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THE DEVELOPMENT OF LOW ELASTIC WEBBINGS FOR USE IN THE FABRICATION OF RESTRAINT HARNESSES

By Douglas Geier and E. F. Perkins

SUMMARY

A development program was conducted to advance the state-of-the-art in restraint harness webbing which would provide more optimum harnesses in the Apollo command module, lunar excursion module, and future space vehicles. The development effort was conducted under NASA contract NAS 9-3697 by Payne and Associates, Raleigh, North Carolina. A contract statement of work is presented in the appendix. The results of this program was the development of a nylon-linen webbing material which has a nominal 5 percent elongation characteristic and breaking strength equal to or greater than existing webbings of comparable size.

INTRODUCTION

Recent investigations of the dynamics of the human body subject to impact loadings have verified empirical indications that human body restraint systems should be as inelastic as possible in order to minimize the amplification of vehicle or couch accelerations transmitted to the crewman. Presently available webbings, (nylon, dacron, cotton) are considerably elastic compared to metal of the same ultimate strength. Furthermore, nylon webbing in characteristic restraint system lengths and with typical torso masses has natural frequencies very close to the natural frequency of the human body in the visceral mode. This means that the nylon restraint system will not only amplify seat or couch impact forces, but will also transmit them to the body at close to the natural frequency of the internal organ complex. This assures that the dynamic response of the internal organs will be maximized for most seat impact accelerations, thus maximizing the probability of internal injury due to the relative displacement between organs and their attachments and bony structure.

Another undesirable characteristic of fabric webbing is their relatively large variability in respect to those mechanical properties which determine dynamic response. Viscoelastic materials such as nylon and dacron exhibit different stiffnesses and damping for different loading rates. They also show marked changes in stiffness after repeated loading. The time interval between loadings also affects these properties. Finally, slight variations in composition and manufacturing methods are reflected in significant differences in the mechanical properties of webbing.

On the other hand, textile webbings, especially nylon, possess definite advantages. They readily may be fabricated into a variety of configuration and integrated with friction adjusters, releases, and other hardware; they distribute dynamic forces over the parts of the body they contact, avoiding point loadings; they are quite durable and require little maintenance or inspection during service; they are relatively comfortable when fitted properly; and they are flexible enough to allow the use of friction adjusters.

The ideal restraint harness material would therefore possess all of these qualities but would be stiff enough in tension to avoid the undesirable dynamic characteristics of the fabric webbings in current use, and would also posses greater predictability in respect to stiffness, damping, and strength.

The small internal volume in the Apollo command module and the multidirectional forces imposed on the crew during the landing phase of the mission can cause extreme movement of the crew with a restraint system fabricated from existing webbing which could result in manequipment collision. Therefore, to provide restraint webbings with low-elongation characteristics to better restrain the Apollo crewman, an investigation of low elastic materials has been conducted.

Results of this development was a nylon-linen webbing fabric with a nominal 5 percent elongation characteristic, and a breaking strength equal to or greater than existing webbings of comparable size.

PROCEDURES

A survey of related technical literature and data was conducted as to materials and their physical characteristics relevant to the restraint webbing application.

In order to obtain a reliable comparison of strap-strain characteristics of the candidate fibers, a series of tests were conducted utilizing a common test procedure of strain rate and test sample length. Tradeoffs were made as to various parameters such as breaking strength, elongation, and costs to elect the prime candidate materials for sample fabrication.

The initial construction and testing was done on a scale prototype basis to allow the investigation of a wider range of constructions. Prototype webs were produced in approximately three-quarter inch widths. The assumption underlying the scaled prototype was that elongation remains the same and that tensile strength varies directly with width with a given weave construction and a given yarn.

Scaled sample webs were fabricated from linen with a nylon cover, fortesan with a nylon cover, fiberglass with a nylon cover and all linen. These samples were tested as to breaking strength and elongation. The test data was projected to full scale webbing which indicated webbing constructed as shown in figure 1 with a linen stuffer and nylon cover would yield the desired results. Quantities of these webs were produced in full scale for testing at the contractor's plant and MSC.

RESULTS

The technical survey resulted in various materials for investigation, as shown in table I. It was determined from this survey that Fortisan, linen, fiberglass among textile yarns, and a variety of metallic filaments were prime candidates for further investigation and tests. These tests indicated a varied range of strengths and elongations depending upon each fibers inherent physical properties and upon their yarn properties of size, twist, and ply.

Table II lists textile yarns and metallic filaments tested and the physical properties determined by tests using a Scott tester and a Thwig-Albert Electro-Tensile Tester with an elongation recorder. As indicated by this table, nylon, dacron, and rayon were eliminated from further consideration as the tensile material for webbings due to their inherent high elongation. They were, however, retained from possible consideration as subordinate weaving yarns (cover, filling, binder).

