

AIR CUSHION VEHICLE SKIRT SYSTEMS

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ABSTRACT

.....This paper reviews the development of molded air cushion vehicle skirt systems, the molding procedure, types of materials and material properties. Improvements over present skirt materials are reviewed as well as new design concepts. The molding technique provides greater flexibility in air cushion vehicle skirt design, which can incorporate very high strength yarns and high abrasion resistant coating materials. A discussion of the effects of material choice on vehicle dynamics is included.

INTRODUCTION

.....It has been estimated that 80% of the maintenance costs of air cushion vehicles relates to the repair or replacement of air cushion skirt systems. An air cushion vehicle is designed specifically to operate in environments where no other vehicle has travelled. This places extremely demanding requirements on the skirt designs and materials that have to accommodate obstacles in the path of the hovercraft travelling at high speeds. Flexibility, abrasion resistance, and tear strength, all have to be designed into a skirt system which when pressurized maintains its desired shape while travelling over unprepared terrain.

.....The majority of skirt systems which have been made to date rely on various forms of biaxially woven nylon neoprene/natural rubber coated rolled material which weigh up to 170 oz./square yard. These current fabrics approach the severe abrasion resistant requirements by adding coating thickness, and approach the strength requirements by adding multiple laminants of nylon fabric. To maintain flexibility and the desired

shape, the designers have developed very intricate skirt geometry. Weak areas of these skirt systems are the seams which occur at regular intervals corresponding to the width of the roll stock used in the construction. Generally large grommets or bolts with large diameter washers are used to reinforce these hot bonded seams as shown in figure 1.

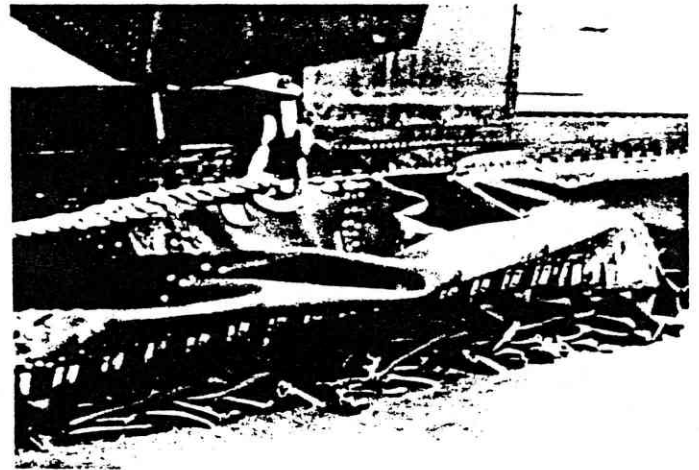


Figure 1 Reinforced Seams

.....The molding technique permits the designer to examine the requirements of each section of a skirt system, select the fundamental elements best suited for each area and mold them into a seamless skirt system. In engineering a material for a molded skirt system the designer can select:

- a) yarn type and weight,
- b) type of coating and thickness,
- c) weave style and number of plies,
- d) integrally woven wear strips,
- e) internal damping, and
- f) porosity

that will best suit each area of the skirt system.

This construction flexibility will allow the designer to reinforce the appropriate faces of each skirt section to withstand higher abrasion.

METHOD

.....The method for molding seamless air cushion vehicle skirt systems is shown in figure 2. An uncured, liquid polyurethane is sprayed onto a male or female mold shape of an air cushion vehicle skirt section. This forms a continuous polyurethane layer on which is laid a substrate of fabric or filament network. Open weave fabrics are usually selected which allow the polyurethane layers to penetrate the substrate and mix together. This open area can vary between 5% and 30% based on the type and weave of fabric selected.



Figure 2 Molding Technique

.....The fabric substrate may be constructed from suitable combinations of biaxial fabrics, triaxial fabrics shown in figure 3, and individual filaments hand woven to suit a specific geometry or

loading condition of the skirt system. The substrate is then coated with a second continuous layer of uncured liquid polyurethane on which another substrate of fabric can be laid. This process is repeated to reach the desired multiple ply construction and coating thickness, while the first layer of polyurethane is still uncured. When the polyurethane is cured, a continuously molded skirt segment is formed which does not exhibit the delamination of multiple layers, traditionally associated with calendered sheet materials.

