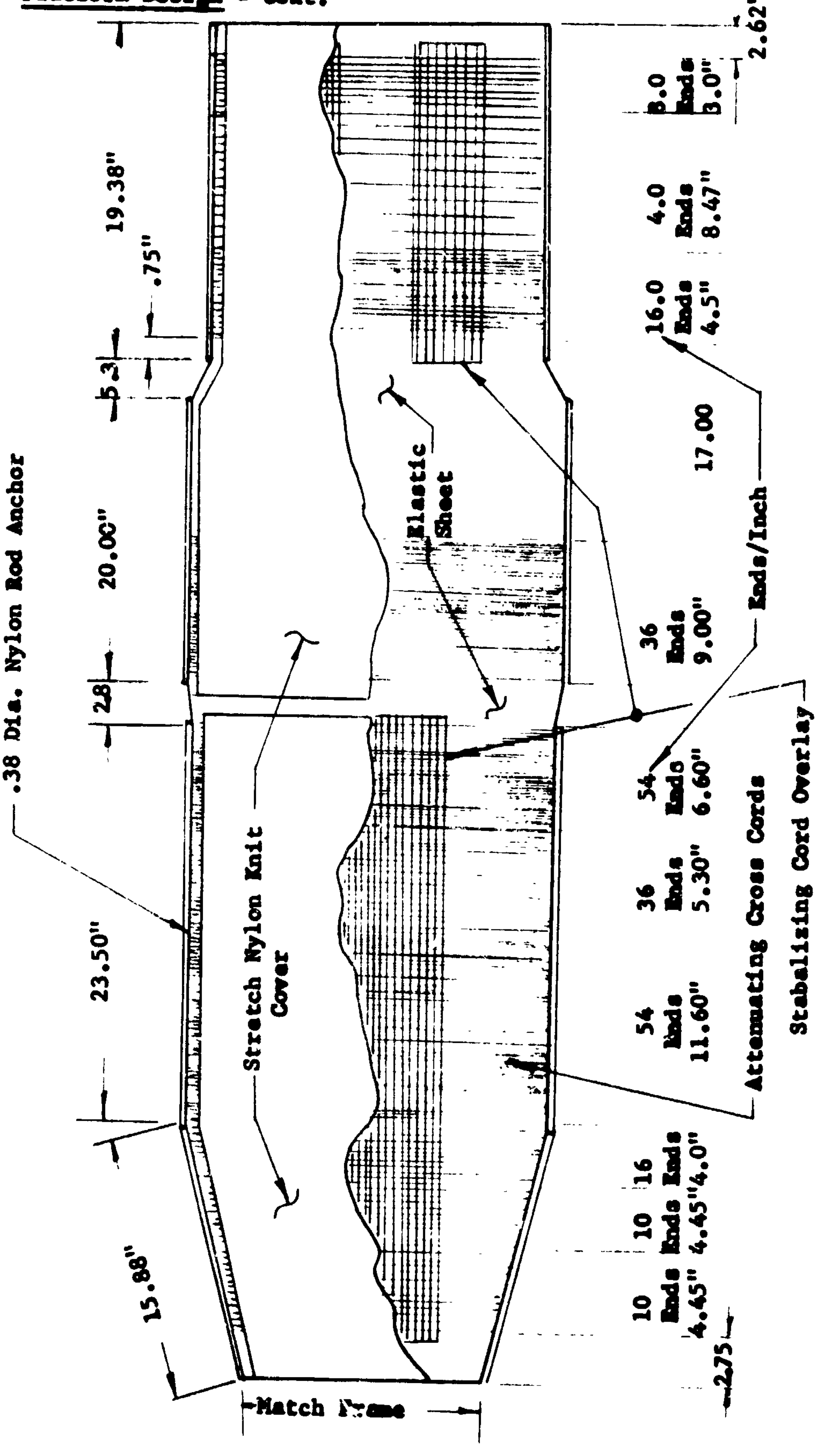


FIGURE 18
CORD DISTRIBUTION
FILAMENT WOUND CONCEPT

3.4.2 Platform Design (continued)

The stabilizing cords consisted of fully drawn 840 denier, 140 filament with 1/2 twist, type 300 duPont Nylon. The low elongation at break of this material is ideally suited to insure a balanced distribution of loading to all the attenuating cords in the design. Its stress-strain characteristic is shown on Figure 19. The stabilizing cords are restricted to a position under the body where, due to friction, the attenuating cords do not elongate.

The knit cover was knit from 8 plys of 70 denier stretchable nylon to a balanced construction of 13 wales and courses per inch.

3.4.2 Platform Design - Cont.

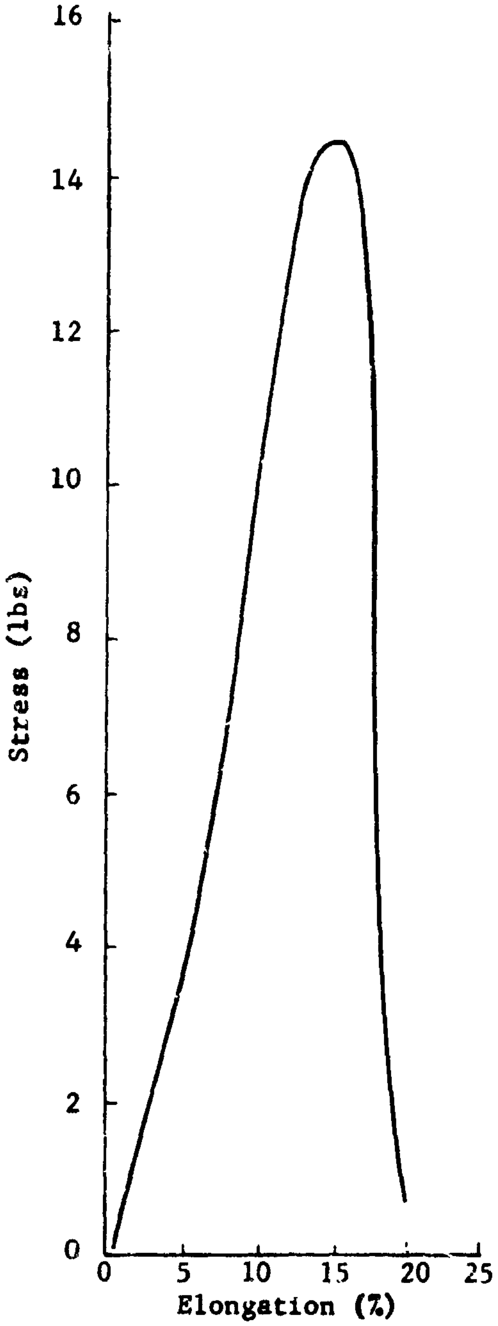


FIGURE 19
STRESS STRAIN OF
840 DENIER NYLON 300
STABILIZING CORD

3.5 Summary of Concept Evaluation Test Program

The static loads were applied at 1-g, 3-g, 6-g and 9-g load levels, and returned to 1-g, with deflections of the body support and couch framework recorded at each step. The system was hydraulically loaded by pressure pads applying the load to an anthropomorphic dummy at the calculated c.g. location for the various body members.

Dynamic testing was conducted at Weber's dynamic test stand. The test specimen was mounted on a sled with the dummy properly positioned and accelerated to the required parameters by a falling hammer striking a spring plunger attached to the sled carriage. By varying the hammer height, spring rate and gross sled weight desired g-levels, velocity changes and onset rates can be imparted to the specimen.

3.5.1 General Performance

The items under this classification applied to those parameters which were not directly related to the static or dynamic performance of the systems. The qualitative parameters, such as comfort and pre-shaped contour, are contained in this section.

3.5.1 General Performance (continued)

The three concepts, as presented for test, all utilized some form of nylon for the hysteritic, energy absorbing material. The woven tape system was the only one to use a specially processed nylon material. The knitted system was braided on machinery which was specially designed and constructed by the manufacturer of that system. The twisted cord from which the filament wound system was constructed was the only concept using techniques generally available in the industry.

The cords used in the filament wound system for test were lively and required a certain amount of pre-tension to prevent them from kinking. The kinking does not appear as a major problem as this is typical of most cords or threads which are machine twisted. This characteristic can be removed by chemical, mechanical, or thermal methods, depending on the end usage of the product. Due to the time limitations in constructing the test systems, it was decided to let the material kink because post processing could affect the system performance.

The knitted concept was generally considered the most comfortable although this parameter was difficult to evaluate because of the excessively long thigh length dimension used in the fabrication of all the body support concepts.

3.5.1 General Performance - Cont.

The woven tape system was the least comfortable due to the high tenacity of the static load tapes which could not conform to the local contour length of the body. The loose construction of the system resulted in a feeling that one might fall through the net and prevented full concentration on the comfort aspects of the system. This system however, was the only one submitted which could be adjusted to accommodate thigh length of an average occupant. The falling through feeling was later reduced by adding a cover layer to the system.

The high tension field in knitted system prevented articulation tests of that system. The net was positioned on the articulating frame such that it pulled behind the pivot points on the frame which forced the framework to the open or closed position limits. The other two systems were satisfactorily articulated and no problems were detected.

The filament wound system and the knitted system both weighed in at 2.5 lbs. each. The woven tape system

3.5.1 General Performance (continued)

weighed 4.3 lbs. The recorded weight was of that portion of the body support which was replaced during the dynamic tests.

The evaluation team determined that the filament wound concept had the best general performance.

3.5.2 Static Performance

The static loads were applied hydraulically to the body supports with total deflections measured along the centerline of the simulated occupant at five positions; head, chest, upper and lower pelvic and shank areas.

Local elongation in the fabrics, measured at centerline and outboard positions at four (4) stations along the torso, were recorded. Couch structure deflections were also measured for possible later use in the design of the couch structure.

Tabulated data points are presented in Reference 6. The static deflections are averaged and summarized in Table 9.

3.5.2 Static Performance - Cont.

TABLE 9

AVERAGE STATIC LOAD DEFLECTIONS, SUMMARY

Parameter	Spec Allowable	Woven Tape Concept	Knitted Concept	Filament Wound Concept
0 - 1-g	1.5	*	1.9	1.9
0 - 9-g	3.0	*	4.0	4.7
Perm set at 1-g	0.0	*	1.03	1.4

* Static load platform failed at 3-g. Average deflection, 1-g to 3-g load was 0.32 inches.

The woven tape concept had a premature release of the static load bearing platform (tapes) at the 3-g load condition. Based on the 1-g to 3-g load deflections this system probably would have conformed well within deflection allowables for the static load test. Investigation of the loading conditions showed that the contour of the dummy did not conform to the circular arc body section assumption used in determining the strength of the bight close-out tape. This resulted in loading the tape at a higher rate than anticipated. Re-evaluation of the loads based on the actual dummy body sections could resolve this problem. See Figure 20 for a photograph of the test set up. The filament wound concept had larger average deflections than the knitted system but the deflection was more uniform.

3.5.2 Static Performance - Cont.

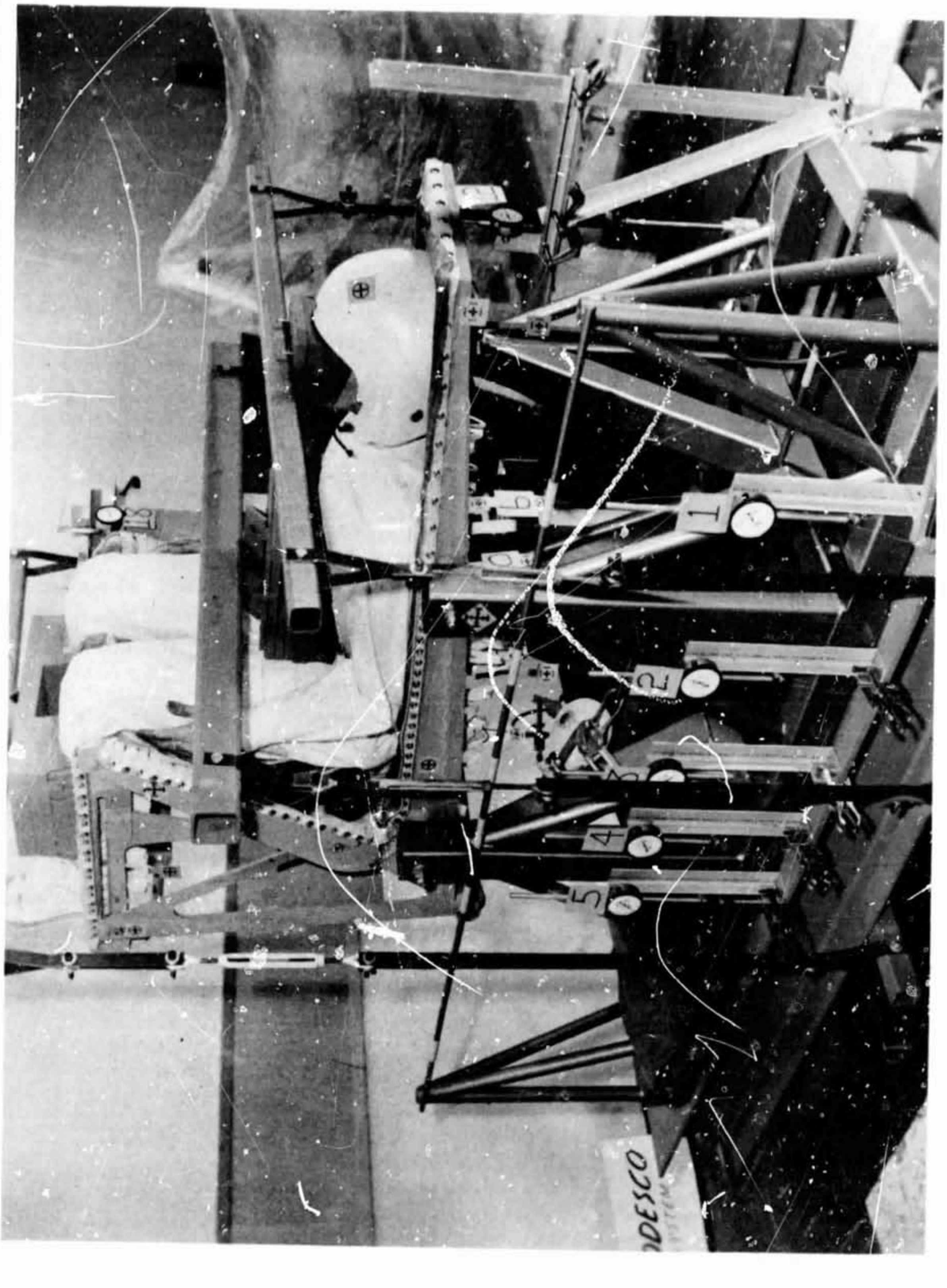


FIGURE 20 - STATIC TEST SET UP

3.5.2 Static Performance (continued)

At the 9-g load level the maximum deviation of the body members from a uniform deflection for the filament wound system was only 2.1 inches where the knitted system was 3.4 inches.

The evaluation team graded the filament wound system as having best static performance characteristics.

3.5.3 Dynamic Performance

Three high speed motion picture cameras at 1400 to 1600 frames per second and four accelerometers were used to record the characteristics of the body support concepts for each test. From the movies (Reference 7) it was determined that the head and torso of the dummy in the woven tape body support moved uniformly until the bight in the elastic load platform was extended causing the head, chest and pelvis areas to bottom out in approximately that order. There were several energy absorbing tapes that failed during the impact. The dummy rebound did not appear to be excessively rapid or severe.

The torso and head deflecting as a unit is mandatory in a system of this type as rapid differential movements of the head and chest can cause severe damage to the

3.5.3 Dynamic Performance (continued)

cervical vertebra and musculature. Although not as sensitive the lumbar vertebra are also subject to the same type of damage, especially fracture of the vertebral head.

Lack of uniform body displacement under various loading conditions was a major problem with the knitted body support concept. This probably could be corrected by rearranging the various strength cords in the system. The movies indicated the head, pelvis and then chest regions bottomed and a rapid rebound was evident.

The dynamic deflection for the filament wound system was the most uniform of the three systems. From the motion pictures it was seen that the torso and head responded as a single, rigid mass. The displacement and rebound were very uniform and a smooth reversal of direction from the arresting deflection to the rebound was indicated.

It should be noted that there was no attempt to restrain the dummy in the body support once the attenuating sequence was initiated. Prior to receiving the acceleration forces the dummy was positioned in a 1-g deflection position to simulate parachute descent. This loading

3.5.3 Dynamic Performance - Cont.

was required because the dummy was positioned in a back vertical position due to the sled being accelerated in a horizontal plane.

One of the most interesting characteristics noted in dynamic testing of the different concepts is that each system had a certain response and, within the limits tested, velocity changes (changes in energy attenuation levels) and body position produced minor changes in the response of the system. Also, preloading the net in static (simulated launch) tests did not result any noticeable effect.

In evaluating the dynamic performance the data obtained from the dummy leg has been eliminated. Since the thigh length of the platforms precluded proper fit of the dummy's leg, it is believed that the resulting data may be misleading.

This problem was resolved during the next phase of the development.

In Table 10 the deflection data has been summarized and shows the overall dynamic response for each concept.

Figure 21 shows the typical response characteristics of the body support concepts.

3.5.3 Dynamic Performance - Cont.

TABLE 10

SUMMARY DYNAMIC DATA

PARAMETER	SPEC ALLOWABLE	WOVEN TAPE CONCEPT		KNITTED CORD CONCEPT		FILAMENT WOUND CONCEPT	
Body Angle	-	66°	108°	66°	108°	66°	66°
Velocity Change	30fps(max)	24fps	26fps	20fps	20fps	19fps	25fps
Input Force	50g(max)	69.8-g	65.6-g	65.3-g	68.1-g	62.1-g	65.0-g
Avg Dummy Acceleration	20g(max)	23.4-g	23.0-g	32.5-g	31.0-g	20.7-g	22.9-g
Avg Dummy Rate of Acceleration	5000g/sec (max)	688-g/s	629-g/s	1810-g/s	1387-g/s	835-g/s	1011-g/s
Avg Dynamic Deflection	9 inch (max)	11.9in	11.3in	6.8in	6.7in	9.8in	10.9in
Maximum Deflection Static & Dynamic	12 inch (max)	13.5in	12.9in	10.9in	11.0in	12.0in	13.1in
Region of Max Defl.	-	Chest	Chest	Pelvis	Pelvis	Pelvis	Pelvis
Avg Perm Set	Design Objective- 9 inches	4.1in	3.3in	1.0in	1.0in	2.5in	1.8in

3.5.3 Dynamic Performance - Cont.

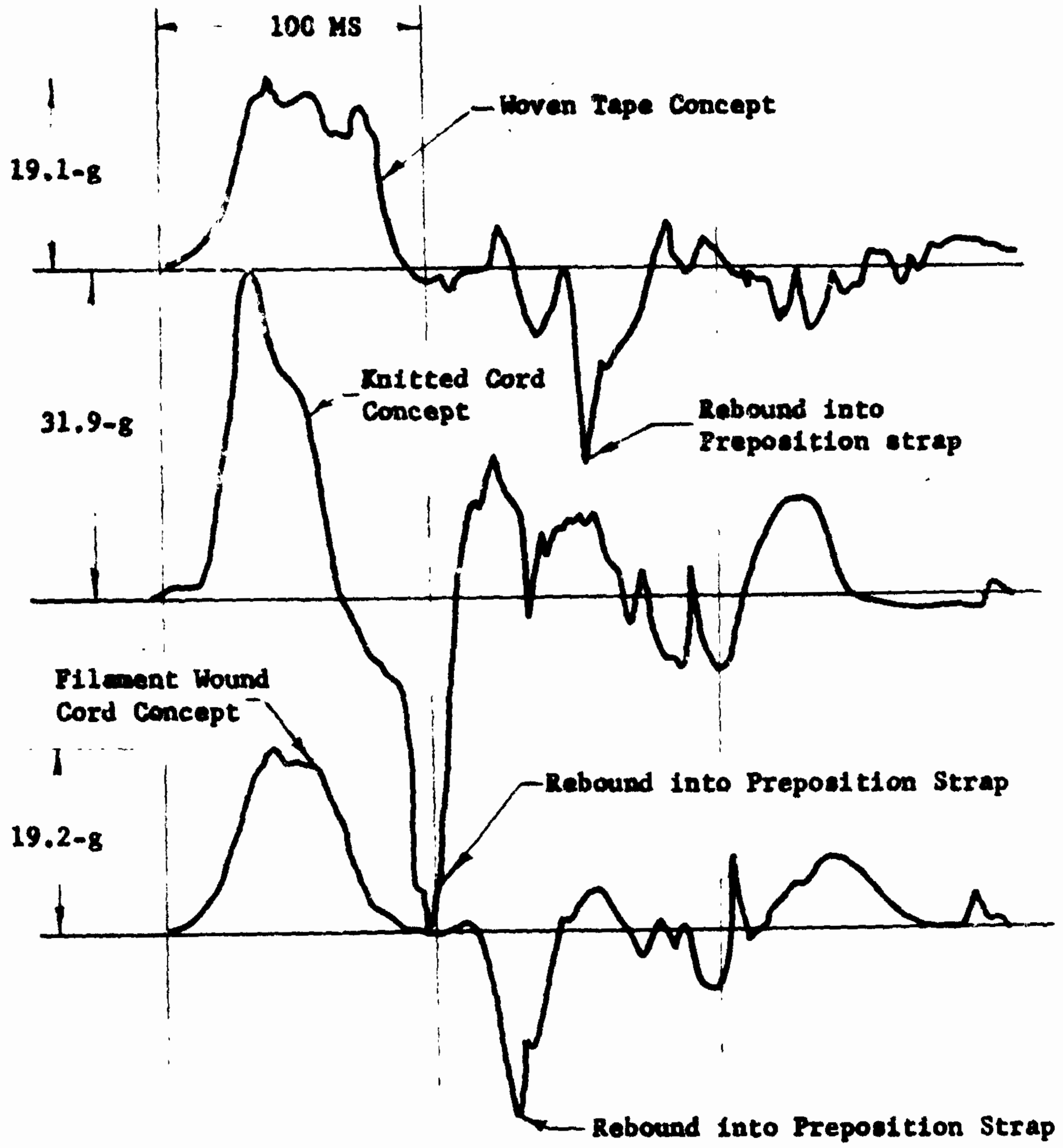


FIGURE 21
DYNAMIC ATTENUATING CHARACTERISTICS OF THE THREE BODY SUPPORT CONCEPTS

3.5.3 Dynamic Performance (continued)

Reviewing the performance of the systems it can be seen that those with the lower dummy acceleration response had a higher amount of permanent set indicating excellent attenuating characteristics. The higher dummy response g-forces of the knitted system corresponds to the lower total deflection for the system and indicates that the system may be over designed. This is further evidenced by the low amount of permanent set for the system.

Reviewing the overall performance of the filament wound concept one of the most outstanding characteristics of the system was the uniformity of deflection.

The spread of high and low forces and deflections recorded for each system can be seen in Table 11. The parameters are for the same test conditions in Table 10.

3.5.3 Dynamic Performance (continued)

TABLE 11

DEVIATION FROM UNIFORM DYNAMIC RESPONSE

PARAMETER	WOVEN TAPE CONCEPT		KNITTED CORD CONCEPT		FILAMENT WOUND CONCEPT	
Body Position	66°	108°	66°	108°	66°	66°
Dummy Acceleration	4.8-g	7.6-g	0.9-g	5.7-g	4.6-g	4.3-g
Dummy Rate of Acceleration	545-g/s	460-g/s	1320-g/s	400-g/s	235-g/s	368-g/s
Dynamic Deflection	3.3 in	2.3 in	2.7 in	3.0 in	1.4 in	1.2 in
Total Static & Dynamic Deflection	3.3 in	2.5 in	4.5 in	4.5 in	1.0 in	0.7 in
Permanent Set	0.8	1.1 in	0.6 in	0.6 in	0.5 in	1.0 in

Uniformity of deflection and forces is indicative to the predictability of material performance for a given set of conditions. The use of mathematical analysis as a tool in designing a body support is very essential to designing the total system, including attachment of body support to the metal structure and stress analysis of the structure. Being able to predict the performance of the body support also enables scale models of the system to be built for component test purposes. Also, structure design can proceed on a parallel basis with the fabric body

3.5.3 Dynamic Performance (continued)

support thus enabling the total couch system to be developed in a minimum of time.

The predictability of the filament wound concept is shown in Table 12.