The metallic filaments yielded the lowest elongations but did not exhibit a desirable strength to weight ratio in comparison to that of the textile candidates. The use of metallic wire filaments having elongations ranging up to 1 percent would necessitate building in a mechanical elongation into the weave construction in order to meet the limit of 3 to 7 percent, as specified in the contract specifications. Other factors, such as seam efficiency, flexibility, strength to weight ratios, and costs made the use of metallic wire less desirable than textile yarns.

It was determined that the most effective weave to obtain the desired result of strength and low elongation evolved about the use of parallel and straight load bearings yarns, and the minimization of mechanical elongation that is built into a woven construction due to the bending of the warp yarns. The "stiffer" type weave and the "multiple layer" weave appeared to be the best constructions to obtain the best mechanical properties, and are shown graphically in figure 1, illustrations I, II, and III.

Prototype samples of the specified webbings were dynamically tested. The formulas for approximating developed forces and the data obtained from these tests are given in table III.

Information obtained from these prototype tests led to full scale construction of the final webs. The final webs were fabricated with a linen stuffer and nylon cover as in figure 1. Construction, test data, and comments on full scale webbings fabricated to meet the contract specifications are presented in table IV and table V.

CONCLUDING REMARKS

1. The webbings developed could readily be used in the design and fabrication of restraint systems for the Apollo command module and lunar excursion module using improved, lighter, simple and/or standard hardware.

2. The low-elongation characteristics of this webbing developed under the contract will provide a definite advantage in crew restraint systems in situations of limited space by providing reduced and more controlled body movements.

3. Due to the results obtained under this contract (NAS 9-3697), it is recommended that the webbing be further investigated for incorporation in the Apollo program to provide higher crew safety.

TABLE I.- LIST OF CANDIDATE MATERIALS RESULTING

FROM LITERATURE SURVEY

Metallic filaments	
Karma	Hastelloy B
Nichrome V	Waspaloy
Rene' 41	Udimet - 500
Inconel 702	Udimet - 700
Chromel R	HS-25
Chromel A	STAP (Nimonic alloy)
Elgiloy	Fine ultrahigh strength steel wire, .85 percent - .90 percent carbon
Molybdenum	High carbon steel music wire
K W Molybdenum	Evanohm
Tungsten	Tophet A
26 percent Rhenium - tungsten alloy	Tophet C
50 percent Rhenium - Molybdenum alloy	

Glass filaments	Textile filaments
E glass	Fortisan
S glass	Polyester (heat stretched and set)
Beta glass	Tyrex rayon
	Nylon
	Linen

TABLE II.- TEST DATA OF CANDIDATE FIBERS

Fiber description	Approximate diameter, in.	Breaking strength, lb	Elongation, percentage
Evanohm wire	0.00275	0.75	0.5
Evanohm wire	.0020	.50	0.5
Evanohm wire	.0015	.35	0.5
Tophet A wire	.0020	.45	0.5
Cupron wire	.0020	.35	0.5
Nickel wire	.0030	.55	0.5
Tungsten wire	.0012	.50	0.5
Tophet C wire	.00275	.45	1.0
150-1/2/3.8 Fiberglas	.0106	7.50	4.0
225-1/0/1	.0065	2.40	4.0
14/2 ply linen	.0220	21.00	4.5
25/3/2 ply linen	.0286	26.00	8.0
1/270/360/2.5 fortisan	.0078	4.60	8.0
2/1100/192/2.5 dacron	.0220	28.00	10.0

TABLE II.- TEST DATA OF CANDIDATE FIBERS - Concluded

Fiber description	Approximate diameter, in.	Breaking strength, lb	Elongation, percentage
1/1100/980/2.0 tyrex rayon	0.0154	11.00	10.0
1/1100/720/2.0 tyrex rayon	.0154	12.50	12.0
1/220 dacron	.0070	3.70	18.0
1/840/140/2.5 nylon 66	.0136	16.00	18.0
1/210/34 nylon 66	.0070	3.90	22.0
2/840/68/2.5 nylon 66	.0196	31.00	22.0
2/840/136/2.5 nylon 6	.0198	30.50	22.0
2/840/56/2.5 nylon 6	.0196	30.50	23.0
1/840/56/2.5 nylon 6	.0136	15.50	24.0

TABLE III.- DYNAMIC TESTING OF TYPES A AND B PROTOTYPES

Basic Formulas

$$F = \frac{WV^2}{2\ gs} \qquad V = (8.02)\sqrt{h}$$

$$\text{Elongation} = \frac{\Delta h}{\sin\alpha}\ (2)$$

$$\text{Percent elongation} = \frac{E}{36}\ (100)$$

Block weight 165 pounds

Sample number	Δh, ft	Drop height, ft:in.	Force, lb
Type A			
I	0.104	1:0	1590
II	Break	2:0	
III	Break	1:6	
IV	Break	1:3	
V	.35	1:0	1228
VI (1)	.104	1:1	1727
(2)	Break	1:1	
VII	Break	1:1.5	
VIII	Break	1:1	
IX	.1197	1:1	1497

