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DESIGN CONCEPTS FOR A COMPOSITE DOOR FRAME SYSTEM FOR GENERAL AUTOMOTIVE APPLICATIONS

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16 Abstract

Conceptual designs, manufacturing process, and costs are explored to determine the feasibility of replacing present steel parts in automotive door structures with various composite materials. The problems of conforming to present Federal anti-intrusion specifications with advanced materials are examined and discussed. Weight savings of 70 to 80 percent were projected for a door beam application and of 50 percent for a total door application. However, these large weight reductions required a substantial per part cost increase. More modest weight reductions, at competitive costs, were identified for the utilization of specific composite materials in automotive door structures.

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TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

1.0 SUMMARY

This report presents the results of a program to develop the conceptual designs, manufacturing processes, and costs of composite door components for a general automotive application. The design aspect of the report included an evaluation of the effects of applying various composite materials to the door structure. Materials such as glass, kevlar, and graphite fibers in both continuous laminate and fiber molding forms were considered in an effort to provide minimum weight, materials, and manufacturing costs. Also included in the manufacturing evaluation was the determination of the optimum manufacturing process to be used for each conceptual design. Manufacturing processes such as filament winding, compression molding, and injection molding were considered from both a strength and economic standpoint.

The development of each concept required the examination of how each of the various loading requirements affected the design. After several design iterations it became evident that the application of composite materials to the general door structure would be dictated mainly by the component stresses developed in the door from the intrusion loading requirements. These requirements were described in the Federal Motor Vehicle Safety Standard report 214 (MVSS No. 214). The intrusion loading condition required that the door structure demonstrate certain energy-absorbing characteristics; and it was this loading condition that developed the highest stresses in the door structure. It was then realized that the design philosophy, not the design goal, exhibited in the MVSS No. 214 loading requirements severly restricted the application of composite materials to an automotive door. The anti-intrusion loading criteria was written around the characteristics of large yielding, deformable materials. Since these characteristics are not inherent in composite materials, the designer must severly restrict the regions where he can apply composite

STAR category 27

1.0 PAGE TWO

materials. Therefore, an understanding of the implications of this loading condition required an extensive preliminary stress analysis of two key components in the door - the anti-intrusion beam and the interior door panel. Numerous beam and panel designs were evaluated on their ability to withstand the stringent intrusion load requirements. Both components efficiently utilized composite materials and enhanced the energy-absorbing capabilities of the door. All other door components remained metal from either economic considerations or from the strain-yielding requirements imposed through the intrusion loading condition (MVSS No. 214).

In conclusion, very significant weight savings were obtained by the use of composite materials in automotive door structures. The area where these benefits appear to be the greatest are in the anti-intrusion beam. The anti-intrusion beam can demonstrate a weight savings of 70-80%.

It must be stated, however, that the MVSS report 214 could be expanded to incorporate the characteristics of composite materials and still provide the car occupants with an equal or greater amount of crash protection than is now provided in the requirements. Expansion of MVSS report 214 to incorporate the material characteristics of composite materials could yield significant cost and weight savings that are not now permissable due to the present design criteria.

2.0 INTRODUCTION

With the emergence and subsequent development of advanced composites during the last ten years, a highly promising new family of materials is now available for consideration in automotive applications. Initial evaluations and applications have indicated that impressive savings in weight can be obtained through the use of these materials.

It was the overall purpose of this program to conduct a comprehensive conceptual design study of the application of composite materials for a general automotive door. This study not only considered the criteria of lower weight, but placed emphasis on minimizing the material and fabrication costs associated with the manufacture of a composite door.

In general, the weight and cost of numerous designs utilizing several materials and manufacturing processes were considered and are described in this report.

3.0 DISCUSSION

The basic objective of this program was to develop conceptual designs and costs of a composite door for a general automotive application. This objective included the evaluation and determination of the potential weight and production costs of individual door components compared to equivalent metal door components. Two methods of applying composites to the door structure were employed. The first method considered replacing an existing metal part with a composite part with no change to the geometry or attachment of the component. The other method involved major component redesign so that more efficient composite designs could be employed. For each composite component, various manufacturing processes were considered from both an economic and strength standpoint.

Since the primary objective in utilizing composite components is to reduce weight at competitive costs, a door from each of two competitive mid-sized automobiles were procured, and disassembled to allow a study of the weight make up of the door. The doors obtained were a complete assembled door from a 1975 Chevrolet Nova and a door structure from a Volare/Aspen. The weights obtained and used in this study are listed in Table 1.

TABLE 1

Car Door Weight Analysis
Complete Door
Model 1975 NOVA 4 door LH (Front) Door

ITEM	DESCRIPTION	WT. (lb)	PERCENT
1	Upholstered Panel (interior)	6.81	7.85%
2	Chrome Trim	.61	.70
3	Rubber Molding and Window Guide	2.04	2.35
4	Window (glass only)	11.30	13.03
5	Window Winder Mechanism	4.82	5.56
6	Window Support	.62	.71
7	Latch and Lock	1.79	2.06
8	Handles	1.85	2.13
9	Nuts, Bolts, Small Plastic Parts	.47	.54
10	Inner Structure	23.97	27.65
11	Anti Intrusion Beam	16.60	19.15
12	Outer Skin	13.04	15.04
13	Outer Skin Coating (dampening)	2.23	2.57
14	Misc.	.57	.66
	TOTAL	86.72	100.00

Structure Only 1975 Nova

1	Inner Structure	23.97	42.93%
2	Anti Intrusion Beam	16.60	29.73
3	Outer Skin	13.04	23.35
4	Outer Skin Coating	2.23	3.99
	TOTAL	55.84	100.00

Structure Only 1976 Volare/Aspen

1	Inner Structure	23.69	40.49%
2	Anti Intrusion beam	17.56	30.01
3	Outer Skin	15.51	26.51
4	Outer Skin Coating	1.75	2.99
	TOTAL	58.51	100.00

3.1 REQUIREMENTS

Before the conceptual designs and costs of the composite door components could be developed, several structural and manufacturing requirements were defined. These requirements established the major part of the guidelines that affected the design and manufacturing philosophy of the program. The following sections list the requirements that were considered in this report.

3.1.1 DESIGN REQUIREMENTS

In order to generate the conceptual composite designs, the following structural design requirements were considered. The door must withstand:

1. A slam test at 6 feet per second for 50,000 cycles without any fatigue failures.
2. A moment of 600 ft.-lbs. at the hinge location with no permanent set and with loads applied in a cantilever bending test at full open and 15° open.
3. Five cycles of hard openings.
4. A vertical load of 250 lb.
5. The intrusion test defined by the Federal Motor Vehicle Safety Standards (MVSS 214).
    - The door must withstand an average load of 2,250 pounds over the first 6 inches of deflection.
    - The door must withstand an average load of 3,500 pounds over the first 12 inches of deflection.
    - The door must withstand a load of 7,000 pounds or two times the curb weight of the vehicle, whichever is less, over the first 18 inches of deflection.
6. A dynamic load applied to the door hinge stops at 4 fps. At the end of 5 cycles, the maximum allowable door set is .060 inches. At the end of ten cycles, the maximum allowable door set is .10 inch.
7. All loading requirements with movable hinge attachments, and numerous cut-outs in the interior panel.

3.1.2 MANUFACTURING REQUIREMENTS

Manufacturing techniques for parts utilizing aerospace composite materials have been developed to produce the parts at the lowest total cost per part. In aerospace applications quantity is extremely low and tooling cost is highly important in the cost of the completed components. Therefore, high strength aerospace parts have been characterized by the use of limited tooling, the input of large amounts of hand labor and low material yields (low finished part weight versus the raw material that is used). The manufacturing requirements for automotive application are directly opposite those used for aerospace parts. The automotive manufacturing process must be capable of producing thousands of parts each day. It must also be capable of producing these components at minimum cost. The extremely high volume of automotive applications does have the advantage of amortizing expensive tooling over large quantities of parts. Especially in the case of structural components that are not visible in the completed automobile. A single component may be utilized for several similar models of cars and may have a life of several model years. This means that the tooling can be amortized in some cases over millions of parts. Therefore, in this study we have limited the consideration of manufacturing techniques to match tool molding. This process offers minimum labor input and minimum material usage.