TABLE 12

PREDICATED VS. ACTUAL DUMMY RESPONSE, FILAMENT WOUND CONCEPT

PARAMETER	PREDICATED	ACTUAL (Average of two tests)
Head Acceleration	20.7-g	19.7-g
Chest Acceleration	19.7-g	21.7-g
Pelvis Acceleration	20-g	24.1-g
Leg Acceleration	20.9-g	25.3-g
Dynamic & Static Deflection (Avg)	13.5 in.	12.6 in.

Photographs of the evaluation tests of the filament wound concept are shown in Figures 22 and 23.

Based on the results of tests and evaluation of overall understanding and capability, the filament wound concept was selected as the best of the three systems submitted.

3.5.3 Dynamic Performance - Cont.

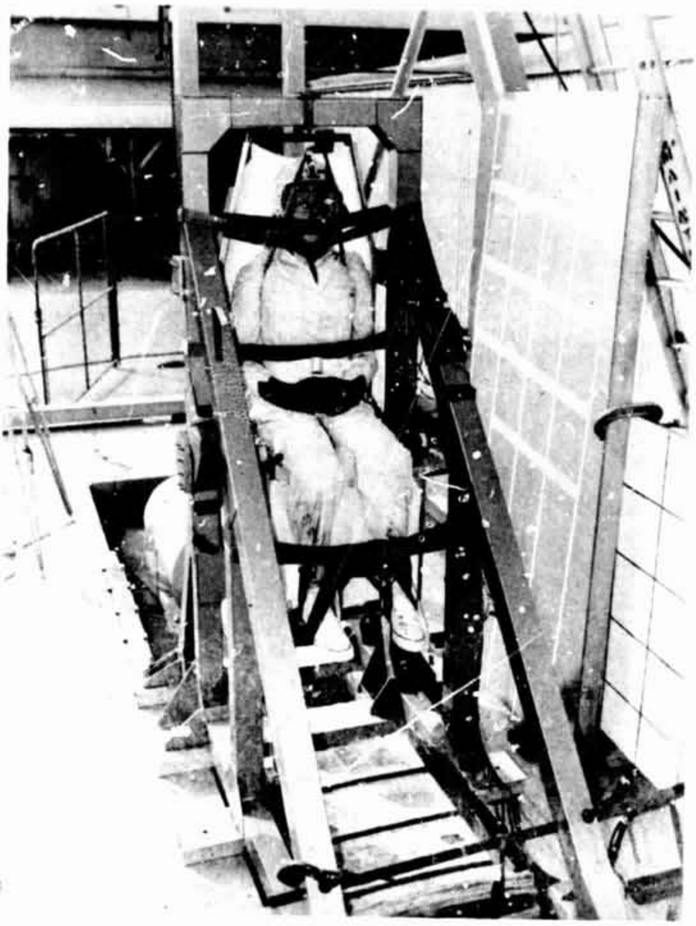


FIGURE 22

DYNAMIC TEST SET UP

3.5.3 Dynamic Performance - Cont.

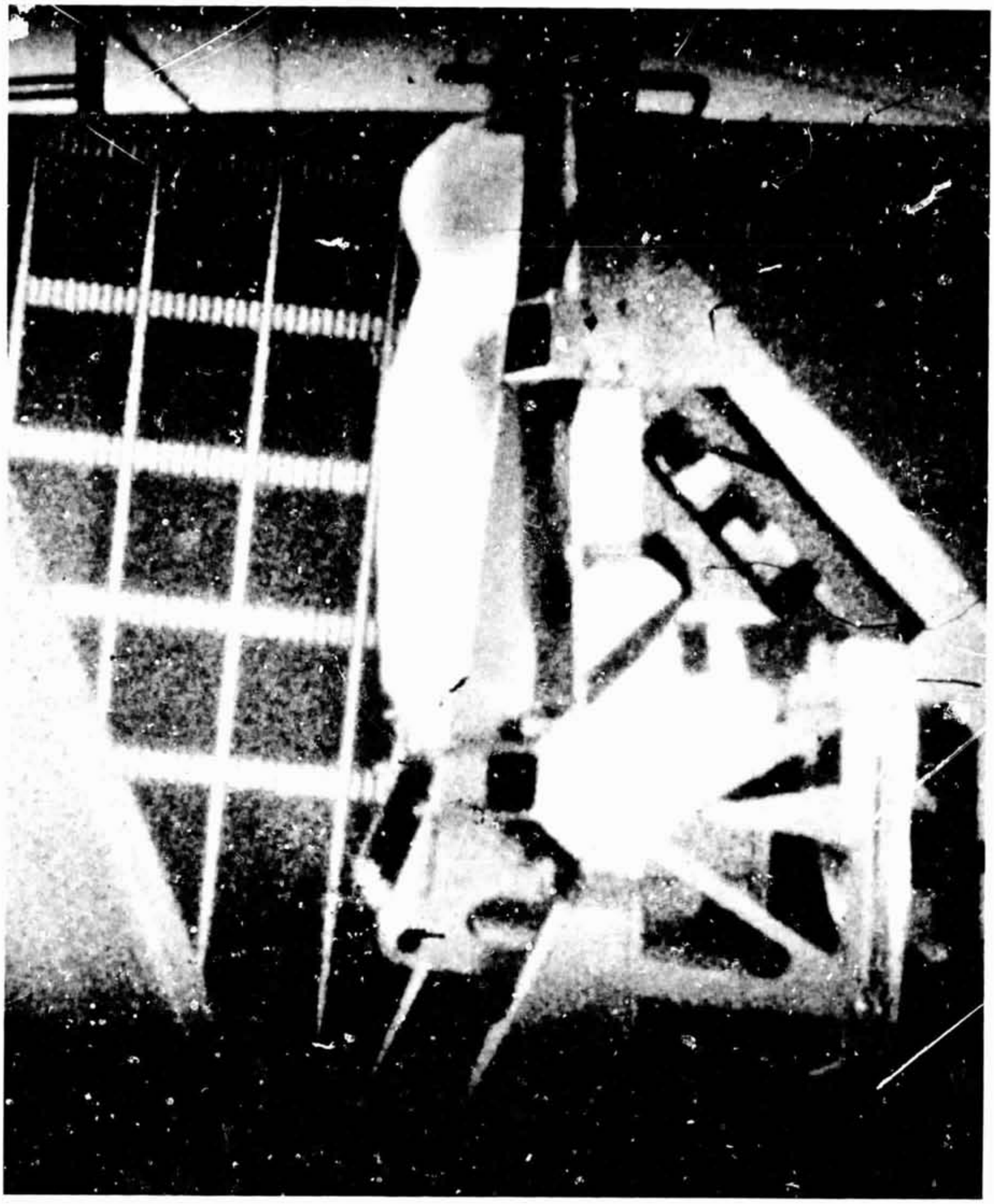


FIGURE 23

DYNAMIC TEST ON APOLLO COUCH
FILAMENT WOUND SYSTEM

4.0 PHASE I - TASK B - DESIGN AND DEVELOPMENT OF COUCH SYSTEM

Analysis of a three couch system and the interface requirements to Apollo Command Module was performed in order to define the specific requirements for a single couch frame to be designed, fabricated and tested. A basic dimension drawing, using engineering drawings of the spacecraft, was established to determine the geometrical limits of the system. The Command Module limits were defined as well as the space permissible for each couch and the suspension structure. Included was the space requirements for the occupants in relation to the couch framework. Detail performance criteria for the couch frame, suspension structure and the body support-restraint assembly was established. Materials of construction and the parameters to be tested and test procedures were established. Details of the work performed are discussed in Reference S.

4.1 Performance Requirements

Basic loads for the couch framework were established to the following limits which are ultimate forces:

+ 75-g, - 15-g in the X axis [eyeballs in (+) and out (-)]

± 15-g in the Y axis (eyeballs left and right)

+ 45-g, - 15 g in the Z axis [eyeballs up (-) and down (+)]

For launch, landing and crash conditions, the couch framework will be in a 66° trunk-thigh body position. The couch assembly, including the frame, body support and restraint system must be capable of being folded into a minimum volume for stowage and simply removed from the suspension structure. It is desirable that the couches

4.1 Performance Requirements (cont'd)

be interchangeable from one position to another on the suspension structure. Additionally, the trunk-thigh angle shall be adjustable to 66°, 108° and the 180° positions.

The body support was to remain essentially the same as submitted for concept evaluation except the elastic limit of the assembly was to be upgraded from a 9-g launch load to 16 ± 2-g to sustain maximum re-entry conditions of the Apollo Command Module. This change was not to affect the 20-g attenuating characteristics of the support. The attachment interface to the couch frame must permit simple installation onto the couch frame. The design considerations of the body support developed for this program will be restricted to eyeball-in forces only, compatible with the articulation requirements of the couch frame.

An occupant restraint system must be designed to prevent flailing of the occupant during associated rebound conditions after the initial impact attenuation has been achieved. Additionally the amount of rebound felt by the occupant shall be limited to a 10-g force. The only rebound force to be considered for this program is in the eyeball-out direction. Materials selection and usage was predicated on Weber's background experience gained in developing escape and survival systems for the X-20 (Dyna-Soar) and the Gemini spacecrafts. The governing environmental condition was the use of materials compatible with the oxygen-rich atmosphere

4.1 Performance Requirements (cont'd)

at reduced pressures. The effects of temperature, humidity, vacuum and radiation on system performance were considered beyond the scope of the technical task; however, the effects of temperature and humidity on the attenuating cords of the body support were investigated and is discussed in Section 3.4. Additionally, common hardware items such as cadmium plated nuts and bolts were used and readily available polyurethane foam and estane cements were used on the body support in an effort to maintain program schedule with realization that usage of alternate materials may be required when the system is designed for actual flight use.

4.2 Framework Development

From the basic dimension layouts, it was evident that a deep, narrow space was available for the structural sections of the couch frame and the necessary suspension structure. Three factors governed the available space for the framework: the desire to maintain the position of the crewmember, relative to the spacecraft, the same as the existing hard couch system; maximum crewmember size; and the attenuation function achieved by the system is obtained by the occupant moving with respect to the fixed framework system. The couch assembly developed to satisfy these requirements is shown in Figure 24.

With this criteria established and the requirement that each couch be easily removed from the suspension structure, the couch framework evolved. The basic sectional shape of the torso structure

4.2 Framework Development - Cont.

FIGURE 24
COUCH ASSEMBLY

4.2 Framework Development (cont'd)

consists of a rectangular section constructed of upper and lower sheet metal caps inter-connected by flat sheet members. Inside the section is located a "Z-member" to provide additional resistance to the inward bending and torsional forces created by the fabric body support being loaded by the occupant.

The requirement of the left-hand couch to move into a docking position (permitting the pilot to view directly out of the spacecraft windows to guide the vehicle during the final phases of rendezvous maneuvers) defined the head area of framework making it necessary to move the structure in towards the occupant to clear the Command Module structure. Because of the circular arch shape of the head beam, the structure was machined from plate stock into an "H" shaped section.

Located in the torso framework are the attachment points of the couch assembly to the suspension system. Each couch has three points for attachment, two at the lower end of the "U" in the hip area and one at the top of the frame in the head beam fitting. This three-point attachment is intended to simplify installation of the couches by the crewmembers during zero gravity conditions. A cross-beam, just below the occupant's buttocks is provided to resist the inward bending forces and section torsion from the body support of the torso platform, and to support the loads from the leg and thigh sections of the couch frame.

4.2 Framework Development (cont'd)

The leg and thigh structures of the frame are also rectangular in section. The section is constructed in two pieces, a shallow channel for the upper cap and a deep channel which forms the sides and the bottom of the beam section.

Machined fittings are provided in the sheet metal structure to transmit the loads through the structural sections into the attachment fittings. Incorporated into the leg, knee and hip joint fittings are the hinges which allow articulation of the frame to its various positions. The mechanism which locks the leg structure in the 66° and 108° leg positions and permits it to articulate to the inflight and stowed positions is housed in the hip joint fitting and is operated by pushing or pulling a control handle located on either side of the occupant.

For stowage of the couch, the thigh and leg structures, with the body support attached, fold over the top of the torso structure. The leg section folds upon itself further reducing the envelope size of the stowed couch. When stowed, the volume size is approximately 46.0" x 23.0" x 12.0", as shown in Figure 25. To stow the couch, it is necessary for the crewman only to loosen a screw on the three restraint harness-to-inertia reel attachments, fold the couch to the stowed position and release the latch which locks the couch structure to the suspension structure. These operations may be performed by suited astronaut without the use of tools. Re-

4.2 Framework Development - Cont.

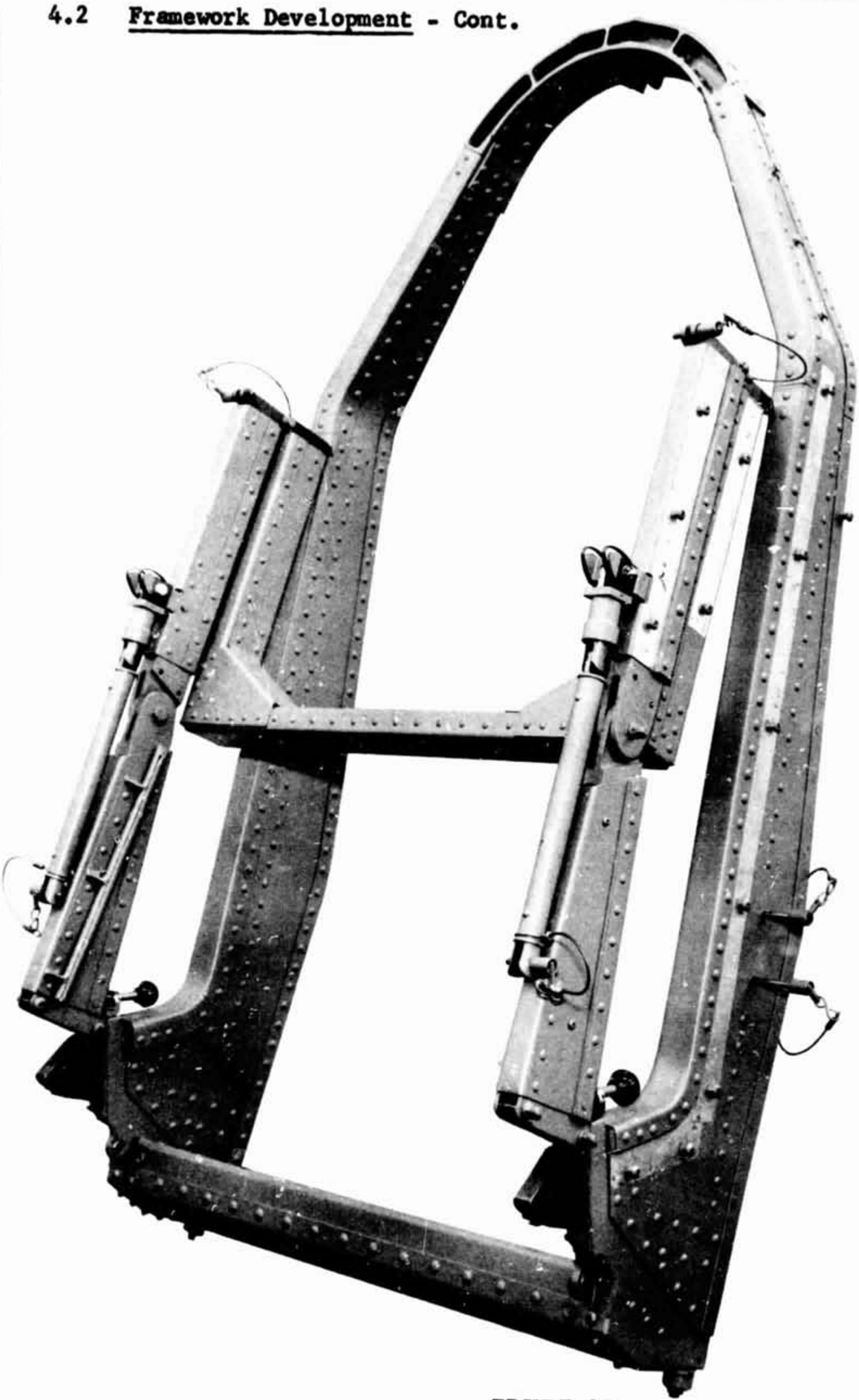


FIGURE 25

COUCH FRAME STRUCTURE IN STOWED CONFIGURATION

4.2 Framework Development (cont'd)

installation is performed in reverse order.

The major objective in designing the restraint system was to obtain one which did not encumber the user or require complex rigging and adjustment. Several methods were investigated and for the unidirectional loading application it was determined that a lap belt/shoulder strap arrangement would adequately restrain the torso and a single leg strap would contain the lower limbs to the body support.

Anchorage of the restraint harness is accomplished by floor mounted inertia reels. The reels are used to take up the slack in the harness during attenuation to prevent excessive rebound of the crewmembers during load reversals. Several tests were made with standard MA-6 reels to determine the time required to retract twelve inches of webbing. It was found necessary to install a heavier retraction spring to reduce the required time from 100 ms to 60 ms. This is required to prevent the occupant from rebounding into slack webbing in the restraint system during sudden load reversals. An attenuating link of undrawn nylon was provided at the attachment to the inertia reel strap to limit the forces experienced by the occupant during rebound to less than 10-g's. Attachment of the body support to the couch frame is accomplished by a lightweight metal clamp which grasps the edge of the body support. The clamp has keyhole-shaped slots on one edge which fit over and slide under shouldered screws which are located on outboard side of the couch

4.2 Framework Development (cont'd)

frame. They are positioned such that the inner edge of the clamp nests against a ledge built into the couch frame section. This ledge absorbs the forces transmitted by the body support as compression from the clamp to the ledge. The loads into the clamp are further reduced by friction losses due to the body support wrapping around the upper cap of the framework as shown in Figure 26.

4.3 Body Support and Restraint Development

Upon concurrence by the procuring agency of the selected concept, a specification was prepared which provided the technical direction to the supplier. This specification, Reference 9, provided that specific attention in the development of the body support and restraint system be given to the following items:

a. Development of an attenuation cord free of a tendency to curl.

b. Upgrade the maximum elastic force from 9-g to 16-g without interfering with the 20-g eyeballs-in attenuating characteristics.

c. Develop a restraint harness capable of restricting and limiting the eyeballs-out exposure to a 10-g maximum force.

d. The developed body support to be capable of being articulated as a part of the couch frame.

Inherent with the development was the selection of materials compatible with the Apollo mission and the development of tools and

4.2 Framework Development - Cont.

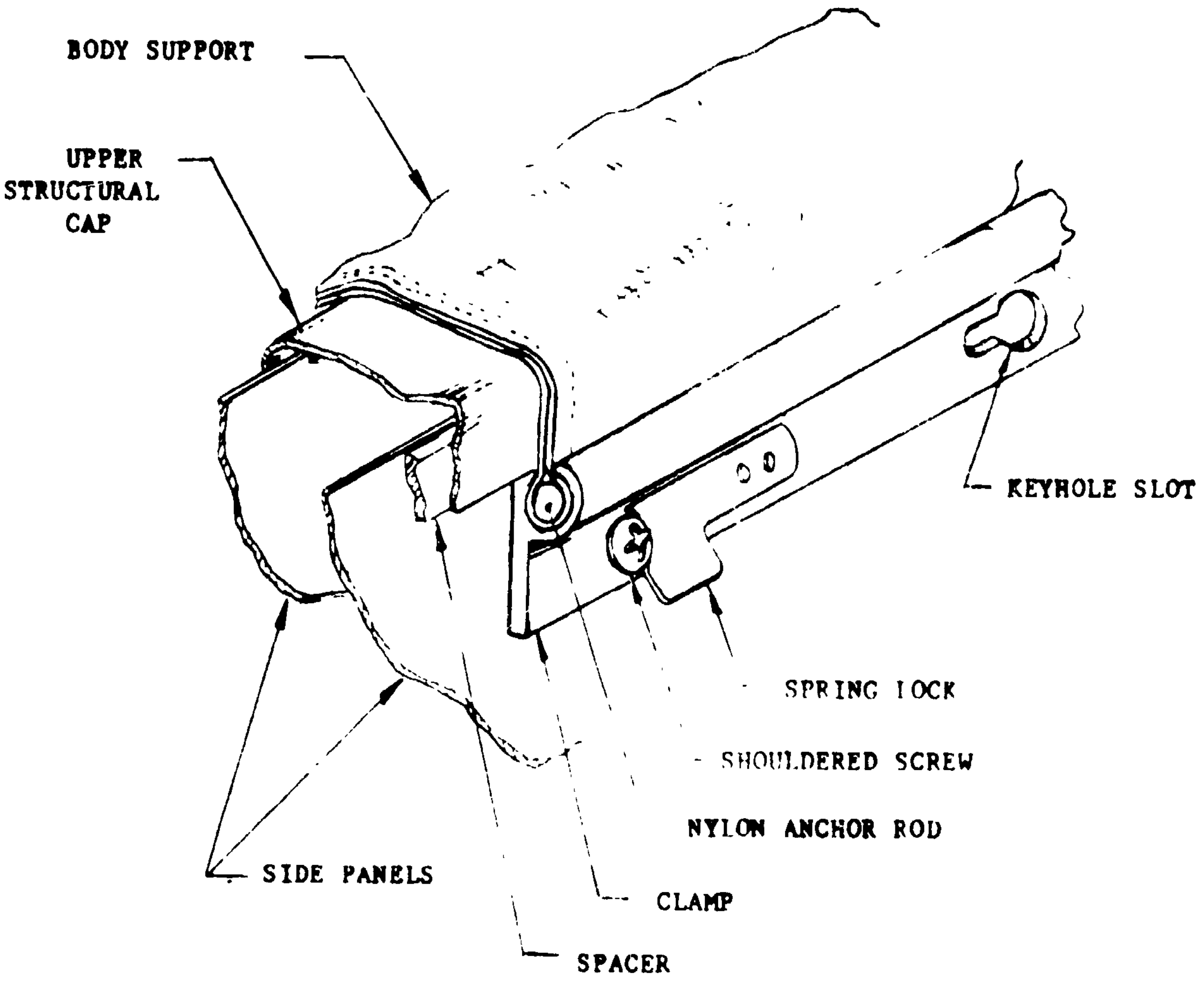


FIGURE 26

ATTACHMENT OF BODY SUPPORT TO COUCH FRAME

4.3 Body Support and Restraint Development (cont'd)

fixtures necessary to reliably and accurately assemble the units.

The design which evolved from this development effort, Figure 27, was influenced to a considerable extent on the need to supplement the static load bearing capability of the primary attenuating cords with a secondary supporting system.

Essentially, the primary support is comprised of suitably spaced undrawn nylon attenuating cords which effectively limit deceleration reactions on impact. Since a cover (fabric) was required to integrate and shield the primary structural elements, the integration of frangible lacings into this basic part was considered a logical step for generating a secondary support. The fabric "apron" that is likewise integrated with the windings, satisfy the anchor requirements of this supplementary system. The secondary lacings are proportioned to supplement the safe, non-deformable, load carrying capability of the primary cords to withstand the maximum static load carrying requirements of the mission. They are designed to "break out" at only slightly higher loads, however, so as not to interfere with the load limiting attenuating capability of the primary system acting on its own. Headrest and leg separators were specified to complement the restraint harness to further reduce the hazard of differential body member displacements.