TABLE III.- DYNAMIC TESTING OF TYPES A AND B PROTOTYPES - Concluded

Sample number	Δh, ft	Drop height, ft:in.	Force, lb
	Type B		
I (1)	0.135	1:3	1540
(2)	.094	1:3	2219
(3)	.083	1:3	2498
II (1)	.135	1:6	1857
(2)	Break	1:6	
III	.135	1:9	2137
IV	Break	2:0	
V	.146	1:10	2088
VI	Break	1:11	
VII	Break	1:10	

TABLE IV.- NUMBER 1 - WEBBING - FULL SCALE FOR ITEM A

LINEN STUFFER WITH NYLON COVER

Construction No. 65 - 294	
Number of warp yarns	
Cover	265/1
Stuffer	248/1
Binder	42/1
Warp ply and count	
Cover	1/840/140/3 - nylon 6.6
Stuffer	14/2 - Linen
Binder	1/840/140/3 - nylon 6.6
Filling ply and count	1/840/140/3 - nylon 6.6
Twist/inch	8.0 T.P.I.
Picks/inch	24
Weave - cover	Closed tubular
- binder	2/2 double shot Illustration no. I, figure 1

Tests	Full scale	Required values
Width, in.	1-3/4	1-3/4
Thickness, in.	.113	.125
Weight, oz/yd	3.03	--
Breaking strength		
Stuffer, lb	3750	3600
Elongation stuffer, percent . .	4.375	5 ±2

The above tests indicate:

(a) Elongation
Within tolerance

(b) Breaking strength
Higher than minimum limit

The prime requirements for strength and low elongation was attained. The webbing has reasonable flexibility for the type of weave construction utilized.

TABLE V.- NUMBER 2 - WEBBING - FULL SCALE FOR ITEM B

LINEN STUFFER WITH NYLON COVER

Construction - Sample 65 - 296	
Number of warp yarns	
Cover	312/1
Stuffer	600/1
Binder	148/1
Warp ply and count	
Cover	1/840/140/3 - nylon 6.6
Stuffer	14/2 - linen
Binder	1/840/140/3 - nylon 6.6
Filling ply and count	1/840/140/3 - nylon 6.6
Twist/inch	80 T.P.I.
Picks/inch	24
Weave - cover	Closed tubular
- binder	2/2 double shot Illustration no. I, figure 1

Tests	Full scale	Required values
Width, in.	3	3
Thickness, in.	.136	.125
Weight, oz/yd	6.80	--
Breaking strength		
Stuffer, lb	9200	9000
Elongation stuffer, percent . . .	4.375	5 ±2

The above tests indicate:

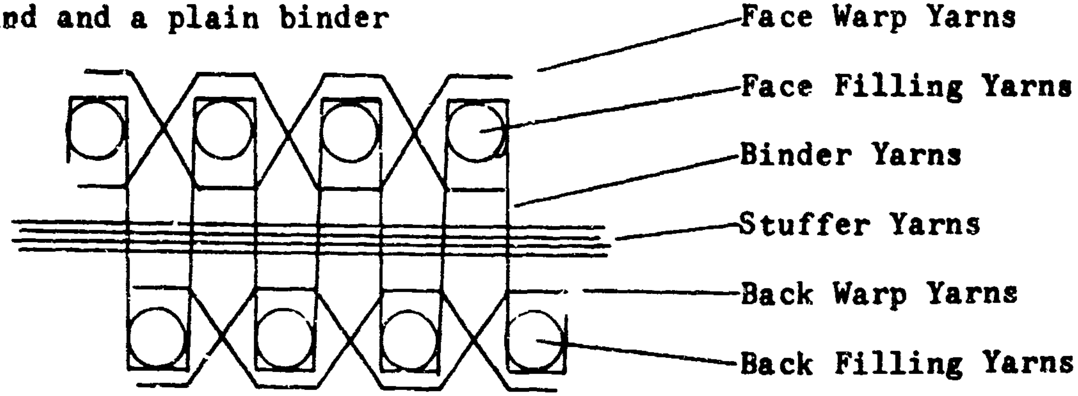
(a) Elongation
Within tolerance

(b) Breaking strength
Higher than minimum limit

The objective of high strength and low elongation was attained. However, the web was firm in flexibility and thickness was higher than desired. Reduction of the number of picks within practical limits would improve these properties.