Injection molding also meets these criteria and was considered briefly. Injection molding was rejected, however, since all known injection moldable materials will not qualify for highly stressed structural applications on the basis of their strength. Normally injection molded materials, even when reinforced with short fibers are several times in strength lower than the continuous filament reinforced compounds which have *been proposed by this study. In order to compensate for the low strength levels of injection moldable materials it would be necessary to increase the sections to the point where weight savings over the steel component to be replaced became negligible. Since most injection moldable compounds, especially those exhibiting the higher strength characteristics, are several times more expensive than steel, injection molding as a viable process was not considered.*

The next problem evident in the utilization of aerospace composites is the cure time required on the resin matrix. Resin matrices for aerospace composites have been formulated to yield the maximum strength, the maximum bond between resin and filament and in many cases, maximum heat resistance obtainable. This has resulted in a large family of resins that are expensive to manufacture and that require lengthy cure cycles. Cure times of several hours are not that uncommon. It is obvious that the utilization of a composite component in an automotive application would require a resin matrix that is capable of curing in under three minutes. Many polyester resins and hybrid epoxies are available with extremely short cure times and further study of this problem would yield resins that could be married to the aerospace reinforcement that would satisfy the cure requirement of the automotive industry. It is also anticipated that any high production automotive use of a composite materials would require the use of on-site material preparation where the reinforcement would be impregnated immediately prior to the molding or the resin would be injected into a mold cavity. In this case the aerospace concerns of long stability of resin matrices could be largely ignored.

3.2 MATERIALS

The composite materials which were considered for application to the study effort, along with their projected costs in the appropriate time period, are shown below.

Material	Cost per Pound	Time
Glass Epoxy	$1.00	1977
Kevlar Epoxy	6.16	1980
Graphite Epoxy	6.48	1980

A number of other types of composite materials exist, but it was felt that either they had too little potential compared to those listed or their developmental stage and/or data availability did not warrant their inclusion at this time in this type of study. All material studies were based on the use of an epoxy matrix. It is realized that automotive production requirements would dictate the use of polyester matrix but almost all data available on aerospace composites is based on epoxy and it was not felt that the strength characteristics would be different enough to cause excessive error in the study (Ref. Table 2).

TABLE 2

MIL-R-7575C Resin, Polyester, Low Pressure Laminating Grade B		MIL-R-9300 Resin, Epoxy, Low Pressure Laminating
65,000	Flexural, Ultimate	75,000
3.2×10^6	Modulus	3.2×10^6
50,000	Tensile, Ultimate	48,000
45,000	Compression, Ultimate	50,000

3.3 DESIGN CONCEPTS AND ANALYSIS

The most stringent requirement that faces the use of composites in the structures of automobile doors is that presented by the Federal anti-intrusion specification. With this in mind, component change that would allow compliance with this specification in its present form are presented here. Figure 3.3.1 presents a trimetric view of the existing door structure of the Volare, two door model with the outer skin removed for clarity. As can be seen, the door has seven main structural parts: inner panel, outer panel, hinge (forward) pillar, lock (aft) pillar, upper pillar connecting beam, lower pillar connecting beam, and anti-intrusion beam. Two anti-intrusion beam substitution concepts are presented and then discussed in the analysis section. One composite inner door panel concept is then presented and discussed in a later section.

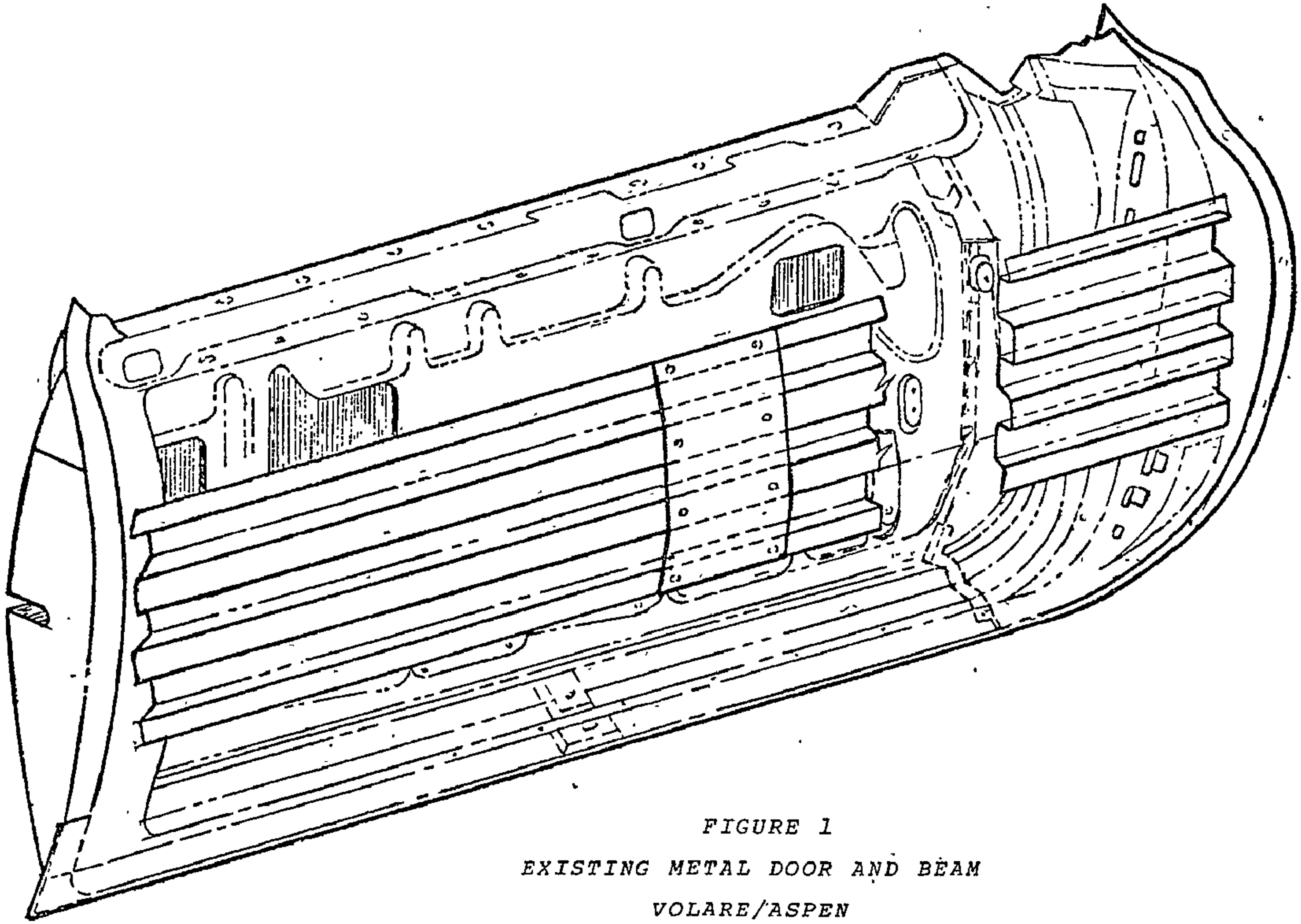


FIGURE 1

EXISTING METAL DOOR AND BEAM

VOLARE/ASPEN

3.3.1 ANTI-INTRUSION BEAM CONCEPTS

Perhaps the single, most beneficial, weight savings possible in applying composites to an automobile door structure is in the direct substitution of an appropriate composite beam for the metal anti-intrusion beam. However, care must be taken in the design of the composite beam as it is inherently a non-yielding structure. This is detrimental as a metal beam's plastic action serves to absorb larger quantities of energy than its elastic deflection. Although the composite beam does not have this plastic ability, it is compensated for by its lower modulus of elasticity which gives a larger deflection for a given load and thus a greater elastic energy capability. A comparison of these load deflection characteristics is deferred to the next section where they are discussed in more detail.

Two possible concepts are proposed for use as an anti-intrusion beam. The first is shown in Figure 2 and is a direct material substitution into the existing beam's geometry. Here the beam behaves in the same manner as the metal beam only it takes advantage of the composites lower Young's Modulus and higher ultimate strength. The left end of the beam is bonded to the existing metal attachment piece which is then welded in place on the door hinge pillar as is currently done. The right end of the beam is bonded to a composite doubler sheet which is in turn directly bonded to the metal lock pillar in the same location that the metal beam is currently welded. The use of the doubler plate gives flexibility in sizing for required bond sheer strengths.

The second concept is depicted in Figure 3. Here, two composite belts are separated by structural foam standoffs.