4.3.1 Development of Non-Curling Attenuating Cord

In a relaxed state (slack) the cords used during concept

4.3 Body Support and Restraint Development - Cont.

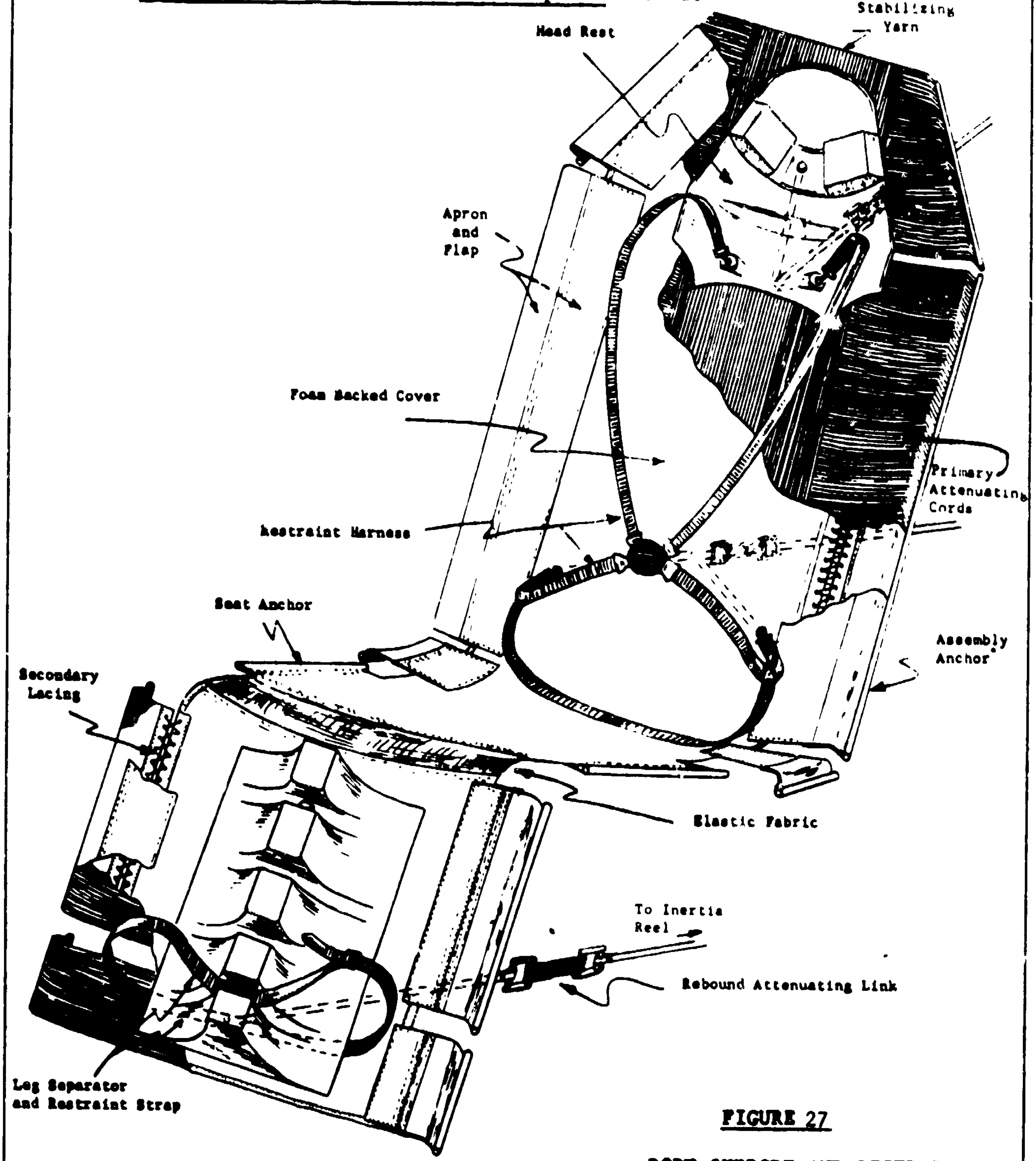


FIGURE 27

BODY SUPPORT AND RESTRAINT ASSEMBLY

4.3.1 Development of Non-Curling Attenuating Cord (cont'd)

evaluation exhibited a tendency to curl, making installation onto the couch frame difficult. In some instances, the curl was so tight that the cords would elongate rather than uncurl.

Three constructions were studied to obtain a cord with low curling tendencies. These comprised:

- Braiding a cord from untwisted yarn
- Balancing single yarn twists against the assembly twist
- Backing off the assembled twist

The braided cord was produced on a commercial braider without affecting the yarn's drawing characteristics, but the yarn strands were loosely combined and highly subject to damage.

Different types of twisted cord constructions were investigated. Several yarn twists and cord twist combinations appeared to have the desired properties except when cut, the severed ends would unwind for several inches unless restrained.

Further investigation determined that cords mechanically unwound one to two turns per inch were "dead" and did not possess a tendency to unravel when cut. It is theorized that elastic strain remaining in the cords after twisting is removed when the cords are unwound. The additional strain caused by the twisting process is released via plastic flow which determines the number of twists found in the "dead" cord.

4.3.1 Development of Non-Curling Attenuating Cord (cont'd)

The cord selected is of 3-ply construction twisted 13.5 turns per inch and mechanically unwound to 12 turns per inch. A 750-denier undrawn nylon 6 yarn was used. The draw properties of this cord are essentially the same as those used during the concept evaluation phase of the program and is shown in stress-strain diagram in Figure 28.

4.3.2 Development of Static Load Capability

As previously stated, to upgrade the elastic static load bearing capability of the system, it became necessary to integrate into the support a frangible cord structure to complement the elastic characteristics of the attenuating cords. The short term creep properties of the attenuating cord were investigated. The tests indicated that creep for short increments of time (launch or re-entry conditions) would be inconsequential if the attenuating cord is subjected to static loads equal to or less than 60% of the cord's inherent draw stress.

Three cords were considered for use as the frangible lacing to complement the attenuating cords in sustaining the 16-g static load; a two-ply twisted dacron cord, a two-ply twisted nylon cord and a four-ply braided nylon cord. All were made of 840 denier high tenacity fibers.

After investigating the properties of each cord, the dacron

4.3.1 Development of Non-Curling Attenuating Cord - Cont.

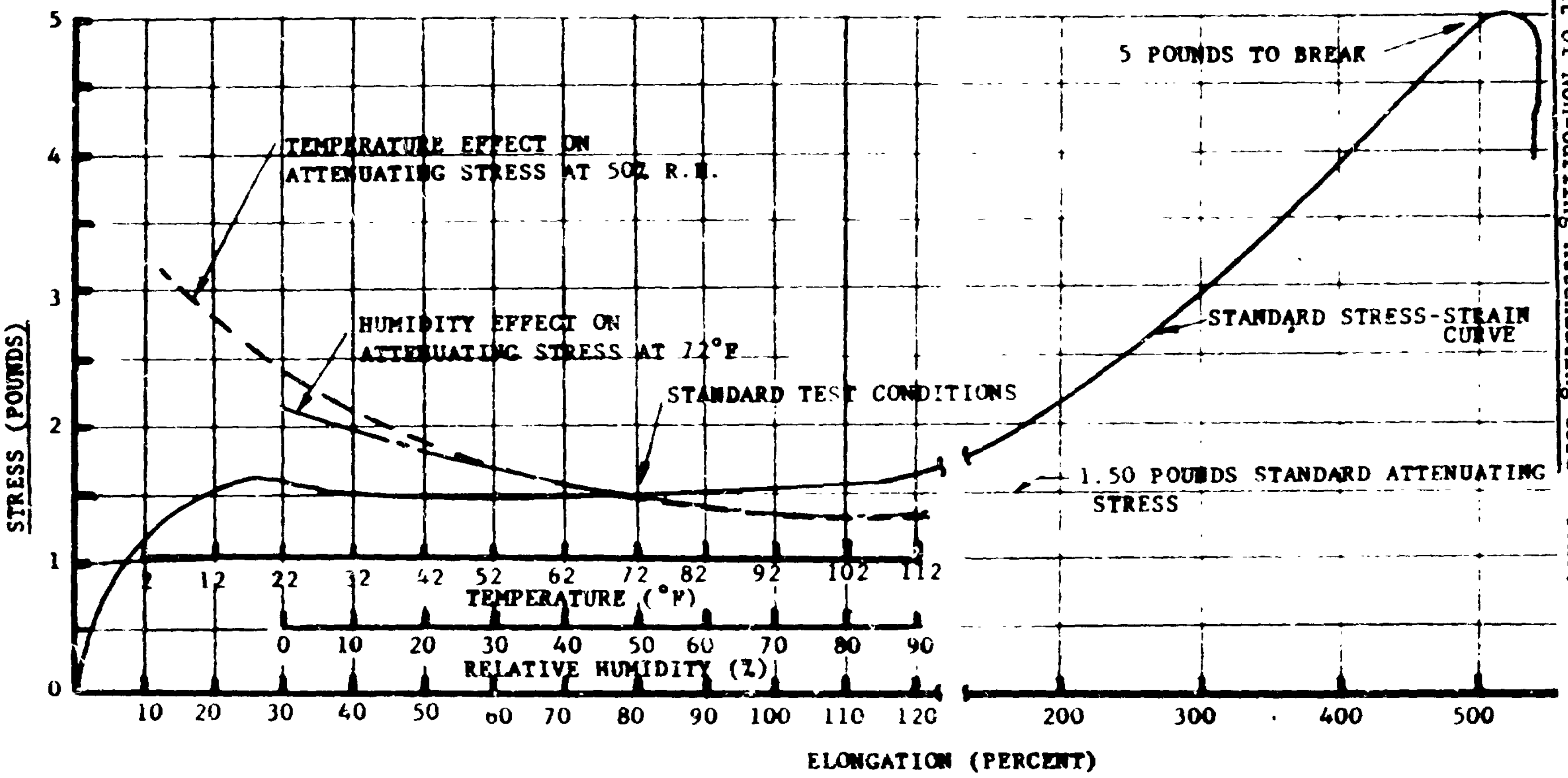


FIGURE 28

PHYSICAL CHARACTERISTICS OF 3 PLY-840 DENIER NYLON ATTENUATING CORD

4.3.2 Development of Static Load Capability (cont'd)

cord was selected because of its slight strength advantage over fully drawn nylon and its higher cord modulus.

4.3.3 Properties of Cover Fabric

The major factors of importance in the selection of the cover fabric were its durable appearance, high modulus in tension and its contact comfort. Seven nylon canvas fabrics were examined and a Wellington Sears fabric number S/SN-260R was selected as best satisfying the requirements for this program. The material was dyed and the center portion of the cover was laminated to a 0.09" thick polyurethane foam backing to increase the comfort level of the body support.

4.4 Body Support Design

With the key elements of construction for the body support determined, they were next assembled into a composite structure. The properties of each element, at ambient conditions are as noted:

Attenuating Cord -	Draw Stress	- 1.85 lbs.
	Elastic Limit (Creep)	- 1.11 lbs.
Frangible Lacing -	Load to Break	- 29.2 lbs
	Elongation at Break	- 30%
Covering Material-	Load to Break	- 696 lbs/in.
	Elongation at Break	- 28.5%

Distribution of the attenuating cords was calculated predicated on

4.4 Body Support Design (cont'd)

the active cord lengths, the specified body mass distribution of the occupant, and the cross-sectional profile of the occupant. With the aid of a computer, the energy absorbed by a pre-selected number of attenuating cords was summarized incrementally until it equalled the input energy of the occupant for each sub-section of the support platform. Each sub-section is a length of body support/occupant/couch frame which has nearly constant geometrical properties.

Based on the geometry, the changing cord lengths for each deflected position were established and the stress level determined from the stress diagram of the cord. This defined a standard curve for each sub-section. A common design deflection for the entire system was selected and the initially approximated cord distribution was adjusted to achieve an energy balance coincident with this deflection.

The results of this analysis are shown in Table 13.

4.4 Body Support Design - Cont.

TABLE 13

PRIMARY SUPPORT SYSTEM SUBDIVISION CONFIGURATION AND INPUT CHARACTERIZATION SUMMARY

SUBSECTION DESIGNATION	WINDING DESIGNATION	SECTION LENGTH (INS)	1-g WEIGHT (LBS)	LBS/INS.	INERTIA REEL PULL	LBS/IN.	16-g LOAD		20-g LOAD	
							TOTAL	LBS/IN.	TOTAL	LB/IN
Upper Head	Head	2-3/4	7.1	2.58	1	.363	114.6	41.6	143	52.0
Lower Head		4-3/4	7.1	1.495	1	.210	114.6	24.2	143	30.15
Upper Neck		1-3/4	5.0	2.855	-	-	80.0	45.7	100	57.1
Lower Neck	Torso	1-3/8	3.85	2.800	2	1.450	63.6	46.3	79	57.5
Shoulder		6	35.23	5.87	2	0.333	565.7	94.3	706.6	117.8
Torso		9.35	62.64	6.71	-	-	1002.2	107.2	1252.8	134.0
Upper Pelvic		6-5/8	49.7	7.50	6	0.906	801.2	121.0	1000	151.0
Lower Pelvic	Pelvic	3.85	22.6	6.46	-	-	361.6	93.8	452.6	117.5
Upper Calf	Calf	1-1/2	11.09	7.37	-	-	176.3	117.7	221.4	147.5
Middle Calf		8-7/8	9.5	1.07	-	-	152	17.1	190.0	21.4
Lower Calf	Foot	2-3/8	2.44	1.028	2	.843	41.0	17.2	50.8	21.4
Foot		3	9.86	3.287	4	1.333	161.8	53.9	201.2	67.1

4.5 Procedure for Calculating Filament Wound Energy Absorbing Cord Distribution

The filament wound couch is designed to support the variable weight of an astronaut with a compensating cord distribution pattern. Mathematically, the energy absorbed by the cords at a compromised deflection is made equal incrementally with the impacting (potential) energy of the astronaut over the entire length of his body. The energy absorbed by the cords is expressed as:

$$E_c = N_c \left(\frac{S_i + S_{ii}}{2}\right)(l_{ii} - l_i) \qquad (1)$$

where N_c = number of cords per inch in the section of couch under consideration

l_i = cord length at the start of an increment of deflection in feet

l_{ii} = cord length at the end of the increment of deflection in feet

S_i, S_{ii} = cord stress at increments of length l_i and l_{ii} respectively in lbs. read from stress-strain curve of cord.

The input or impacting energy of the astronaut's body is expressed as:

$$E_b = M\,(h_f + \Delta \cdot q) \qquad (2)$$

where M = mass in lbs. per inch along body of the section under consideration.

h_f = equivalent free falling height of body in feet based on velocity at moment of impact.

4.5 Procedure for Calculating Filament Wound Energy Absorbing Cord Distribution - Cont.

Δ = preselected deflection increment in feet chosen to summarize the energies involved.

q = number of increments involved for the cord length l_{ii}.

To calculate the cord distribution for a couch, the latter is divided into sections which support reasonably uniform portions of the body as regards weight distribution and shape. A rough estimate of the cords/inch required is then obtained by the formula

$$N_c = \frac{M}{2\ S_d} \qquad (3)$$

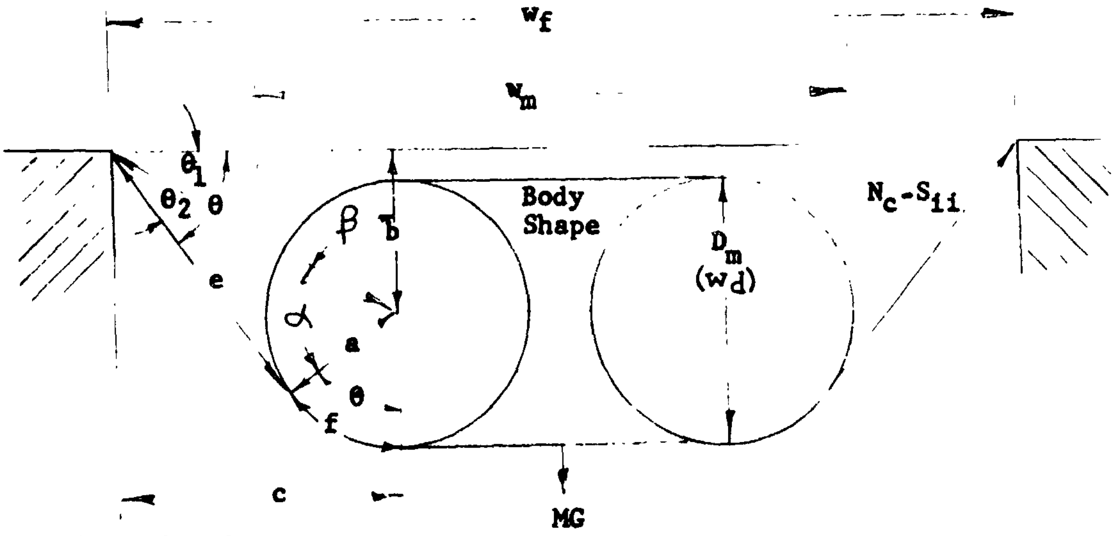
where S_d is the inherent stable draw stress of the cord used. With the supporting configuration (which will be discussed later), the approximated N_c, M, a selected Δ and the restraint cord's stress-strain diagram established; E_c and E_b are summarized with a computer for each couch section until the former exceeds the latter by several increments of deflection. Numerous variables are simultaneously printed out including the cord support angle, θ, l_{ii}, Δ.q, $\frac{l_{ii} - l}{l}$ or % cord elongation, S_{ii} and the g-load being experienced.

At this time, the total deflection at the point where E_c equals E_b and the associated g-force for all the couch sections are tabulated and a single deflection is selected for the system which will best satisfy the original design specifications. By interpolation a new N_c (cords/inch) for each section is now determined and the

4.5 Procedure for Calculating Filament Wound Energy Absorbing Cord Distribution- Cont.

energy absorbed in the cords and g-loadings are corrected by multiplying each by the ratio $\frac{N_c \text{ (interpolated)}}{N_c \text{ (initially approximated)}}$. Based on these corrected values, the position of energy balance and anticipated g-loading is again determined. These corrected N_c and g-loading values are used to fabricate and appraise the couch system.

The supporting configuration as mentioned in the summary above is concerned with the variable restraint cord support angle θ and cord length l, l_i or l_{ii} as they are related to the variable deflection, $\Delta \cdot q$, body shape and couch width dimensions. This is shown by the sketch below.



From the above

$$l_{ii} = 2 \cdot e + 2 \cdot f + w_m - w_d \tag{4}$$

$$\Delta \cdot q = a + b \tag{5}$$

$\Delta \cdot q$ is arbitrarily selected and l_{ii} is determined. w_f is given

4.5 Procedure for Calculating Filament Wound Energy Absorbing Cord Distribution - Cont.

and w_m and D_m are approximated to achieve the best match possible with the body shape - over each section into which it is divided. All angles are recorded in radians.

Solving for l_{ii} in equation (4)

$$l = \sqrt{d^2 - a^2}$$

$$d = \sqrt{b^2 + c^2}$$

$$b = \Delta \cdot q - a$$

$$a = D_m/2$$

$$c = \frac{w_f - w_m}{2} + a$$

Also

$$f = a \cdot \theta$$

$$\theta = \pi - (\alpha + \beta)$$

$$\alpha = \sin^{-1} \frac{e}{d}$$

$$\beta = \sin^{-1} \frac{c}{d} \text{ or } (\pi - \sin^{-1} \frac{c}{d}) \text{ if b is negative}$$

After solving for l_{ii} over the series of $\Delta \cdot q$'s (for each couch section) the percentage cord elongations are calculated from the formula

$$\text{strain (in \%)} = \frac{l_{ii} - l}{l} \qquad (6)$$

Applying this value to the stress-strain diagram for the restraint

4.5 Procedure for Calculating Filament Wound Energy Absorbing Cord Distribution - Cont.

cord produces a cord stress, S_{ii}, for each l_{ii} calculated. The g-loading for every increment of Δq can now be calculated by the relationships:

$$MG = 2 \sin \theta \, S_{ii}$$

which can be transposed into

$$G = \frac{2 \sin \theta \, S_{ii}}{M} \tag{7}$$

The support angle θ is simply $\theta_1 + \theta_2$ or by substitution

$$\theta = \pi - \left(\sin^{-1} \frac{e}{d} + \sin^{-1} \frac{c}{d}\right) \tag{8}$$

The sample print out computer calculation, Table 14, is for the upper pelvic section of the couch with conditions as stated. M_1 is the assigned mass/inch including both body and suit weights and M_2 (a constant) is the inertial reel pull.

Finally, the computer calculations were refined as follows:

a. The deflection at zero cord stress for any initially stated condition is automatically interpreted and fed into the calculation.

b. The effect of the inertial reel pull is woven into the computer solutions.

c. A formula was developed for the stress curve by which the variable stress S_{ii} is automatically fed into the calculations.

4.5 Procedure for Calculating Filament Wound Energy Absorbing Cord Distribution Cont.

TABLE 14

SAMPLE COMPUTER PRINT-OUT CALCULATION

Load Limits 06541 17766
:=1 W_f W_b W_d h_p M_1 M_2 N_c (approximated)
:=20.5 13.5 10.25 168. 7.5 .906 51
:=2.05 (zero stress $\Delta \cdot q$)

$\Delta \cdot q$	θ	$\ell_{ii}{}^1$	% Elong	S_{ii}	G	E_c	E_b
2.05	0.25	21.00	0.00	0.00	0.12	0.00	1275.38
2.30	0.28	21.14	0.63	0.10	0.28	0.35	1277.25
2.55	0.32	21.28	1.33	0.22	0.82	1.58	1279.12
2.80	0.35	21.45	2.11	0.35	1.51	3.96	1281.00
3.05	0.38	21.63	2.95	0.49	2.36	7.79	1282.87
3.30	0.41	21.82	3.87	0.62	3.28	13.28	1284.75
3.55	0.44	22.03	4.86	0.77	4.35	20.64	1286.63
3.80	0.48	22.25	5.91	0.92	5.59	30.16	1288.50
4.05	0.51	22.48	7.04	1.00	6.50	41.71	1290.37
4.30	0.54	22.73	8.22	1.09	7.44	54.99	1292.25
4.55	0.57	22.99	9.47	1.17	8.46	70.11	1294.12
4.80	0.60	23.27	10.78	1.24	9.35	87.03	1296.00
5.05	0.63	23.56	12.15	1.28	10.13	105.51	1297.87
6.05	0.74	24.82	18.17	1.45	13.18	193.63	1305.37
7.05	0.84	26.24	24.93	1.50	15.05	300.49	1312.87
8.05	0.92	27.78	32.28	1.50	16.17	418.63	1320.37
9.05	1.00	29.43	40.09	1.50	17.03	544.16	1327.88
10.05	1.06	31.14	48.26	1.50	17.69	675.35	1335.37
11.05	1.11	32.91	56.69	1.50	18.19	810.86	1342.87
12.05	1.16	34.73	65.33	1.50	18.57	949.65	1350.37
13.05	1.20	36.57	74.12	1.50	18.86	1090.97	1357.87
14.05	1.23	38.45	83.04	1.50	19.09	1234.25	1365.37
15.05	1.26	40.34	92.05	1.50	19.28	1379.06	1372.87
*STOP	0 at 06540						

4.5 Procedure for Calculating Filament Wound Energy Absorbing Cord Distribution - Cont.

d. The lateral spring in the couch frame was related to the loading on the couch and can be fed into the calculations. Determination of the inline movement of the couch frame was not taken into consideration in these calculations. This refinement would have the effect of reducing the system deflection noticeably and the design cords/inch only slightly.

The secondary support lacing is calculated in the following manner:

1. The elongation at break of the secondary lacing and cover is estimated.
2. This is added to the primary cord length established for a 1-g loading. (The zero stress length of the secondary winding is made equal to the 1-g loaded length of the primary winding and thus does not affect the 1-g loaded deflection of the latter.)
3. The maximum instantaneous load carrying capacity of the primary cords at the length established by Step 2 is determined from the computer calculation of the system.
4. The maximum secondary breaking load tolerable is established by subtracting the instantaneous primary capability from 20-g.

4.5 Procedure for Calculating Filament Wound Energy Absorbing Cord Distribution - Cont.

5. The stress in the primary cord for the load established by Step 3 is determined from the computer calculations. (This always turned out to be greater than 60% of cords inherent draw or attenuating stress.)

6. The load carrying capacity of the primary system at breakout of the secondary, assuming that the cord's stress has decayed to 60% of its inherent draw stress, is determined by multiplying the maximum load carrying capacity (Step 3) by the ratio (60% cord draw stress ÷ stress from Step 5).

7. The minimum breaking load capacity of the secondary winding is found by subtracting the results of Step 6 from 16-g.

8. The maximum and minimum breaking stresses in the secondary winding relating to the maximum and minimum loads (Steps 4 and 7) are determined by multiplying the latter by the sine of the support angle as established by the computer calculations. (This is the angle existing at the breakout of the secondary lacing as summarized in Step 2.)

9. The design breaking stress for the secondary lacing is taken as the average of the maximum and minimum calculated by Step 8.