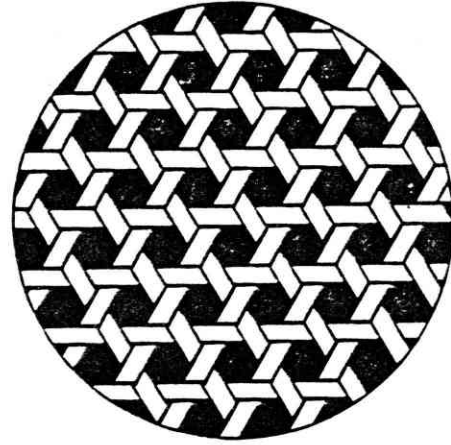


Figure 3 Triaxial Weave

FEATURES OF A MOLDED SKIRT SYSTEM

.....The molding technology allows the designer to individually optimize each component of a skirt system for its structural and dynamic requirements. Elasticity, flexibility, abrasion wear, porosity, damping and strength can be varied within each component.

.....The molding technique can produce seamless air cushion vehicle skirt systems, which are extremely tear resistant and are formed of integrally bonded material, thereby being highly resistant to delamination as shown in figure 4. All seams and joints which are created when gluing or hot bonding flat roll stock neoprene/rubber materials are removed in this technique.

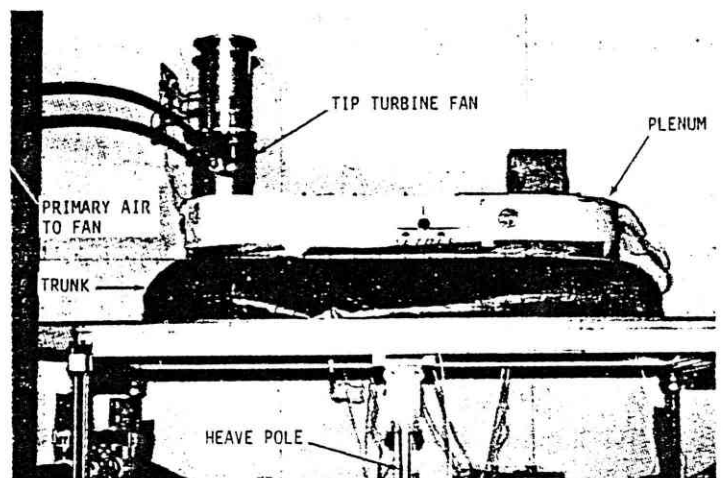


Figure 4 Seamless Molded Skirt System

This molding technique eliminates the current practice of replacing worn segments when the overall vehicle performance degrades to a predetermined limit. The various polyurethane layers can be color coded, facilitating positive identification of high abrasion areas. Since polyurethane cures at room temperature, worn areas can be cleaned with solvents and resprayed to their original thickness during regular maintenance, while the segments are still attached to the vehicle. The coating thickness can be increased in these specific areas of high wear.

.....Several grades of polyurethane can be incorporated into the same skirt system. For example, a very soft flexible grade could be used at the tip of the skirt segment where abrasion is the primary concern and a very hard durometer grade could be used at the top of the segment to form mounting "brackets" or reinforce "grommet" locations. Attachment points and grommets can be molded into the material without breaking or cutting the filaments.

.....As vehicles become larger, skirt systems can be constructed with tapered walls allowing designers to create deeper "inelastic" skirt systems. Skirt components can be reinforced with multiple layers of fabric to match the cumulative forces as they increase towards the hard structure of the vehicle. This produces skirt systems which are more flexible at the ground contact area.

..... Porosity can be molded into skirt systems. During the molding process sections of the mold and fabric maybe masked to produce uncoated areas of substrate as shown in figures 5 and 6. These areas may later be sprayed with liquid polyurethane to produce a permeable section in the air cushion vehicle skirt, segment, or trunk. This porous section is comprised of continuous unbroken filaments, thus maintaining the full strength of the fabric. These permeable sections reduce abrasion, knuckle-under drag, spray and undesirable vibration and tramping problems associated with skirt sections sealing off against the ground as demonstrated in figure 7.