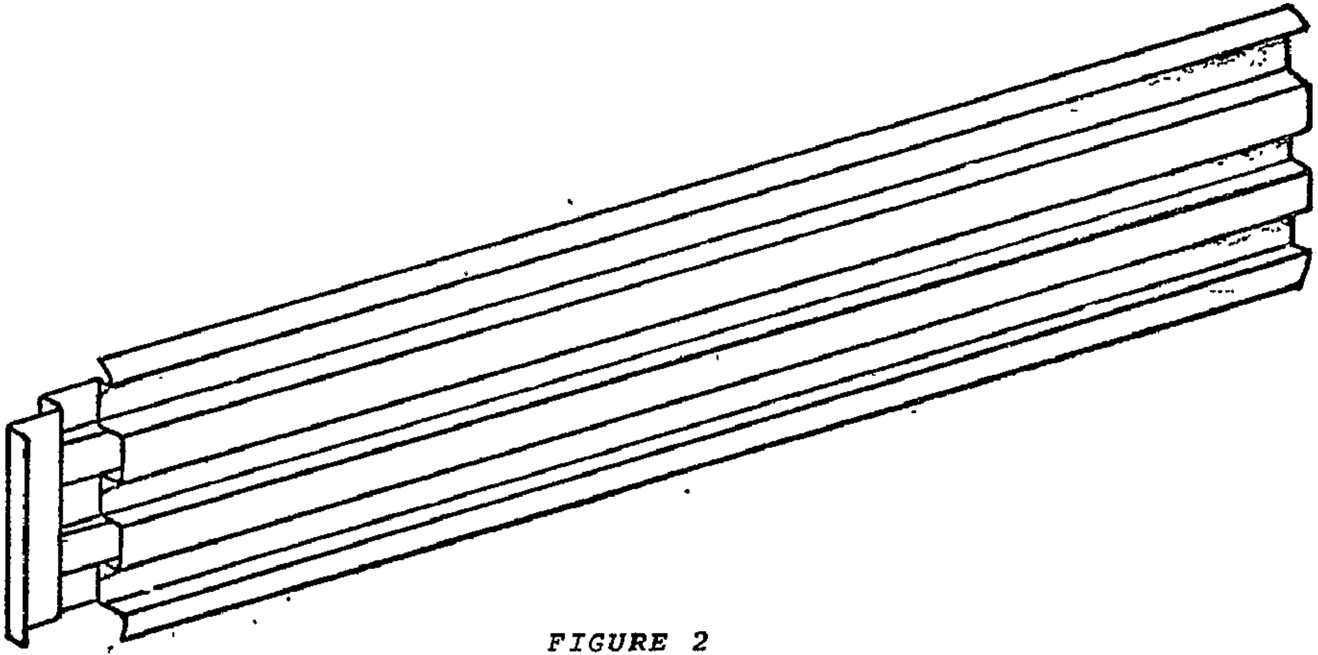


FIGURE 2

COMPOSITE BEAM DIRECT SUBSTITUTION

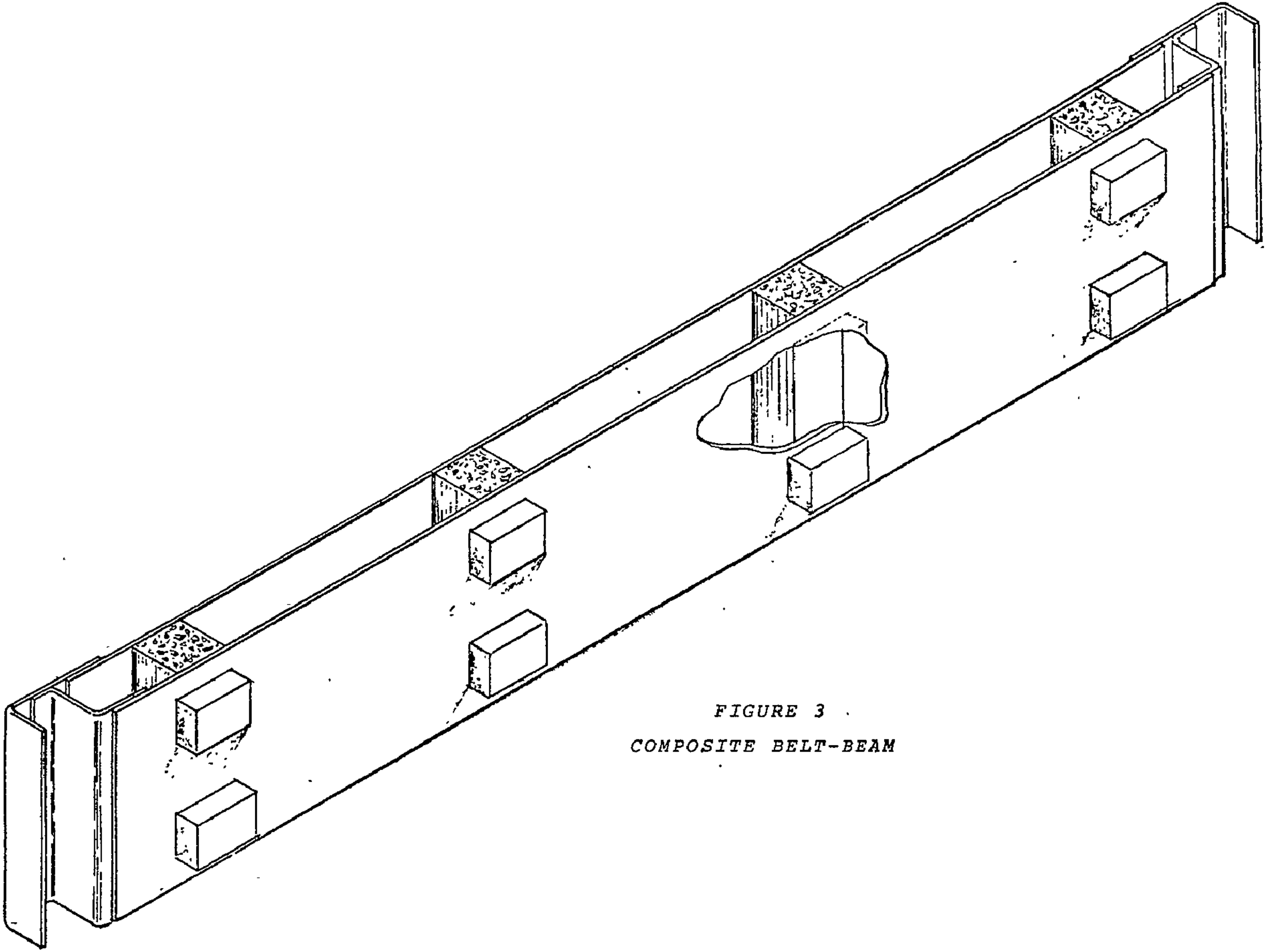


FIGURE 3

COMPOSITE BELT-BEAM

3.3.1 PAGE TWO

The ends of the beam are bonded to high strength steel plates which are in turn welded to the door pillars. Local external foam standoffs are also shown. These are pressed against the outer door skin and would act as vibration dampers to give the door a "solid" closing sound. They are shown in this figure but are also applicable to both the previous concept and the existing metal beam. Use of the vibration standoffs would allow for the elimination of the sound suppression material that is sprayed on the inside of the exterior door skin on many models. This would result in both cost and weight savings. However, this benefit is not further detailed in this study.

The double belt concept acts in a dual mechanical fashion. Initially, the internal standoffs make the composite belts behave together as a beam. After a predetermined load is reached, the standoffs would shear away and allow the belts to act independently. In this mode the prime load carrying would be by membrane action of the individual belts. It is this mode that forces the use of high strength steel on the ends of the beam as it must also be capable of carrying the developed membrane loading.

3.3.2 ANTI-INTRUSION BEAM ANALYSIS

Replacement of the metal anti-intrusion beam with a composite structure such as the concepts outlined in the previous section must be accomplished in a manner that allows the door to meet Federal Motor Vehicle Safety Standard No. 214. This standard outlines motor vehicle side door strength requirements that minimize the safety hazard potential of foreign object intrusion through a door into the passenger compartment. Summarily, the test door is centrally loaded by a device that records applied load vs. outer skin deflection over a total travel of 18 inches. To meet the standard, the average force over the first six inches of travel must exceed 2,250 lbs., the average force for the first 12 inches must exceed 3,500 lbs., and the maximum load recorded over the entire test must be greater than 7,000 lbs.

The results of a typical intrusion test are shown in Figure 4. The values shown are representative and are used to illustrate the influence of the various structural components as they each in turn contribute to the intrusion resistance.

As can be seen from Figure 4, the intrusion beam plays an important part in energy absorption during the initial phase of the test. In the Volare configuration, the outer skin carries the intrusion load alone for the first 0.75 inches until it bottoms out against the anti-intrusion beam. From here the intrusion beam acts in series with the outer skin. Elastically, the beam adds load linearly with intrusion until the beam outer fibers reach their yield point. This occurs at approximately 2.5 inches and at a stress value of 50,000 psi in the beam which is typical of the lower strength steels used by the industry in anti-intrusion beam applications.