10. The grommet spacing for the secondary lacing is determined

4.5 Procedure for Calculating Filament Wound Energy Absorbing Cord Distribution - Cont.

from the formula:

$$G_s \cdot S_d = 2 \cdot C_b \cos \alpha \qquad (9)$$

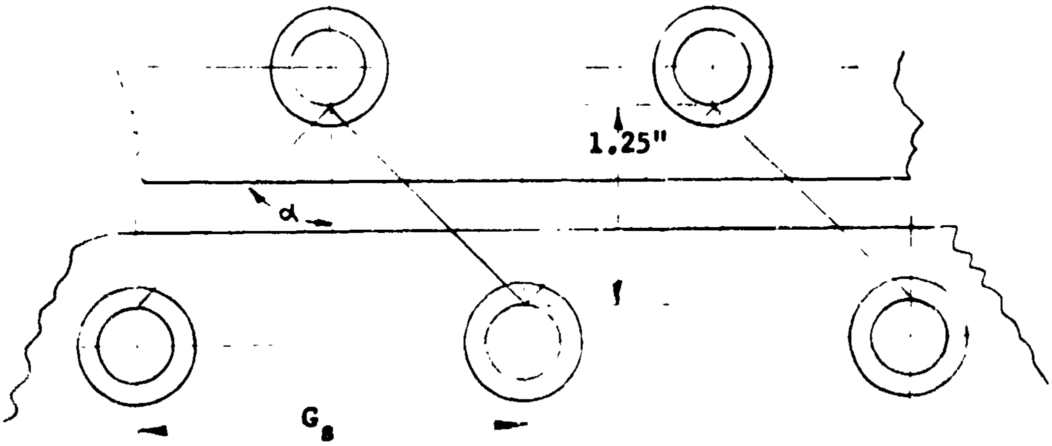
where G_s is grommet spacing

S_d is the lacing design stress

C_b is the cord breaking strength and

$\alpha = \tan^{-1} \frac{S_p/2}{1.25}$

as shown by the sketch:



4.6 Restraint Harness Design

The restraint system is anchored to the spacecraft via inertia reels one for the legs and two restraining the torso. The torso reels are positioned such that during an eyeballs-out force, a force parallel to the occupant's torso is created, the lap belt introducing an upward force, the shoulder belt generating an equal down force. By locating the reels in this manner, a degree of up and down stability is introduced during the eyeballs-out rebound.

To prevent the occupant from "submarining" under the lap belt, a webbing arrangement was devised whereby the belt across the lap passes through a second webbing which goes around the ischial tuberosities, similar to a parachute harness lift web. The geometry of the arrangement precludes the necessity of crotch straps, requiring only a single conventional lap belt buckle to be fastened. The shoulder straps are held in position by the occupant's shoulder and buckle into the lap belt.

The restraint webbing is mechanically fastened to the body support by screws passing through grommets in the body support. Fittings are secured to the screws on the side away from occupant and are connected to the inertia reel webbing by parachute riser fittings. Incorporated into the reel webbing are lengths of braided undrawn nylon cords which at a 6-g to 10-g eyeballs-out force draw, limiting the force received by the occupant. The cords are assembled as shown in Figure 29.

4.6 Restraint Harness Design - Cont.

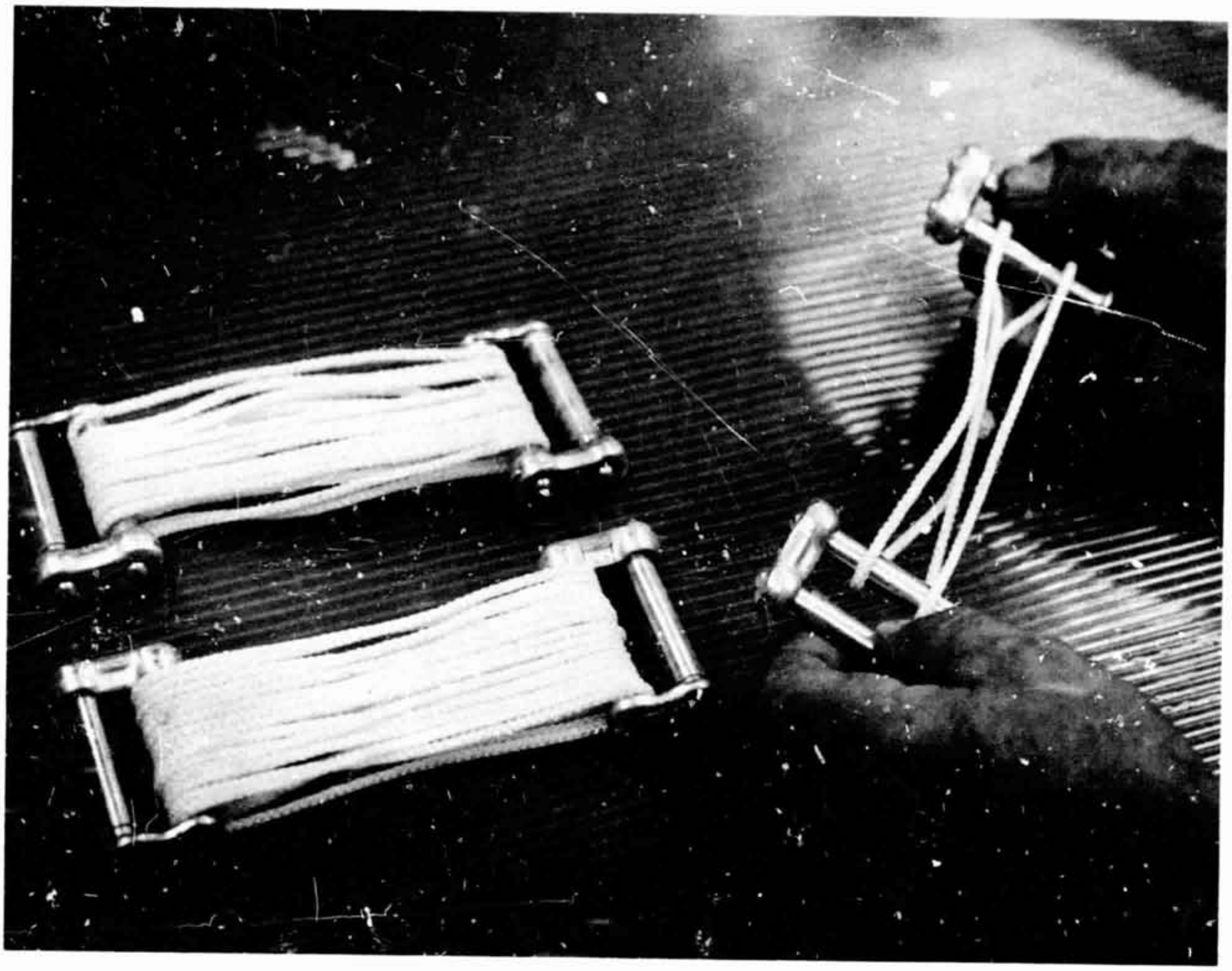


FIGURE 29

ATTENUATING LINKS OF THE RESTRAINT SYSTEM

4.7 Headrest and Leg Separator Design

A leg separator has been provided to prevent the legs and knees of the occupant from being forced together during the attenuating deflection. Being at the apex of the "V" formed by the body support, a force tending to press the legs together is created by the support platform, which could injure the occupant. The configuration of the separator is intended to reduce this hazard.

The headrest serves the following purposes:

a. Elevates the head to natural position.

b. Continues the basic torso configuration of body support to the top of the platform, avoiding major support angle irregularities.

c. Supplies an anchor point for restraining the elastic rebound of the body support in the head region without holding onto the occupant's helmet.

Both the headrest and leg separator are vacuum formed in an impact resisting ABS gum plastic. Formed in the components are webs and gussets to provide the required rigidity. The headrest and leg separator are shown in Figure 30, assembled as part of the body support and restraint system.

4.8 Prototype Couch Frame Development Testing

The results of the Weber conducted evaluation tests, presented in Reference 10 indicate that all of the objectives of the program have been achieved but not without unanticipated difficulties.

4.8 Prototype Couch Frame Development Testing - Cont.

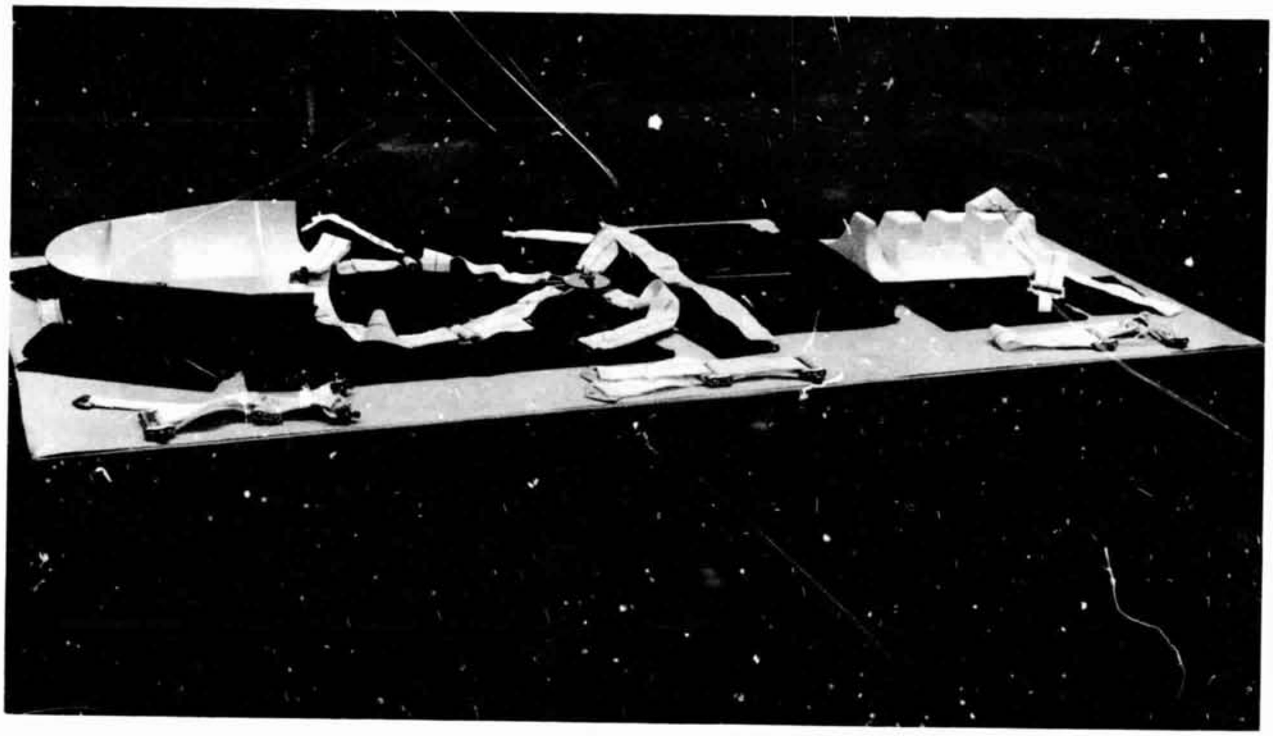


FIGURE 30

COMPLETED BODY SUPPORT ASSEMBLY

4.8 Prototype Couch Frame Development Testing (cont'd)

The initial static tests were halted due to a structural failure in the torso platform structure. Post-test analysis indicated that the body support tension angle was less than that used for the stress analysis of the couch frame. This resulted in inward bending forces on the couch frame three to four times greater than anticipated. The torso frame was subsequently redesigned to accommodate the larger forces and a new torso structure was fabricated.

The system was then installed on the static test fixture and a simulated launch load was applied to the couch net and frame through an anthropomorphic dummy. The forces were applied at a constant rate until the frangible cords ruptured at 13-g's. Data from the static tests is summarized in Table 15.

TABLE 15

STATIC TEST DATA - PROTOTYPE COUCH ASSEMBLY

LOADING	1-g	8-g	13-g*	1-g RETURN
Average Deflection	1.1	2.2	2.9	1.6
Allowable Deflection	1.5	-	3.0	1.5

* Rupture of frangible cords.

The impact test, simulating ground landing of the spacecraft, yielded an average attenuation force of 19.2-g's which is favorably less than the 20-g objective. The high speed movies indicated a uniform dummy deflection with no discernible racking or non-uniform displacement of the dummy body members.

4.8 Prototype Couch Frame Development Testing (cont'd)

The inertia reel lagged behind the initial displacement of the occupants as anticipated, but reeled in the slack webbing before the dummy was able to rebound a measurable distance. The eyeballs-out rebound forces are well below the maximum 10-g requirement. A summary of the dynamic test data is shown in Table 16.

During the vibration tests, a natural frequency of 10 cps was measured at the dummy's chest during the vibration tests. A dampening effect was recorded at the head, pelvic and leg areas of the dummy throughout the 0-60 cps frequency scan.

4.8 Prototype Couch Frame Development Testing (cont'd)

TABLE 16

DYNAMIC TEST DATA
PROTOTYPE COUCH ASSEMBLY

PARAMETER	EBI	EBO
[illegible]out		
Requirement	50-g (max)	-
Calibration Run	46.9-g	-
Test Results	33.8-g	16.7-g
Dummy Response		
Requirement	20-g	10-g (max)
Test Results (average)	19.2-g	5-g
Dummy Deflection		
Requirement	10.5 ins(max) from 1-g	
Test Results	6.1 ins(avg) from 1-g	
Velocity		
Requirement	30 FPS(max)	
Calibration	28.8 FPS	
Test Results	27.4 FPS	
Permanent Set		
Inches (avg)	0.9 (Body Support)	0.9 (Restraint Link)
Inertia Reel Take-up	3.8 ins (avg)	

4.9 NASA-MSC Supplemental Tests

A series of drop tests were performed at MSC facilities to augment the dynamic tests conducted at Weber.

Two tests were performed on the couch system. The first drop was performed to determine the low level characteristics of the system. The forces received by the dummy were higher than the input force of 9-g which is a typical response characteristic of a net or fabric type couch system for low input forces.

The second drop tested the system at the maximum anticipated impact conditions. This resulted in total structural collapse of the torso frame structure and failure of the latch mechanism which locks the leg platform in its various positions. The accelerometer traces for these tests are shown in Figures 31 and 32.

After review of the high speed movies, it was initially concluded that during the free fall drop the near zero-g force permitted the dummy to move out of position by several inches. Since the dynamic tests at Weber demonstrated that the body support does attenuate slightly below a 20-g level, the high-g forces experienced by the dummy's chest and pelvis (from the drop tower tests) suggest that the body support was "short circuited" out of the system, permitting the full impact load to be transmitted to the dummy through the couch frame.

4.9 NASA-MSC Supplemental Tests - Cont.

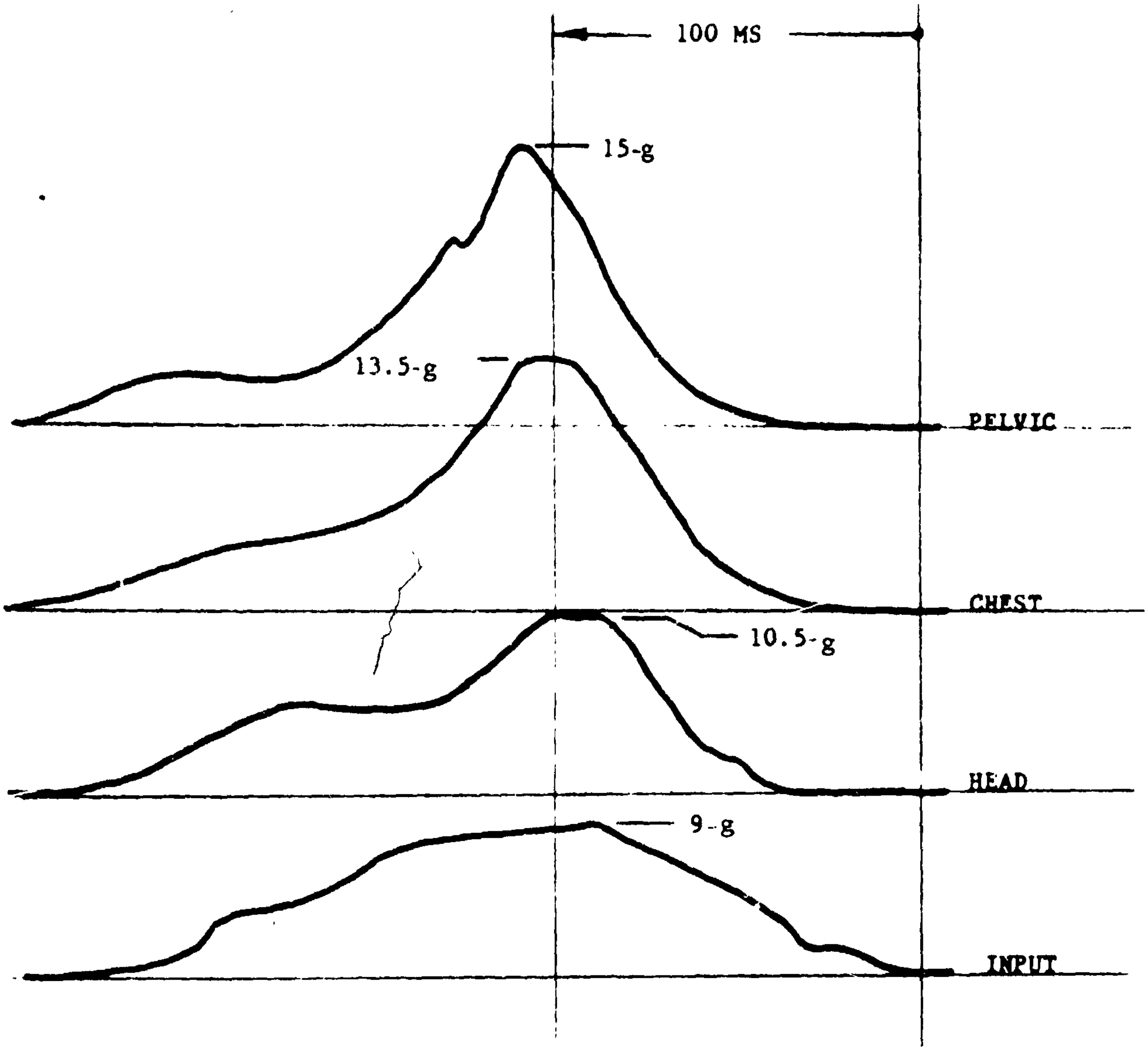


FIGURE 51

SUPPLEMENTAL DROP TEST ACCELEROMETER DATA
32.8 FPS VELOCITY CHANGE

4.9 **NASA-MSC Supplemental Tests - Cont.**

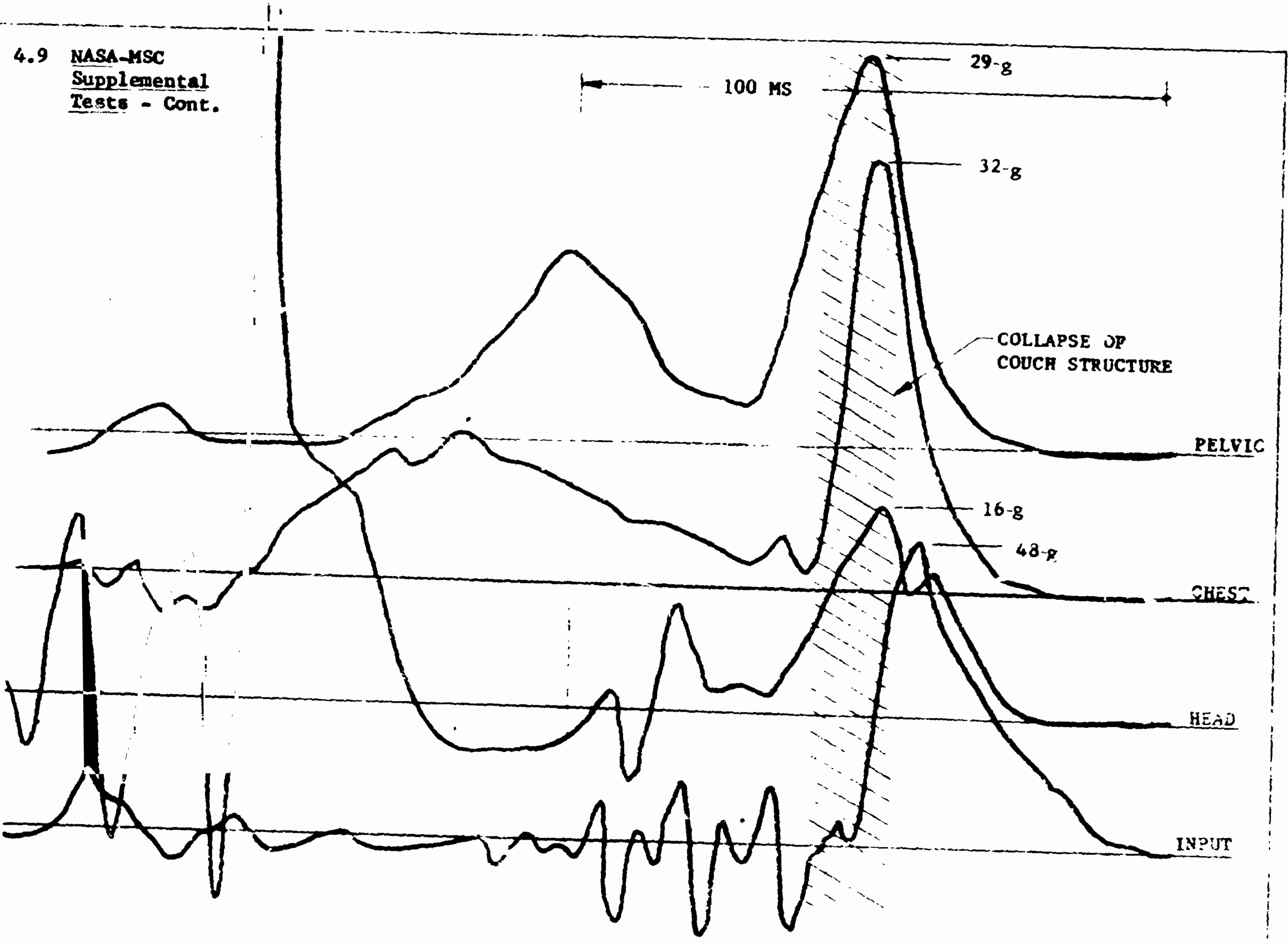


FIGURE 32 - SUPPLEMENTAL DROP TEST ACCELEROMETER DATA - 32.4 FPS VELOCITY CHANGE

4.9 NASA-MSC Supplemental Tests (cont'd)

The movies indicated that the instrumentation leads from the dummy were trapped between the couch frame and upper arm of the dummy and, as the arm came in contact with the frame, the frame yielded and finally broke symmetrically, right at the shoulder.

The fact that the peak dummy forces were very near the design ultimate force of the couch frame seemed to further substantiate localized load points instead of a load distributed by the body support. The high speed movies show the legs deflecting and stretching the fabric as desired. The movies also indicated that the leg inertia reel performed satisfactorily. (All of the reels functioned properly after the test.)

Further analysis of the movies and inspection of the couch frame indicated that the secondary failure of the leg platform latch mechanism occurred when the torso frame struck the angled braces on the test fixture and momentarily racked the lower portion of the frame such that the pivot pins were wrenched out of the locked latches. Bearing failure of the latch bores indicated no sliding of the latch which might release the pivot pin.

Subsequently, six drop tests were performed with the body supports installed on an MSC furnished "boilerplate" couch frame. These tests indicated that the high forces experienced by the dummy may not have been caused by the dummy riding on the couch frame during impact.

4.9 NASA-MSC Supplemental Tests (cont'd)

During the tests non-uniform displacement and high forces were received by the dummy. Small displacement and high acceleration forces were noted primarily in the shoulder area of the dummy. The leg section of the body support, however, functioned as designed. The results of these tests are summarized in Tables 17 and 18. The accelerometer data is presented in Figures 33 through 38.

A review of the body support design was conducted to determine if the cause of the erratic performance could be isolated. Cognizant MSC, Weber and body support supplier representatives were present.

A review and discussion of the equations and computer analysis technique used by the body support supplier to calculate the cord distribution and attenuating level of the system was conducted. There did not appear to be any obvious areas in their approach which could cause the unpredicted results attained during the drop tower tests.

4.9 NASA-MSC Supplemental Tests (cont'd)

TABLE 17

SUPPLEMENTAL NASA-MSC DROP TEST

g-FORCE DATA

DROP NO.	VELOCITY CHANGE	INPUT FORCE (g's)	DUMMY RESPONSE		
			HEAD EBI-g's	CHEST/SHOULDER EBI-g's	LEGS EBI-g's
1	33.0	8.5	13.0	14.0	-
2	31.0	13.0	20.0	24.0	-
3	30.0	17.0	28.0	27.5	-
4	30.8	26.0	39.0	30.0	33.5 (est)
5	32.0	45.0	50.0	34.0	54.0
6	33.0	43.0	42.5	51.0	30.0

NOTE: Drops 1 through 5 were successive tests performed on a single body support assembly.