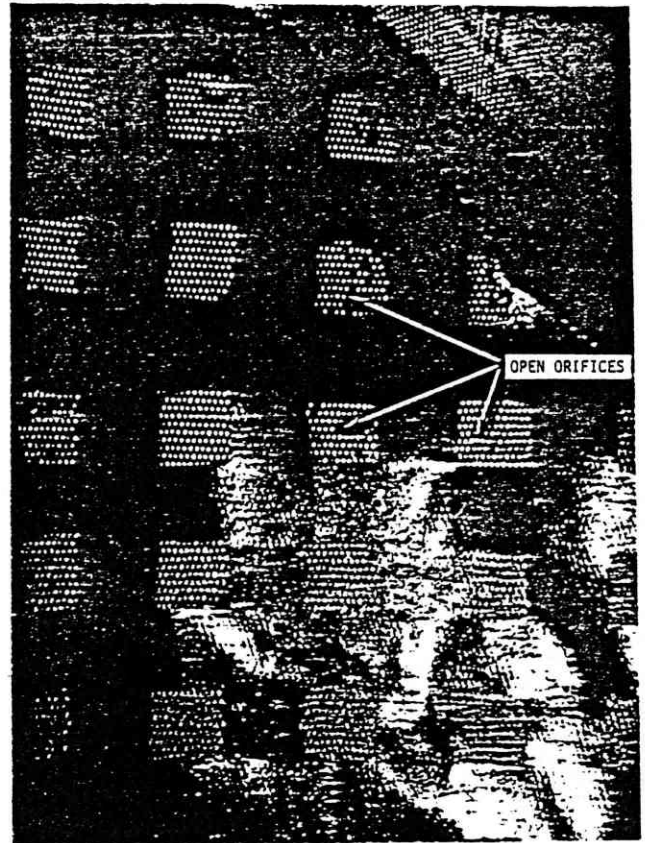


Figure 5 The Checkerboard Pattern of the NASA Test Vehicle Trunk Orifices Ref. 5

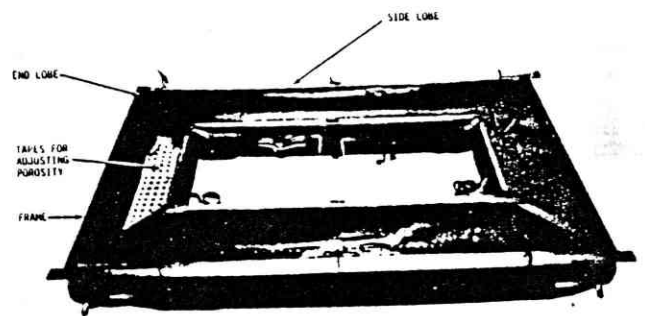


Figure 6 The Segmented Trunk for the NASA ACLS Vehicle Ref. 5

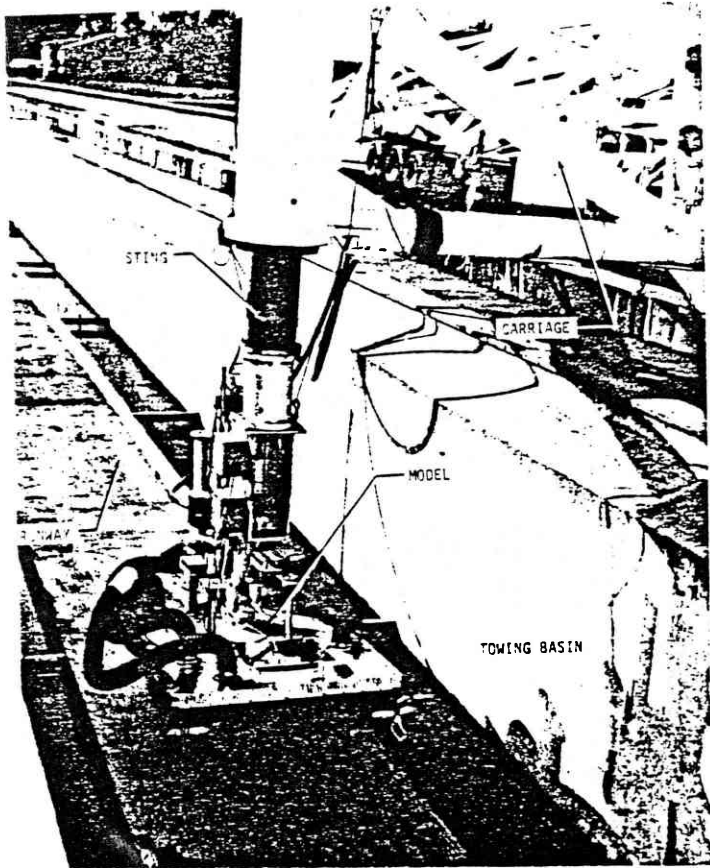


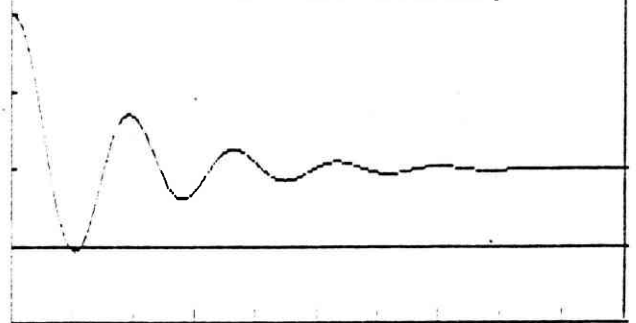
Figure 7 Air Cushion Model supported on Carriage Sting Ref. 2

.....A porous skirt can affect the dynamic response of a cushion overland. Molding a porous band into the bottom of a skirt reduces the rate of change of the cushion air discharge with respect to heave height. This produces a stabilizing effect as illustrated in figure 8 A-B-C, which displays vehicle heave height versus time. This nonlinear dynamic simulation assumes the porous band of the skirt is in contact with the ground. Three porosities are shown, 8 A-100%, 8 B-35%, and 8 C-5%, for the same cushion pressure and flow rates which resulted in different equilibrium hover heights for each porosity. However, as porosity is reduced to 0% the skirt system may become statically unstable and not be able to support itself. In each case the vehicle was dropped from 2 X its equilibrium hover height.

The results indicate porosity can be varied to optimize the damping of a skirt system consequently improving its dynamic stability while still maintaining its static stability.

WINDOW: 0 -1 12 6
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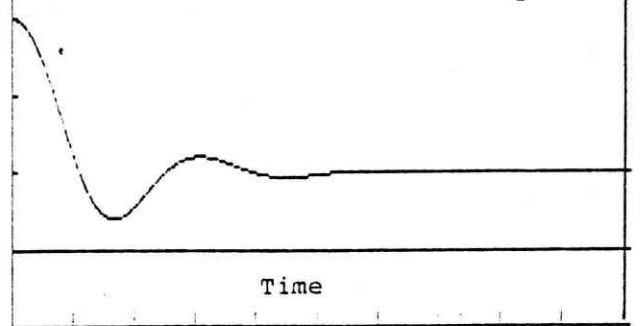
8 A 100% Porosity



WINDOW: 0 -1 12 6
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 INPUT OMEGA= 0 ;AMPLITUDE= 0 STEP SIZE= .01

H/He

8 B 35% Porosity