Subsequent plastic beam deformation to approximately 4 inches intrusion adds considerably to the energy absorption

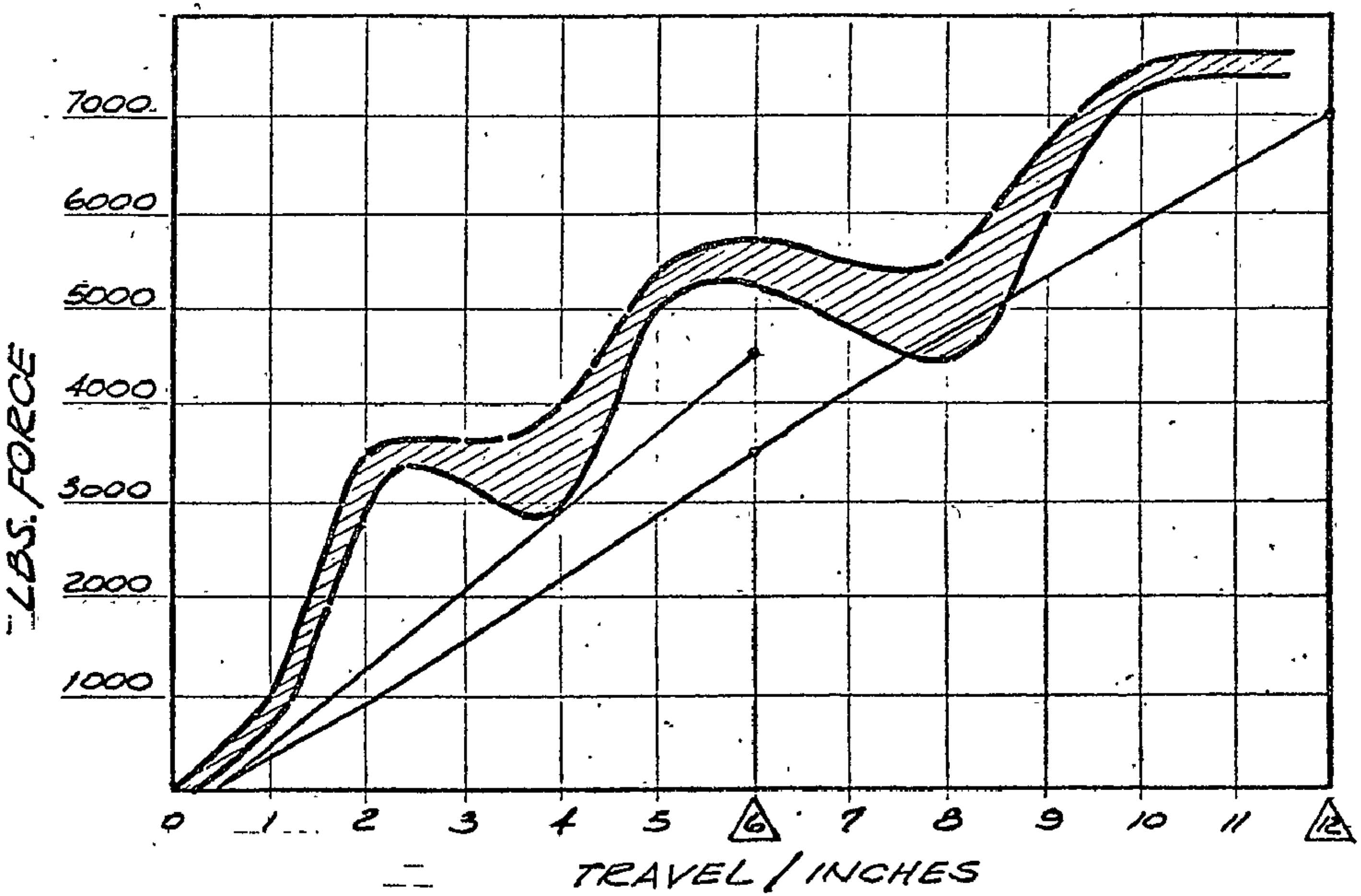


FIGURE 4

TYPICAL LOAD DEFLECTION CURVE

EXISTING METAL DOOR

at which time the window glass and supporting structure act in series with the beam. The intrusion test continues with a shattering of the window glass, subsequent pick up of the inner panel structure at approximately 9 inches intrusion, and continued load application until test completion. If the peak load requirement of 7,000 lbs. is satisfied within the first 12 inches of intrusion, the test is often terminated here as all necessary data has been obtained.

The exact behaviors of the various door structural components during the intrusion test is very complex in nature. For example, the outer door skin very quickly leaves the realm of small deflection plate behavior. With large deflections, a considerable membrane force is developed in the skin and at some point plasticity further complicates matters. Likewise, this behavior of the anti-intrusion beam quickly develops into non-linear, large deflection, plastic action. Additionally, the reaction loads of the outer skin and beam, tend to deform their attachments points on the hinge and lock pillars. Classically, then, the skin and beam must be considered as fixed to yielding supports.

As one can imagine, the exact analytical prediction of the behavior of a door subjected to the anti-intrusion test is a very complex sequence of events. Testing is currently, and for some time will remain, the least expensive method of determination of suitability. However, some general guidelines can be postulated to guide the redesign of various components of the door.

For example, in considering the replacement of the anti-intrusion beam, classical analysis of a centrally loaded, simply supported beam can be considered from a load deflection standpoint. The area under the load deflection curve that characterizes a particular design should be at least equivalent to the corresponding curve for the original metal beam.

3.3.2 PAGE THREE

Likewise, on an inner skin replacement, the energy absorption capability of the replacement structure should equal or better that of the existing item when considered in a simplified analytical sense. The above philosophy is the one adopted here to judge the suitability of metal component replacement with composite counterparts.

The results of such a load deflection analysis for the case of the direct substitution of composites for metal using the existing Volare anti-intrusion beam geometry are shown in Figure 5. Here, three composite materials' (Graphite, Kevlar, and XMC-2 Glass) behavior is compared to that of the existing beam. Recalling that energy absorbed is equal to the area under the load deflection curve, it can be seen that the composite beams absorb more energy. Table 3 lists the energy absorption for each of the four beams. Thus with a direct substitution of either of the three composite beams for the existing metal beam, the requirements of the Federal intrusion specification would be met if design of the metal end pieces would allow sufficient deflection. Table 4 lists the weight savings of each of the three composite substitutive beams (XMC-2 Glass, graphite/epoxy, kevlar/epoxy) as compared to the present metal beam. As can be seen in the table, the composite beams demonstrate a 72-78% weight savings over the present metal beam.

Another beam replacement concept was shown in Figure 3. There, energy absorption was primarily dependent upon membrane type action of belts of composite material. In this situation, as is true of all very thin plate type structures, bending is negligible and the plate belt is limited at the point when the tensile stress of the cross section reaches ultimate. This is inherently more efficient than the use of a beam where bending induced tensile stresses on the outer fibers are the limiting quantity. However, in order for the composite to act as a membrane, it must be very "thin" in comparison to the existing