4.9 NASA-MSC Supplemental Tests (cont'd)

TABLE 18

SUPPLEMENTAL NASA-MSC DROP TEST - DEFLECTION DATA

POST-DROP DEFLECT (INERTIA REELS LOCKED)	INCHES OF DEFLECTION			
	HEAD	CHEST	PELVIC	LEGS
Drops 1, 2 & 3	1.44	1.12	3.50	7.19
Drops 4 & 5	2.56	6.00	6.25	12.75
Drops 1 thru 5	4.00	7.12	9.75	19.94
Permanent Set After Drop 5 (reels released)	2.06	3.75	6.25	11.25
Drop 6	2.88	1.12	4.50	7.30
Permanent Set After Drop 6	Small	.62	Small	6.00

4.9 NASA-MSC Supplemental Tests - Cont.

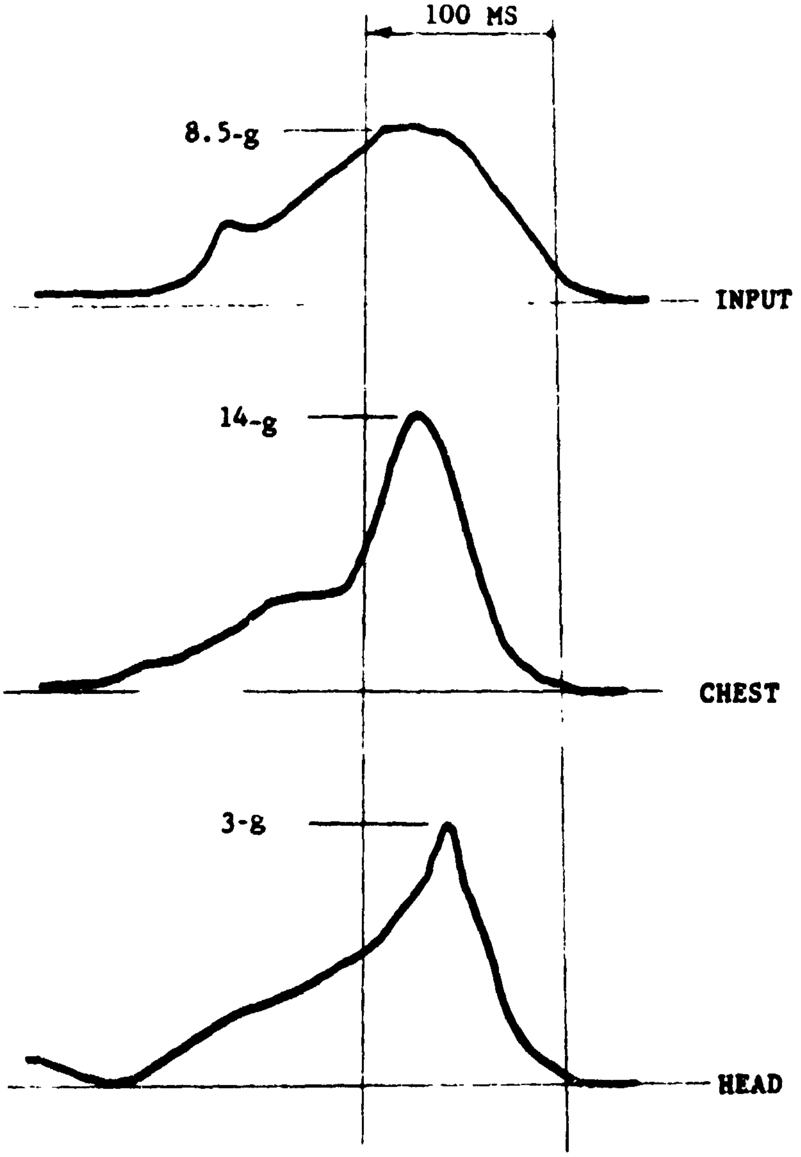


FIGURE 33

SUPPLEMENTAL DROP TEST DATA
BODY SUPPORT ASSEMBLY
33.0 FPS VELOCITY CHANGE

4.9 NASA-MSC Supplemental Tests - Cont.

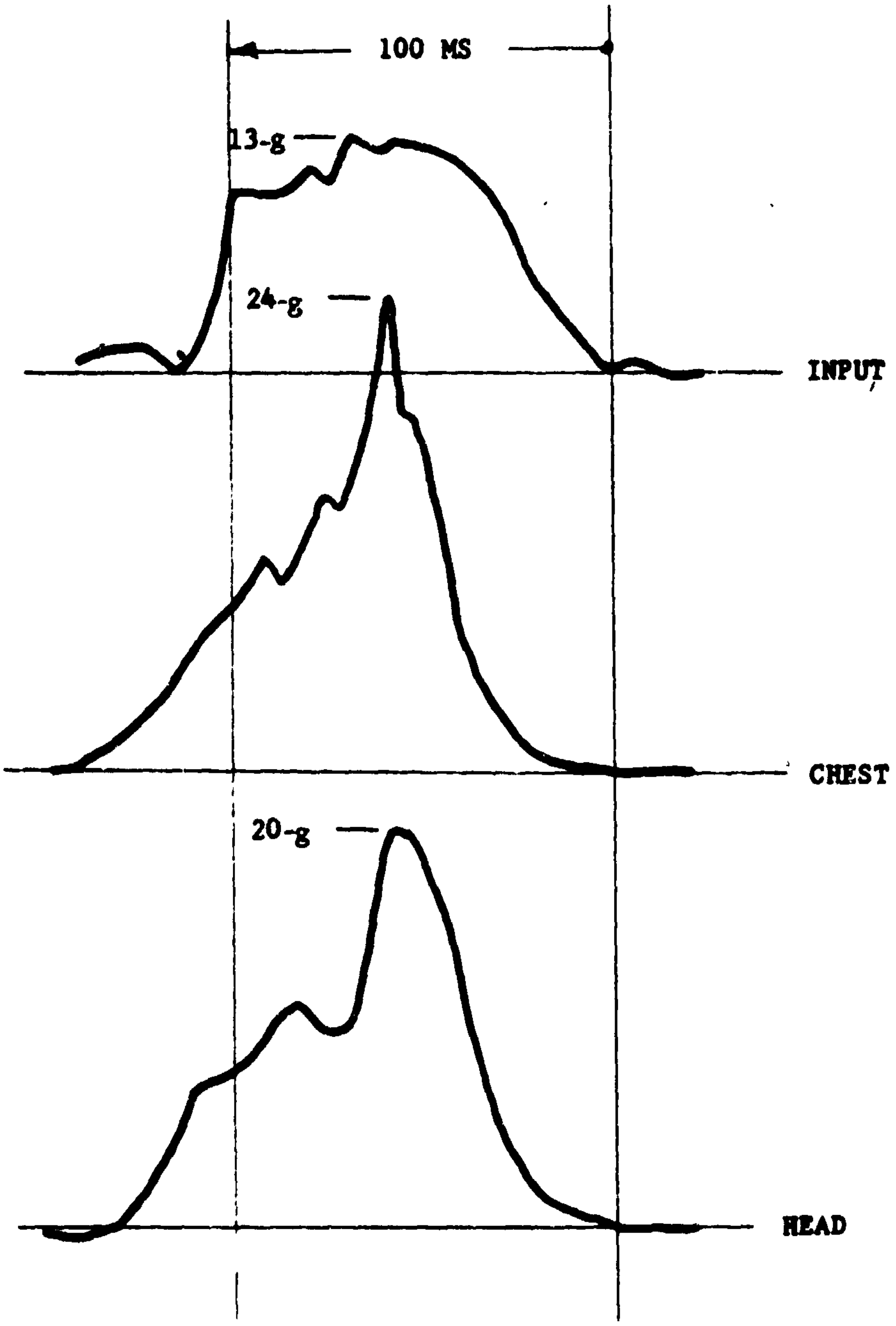


FIGURE 34

SUPPLEMENTAL DROP TEST DATA
BODY SUPPORT ASSEMBLY
31.0 FPS VELOCITY CHANGE

4.9 NASA-MSC Supplemental Tests - Cont.

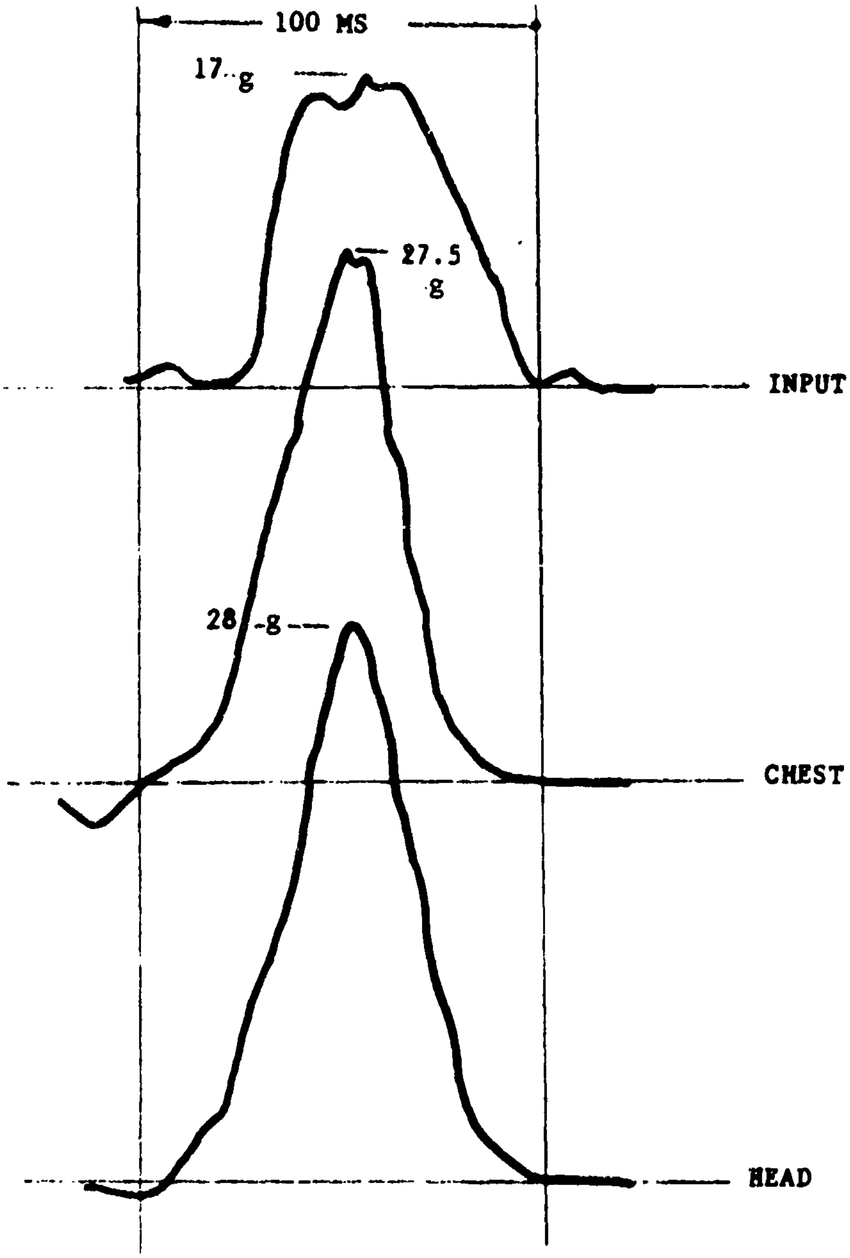


FIGURE 35

SUPPLEMENTAL DROP TEST DATA
BODY SUPPORT ASSEMBLY
30.0 FPS VELOCITY CHANGE

4.9 NASA-MSC Supplemental Tests - Cont.

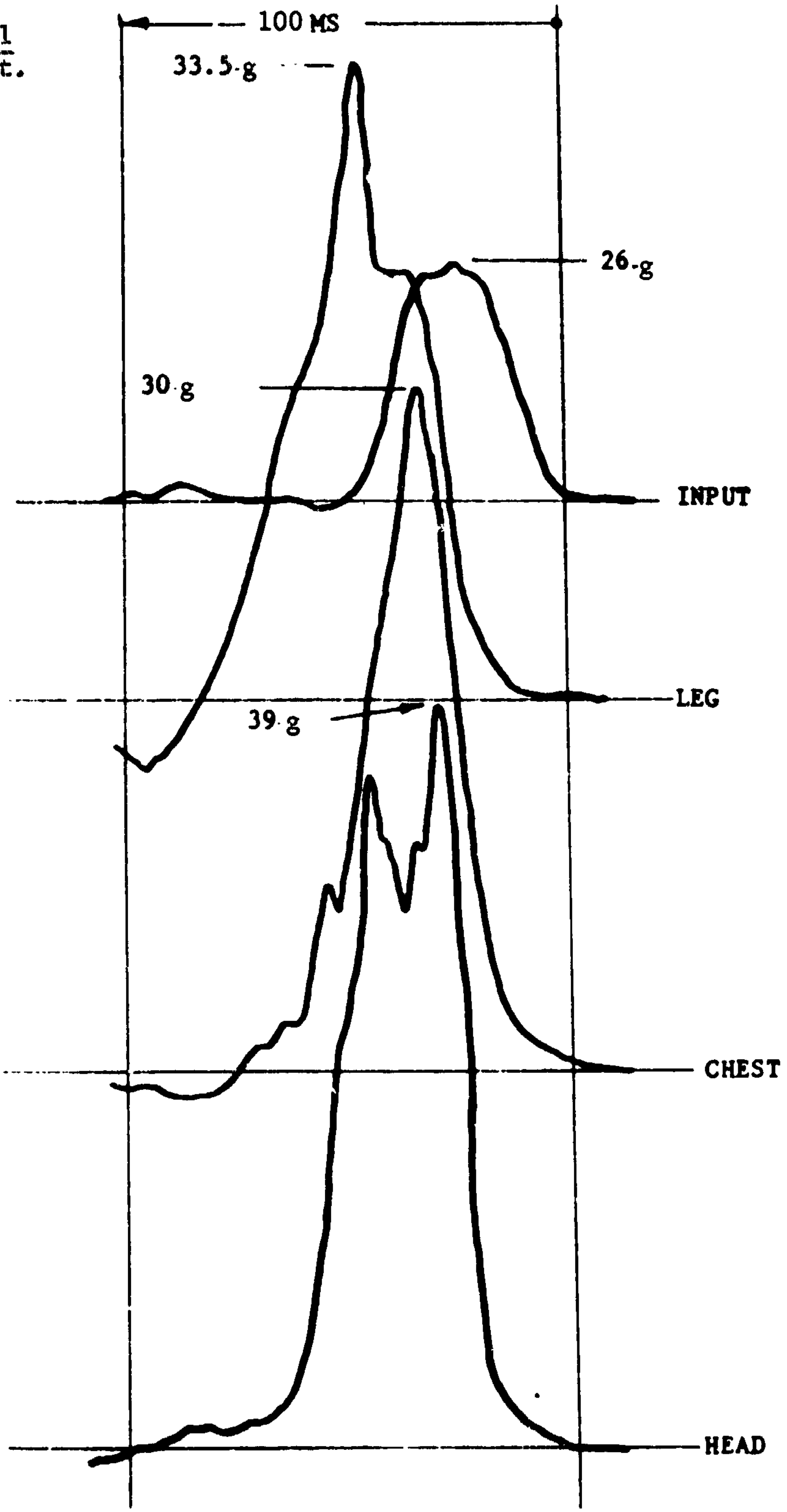


FIGURE 36

SUPPLEMENTAL DROP TEST DATA
BODY SUPPORT DATA
30.8 FPS VELOCITY CHANGE

4.9 **NASA-MSC Supplemental Tests - Cont.**

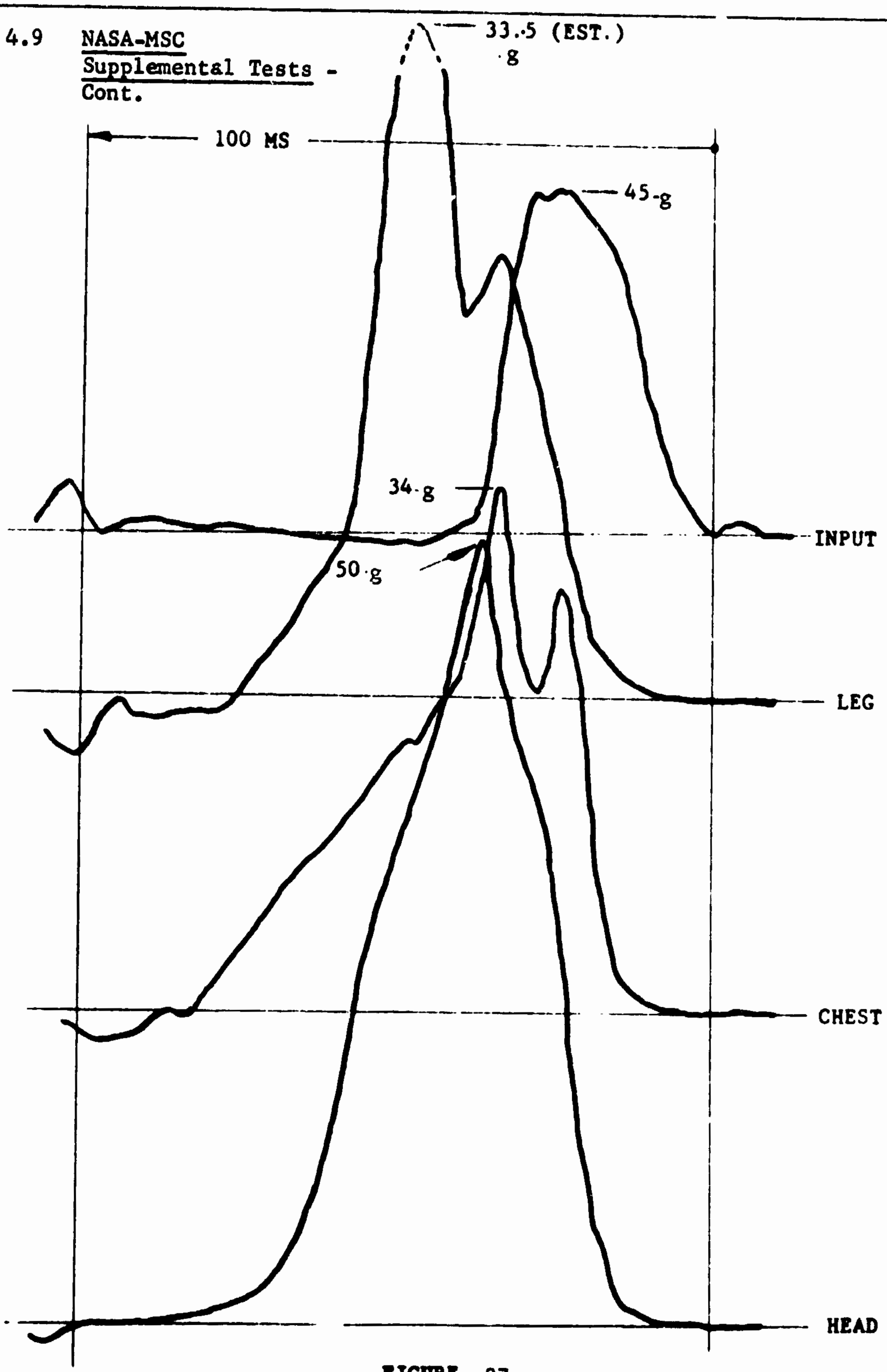


FIGURE 37

SUPPLEMENTAL DROP TEST DATA
BODY SUPPORT ASSEMBLY - 32.0 FPS VELOCITY CHANGE

4.9 NASA-MSC Supplemental Tests - Cont.

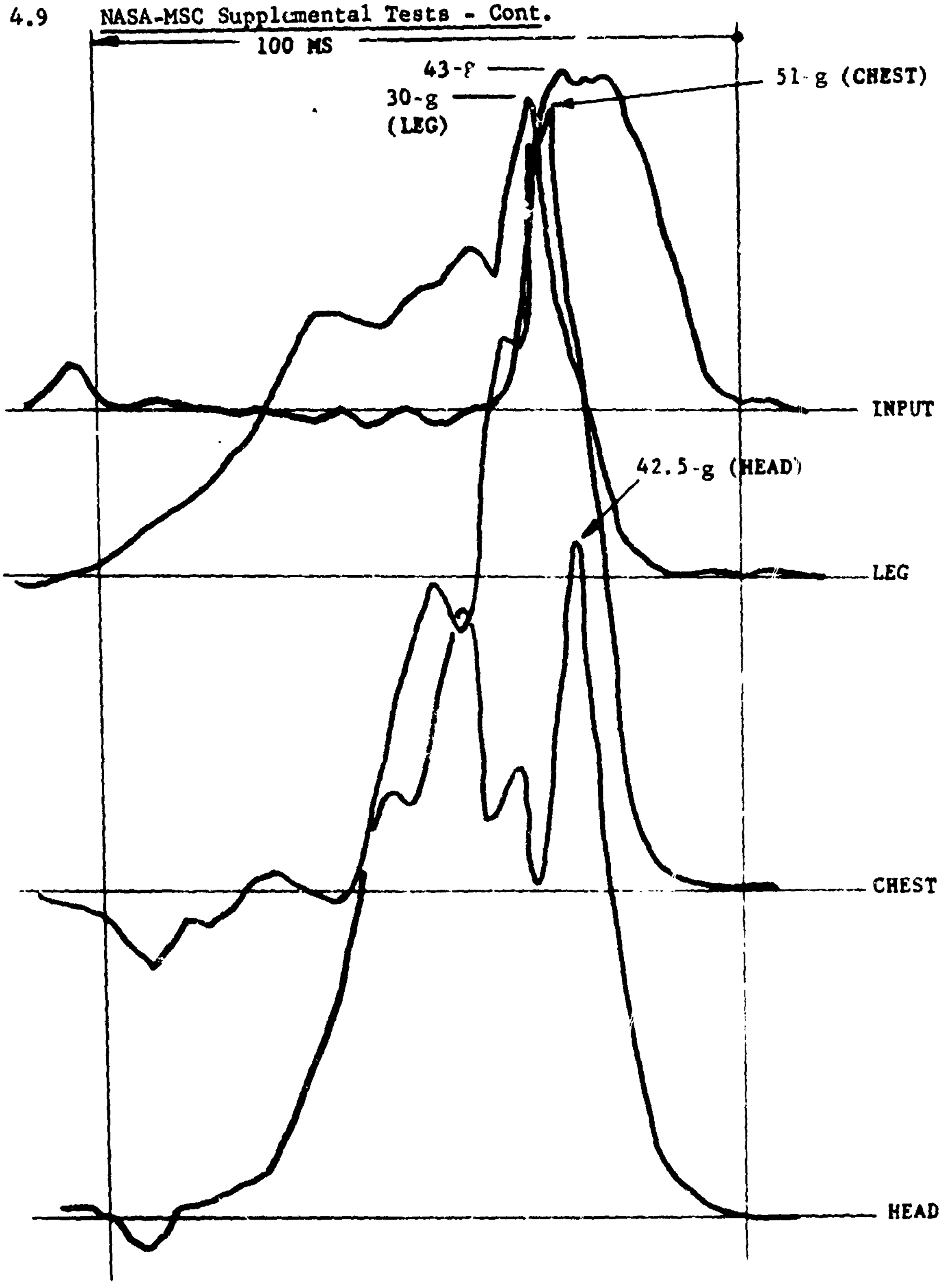


FIGURE 38

SUPPLEMENTAL DROP TEST DATA
BODY SUPPORT ASSEMBLY - 33.0 FPS VELOCITY CHANGE

4.9 NASA-MSC Supplemental Tests (cont'd)

A general discussion relating to all known variables was held and the possible effect of these variables on the dynamic performance of the system was estimated with the following results:

Possible Causes	Estimated Possible Effect on Attenuation Level
Weight differences in dummy from spec.	4-g
Weight differences of equipment from spec. (pressure suit, helmet, boots, etc)	4-g
Dummy position	0 to 5-g
Ambient conditions (Temp., etc.)	0-g
Couch frame deflection	0 to (-1)-g
Fiber Unknowns	2-g
Dummy Cross-sectional shape, change from Assumed Configuration	0 to 2-g

The sum of the possible variables could increase the attenuating level by 17-g's. This reflects a maximum accumulation of the worst possible conditions. An increase of 30-g's however, was recorded during the MSC drop tower tests where a level of 20-g's was desired, but a 50-g level was attained in the shoulder area.

The only remaining major cause that could be seen was a friction force created by the cover flap. This flap is provided on the body support to protect the frangible lacing cords. It overlaps the centerpiece of the body support cover and is sewn to the outer portion which is attached to the couch frame. When the dummy is

4.9 NASA-MSC Supplemental Tests (cont'd)

positioned on the couch, its shoulders bear directly on the flap, pressing it onto the center portion of the body support cover. It is theorized that during the initial input force, the cover flap is "pinched" between the shoulders of the dummy and the body support cover, relieving the frangible cords and the attenuating cords of a substantial amount of force.