Time

WINDOW: 0 -1 12 6
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8 C 5% Porosity

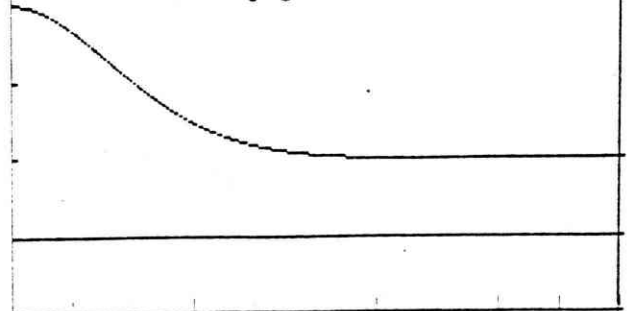


Figure 8 Effect of Porosity on Dynamic Stability

.....Elastic deformation of the skirt can affect the response in several ways; through volume changes in the skirt which result from pressure modulation, another is the modulation of the hovergap. Examples of these effects are shown in figures 9 & 10. The influence on the dynamics is illustrated by shifts on the stability boundaries. In general, the farther the operating point of cushion is from a stability boundary, the more damped the cushion response will be. The results shown in figures 9 & 10 are for a single cell conical skirt, free to move in heave. In the results shown in figure 9 the stiffness of the skirt in the hoop direction is varied but the axial dimension of the skirt is assumed to remain constant. Therefore the cushion volume expands under pressure. The resulting curves show that as the material weakens the unstable region grows larger which is undesirable. Thus a cushion with an inelastic hoop stiffness is more desirable. Figure 10 shows the results for the same skirt except that the axial dimension of the skirt is assumed to shrink as the hoop direction increases, that is, a Poisson's ratio type of effect occurs. The result is that the cushion exit flow is increased as the volume increases. This increases cushion damping as shown by the increase in the stable area of operation. Therefore optimizing the stiffness of the skirt material to the skirt design could be used to provide a more favourable response.