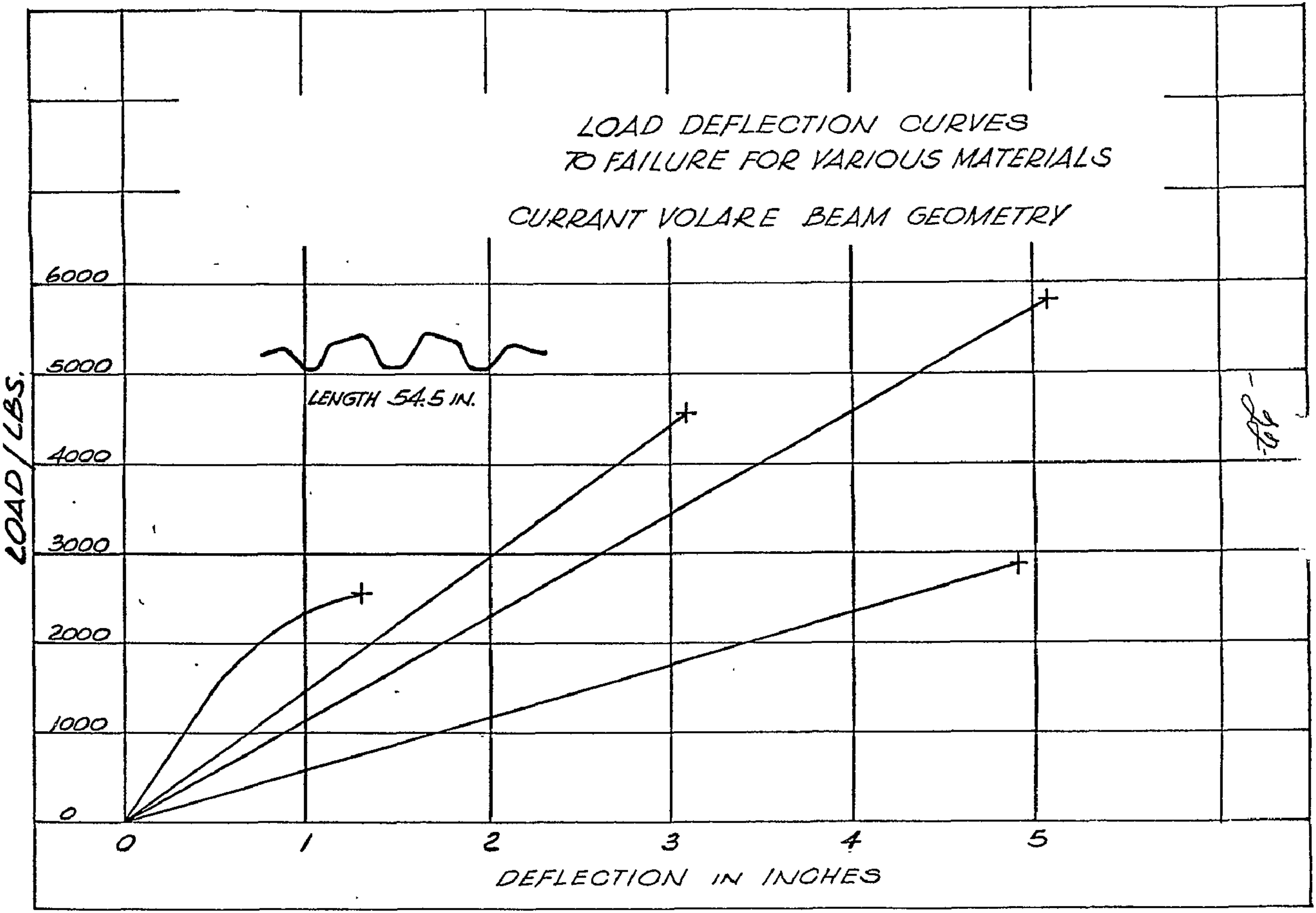

LOAD DEFLECTION CURVES
TO FAILURE FOR VARIOUS MATERIALS
CURRANT VOLARE BEAM GEOMETRY
LENGTH 54.5 IN.
LOAD / LBS.
6000
5000
4000
3000
2000
1000
0
0
1
2
3
4
5
DEFLECTION IN INCHES

FIGURE 5

TABLE 3

Table 3 - Energy absorption capability for various materials in existing Volare anti-intrusion beam geometry.

Material	Total Energy Capability	Improvement Over Metal Beam
Metal	1942 in. lb.	0%
XMC-2	7220 in. lb.	272%
Graphite	7004 in. lb.	261%
Kevlar	14845 in. lb.	664%

TABLE 4

Table 4 - Weight Savings of Direct Substitution Beams

Beam Material	Beam Weight (lb.)	% Weight Savings
Glass/Epoxy	4.86	72%
Graphite/Epoxy	4.22	76%
Kevlar/Epoxy	3.93	78%
Steel	17.56	0%

beam's cross section. As an example, consider the membrane load deflection curve for a 54.5 inch long "belt" that is 8 inches wide by 0.050 inches thick. Figure 6 shows the load deflection curve for a Kevlar, a Graphite, and a XMC-2 glass "belt". Also shown is a "belt" that uses the same type of steel as is in the current Volare anti-intrusion beam. Again, we can integrate under the curves to obtain the energy absorption capabilities of the various belt materials. Table 5 gives a comparison of the energy absorbed and percentage difference when compared to the current anti-intrusion beam. As can be seen from the table, the composite belt design has the potential of absorbing more than twice the energy of the direct composite substitution beam design. In fact, a single Kevlar belt alone could satisfy the initial crush resistance value, account for up to 70% of the intermediate crush resistance value, and satisfy the peak load requirements.

Considering, once again, the load deflection curves for the composite belts, it can be seen that very little energy is absorbed over the first few inches of deflection. This can be remedied by using two or more belts with structural foam standoffs between them. The standoffs would be sized to make the belts behave in unison, i.e. like a beam, over the initial deflection stage. Since the belts are separated from the "beam" center of gravity, a substantial inertia is obtained. This would then give rise to higher loadings during the early deflection stages than if the belts were acting alone. Then by strategic sizing, the standoffs would shear apart at a certain load value and allow the belts to act individually in their high load-carrying regime. Thus the best of both worlds, initial behavior as a beam and final behavior as a membrane

FIGURE 6 - LOAD DEFLECTION CURVE BELT-BEAM

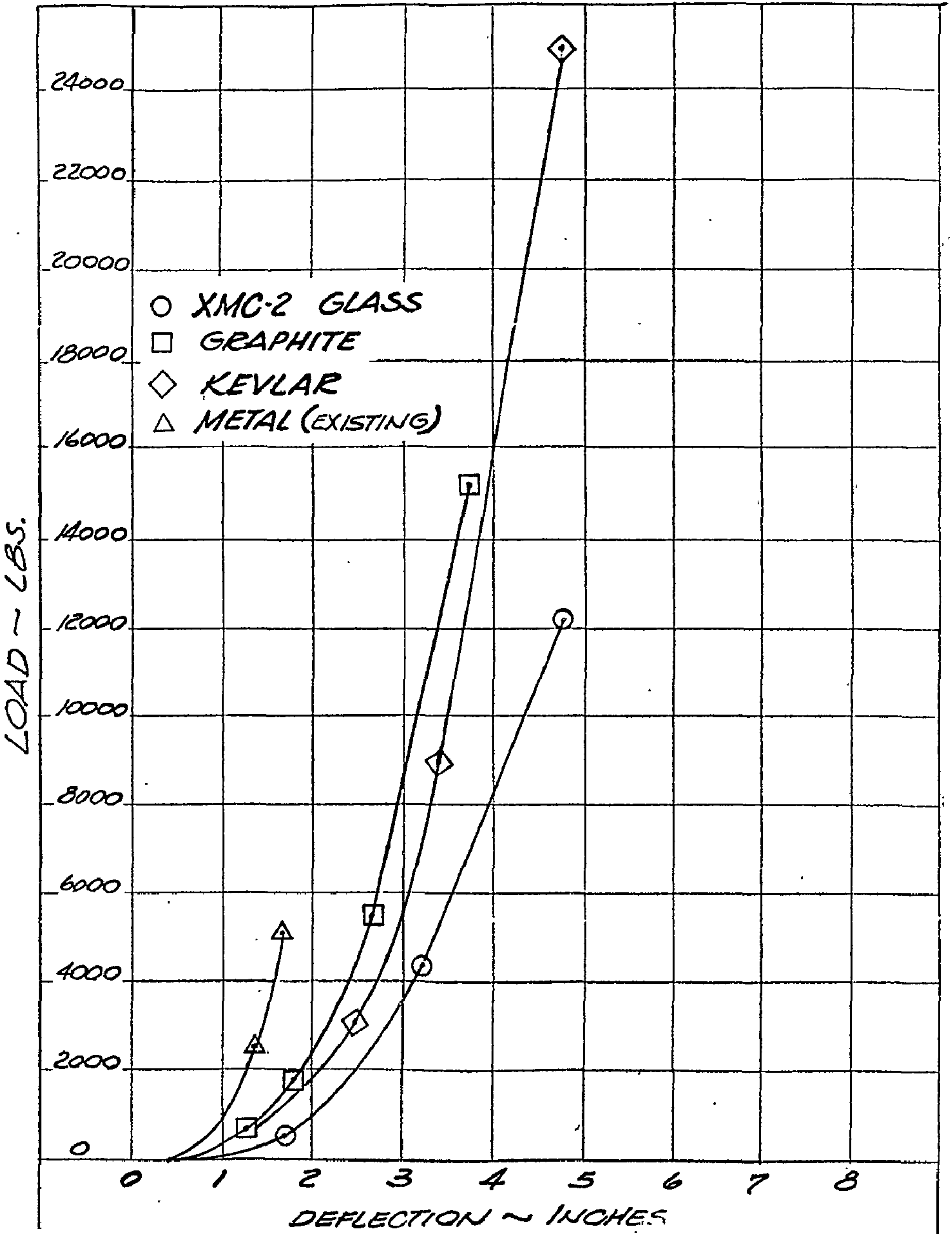


TABLE 5

Comparison of "belt" energy absorption values with existing anti-intrusion beam.

Beam Material and Type	*Total Energy Absorption Capacity*	*% Difference From Existing Beam*
Existing metal beam	*1,942 in. lb.*	*0%*
Metal Belt	*1,303 in. lb.*	*-33%*
XMC-2 Belt	*14,614 in. lb.*	*653%*
Graphite Belt	*14,411 in. lb.*	*642%*
Kevlar Belt	*29,981 in. lb.*	*1,444%*

3.3.2 PAGE FIVE

belt are obtained.

Table 6 lists the weight savings of each of the three composite "belt" beams (XMC-2 Glass, graphite/epoxy, kevlar/epoxy) as compared to the present metal beams. As shown in Table 6, the composite beams exhibit a 69-73% weight savings over the present metal beam.