A friction test, using materials similar to those used in the support system was performed. The materials were assembled and statically loaded such that it simulated the loading condition of the cover flap trapped between the body support cover layer and the suited dummy. It was found that the force required to move the center layer of material simulating the cover flap slightly exceeded the applied force. This test appears to substantiate the analysis which indicated the major single factor increasing the system attenuation level is the friction caused by the cover flap.

Analysis of the supplemental tests concluded the Phase I effort of the program and served as the basis for determining the modifications and additional tests to be accomplished during Phase II.

5.0 PHASE II - FABRICATION AND TEST

All work accomplished during Phase I of the program was approved and the detailed Phase II design modification task, as provided in the contract was outlined.

Phase II of the program was provided to incorporate modifications to the couch frame and body support resulting from the Phase I tests, to perform additional tests as may be required and to design and fabricate a three-man couch system capable of being installed in the Apollo Command Module.

A sufficient quantity of body supports and restraint assemblies to permit evaluation of the three couch system by MSC were provided.

5.1 Three Couch System

Authorization to proceed with the design and fabrication of the couch suspension structure concurrently with the fabrication and testing of the prototype couch assembly was received.

The structure as designed and constructed consists of rigid struts to position the three couches in the Command Module. Four X-X struts attach to two couch support beams which are positioned in the plane of the Z-Z and Y-Y axes.

5.1 Three Couch System - Cont.

The largest of the two beams is located below the buttocks of the crew member and supports most of the spacecraft launch and landing loads; the balance of the load is sustained by the upper beam. The buttock, or tail beam, is a continuous structure which, in addition to containing two attachment points and latching mechanism for each couch, also provides a track which guides the left couch into the docking position. Large pads on either end of the beam transmit compression loads into the Y-Y bearing plates of the Apollo Command Module. A second beam is located above the heads of the crew members. The single upper attach point of each couch and the second pair of X-X struts are pinned to this beam. The tail and head beams are interconnected by a light stabilizing beam to which Z-Z struts are attached. The suspension structure is shown in Figure 39.

Figure 40 shows the completed Apollo three man couch system. The weight of the three man uni-directional netting type couch system, utilizing actual component weight is as follows:

5.1 Three Couch System - Cont.

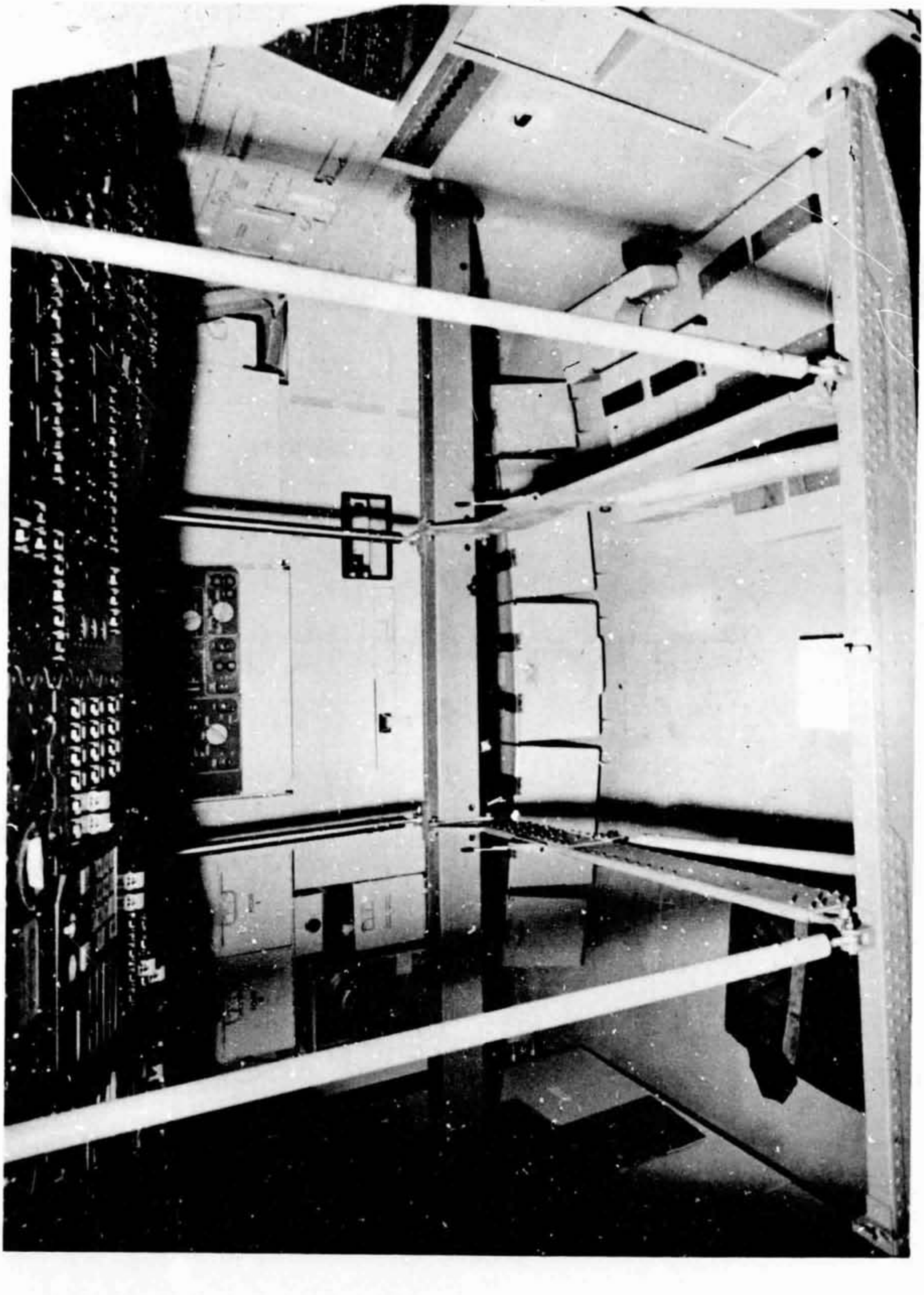


FIGURE 39 - SUSPENSION STRUCTURE FOR THREE COUCH SYSTEM

5.1 Three Couch System - Cont.

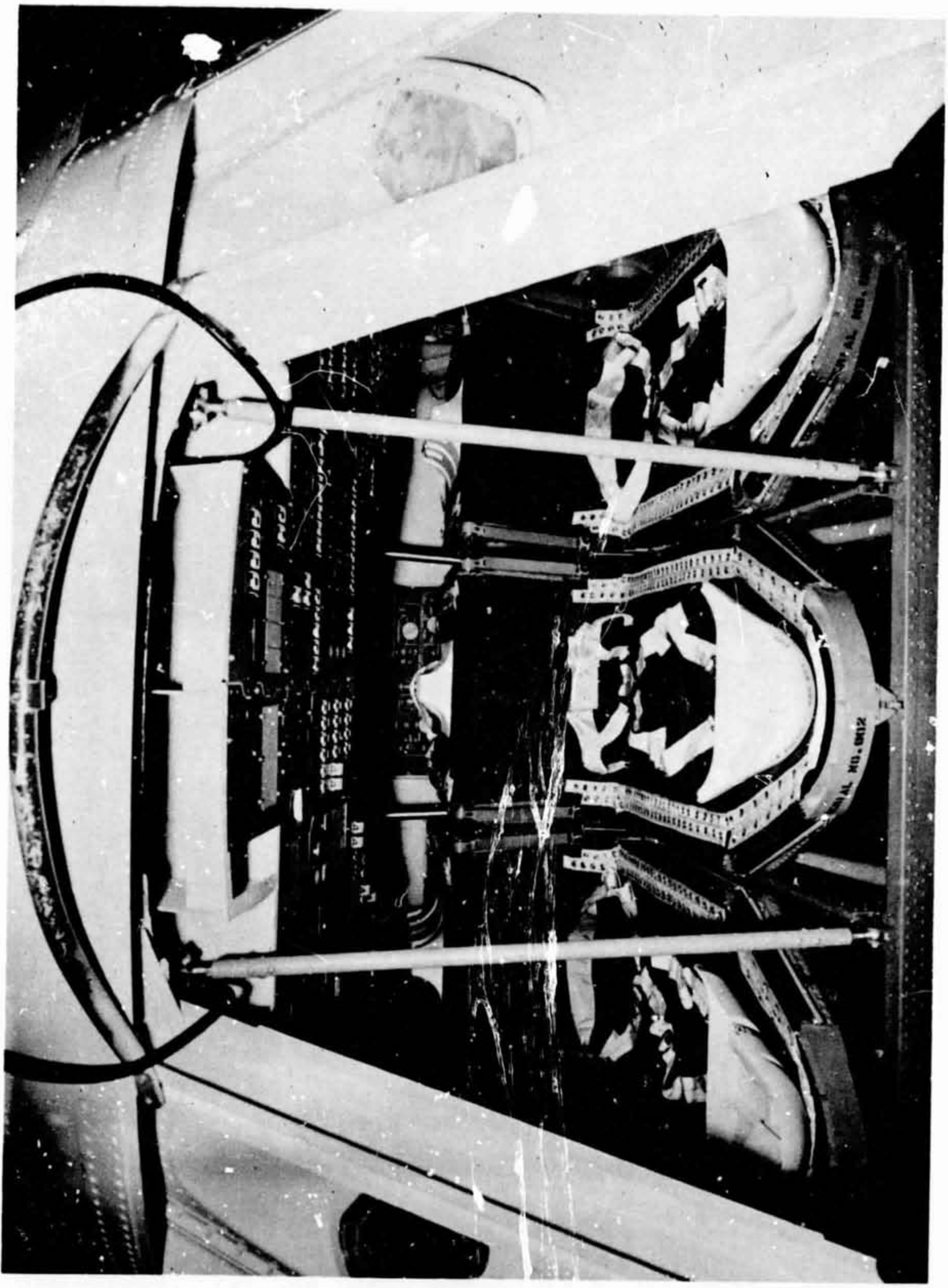


FIGURE 40 - APOLLO NET COUCH SYSTEM

5.1 Three Couch System - Cont.

Assembly		Weber Drawing
Couch Structure Assy	23.5	SK-10343 (Basic)
Body Support Assy	9.0	SK-10344-401
Inertia Reel & Controls Instl.	4.1	SK-10365 (Basic)
Total Couch Assembly	36.6 lbs.	
Three Couch Assemblies	109.8	
Suspension Struct. Assy	55.0	SK-10342-201
S/C Controller Fittings	.4	SK-10376 (Basic)
Total System Weight	165.2 lbs.	SK-10342-401

5.2 Phase II Couch Modification and Tests

Prior to fabricating the balance of the hardware and software items additional testing were performed at MSC to substantiate the structural adequacy of the couch frame and the attenuation properties of the body support during the maximum impact conditions.

Only minimum design changes to assure structural integrity of the couch structure were made. As a result of the previous couch frame collapse the torso frame structure was strengthened, primarily by eliminating a structural splice in the beam section at the shoulder area.

5.2 Phase II Couch Modification and Tests - Cont.

Three body support assemblies were fabricated, salvaging usable components from previously tested assemblies. Two body supports were fabricated in the same configuration as previously tested except extra attenuating cords were provided. The final cord distribution was to be determined after a series of draw force tests were performed at the Systems Test Branch. A third support of a slightly different construction was also provided by the supplier.

5.3 Additional Prototype Couch Testing

To determine the number of required attenuating cords, samples were taken from the test specimen and tested on an Instron at the Systems Test Branch facility just prior to each test. These results were compared to the draw force of cords brought by body support supplier directly from his laboratory. In all cord samples, draw started at 1.6 to 1.7 pounds. It was then decided to take several samples and subject them to different environments for 24 hours to determine what effect it may have on draw force. Samples were subjected to vacuum at room temperature, $160^{\circ}F$ at room atmosphere, and standard laboratory environmental conditions of 70° - $72^{\circ}F$ at 41% to 46% relative humidity.

5.3 Additional Prototype Couch Testing - Cont.

The results of these tests appear to suggest that the moisture content contained in the fibers as being the factor having the greatest single effect on the draw force level. The results of these tests are tabulated in Table 19.

Based on the cord draw force test results, the cord distribution for the first drop was calculated on a 1.8 draw force per cord. Review of the elongation requirements for the various cords in the body support at maximum deflection indicated that for most of the support, 80% to 120% elongation is required. In the shoulder area, however, elongation on the order of 160% to 200% is required due to restricted effective cord length.

Since the supplementary body support tests indicated this area of support might be too strong, and the just performed draw tests indicated an increase of draw force to 2.2. lbs. at 200% elongation, it was decided to compensate for this increase in the shoulder-upper arm area.

Additionally, previous laboratory tests indicated that when several cords are drawn over a hard edge, such as the

5.3 Additional Prototype Couch Testing - Cont.

TABLE 19

ATTENUATING CORD DRAW FORCE TESTS

CORD SAMPLE	DRAW FORCE AND % ELONGATION AT START OF DRAW	DRAW FORCE @ 100% ELONGATION	DRAW FORCE @200% ELONGATION
Test Results at Supplier's Laboratory 72° 50% R.H.	2.3 lb. to 2.9 lb.	-	-
From Couch at MSC for 4 days	1.5 lb. @ 15%	1.5 lb.	2.2 lb.
From Supplier's Spool, Uncontrolled Environment	1.8 lb. @ 20%	1.8 lb.	2.2 lb.
From Spool after 24 Hr @ 70°F, 42% to 46% R.H.	1.8 lb. @ 20%	1.8 lb.	2.3 lb.
24 hr. soak in Vacuum @ 70°F	2.1 lb. @ 20%	2.1 lb.	2.1 lb.
24 hr. soak in oven at 170° ± 10°F	2.2 lb. @ 15%	2.2 lb.	2.2 lb.

NOTE: All cords broke between 5.5 to 6.5 lbs. force @ 400% to 600% elongation.

5.3 Additional Prototype Couch Testing - Cont.

inside corner of the couch frame, the draw force increases 15% to 20%. This factor was also taken into account in determining the final number of cords to be used in the body support.

With these factors taken into consideration, the final cord distribution in the shoulder area was based on a 2.4 pound draw force, the remainder of the body support predicated on a 2.15 pound draw force.

For the first test body support, S/N 005, was installed on the MSC "boilerplate" couch, its secondary cover flaps taped back out from under the dummy and tested with a Weber furnished dummy, which was ballasted to the specification weight distribution.

The accelerometer data and post-test deflection data from this test is presented in Table 20 as Drop number 1. The results indicate good attenuation levels, somewhat below the 20-g requirements and a large amount of nearly uniform permanent set (plastic deformation) in the attenuating cords. However, large spike g-forces were recorded by the dummy accelerometers. This was determined to be unacceptable.

5.3 Additional Prototype Couch Testing - Cont.

TABLE 20

PROTOTYPE COUCH DROP TESTS

		DROP 1	DROP 2	DROP 3
	Velocity Change (FPS)	31.4	32.0	32.0
	Input Force (g)	41.0	44.2	44.0
Dummy Response (g)	Head	17.4	19.2	18.5
	Chest	18.0	16.0	18.0
	Leg	19.7	19.2	20.0
Dummy Displacement (post test-reels locked) Inches	Head	5.81	10.00	9.13
	Chest	5.50	8.81	9.25
	Pelvic	4.62	7.75	7.88
	Legs	5.00	5.25	6.00
Dynamic Displacement of Dummy Inches	Head	8.81	12.00	11.13
	Chest	8.50	10.81	11.25
	Pelvic	7.62	9.75	9.88
	Legs	8.00	7.75	8.00
Permanent Displacement due to stretch of body support	Head	5.94	9.87	9.38
	Chest	5.25	8.62	8.50
	Pelvic	4.25	7.75	7.88
	Legs	2.00	5.00	5.75
Inertia Reel Take Up Inches	Shoulder	6.50	9.25	9.88
	Lap	6.25	8.62	8.63
	Leg	5.00	6.25	6.25

5.3 Additional Prototype Couch Testing - Cont.

It was subsequently decided to utilize an experimental body support, designed and fabricated by the body support supplier to conduct an additional test with the system installed on the boilerplate couch. The cord distribution of this support, S/N 007, was the same as the previous test except in the shoulder area where, due to the special cord assembly, the draw force was based on the same 2.15 pound draw as the remainder of the platform.

The secondary support lacing, which provides the 16-g static load capability of the body support, was removed to see if it was the cause of the sharp acceleration forces recorded on the first drop. The protective cover flaps were also held back so they would not influence the attenuation of the dummy. An additional accelerometer was added to the boilerplate couch frame in the shoulder area to determine if there was any significant amplification or attenuation of the input force by the frame. The results of this test, Drop Test 2 shown in Table 20, indicate the elimination of the large spike force noted in the first drop with similar attenuation levels and a significant increase in dummy displacement.

5.3 Additional Prototype Couch Testing - Cont.

The body support used for this test employed a diagonal cord winding in the shoulder area to effect a longer unrestricted cord length, reducing the required percentage of cord elongation from 160% to 200% down to 80% to 120% elongation, similar to the rest of the body support attenuating cords. This, it was believed, might provide a more uniform attenuation level in the shoulder area.

The configuration resulted from the fact that the effective cord length in the shoulder area with the straight winding construction of the standard support assembly results in restricted effective cord length due to the width of the shoulders and it was believed, might partially contribute to the low displacement and high g-forces recorded in the shoulder area during the body support evaluation tests performed earlier. It was evident from this second drop test that this type of construction does improve the attenuation characteristics, but allowance for the change in draw force due to the higher percentage of elongation does also. Allowance for higher draw force results in a simpler construction method and is much easier to fabricate.

5.3 Additional Prototype Couch Testing - Cont.

The third drop was performed with the Weber couch frame, SK 10343-403 S/N 001, body support SK 10344-401 S/N 006, and the Weber dummy. The cord distribution of the first drop was used, the protective flaps were positioned clear of the dummy and the secondary lacing cords were removed.

The results of this test, similar to those of Drop 2, were considered excellent. The data shown as Drop 3 in Table 20 indicates this test resulted in the best dummy response of the three tests performed.

The accelerometer traces for this series of tests are shown on Figures 41, 42 and 43. Figure 44 shows the dummy in the attenuated position after Drop test 3.

In all tests it was noted that a small peak is recorded on the dummy accelerometers after decay of the input acceleration. This peak, most noticeable in the dummy chest accelerometer, is of interest.

The method of rigging the dummy may produce this effect since the knees of the dummy were tied to its upper arms to control the leg angle during the freefall phase of the drop. During the impact phase, the legs may have tried to lift the dummy's shoulders. This was not noticeable in the high speed photography.