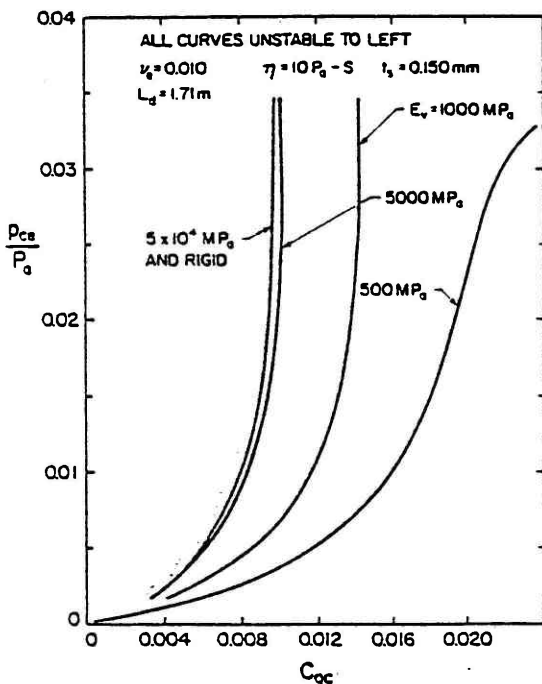


Figure 9 Predicted Effect of Elastic Modulus on Dynamic Stability

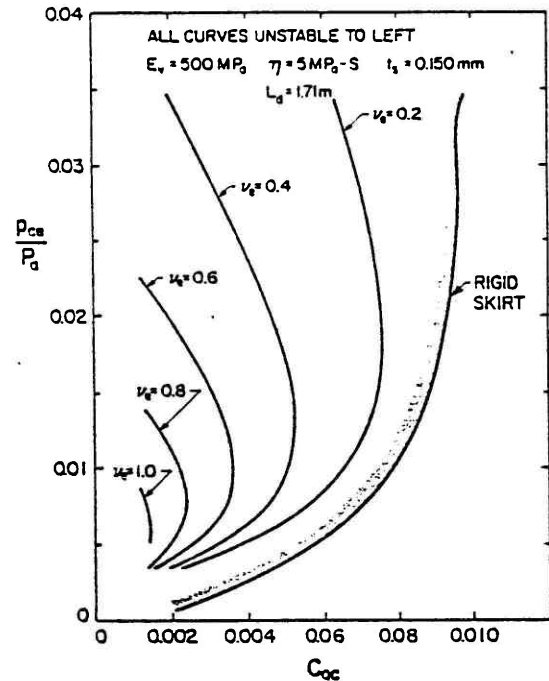


Figure 10 Effect of Skirt Contraction on Dynamic Stability Ref. 3

MATERIAL PROPERTIES

.....The elongation characteristics of a skirt system are a function of three principle components:

- (1) type of yarn - Kevlar versus Nylon
- (2) the weave - triaxial versus biaxial
- (3) construction technique - molding versus hot bonded rolls.

.....TENACITY vs. ELONGATION graph shown in figure 11 demonstrates that the type of yarn chosen for any skirt system will significantly alter its performance. Three materials are displayed on this graph. Linear Low Density polyethylene (LLPE), two types of nylon 66, and two types of Kevlar 29 and 49. The Linear Low Density Polyethylene (LLPE) shown in this graph is significantly stronger than the Low Density Polyethylene (LDPE) films being used in research models. Polyethylene is sometimes chosen for research models because of its isotropic stiffness behaviour. Light weight dacron materials and nylon materials have been widely selected for scaled model tests. These materials exhibit a similar performance depicted by the nylon 66 curves. They stretch approximately 25% to breaking point and although considerably stronger than the polyethene materials still produce an elastic skirt system. In contrast, Kevlar 29 and Kevlar 49 only stretch 4% to 5% to a breaking point which is approximately 3 times the strength of nylon. Kevlar has been incorporated into inelastic skirt systems which although flexible exhibit very little heave.