TABLE 6

Weight Savings of Composite "Belt" Beams

Beam Material	Beam Weight	% Weight Savings
Glass/Epoxy	5.45	69%
Graphite/Epoxy	5.00	72%
Kevlar/Epoxy	4.79	73%
Steel	17.56	0%

3.3.3 INNER PANEL CONCEPTS

Composites in the form of molding compounds can be used to replace the inner door panel structure. On the Volare, the inner panel is welded onto the lock and hinge pillars. The composite substitution would be bonded on at the existing weld lines. The upper and lower metal framework at the inner skin would be maintained. Locally, the composite inner panel would be thickened as needed to counteract the brittle behavior of the composite in the stress concentration areas of the inner panel access cutouts. Thickening would also occur in the area of the arm rest attachment. Metal bushings would be molded in place to allow attachment of the arm rest. The inner panel substitution is depicted in Figure 7.

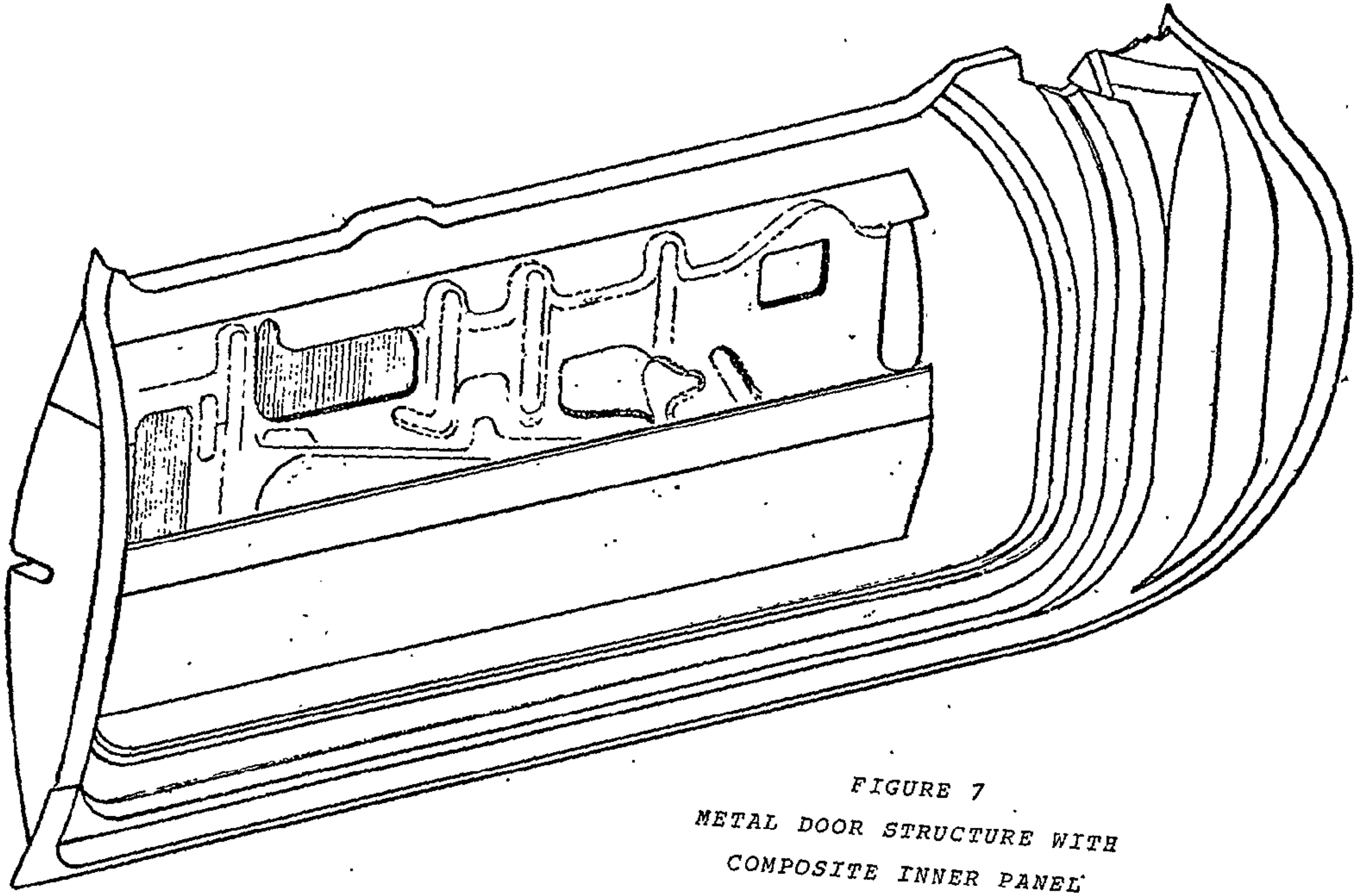


FIGURE 7
METAL DOOR STRUCTURE WITH
COMPOSITE INNER PANEL

3.3.4 INNER PANEL ANALYSIS

The inner panel is the last item to pick up direct loading on the anti-intrusion test. Referring to Figure 4 it can be seen that the inner panel begins to contribute to the energy absorption at 8 inches of deflection into the test. Since the total test requirements are usually met by 12 inches total deflection, the inner panel contributes only over the last 4 inches of test travel. From the figure it can be seen that over its first 2 inches of deflection, the inner panel adds 2,000 lbs. of load to the structural resistance. This then gives an effective spring constant of about 1,000 lbs./in. Since the spring constant is directly proportional to the Young's Modulus of the material used, a typical composite molding compound (Thornelmat) would yield a spring constant of about 170 lbs./in. This is about 1/6th of the metal beam's value. Because we are considering essentially a deflection limited load range of 4 inches, the composite inner panel would absorb 1/6th of the energy of its metal counterpart. Thus, in order to apply composites to the inner door panel we must do one of the following:

- Use the composite inner door panel in conjunction with a stronger composite anti-intrusion beam.
- Tradeoff a portion of the weight savings of a composite inner panel into a stronger, heavier metal anti-intrusion beam and use it to absorb the decreased energy absorbing capabilities of the inner panel.

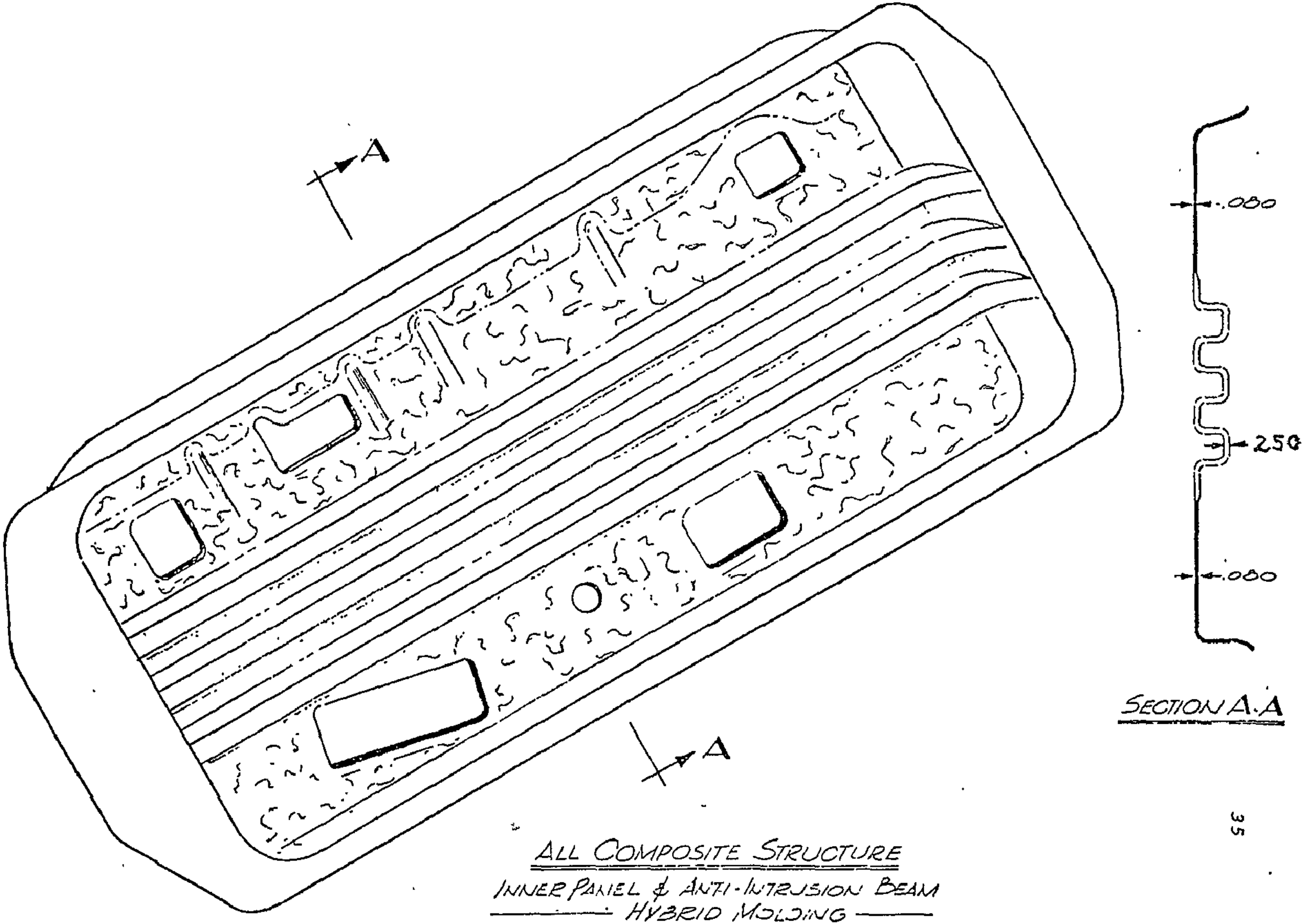
The weight of the replacable portion of the current inner panel is five pounds. Local thickening of the composite substitution is necessary to overcome the yielding behavior of the molding compound in areas of stress concentrations around the panel cut-outs. In these areas, the metal panel simply yields and redistributes the load through the rest of the panel. In the composite application, the part would crack at these high stress points and then propagate the crack to failure without an additional loading increase. Local thickening around these cut-outs would serve to decrease the local stress values and forestall failure. Local thickening would also have to be incorporated in the arm rest attachment region in order to transfer large vertical loads into the door structure. The basic thin sheet with many thickened areas dictates the use of a soft flow molding compound. It is extremely difficult to mold these compounds in thicknesses under .080". The locally thickened area would yield an estimated average thickness of approximately .125". The steel inner panel studied for replacement measured .037" thick. Size of the panel is 20" x 44", taking the various cutouts into consideration, the panel has a projected area of 480 square inches. A substitution of this area using a composite average thickness of .125" yields a structure of 60 cubic inches. Assuming a density of .069 lbs/cu. in., the plastic structure would weigh 4.14 lbs. Comparing this weight with a steel weight of 5 lbs. yields a weight savings of less than one (1) lb. per door.