Illustration I. Filling Cross-Section

Stuffer weave with a double plain ground and a plain binder



Basic Weave for Types A and B

Illustration II. Warp Cross-Section

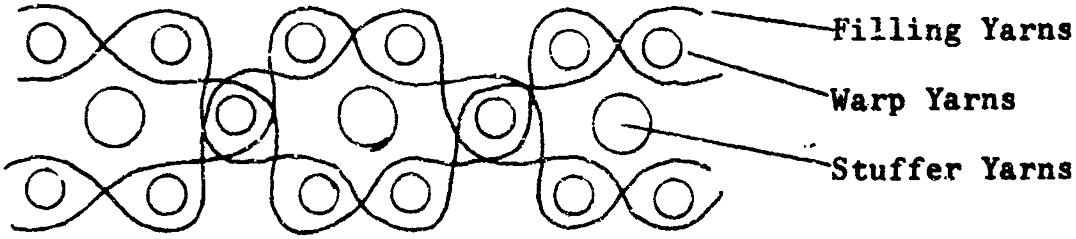


Illustration III. Filling Cross-Section

Multiple Layer Weave

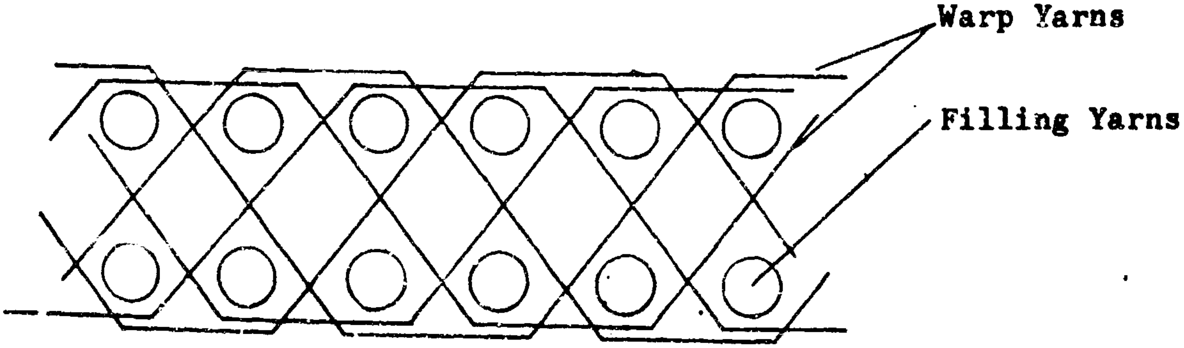


Figure 1.- Graphical representation of webbing construction.

APPENDIX

STATEMENT OF WORK

Background

Recent investigations of the dynamics of the human body subjected to impact loadings have verified empirical indications that human body restraint systems should be as inelastic as possible in order to minimize the amplification of vehicle or couch accelerations transmitted to the crewman. Presently available webbings (nylon, dacron, and cotton) are considerably elastic compared to metals of the same ultimate strength. Furthermore, nylon webbing in characteristic restraint system lengths and with typical torso masses has natural frequencies very close to the natural frequency of the human body in the visceral mode. This means that the nylon restraint system will not only amplify seat or couch impact forces, but will also transmit them to the body at close to the natural frequency of the internal organ complex. This assures that the dynamic response of the internal organs will be maximized for most seat impact accelerations, thus maximizing the probability of internal injury due to the relative displacement between organs and their attachments and bony structure.

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On the other hand, textile webbings, especially nylon, possess definite advantages. They readily may be fabricated into a variety of configurations and integrated with friction adjusters, releases, and other hardware; they distribute dynamic forces over the parts of the body they contact, avoiding point landings; they are quite durable and require little maintenance or inspection during service; they are relatively comfortable when fitted properly; and they are flexible enough to allow the use of friction adjusters.

The ideal restraint harness material would therefore possess all of these qualities but would be stiff enough in tension to avoid the undesirable dynamic characteristics of the fabric webbings in current use, and would also possess greater predictability in respect to stiffness, damping, and strength.

Objective

The ultimate goals of this effort are: (1) to develop restraint harness webbings having greater tensile stiffness and less variability of mechanical characteristics than currently available textile webbings; (2) to develop hardware to provide release, adjustment, and attachment functions with this webbing; and (3) to develop simple and reliable fabrication techniques with which to construct complete restraint systems with this hardware and webbing.

Contractor Effort

The contractor will accomplish the following tasks:

1. Survey of organizations and literature to gather any available data on previous developments of low-elongation webbings and other relevant materials.

2. Generation and analysis of various approaches to the construction of low-elasticity webbing, restraint fitting design, and restraint system fabrication techniques to meet the requirements outlined below.

3. Design, fabrication, and preliminary tests of those approaches which appear practical; selection of most promising method(s) for further development.

Technical Requirements

Webbing specifications			
Type	Size, in.	Breaking strength, lb	Elongation, percent
A	1.75 by .125	3600	5 ±2
B	3 by .125	9000	5 ±2
C	1.75 by .125	9000	5 ±2