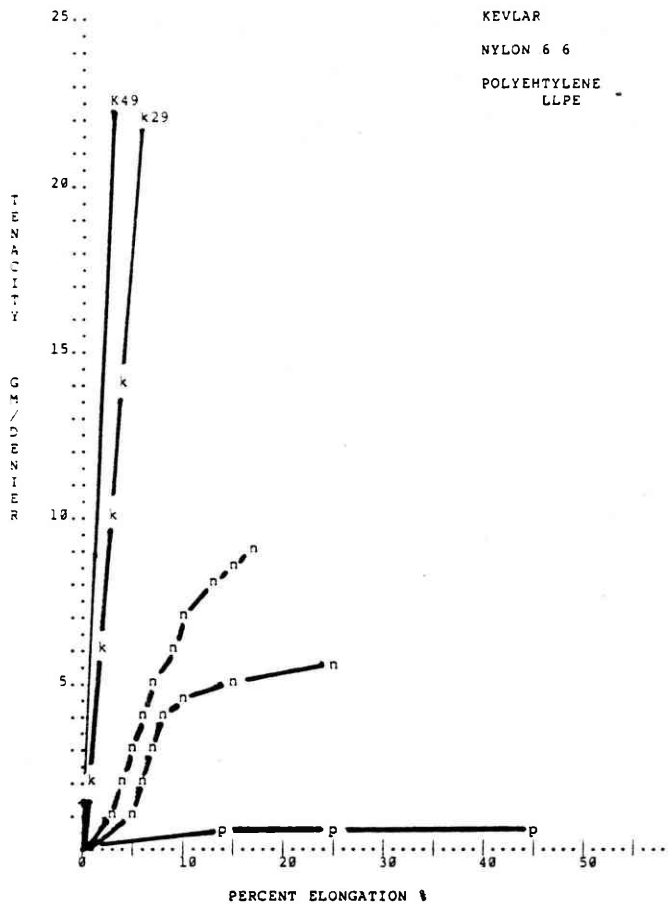


Figure 11 Tensile Strength Ref. 9 Ref. 10

.....The GRAB and TEAR STRENGTH vs. COATED FABRIC WEIGHT, figure 12 displays a typical suppliers' published material specifications. Grab Strength (g), tear strength (t), and adhesion peel (ap) are shown. Again, Kevlar demonstrates its superior strength to weight per ratio over nylon. Note, the adhesion peel of the neoprene/natural rubber does not increase with grab strength or tear strength resulting in delamination and weak seams. Figures 13-16 show tear propagation in biaxial and triaxial fabrics.

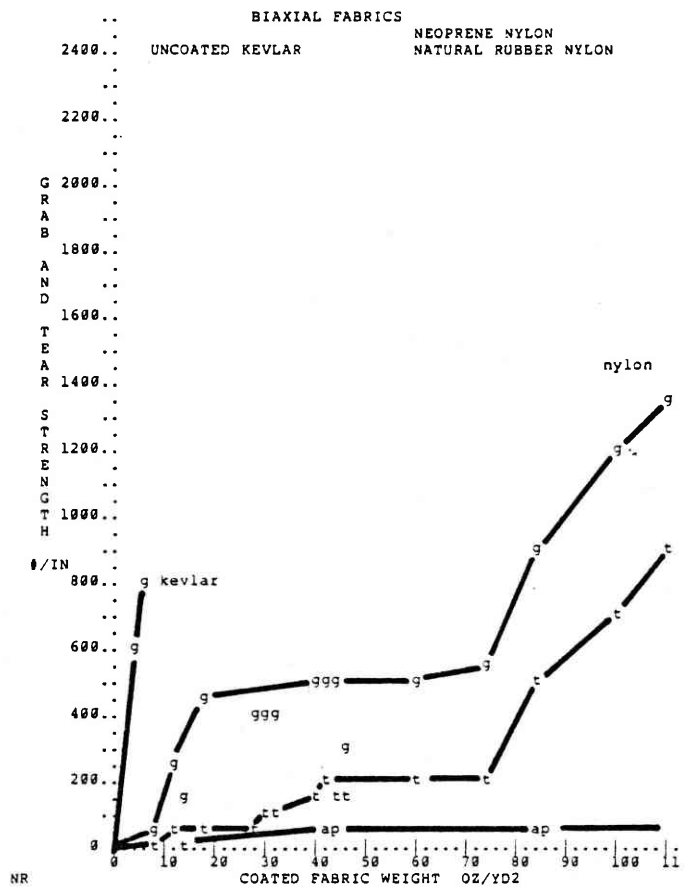
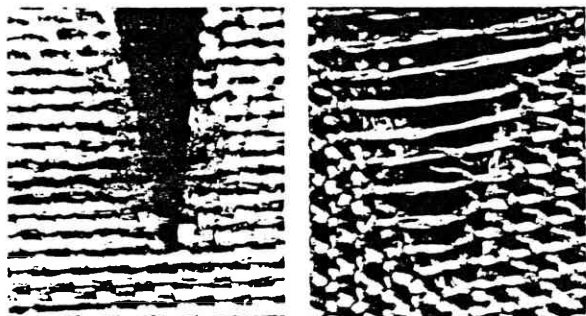
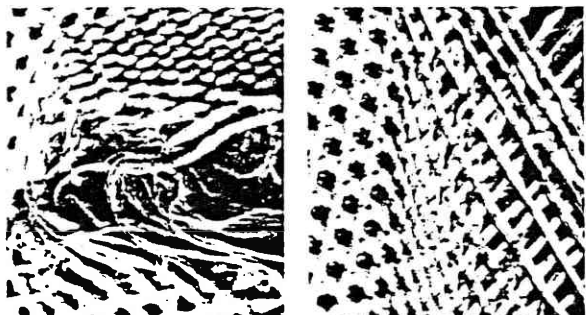