It is highly doubtful that the problem associated with a conversion to composite materials on this application could be justified by the relatively small weight advantage.

3.3.5 ALL COMPOSITE STRUCTURE

At the beginning of the program an obvious goal was to develop a concept for an all composite door structure. The deflection requirements of MVSS 214, however, made any reasonable all composite structure impractical to achieve. Even the composite anti-intrusion beams developed (Figures 2 and 3) rely on metal end plates to achieve the deflection requirements of MVSS 214. An assumption was then made that the deflection requirements of MVSS 214 could be modified to include the characteristics of a composite. The concept then developed is shown in Figure 8. The design shows a combination inner panel and anti-intrusion beam. Materials proposed are a continuous filament molding compound in the area of the anti-intrusion beam and pillars and a chopped fiber molding compound in all other areas. Preforms would be loaded for the entire structure which would then be molded simultaneously. The weight of the all composite structure would be 27 lbs., which would replace 41 lbs. in the metal door for a weight savings of 14 lbs. per door, or 34 % on this structure. This weight is calculated on the use of XMC-2 molding compound for the anti-intrusion beam and pillars and HMC molding compound for the remainder of the structure. Similar molding compounds of other materials could be utilized for further weight savings at a cost penalty.

The anti-intrusion beam was sized to carry the peak load of 7,000 lbs. force with no contribution from the outer skin or the inner workings of the door. The long travel of the outer skin before contact is made with the beam would cause failure of the pillar attach points and the outer skin and anti-intrusion beam could not work in parallel. A more efficient design would be to combine the anti-intrusion beam and the outer skin panel, but due to finishing problems, this study provides that the outer skin would remain metal. Although the peak load of 7,000 lbs. would be carried by the all composite



ALL COMPOSITE STRUCTURE

INNER PANEL & ANTI-INTRUSION BEAM

HYBRID MOLDING

FIGURE 8

structure, total deflection prior to failure would be in the range of 2-3 inches, thereby failing the intermediate crush resistance requirement of the current MVSS 214.

3.4 CONCEPT OF FABRICATION

Compression molding is the favored method for fabricating all of the design concepts presented. Compression molding offers the only viable method of producing economical parts of requisite strength. The presses used would be hydraulically actuated with quick acting features. All molds would be of hardened chrome-plated tool steel, with built-in shear edges for part trimming and cutouts, and with automatic loading and ejection systems. For high quantity production, all materials would be prepared on-site. All reinforcements would be pre-impregnated rather than produced with a wet process to allow the closer control of resin-reinforcement ratios attainable with a pre-impregnated system.

Although the fabrication concepts presented are based upon the use of on-site impregnated materials and very high quality production tooling, any of the concepts may be simulated for test and prototype purposes by utilizing easily obtainable standard aerospace composites and relatively low cost tooling.

3.4.1 ANTI-INTRUSION BEAM FABRICATION

Both the direct substitution composite beam as shown in Figure 2 and the composite belt beam as shown in Figure 3 would have the reinforced composite components compression molded. Both designs utilize metal end attachments which are produced on conventional stamping equipment. The metal end pieces are used for conventional welding attachment to the lock and hinge pillars and are also to provide adequate deformation to met the requirements of MVSS 214. The metal end attachments would be adhesively bonded to the reinforced composite beam sections prior to installation into the inner door structure. The type of adhesive and the bonding area would have to be

3.4.1 Cont.

determined by a physical testing program. The adhesive used should have a high shear strength with some elastomeric properties as the loading on the adhesive bond line would change in character as the beam is deflected. The foam inner blocks and standoff pads shown in Figure 3, Composite Belt Beam, could be fabricated off-site and simply bonded on with a contact adhesive.

3.4.2 INNER PANEL FABRICATION

The separate inner panel would be compression molded from various types of molding compounds with random reinforcement orientation. As noted in paragraph 3.3.4, the primary problem with this structure is its relatively high weight due to minimum practical molding thicknesses on standard molding compounds. Future development of molding compounds capable of being processed with reliable strengths to very thin sections may make the application of a molded composite inner panel more practical than it appears at present. If such a method were developed, the inner panel would then be bonded to the hinge and lock pillar utilizing a fast curing adhesive.

3.4.3 ALL COMPOSITE STRUCTURE

The all composite structure as shown in Figure 8 would be compression molded at one time using two types of material. The oriented molding compound, such as XMC2 or other material with oriented reinforcement, would be preformed or laid in a pattern for the anti-intrusion beam, lock and hinge pillar portions of the door structure. In addition, two preforms of

<u>*3.4.3 Cont.*</u>

a bulk molding compound, such as HMC-2, would be loaded in the inner panel portion of the mold, then the entire structure would be molded and co-cured. Co-curing of the oriented compound, together with the bulk molding compound, has an added advantage in that the high flow bulk molding compound will fill out any low areas in the oriented composite preform. This means that the oriented portion of the preform may be much less precise than a preform fabricated of all oriented materials.

3.5 COST ANALYSIS

The advantages of composite structures in aircraft have long been acknowledged due to their special advantages of strength to weight ratios and other desirable properties. Unfortunately, composites, especially advanced composites, have also long been characterized by their high costs. This has effectively limited their use in aerospace and other highly specialized, low volume applications. Two factors have combined to make the use of advanced composites worthy of study for high volume automotive applications. First is the growing scarcity of fossil fuels and the resulting necessity of producing lighter, more efficient automobiles. Second is the lowering cost of advanced composites. For example, a few years ago graphite/epoxy was selling at prices up to $300.00 a pound. Current pricing is in the range of $30.00 to $50.00 a pound. Current and anticipated technical breakthroughs have allowed us to project the cost of graphite in the 1980 to 1985 time period at less than $10.00 a pound. Kevlar fibers developed by DuPont were marketed a few years ago in the $20.00 to $25.00 a pound range while current pricing lists commercial grade Kevlar as low as $7.50 a pound. It is anticipated that high volume usage of these materials by the automotive market would further lower these costs.

Advanced aerospace composites currently are processed by various low volume, high cost manufacturing steps. The metal automotive components are manufactured by highly automated efficient methods which have been perfected over many years. It is anticipated that the application of expensive tooling and automated methods will greatly reduce the cost of producing composite parts in high volume. Achieving efficiency approaching metal fabrication will be a long process and only in very special cases will composite components be able to compete with metal parts on a one to one basis. In the meantime, however, the long term cost of composite components may be less than metal parts due to the increased efficiency of the vehicle.