5.3 Additional Prototype Couch Testing - Cont.

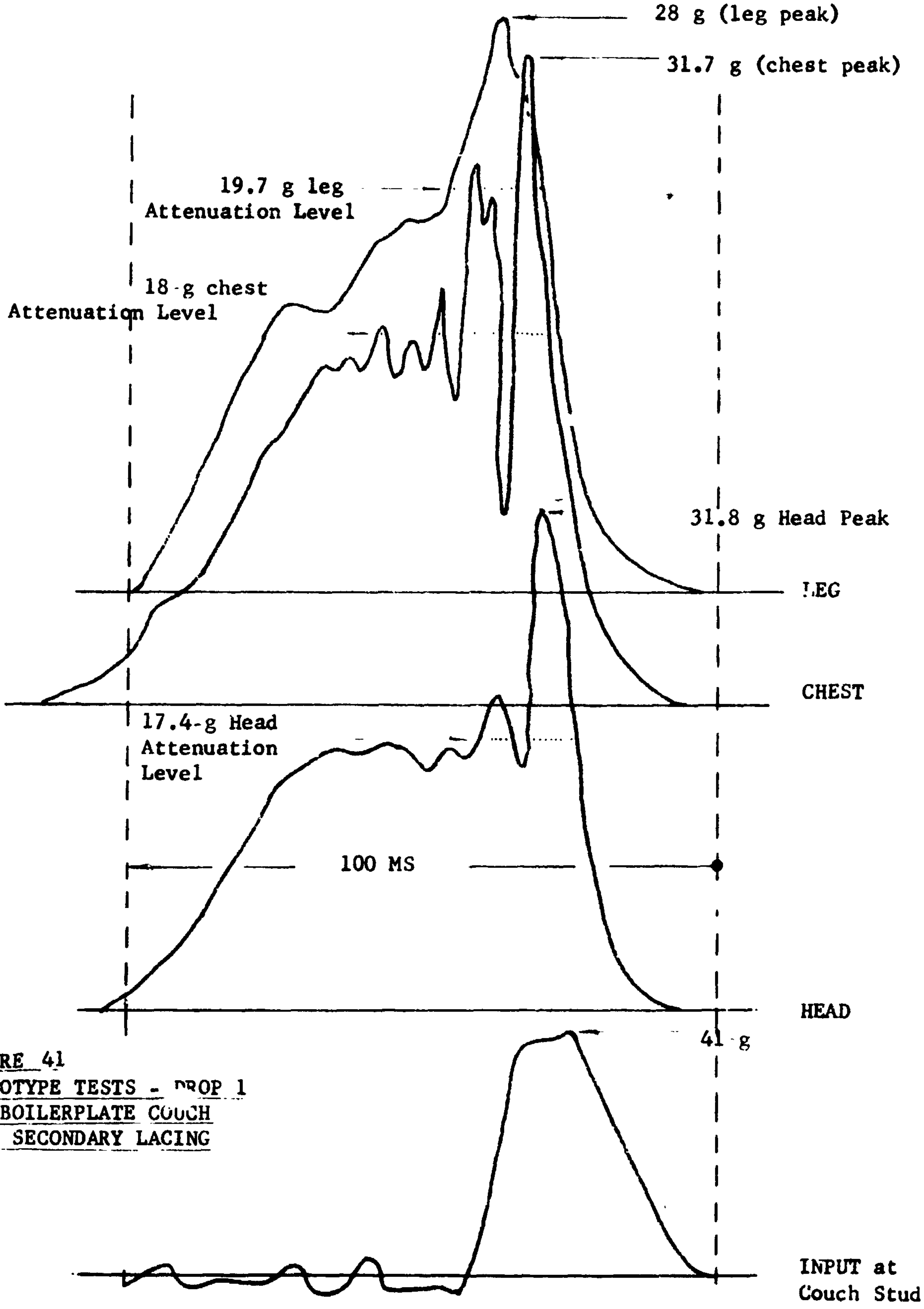


FIGURE 41
PROTOTYPE TESTS - DROP 1
MSC BOILERPLATE COUCH
WITH SECONDARY LACING

5.3 Additional Prototype Couch Testing - Cont.

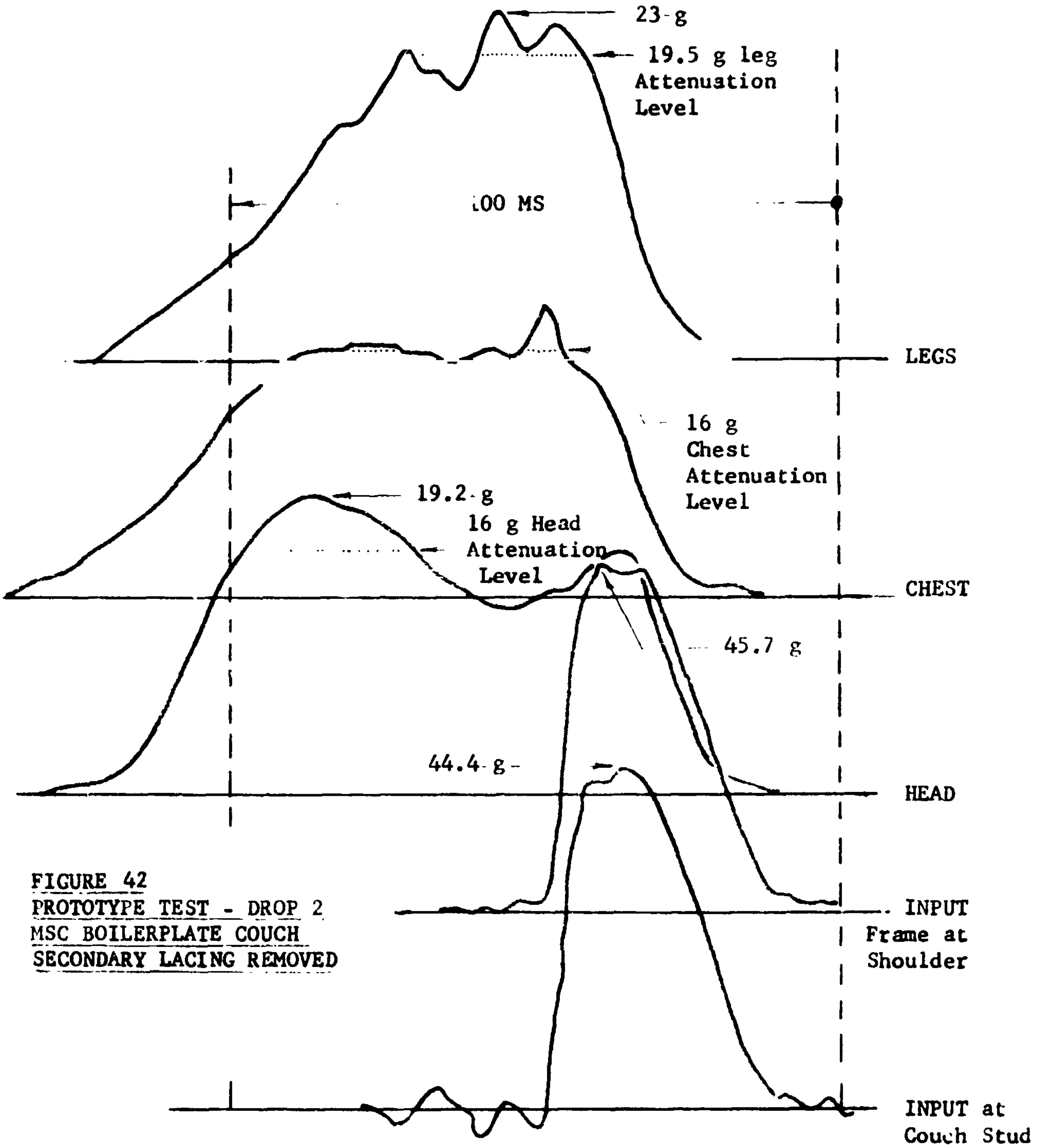


FIGURE 42
PROTOTYPE TEST - DROP 2
MSC BOILERPLATE COUCH
SECONDARY LACING REMOVED

5.3 Additional Prototype Couch Testing - Cont.

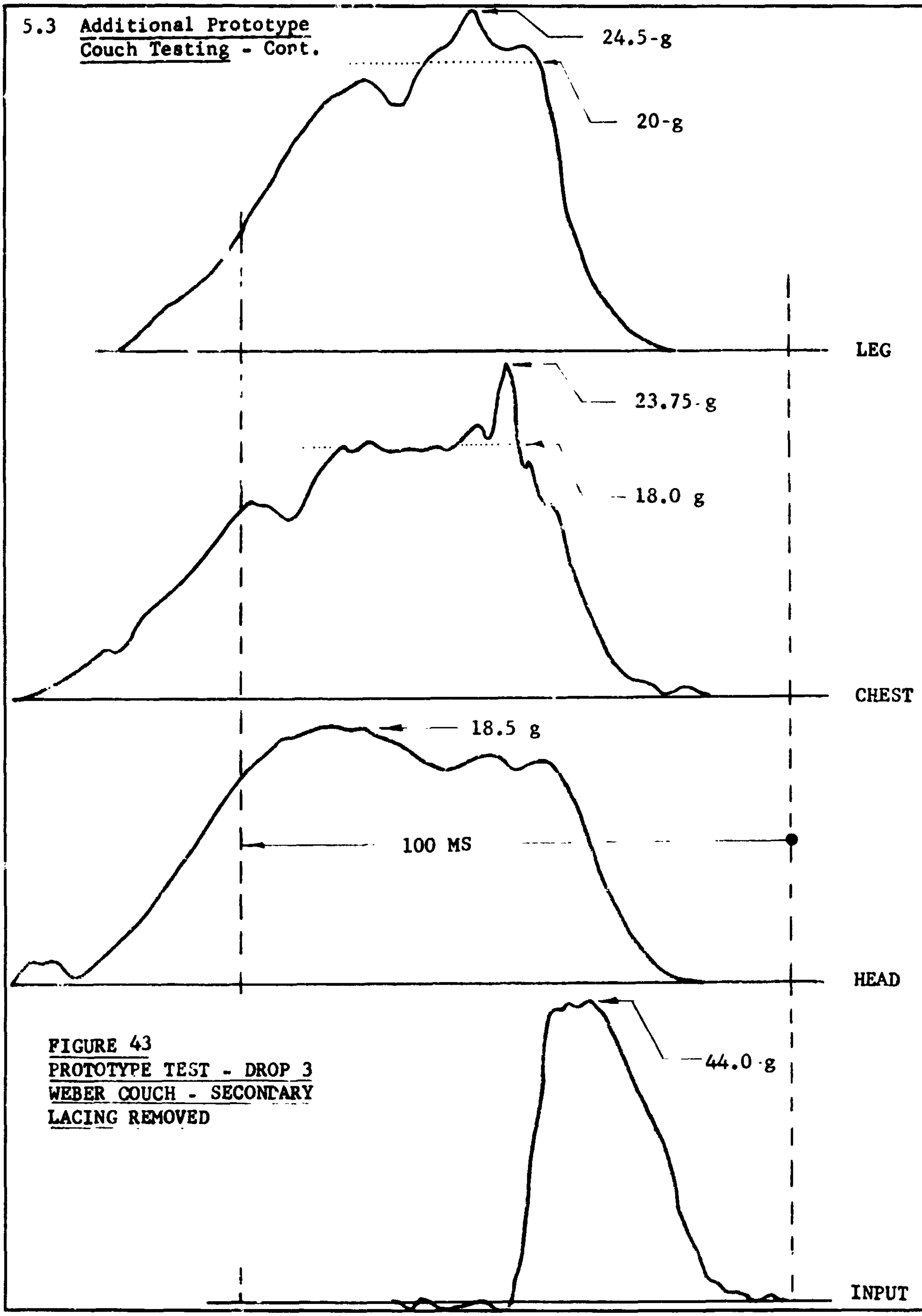


FIGURE 43
PROTOTYPE TEST - DROP 3
WEBER COUCH - SECONDARY
LACING REMOVED

5.3 Additional Prototype Couch Testing - Cont.

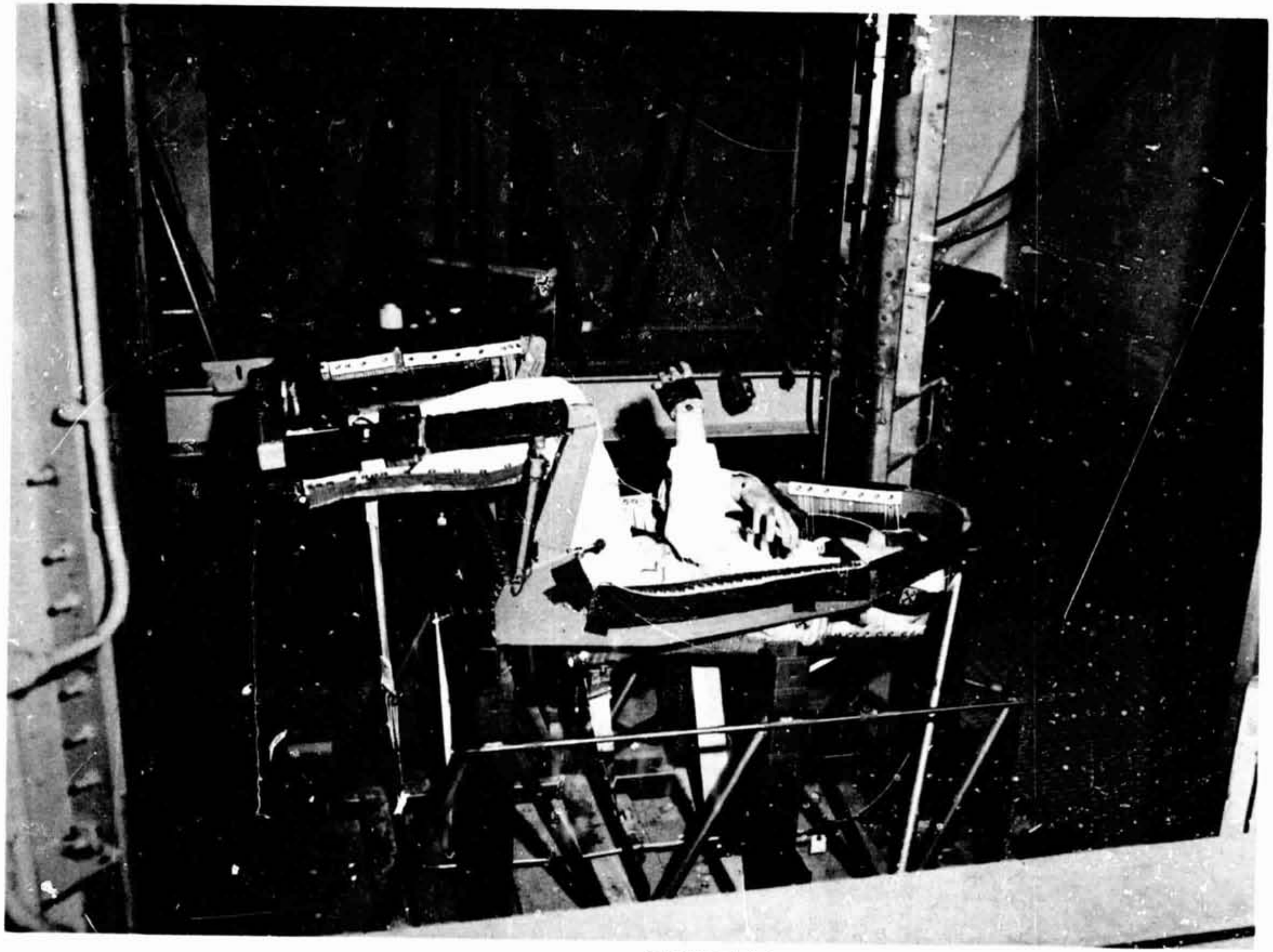


FIGURE 44
DROP TEST NO. 3 - DUMMY IN ATTENUATED POSITION

5.3 Additional Prototype Couch Testing - Cont.

It is believed that this peak is more likely caused by the release of elastic energy stored in the couch framework due to frame deflections during the input pulse of the impact force. Disregarding the high peaks recorded by the dummy during the first drop, there are three lower magnitude peaks/plateaus recorded by all dummy accelerometers for each drop. These occur at nearly constant intervals of 10 to 15 milliseconds.

When compared to the relative rigidity of each section of the couch framework, a correlation of rigidity and smoothness of the dummy's response can be seen. Large undulating excursions of the leg accelerometer with the relatively non-rigid leg platform structure, a sharp, initial spike and small excursions of the more rigid torso platform structure. The head frame structure is subject to less inward deflections than the rest of the structure, but due to the structural change in direction is subject to larger torsional deflections which could effect the smoother attenuating response. Only additional testing could substantiate this theory of elastic response.

5.3 Additional Prototype Couch Testing - Cont.

The conclusion of this test series established the following facts:

A. The primary, attenuating cord system of the body support is functioning as designed.

B. The secondary cover protective flap was the cause of the unpredictable and non-uniform dummy response experienced during the two previous test series at MSC.

C. The frangible cord of the secondary support system produces unacceptably high, though temporary, g-forces on the dummy.

D. The temperature-age history of the attenuating material has a negligible effect on its attenuating properties. Changes in moisture content, however, result in significant changes.

E. The prototype couch frame, designed and fabricated by Weber, is satisfactory when the body support functions properly.

F. Item (B) in conjunction with Item (C) was the probable cause of the structural failure of the couch frame during the first test series at MSC.

5.3 Additional Prototype Couch Testing - Cont.

Based on the evaluation of the prototype couch at MSC, Weber was directed to incorporate the following changes to the body support:

A. Eliminate the protective cover flap of the secondary support system.

B. Determine a method to effect smooth transition of impact forces from the secondary support to the primary support system without reducing the static load bearing capability of the body support.

C. Provide method to adjust the length of each lap belt half.

D. Reduce the height of the headrest stiffening web in the area of the occupant's neck and trim the length of the headrest so it will not impair the comfort of the occupant.

The couch structure was found satisfactory as delivered for test.

5.4 Body Support Section Tests

Additional body support tests were laid out to investigate the possibilities of eliminating the attenuation spike curve in further platform designs. A 12 inch specimen, representing a typical body torso section was selected for the test program which consisted of both low speed load application and high speed impact (drop) tests.

An 88.5 pound drop weight with a profile simulating the lower torso of the occupant was used. The test specimens consisted of a primary attenuating support and superimposed, various secondary lacing supports. Lacing cords used are described in Table 21.

The primary attenuating cords calculated for the weight and cross section of the simulating torso section resulted in:

51 ends/inch based on a draw stress of 1.5#
36 ends/inch based on a draw stress of 2.1#
32 ends/inch based on a draw stress of 2.4#

Thirty-six cords per inch were used for two drop tests. Thirty-two however, more nearly produced the attenuating characteristics desired and were used for the remainder of the tests conducted.

5.4 **Body Support Section Tests - Cont.**

TABLE 21

LACING CORD CHARACTERISTICS

Specimen No.	Material	Construction	Twist	Treatment	Strength # to Break	Strength Gr/Denier	% Elong. @ Break
1	Dacron Type 52	2/1100	13/13	None	32.75	6.74	18.0
2	Dacron Type 52	2/1100	13/13	Estane Coated	32.75	6.74	19.5
3	Dacron Type 52	2/1100	13/13	Covered with Braided Nylon	33.375	6.97	20.0
4	Dacron Type 68	2/840	13/13	None	29.55	7.97	16.25
5	Dacron Type 52	4/1100	13/13	Estane Coated	50.00	5.05	
6	Nylon Type 714	2/840	13/13	None	30.5	8.23	27.25
7	Nylon Type 6	1/1260	1/0	None	25.0	9.0	18.75
8	Rayon High Tenacity	1/2200	1/0	None	21.87	4.51	9.25
9	Rayon Low Tenacity	6/900	13/13	None	19.7*	2.02	20.5*
10	PVA (Vinal)	2/1200	13/13	None	35.87	6.76	14.87

* Based on test of single untwisted 900 denier yarn.

5.4 Body Support Section Tests - Cont.

Calculations of the secondary lacing, predicated on using a double lay up of Specimen 4 above and an effective breaking strength of 18 lbs. (in accordance with the practice followed prior to this test series) established a grommet spacing of .857". This facilitates 28 single cord crossovers in a 12" section or 56 assuming the doubled lacing. The design strength of 18 lbs. is only 61% of the cords' normal tensile strength.

Because tests suggested that the elongation at break of a lacing or the secondary support structure is greater than originally anticipated, a revised input became available and new calculations of the secondary lacing for the test section were made. These disclosed that a lacing only 82% as strong as originally calculated will best satisfy the design specifications.

Results of the drop tests conducted are summarized in Table 22. A grommet spacing established by the first described calculations was incorporated into the samples tested. The input parameters were 30-32 fps velocity, 40-45-g's.

5.4 **Body Support Section Tests - Cont.**

TABLE 22

BODY SUPPORT SECTION DROP TESTS

Drop Test No.	No. of Primary Cords	Lacing Cord Material	No. of Lacing Cross-overs	Theoretical① Lacing Strength	Percentage of Initial Calculated Requirement	Percentage of Revised Calculated Requirement	Recorded -g's Input	Recorded -g's Spike	Recorded -g's Plateau
1	36	None (Control)[2]	-	-	-	-	48	16	11
2	36	Dacron Type 68	41	57.3	73.2	91.8	40	25[3]	21
3	32	Vinal PVA	38	64.5	82.4	103.3	41	21.5	19.5
4	32	Dacron Type 68	46	64.3	82.1	103.0	40	20[3]	19
5	32	H. Ten. Rayon	62	64.2	82.0	102.8	41	27	19.5
6	32	Nylon Type 6[4]	54	63.9	81.6	102.2	43	25	19
7	32	Dacron Type 52[5]	41	63.6	81.3	101.8	44	22.8[3]	19
8	32	Dacron Type	41	63.6	81.3	101.8	44	20.7[3]	18
9	32	Low Ten. Rayon	68	63.6	81.3	101.8	42	27	19
10	32	Dacron Type 52[6]	40	63.1	80.7	101.1	42	22.8	19
11	32	None (Control)	-	-			46	21.4	18.5
12 [7]	32	Dacron Type 52	44	68.1	87.0	109.0	44	28	20
13	32	Dacron Type 52	54	83.6	81.3	134.0	43	25.5	20
14	32	Nylon Type 714	44	63.4	80.9	101.4	44	23.5	20.5

1. Assumes 61% strength efficiency in laced configuration.
2. Data questionable.
3. Delayed spike.
4. High tenacity.
5. Estane coated.
6. Undrawn nylon braided cover.
7. Rubber lined grommets

5.4 Body Support Section Tests - Cont.

For each test made, the drop weight was first placed on the primary windings. Under the 1-g loading, the secondary lacings were snugged up and fastened. High speed load tracings of several drops are shown in Figure 45 through Figure 48.

Next - pull tests were made on a full scale, 12" wide, secondary support section which duplicated the corresponding elements of the drop test samples. The results of these are summarized in Table 23.

It is apparent that the single saw-tooth lacing is superior to the other lacing configurations. Considering this type only, a 61% lacing efficiency as was previously assumed does not appear to be out of line.

5.4 Body Support Section Tests - Cont.

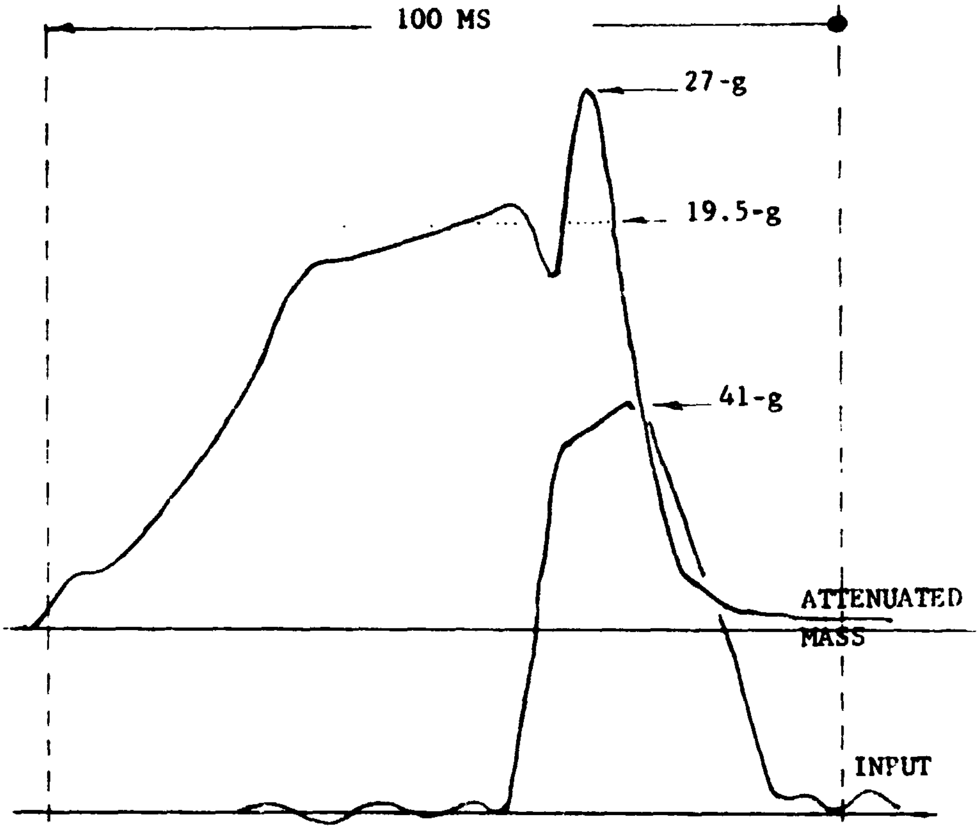


FIGURE 45
BODY SUPPORT SECTION DROP TEST 5
(HIGH TENACITY RAYON LACING)

5.4 Body Support Section Tests - Cont.

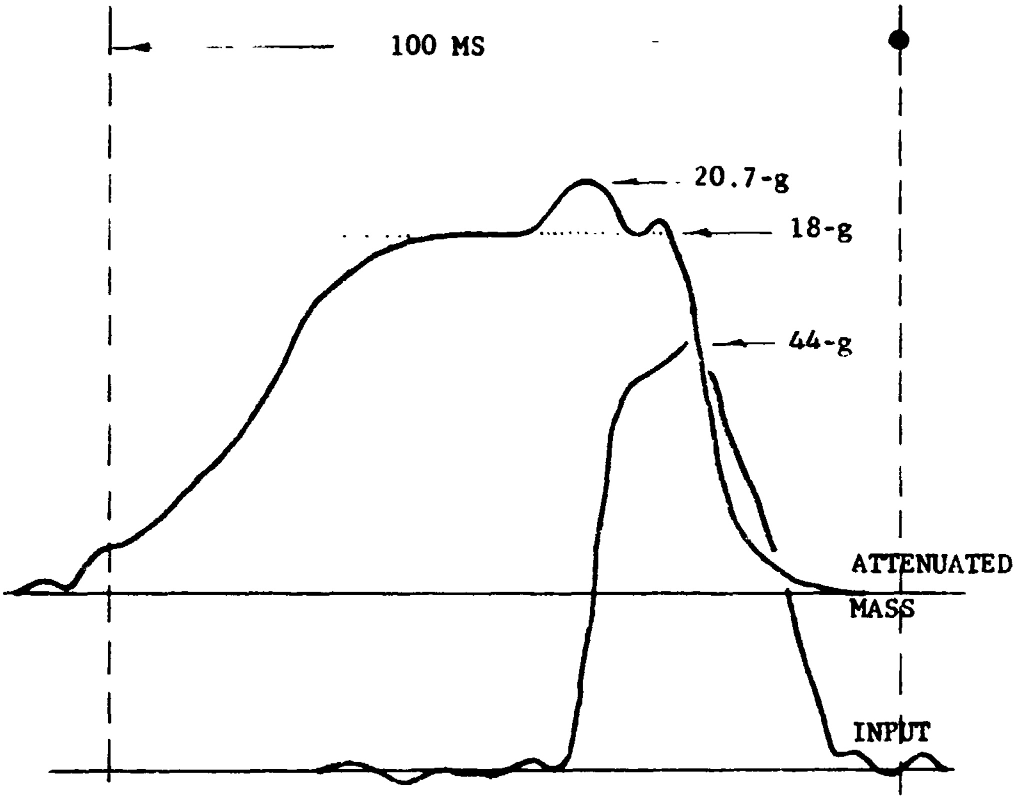


FIGURE 46

BODY SUPPORT SECTION DROP TEST 8
(FINAL DESIGN CONFIGURATION DACRON 52 LACING)

5.4 Body Support Section Tests - Cont.

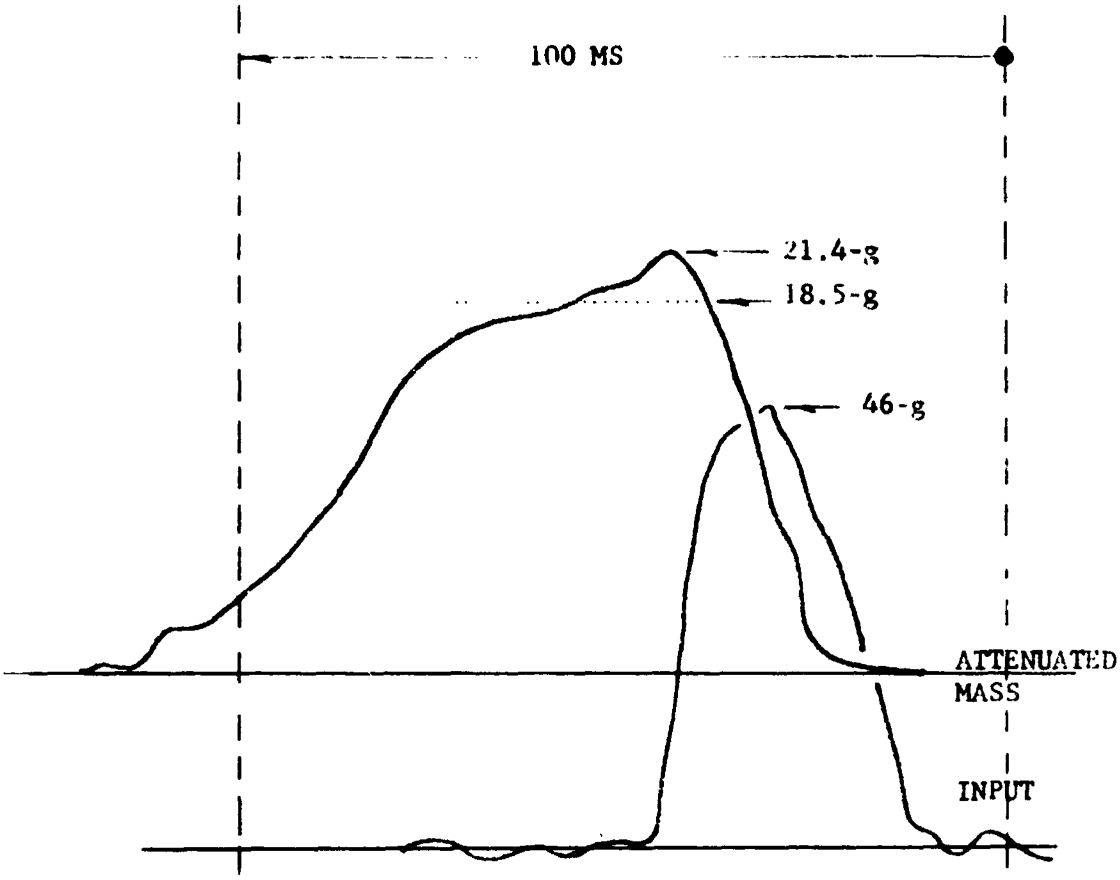


FIGURE 47

BODY SUPPORT SECTION DROP TEST 11
(PRIMARY CORDS ONLY)