Figure 12 Ref. 11 Ref. 12



Tear propagation in a biaxial woven (crack propagation test method). Only one yarn system opposes tear. Tear propagation in triaxial woven (crack propagation test method). Two yarn systems oppose tear.



"Roping" of yarn inherent to triaxial weaves inhibits tearing. Trapezoidal-tear test of triaxial woven (note two opposing yarn systems and "roping" of yarns).

Figures 13,14,15,16 Ref. 8

.....The MULLEN BURST vs. COATED FABRIC WEIGHT figure 17 shows that the type of weave chosen also has a significant effect on the ability of a skirt system to resist distortion under load. The Mullen Burst Strength of a triaxially woven nylon material (3m) is approximately 9 times the Mullen Burst Strength of a biaxially woven nylon. A 14 ounce triaxial Kevlar was also tested, however the material exceeded the capacity of the equipment at 2000 lbs. per inch (3mk). This graph also shows that increased coating thickness does not increase the strength of the basic fabric.

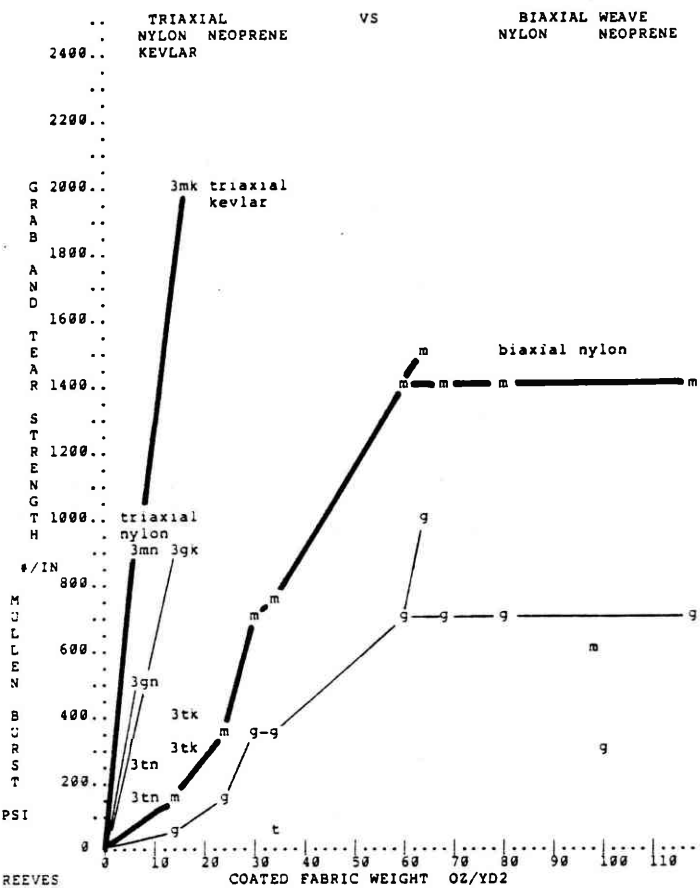


Figure 17 Ref. 12

.....CRACK PROPAGATION. Biaxial fabrics will generally tear along a straight line which is a path of minimum resistance shown in figure 18. Two opposing yarn systems in the triaxial fabric shown in figures 19-21 cause a tear to change direction, resulting in the crack propagation being arrested in a shorter linear distance. The triaxial weaves show greater resistance to small ruptures propagating into a major catastrophic failure of the textile structure.

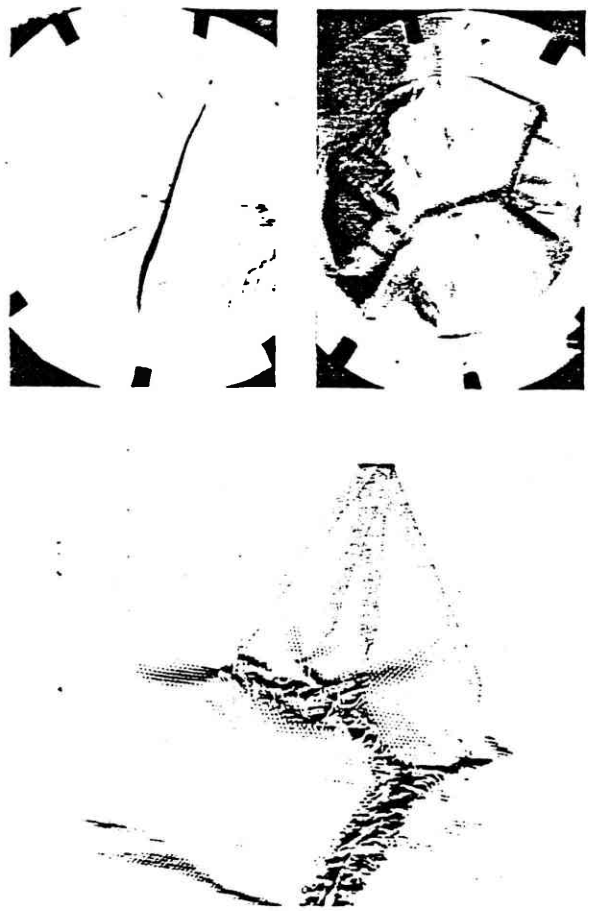


Figure 18,19,20,21 Ref. 8

.....The ABRASION WEAR vs DISTANCE chart shown in figure 25 compares Kevlar, Chopped E Glass and Oak Wood as reinforcing materials. In this abrasion test all the various materials were imbedded in identical polyester resin blocks which were then weighted and pulled over an asphalt road surface for 40 miles. The Kevlar 29 Felt sample showed only 2.2 mm of wear which is 30% of the chopped E Glass sample wear. Similar results can be expected when Kevlar 29 felt is imbedded in the thick polyurethane coating which covers the high abrasion wear areas of an air cushion vehicle skirt system.

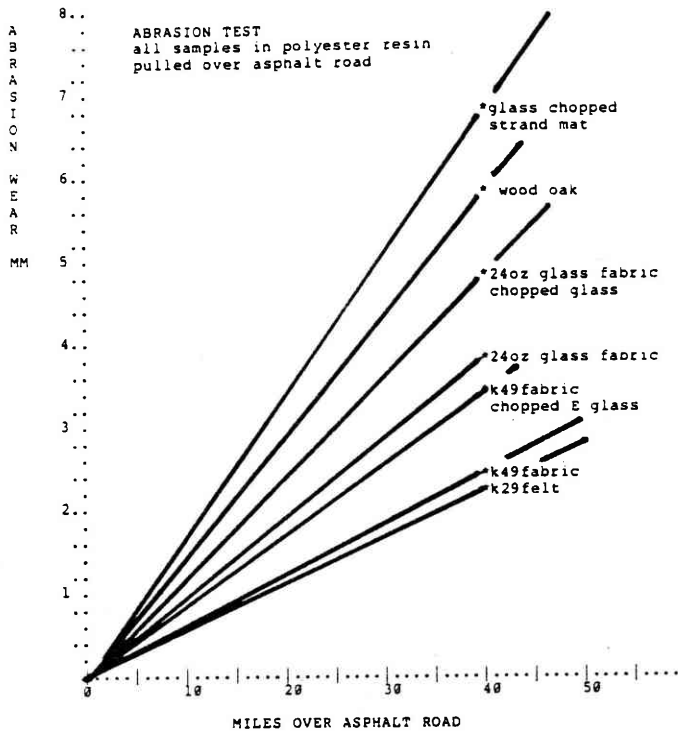


Figure 25 Abrasion Test

CONCLUSION

After completing a parametric study of the new concepts and structural capabilities available through this moulding technique designers will be able to extend the current operating window of their vehicles and reduce maintenance costs.

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