5.4 Body Support Section Tests - Cont.

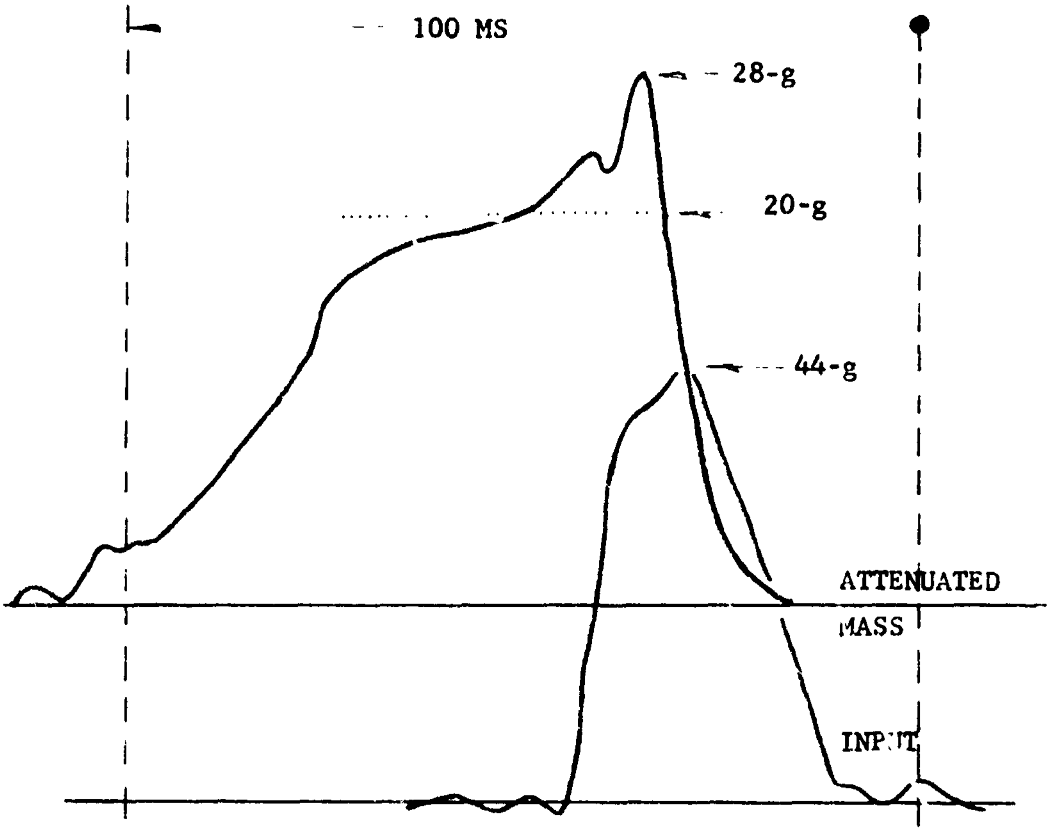


FIGURE 48

BODY SUPPORT SECTION DROP TEST 12
(DACRON 52 LACING WITH RUBBER LINED GROMMETS)

5.4 Body Support Section Tests - Cont.

TABLE 23

SECONDARY LACING STATIC LOAD TESTS 12" SECTION

Test No.	Lacing Cord Material	No. of Lacing Cross-overs	Theoretical⑩ Lacing Strength -lbs.	Test Breaking Load lbs.	Elongation @ Break (inches)	Actual⑯ Lacing Efficiency
1	Dacron Type 52	41③	63.6	620 ⑪	2.7	49.6
2	"	41③	63.6	580 ⑫	1.8	46.3
3	"	41③	64.8	605 ⑬		47.5
4	"	41③	64.8	655 ⑭	1.9	51.4
5	"	54④	83.7	760	2.2	46.1
6	"	28⑤	43.4	500	1.5	57.7
7	"	32⑥	49.6	435	2.1	44.5
8	"	41⑦	63.6	600	1.8	48.0
9	"	28⑧	43.4	460	1.5	53.9
10	"	28⑨	43.4	590⑮	1.7	68.1
11	" ②	28⑤	66.2	840⑪	2.6	64.4
12	" ②	28⑤	66.2	840⑫	2.4	64.4
13	" ②	28⑤	66.2	900⑫	2.4	69.0

1. Braided cover of undrawn nylon.
2. Estane coated.
3. Lacing doubled and criss-cross in center of sample, single lacing on sides.
4. Lacing doubled and cross-crossed over nearly full sample width.
5. Single sawtooth lacing.
6. 16 doubled and parallel crossovers near center of sample width only.
7. Lacing doubled and parallel near edges of sample, single lace in center.
8. Straight cross over lacing.
9. Standard saw tooth lacing one end, straight cross-over lacing other end.
10. Assumes 61% strength efficiency in laced configuration.
11. Upper lacing broke.
12. Upper lacing replaced and broke again.
13. Bottom lacing broke.
14. Bottom lacing replaced and broke again.
15. Straight lacing broke out.
16. Based on strength of individual cord.

5.5 Body Support Design Summary

The completed secondary lacing tests and review of the design techniques employed in determining the body support configuration resulted in the following conclusions:

1. The drop tests conducted at Houston proved Dacron to be a good choice for a lacing cord. Treatments had little effect on the test results. The tests exemplified the importance of properly positioning the primary and secondary supports one with the other.
2. Pull tests made on a 12" broad secondary support section verified previous conclusions that the design stress of a lacing cord is approximately 65% of the cords individual tensile breaking stress. The elongation of the section was somewhat greater than previously thought. Doubled up lacing configurations are not as reliable as the single cord configuration.
3. A 4 ply 1100 denier Type 52 Dacron cord will be adopted for the lacing in the couch platform. Two ply cord will be used elsewhere. The density of the secondary lacing will be reduced as affected by correcting the anticipated elongation at break in the design calculations.
4. The Houston drop tests showed that the apparent draw stress of the primary attenuating cords was ideally 2.40 pounds per cord end. The semi-production platforms will be designed to a 2.10 pound draw stress

5.5 Body Support Design Summary (Continued)

(1.85 pounds corrected for bunching). The extra cords may be eliminated by the ratio 2.10/2.40 if found necessary during subsequent tests. The 2.10 pound draw stress should, however, result in a nominal 20-g attenuation.

A summary of tests conducted on the twisted cord, filament wound body supports is presented below. As can be seen that except for the addition of the secondary lacing to attain higher static load bearing capability, only minor changes have been made to the initial design configuration of the selected body support concept.

Original Units (2) Phase I-A Evaluation Tests

Design based on:

- Weight distribution per design specifications.
- Body cross section as scaled from live human subjects
- Cord attenuating stress of 1.78 pounds.

Tests made with:

- Weber Drop Hammer
- Weber 75 percentile dummy weighted to 220 pounds
  1158 attenuating cords

Results - 18 to 25 -g attenuation

6 to 7 -g static load bearing capability

5.5 Body Support Design Summary - Cont.

Prototype Support S/N 001

Design based on:

Weight distribution per design specifications

Body cross section as scaled from Air Force and civilian personnel.

Cord attenuating stress of 1.85 pounds

Balanced secondary lacing for 225 pound dummy

Test made with:

Weber Drop Hammer

Weber 75 percentile dummy weighted to 220 pounds

1308 attenuating cords

Results - 17 to 20 -g attenuation level

13 to 14 -g static load bearing capability

Prototype Support S/N 003

Design same as S/N 001 support.

Test made with:

MSC drop tower

MSC 180 pound 75 percentile dummy

1308 attenuating cords

Test results - couch frame collapsed at 32 -g peak at shoulder

5.5 Body Support Design Summary - Cont.

Prototype Supports S/N 002, 004

Design based on:

Weight distribution per Weber Specification based on a 225 pound dummy

Body cross section as scaled from civilian and Air Force personnel

Cord attenuating stress of 1.85 pounds

Balanced secondary lacing for 225 pound dummy

Test made with:

MSC drop tower

MSC boilerplate couch frame

MSC 180 pound 75 percentile dummy

1148 attenuating cords

Test results - Maximum attenuation forces between 40 and 50 -g's were recorded at head, shoulders and legs of dummy. Non-uniform displacement of body members occurred.

Prototype Supports S/N 005, 006

Design based on:

Weight distribution per Weber 220 pound 75 percentile dummy

Body cross section per Weber 220 pound 75 percentile dummy

Cord attenuating stress of 2.40 pounds for shoulder and and arm, 2.10 pounds for the remainder of the support.

Lacing same as for couches 001-004

5.5 Body Support Design Summary - Cont.

Test made with:

MSC drop tower

MSC boilerplate and Weber couch frames

Weber 220 pound 75 percentile dummy

1053 attenuating cords

Protective flaps folded back out from under dummy

Lacing on S/N 005, none on S/N 006

Results - 18 to 19 -g attenuation

S/N 005 (with lacing) produced high g- 'spike' force (31.8 -g)

Prototype Support S/N 007

Design based on:

Weight distribution of Weber 220 pound 75 percentile dummy

Body cross section of Weber 220 pound 75 percentile dummy

Cord attenuating stress of 2.76 pounds for shoulder and arm, 2.42 pounds for remainder of support

Test made with:

MSC drop tower

MSC boilerplate couch frame

Weber 220 pound 75 percentile dummy

917 attenuating cords

Protective flaps folded back secondary lacing removed

Test results - excellent 16 to 25 -g attenuation level

5.5 Body Support Design Summary - Cont.

Semi-Production Prototype (Deliverable Units)

Design based on:

- Weight distribution per design specifications
- Body cross section of 75 percentile Weber dummy
- Cord attenuating stress 2.10 pounds
- Protective flaps removed
- Dacron 52 lacing, 65% cord efficiency

Total cords 1177

6.0 CONCLUSIONS AND RECOMMEDATIONS

All objectives set forth in the initial phases of the program have been met or exceeded. The concept resulting from this research and development effort warrants additional refinement to produce an operational configuration, retaining the present stowable and light weight features while adding multi-directional crew restraint and support features. It is believed that a qualified spacecraft, man-rated system, employing the concept developed during this program, can be perfected for the Apollo Command Module or other manned space vehicles.

6.1 Conclusions

As a direct result of this development program the state-of-the-art in crewmember support and restraint has been substantially advanced. Specifically the developed concept demonstrates the following:

- Utilization of undrawn nylon fibers to attenuate impact forces within the limits of human tolerance is a practical method to afford crew protection from emergency load conditions.
- Undrawn nylon fibers eliminate crewmember post impact rebound normally associated with netting type crew support systems.

6.1 Conclusions - Cont.

- Uniform displacement of the occupants' body members, during the attenuation mode, may be accomplished by judicious placement of the energy absorbing undrawn nylon cords.
- A body support and restraint which can adapt to 15th through 90th percentile occupant sizes without special adjustment provisions is practical.
- The permanent displacement, energy absorption action required to eliminate post impact rebound can be delayed until a desired force, less than the attenuation level, is attained. This allows the occupant to be subjected to normal launch, entry flight forces and emergency entry and abort loads without degradating the energy absorbing capability of the system for emergency landing modes.
- A floor mounted restraint system will adequately restrain the crewmember to the moveable body support platform.
- A one piece body support and restraint concept which may be readily replaced and easily handled, if necessary, in flight by the crewmember.

6.1 Conclusions - Cont.

- A framework system can be devised to allow the necessary occupant displacement for force attenuation while still maintaining the required structural integrity.
- Foldable couch assemblies which may be removed from the suspension structure and stowed in the vehicle during space flight.
- A couch system weight which is less than half that of the present hard couch system incorporated in the Apollo Command Module.

6.2 Recommendations

The inherent weight savings and stowable features of this couch concept is particularily desirable for application to several types of space vehicles.

It is particularly suitable to multi-man transport - supply and rescue vehicles which may require three crewmembers and, depending on mission requirements, carry cargo to an orbiting space station and return with four or five passengers. When in the cargo configuration the couch system may be stowed to its minimum volume maximizing the allowable volume for the cargo. The vehicle may readily be converted to the passenger configuration at the space station for the return trip. On rescue missions it may be found desirable to design the couch so it can be made into

6.2 Recommendations - Cont.

a litter for returning incapacitated passengers. The litter configuration may also be used for a sleep station on extended missions.

The present Apollo Command Module and vehicles under study for Mars missions are limited in available space. Couches which may be stowed in the vehicle will permit more space for exercise, recreation, set-up and performance of complex experiments.

The light weight and stowable couch developed under this contract, with refinements, is ideal for application to these types of space vehicles.

The configuration developed to meet the objectives of the present program work statement is limited to application of loads in one axis, eyeballs in and out. However, the articulation requirements and stowable features for a translunar mission have been incorporated and are demonstrated by the developed couch.

Expansion of the loads to three axis considerations and specific definition of environmental requirements would be the next step in obtaining an operational crew couch system. Design verification tests, including intergration tests in the applicable spacecraft and impact tests, with

6.2 Recommendations - Cont.

inertial forces applied to simulate the critical load conditions in each axis of the spacecraft would be prerequsite to a final configuration of a man-rated and spacecraft system.

6.2.1 Multidirectional Crew Couch Requirements

Predicated on application to a translunar mission with the present Apollo Command Module configuration, Table 24 outlines the essential load requirements for the couch system. Table 25 depicts the minimum environmental requirements for the system.

The couch geometry would be modified to allow the required occupant displacement for attenuation of the emergency landing impact forces inthe eyeballs up and down direction. It may be found necessary however, to provide an attenuating structure in the eyeballs left and right directions to reduce the impact forces. If it is found desirable to incorporate this feature, it may be possible to adopt the present Apollo hard couch Y-Y attenuation strut to the system or, preferably, utilize the attenuating device developed under the Manned Spacecraft Center contract NAS 9-3533. This device employs a cyclic material deformation concept of energy absorption which is accomplished by rolling ductile tori elements in friction contact between concentric tubes. The advantages

TABLE 24
CREW COUCH LOAD REQUIREMENTS - APOLLO TRANSLUNAR MISSION

Direction of Applied Forces (three axes)	NOMINAL			EMERGENCY		
	Input		Occupant Response (Max.)	Input		Occupant Response (Max.)
	Limit Force	Velocity Change		Limit Force	Velocity Change	
Sustained Booster Forces (EBI)	3-5-g	25,000+ FPS	3-5-g	--	--	--
Pre-Orbital Abort & Entry Emergency Forces	--	--	--	16-g	--	16-g
Impact EBI	20-25-g	5 FPS	10-g	35-40-g	30 FPS	20-g
Impact EBO	← Rebound →		10-g	← Rebound →		10-g
Impact EBD	15-g	15 FPS	10-g	25-g	15 FPS	15-g
Impact EBU	15-g	15 FPS	10-g	25-g	15 FPS	15-g
Impact EBL EBR	10-g	15 FPS	5-g	20-g	15 FPS	10-g

TABLE 25
ENVIRONMENTAL CONDITIONS - APOLLO TRANSLUNAR MISSION

PARAMETER	LAUNCH	FLIGHT	RE-ENTRY & IMPACT	SHELF & EXPOSURE	EMERGENCY
Temperature	60°-80°F	60° to 80°	60° to 80°	5° to 120°F	-170°F +160°F
Atmosphere	85-95% O_2 ①	85-95% O_2 ①	85-95% O_2 ①	Ambient	Space Vacuum
Pressure	21.7 psia for 2 hours	5 psia 288 hrs.	5 to 21.7 psia .5 hrs (est)	14.7 psia nominal	10^{-4} mm Hg. 100 hrs.
Humidity	50% R.H. Max.	40-70% R.H.	40-70% R.H.	10-100% R.H.	0 to 100% R.H.
Vibration		12.5 min. from SPS To Be Determined (3 Axis)			Abort - 10 sec.
Sand & Dust	Design Consideration Only				
Fungus	Use Non-Nutrients or Treat with approved Fungicidal Agent				
Salt Atmos.	1% Salt solution (by weight) for 48 hrs at 95°F, ambient pressure				
Ozone	Design Consideration Only				
Nuclear Radiation	Design Consideration Only				
Electromagnetic Radiation	Design Consideration Only				
Meteoroids	Design Consideration Only				
Shock & Accel.	See Table 24				
Acoustics	To Be Determined				

1 Cabin Atmosphere (Nominal)

O_2	4.638 psia.	92.76% Volume	93.49% Weight
CO_2 (max)	.147 psia	2.94% Volume	4.07% Weight
Water (Nom)	.215 psia	4.30% Volume	2.44% Weight

6.2.1 Multidirectional Crew Couch Requirements - Cont.

of this device over the present hard couch strut is that the strut may be used in cyclic load applications where load reversals may occur, the attenuation level may be made readily adjustable, it is lighter in weight and may be made more compact than the hard couch strut. This strut may also be tested to determine its exact output and reset capabilities prior to installation in the spacecraft.

The body position adjustments of the couch frame would be revised to be compatible with the present hard couch system. These positions are:

96° Thigh-torso angle for launch, entry impact.
170° Thigh-torso angle for G & N station work.
270° Thigh torso angle for access to the LEB

In addition, the center couch and the right hand couch with their supporting structure will be configured to allow disassembly and stowage while in space flight. It is desirable that the disassembly be accomplished easily and without the use of special tools.

6.2.2 Program Plan - Operational Apollo Crew Couch

Figure 49 displays an approximate schedule required to up grade the present system to an operational status. It is divided into several tasks and phases to provide milestones by which the progress of the program may be measured. An 18 month effort to deliver the first production unit is contemplated.

Study Phase

The study phase is divided into three subtasks. The first is to establish firm operational and performance requirements including loads, environmental, articulation, and stowage features. The internal arrangement of the Command Module will be reviewed to define the interface requirements of the couch system. The work to be accomplished by each crewmember during a typical mission will be reviewed to assure couch compatibility with the astronaut's tasks.

With these parameters defined, the second task to prepare preliminary layouts of the system and establish the basic features of the couches and support structure will be accomplished. The third task of the Study Phase will be to fabricate a mock-up of the proposed configuration to re-affirm the basic geometerical concept with respect to articulation, stowability, Command Module interface and compatibility with the astronauts work tasks.

6.2.2 Program Plan - Operational Apollo Crew Couch - Cont.

Changes will be incorporated into the system. The production design of the system will be established and engineering drawings will be prepared. This effort will entail all the facets of design, reliability and quality assurance necessary to provide an operational system.

To verify the structural integrity of the couch and multi-directional load capability of the concept, static and dynamic loads will be applied to a single couch structure and the results evaluated before fabrication of the qualification systems.

System Qualification Phase

Preparation of the test plans and procedures will be accomplished during the system design phase. These documents will specify in detail all test conditions and criteria to establish satisfactory completion of the tests. If necessary, failure analysis will be made and the corrective action to be taken specified. Results of all tests will be documented and submitted to the National Aeronautics and Space Administration.

6.2.2 Program Plan - Operational Apollo Crew Couch - Cont.

Completion and approval of the Qualification Phase will initiate the Production Phase of the program. Adoptation of the Quality Assurance and Control functions employed by Weber in the production of the Gemini Escape System will be used to provide the necessary elements of control over the manufacture of the production units, commensurate with a man-rated aerospace system.

175

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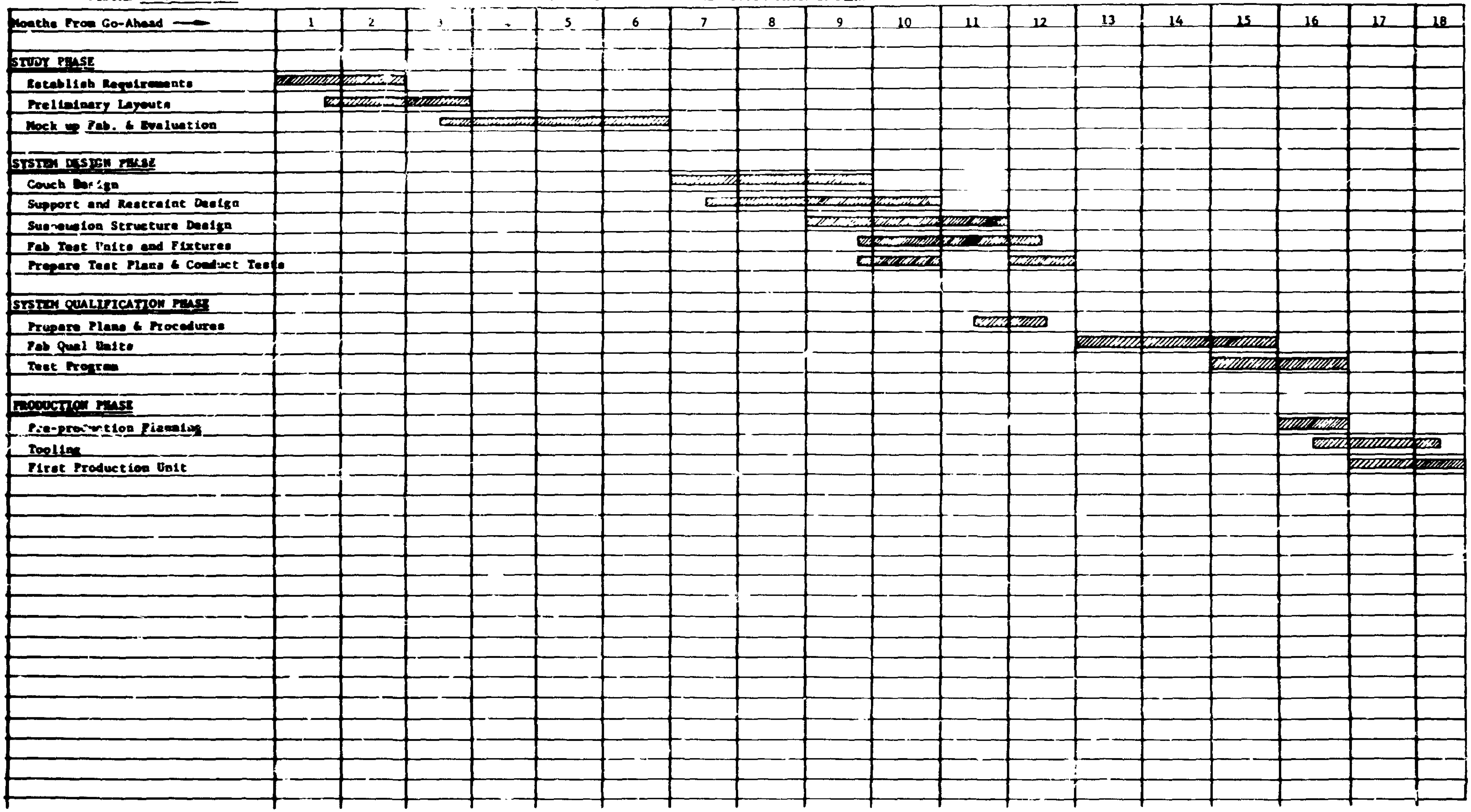
ENGINEERING PROGRAM SCHEDULE

PREPARED BY: gcl	PAGE 175
CHECKED BY	REPORT NO
DATE 7-13 66	

FIGURE 49

TITLE: OPERATIONAL APOLLO CREW COUCH PROGRAM PLAN



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