3.5.1 MATERIAL COSTS

Various assumptions have been made on the costs of advanced composites in the 1980-85 time period. The assumptions anticipate projected breakthroughs and lower costs due to increasing volume:

1.	*XMC-2 Glass Reinforced Epoxy*		*$1.00/lb.*
2.	*Graphite-Epoxy*		
	Graphite Reinforcement @ $8.00 x .65 =	*$5.20*	
	Resin Matrix @ $.80 x .35 =	*.28*	
	Impregnation Cost	*1.00*	
	Total per pound cost	*=*	*$~~6.48~~/lb.*
3.	*Kevlar Epoxy*		
	Kevlar Reinforcement @ $7.50 x .65 -	*$4.88*	
	Resin Matrix @ $.80 x .35 -	*.28*	
	Impregnation Cost	*1.00*	
	Total per pound cost	*=*	*$6.16/lb.*
4.	*Steel SAE 1015*		*$ .20/lb.*

Therefore, approximate materials costs for the proposed anti-intrusion beams would be as follows:

		RATIO
Metal Beam 17.5 lbs. @ .20	*$ 3.50*	*1.0*
Direct Substitution Beam		
Glass/Epoxy 4.86 lbs. @ 1.00	*4.86*	*1.39*
Graphite/Epoxy 4.22 lbs. @ 6.48	*27.35*	*7.81*
Kevlar/Epoxy 3.93 lbs. @ 6.16	*24.21*	*6.92*
Belt-Beam		
Glass/Epoxy 5.45 lbs. @ 1.00	*5.45*	*1.56*
Graphite/Epoxy 5.00 lbs. @ 6.48	*32.40*	*9.26*
Kevlar/Epoxy 4.79 lbs. @ 6.16	*29.51*	*8.43*

3.5.1 PAGE TWO

Approximate materials costs for the All Composite Structure would be as follows:

		RATIO
Metal Structure 41 lbs. @ .20	$ 8.20	1.0
All Composite Structure		
Glass/Epoxy 27 lbs. @ 1.00	27.00	3.29
Graphite/Epoxy 23.5 lbs. @ 6.48	152.28	18.60
Kevlar/Epoxy 22.0 lbs. @ 6.16	135.52	16.52

It can be seen from the above information that even with projected economies in the future production of composites that their use involves a substantial material cost penalty.

3.5.2 MANUFACTURING COSTS

The calculations of manufacturing costs are necessarily imprecise due to the unknowns involved. Assumptions made are that a sufficient amount of investment in facilities and tooling will be made to allow the lowest possible labor input into the manufacturing of a composite anti-intrusion beam. Manufacturing cost has in all cases been based on a rate of $20.00 per direct labor hour.

Metal Beam		
Current Production Cost (Est.) *(at $.25 per lb.)*		*$4.40*
Direct Substitution Beam		
One Molding	*$1.00*	
End pcs.	*.50*	
Bonding	*1.00*	
Total Cost		*$2.50*

Belt Beam		
Two Moldings	*$2.00*	
End pcs.	*2.00*	
Foam Blocks	*.50*	
Total Cost		*$6.00*

All Composite Structure		
One Molding (Large)	*$1.50*	
Trim	*1.50*	
Total Cost		*$3.00*

Other costs such as materials handling and assembly into the door structure are assumed to be equal although the composite beam may have a slight advantage due to its lower weight. The approximate costs of the various designs is summarized as

3.5.2 PAGE TWO

follows:

	COST	RATIO
Metal Beam	$7.90	1.00
Direct Substitution Beam		
Glass/Epoxy	7.36	.93
Graphite/Epoxy	29.85	3.78
Kevlar/Epoxy	26.71	3.38
Belt-Beam		
Glass/Epoxy	11.45	1.45
Graphite/Epoxy	38.40	4.86
Kevlar/Epoxy	35.51	4.49

The above data demonstrates that the Glass/Epoxy beam comes very close to demonstrating cost effectiveness versus the metal beam. The Graphite/Epoxy and Kevlar/Epoxy show costs 3 to 5 times that of the metal beam. It should be noted, however, that the Graphite and Kevlar costs are primarily traced to material costs. If a standard can be developed in MVSS 214 for the inclusion of composite beams, a testing program may reveal that the material weight and, thereby, the costs may be substantially reduced.

The all composite structure costs are summarized as follows:

	COST	RATIO
Metal Structure	$ 18.45	1.00
Glass/Epoxy	30.00	1.63
Graphite/Epoxy	155.28	8.42
Kevlar/Epoxy	138.52	7.51

3.5.3 CAPITAL COSTS

The manufacturing costs of composite components as estimated in paragraph 3.5.2 can only be obtained with sufficient facilities and tooling. This section will roughly estimate the capital costs associated with production of composite anti-intrusion beams. The estimate assumes a production requirement of 1,000 units per 8 hour shift.

DIRECT SUBSTITUTION ANTI-INTRUSION BEAM

Facility Items

1.	Single purpose treating machine	$250,000.00
2.	6-8 100 ton presses	300,000.00
3.	Adhesive curing apparatus (Oven or IR)	50,000.00
4.	Associated Equipment	100,000.00
	Total	700,000.00

Tooling

1.	6-8 Molds	$160,000.00
2.	Metal	30,000.00
3.	Fixtures	60,000.00
	Total	250,000.00
	GRAND TOTAL	$950,000.00

ALL COMPOSITE HYBRID STRUCTURE

Facility Items

1.	Single purpose treating machine	$250,000.00
2.	6-8 100 ton presses	300,000.00
3.	Associated Equipment	100,000.00
	Total	650,000.00

3.5.3 PAGE TWO

Tooling

1.	*6-8 molds*	*$280,000.00*
2.	*Fixutres*	*100,000.00*
	Total	*380,000.00*
	GRAND TOTAL	*$1,030,000.00*

Although the above estimates are imprecise, they show that the establishment of such an operation is not priced beyond reach. Prior to the commitment of any such sums, a great deal of work is required to develop and test the component on a prototype basis.

4.0 CONCLUSIONS

The conclusions reached during this program are summarized below and are based on the information shown and discussed in Section 3.0. The major value of the program was in identifying and designing door components which showed the greatest benefit through the use of composite materials and of quantifying these benefits.

1. The door component that offers the most dramatic improvements through the use of composite materials is the anti-intrusion beam. This component exhibits high weight savings, competitive long term costs and increased energy absorption over the existing metal components while still satisfying the stringent anti-intrusion load requirements. The composite anti-intrusion beam can provide an impressive weight savings of 70-80% (12-13.5 lbs.).
2. From a structural standpoint, the KEVLAR anti-intrusion beam offers the highest weight savings, i.e. 78% which is equal to 13.5 pounds per door; and the highest energy absorption, i.e. 1444% increase over the existing beam which is equal to 28,000 in.-lb.
3. The anti-intrusion loading criteria defined by the Federal Motor Vehicle Safety Standard report number 214 restricts the application of composite materials to an automotive door. MVSS report 214 was written around the characteristics of large yielding, deformable materials such as inherent in many common metals. The report must be expanded to incorporate the characteristics of composite materials. If MVSS 214 can be expanded, the all composite door structure should be further investigated. This concept would yield both the highest weight savings and the widest use of composite materials.

4. *Two composite anti-intrusion beam concepts were presented, the belt-beam and the direct substitution. It is fairly certain that the belt-beam concept could be used as shown to meet the current MVSS requirements. The belt-beam, however, has significant cost penalties as shown in Section 3.5. Use of the direct substitution beam would be, in part, dependent upon the end fittings having sufficient yielding properties to allow a minimum of 12 inches movement of the beam. Incorporation of the properties of composites into the MVSS document should easily allow use of the direct substitution beam.*
5. *Use of composite components for weight savings on structures such as the inner door panel that are characterized by large area to material thickness ratios is extremely limited. Little weight savings can be achieved and the cost would be prohibitive. This type of application would be limited to extremely low production components (such as the Corvette body panels) where lower tooling cost for composites is a factor, or where the component carries no appreciable structural load (such as inner panels) where the economics of injection molded inexpensive unreinforced thermoplastics can be utilized.*

5.0 RECOMMENDATIONS

Based on the information developed by this study, the following recommendations are made:

1. *A program should be established that requires the fabrication and testing of several anti-intrusion beams. This program would firmly establish the structural viability and manufacturing costs of composite door components. Structural soundness would be assured by both isolated component testing and integrated door testing; whereas, valid manufacturing costs would be established through the fabrication of an adequate number of components.*
2. *Establish a program that would incorporate proven anti-intrusion beams into a small fleet of automobiles. After a fixed period of time the beams would be removed, examined, and tested to establish the effects of the environment and loads on the components.*
3. *A study should be made to expand the Federal Motor Vehicle Safety Standard report 214 to incorporate the characteristics of composite materials. This study would not change the protection now provided to the car occupants, but would expand the definition of the crush resistance required by any automotive door structure.*
4. *An extensive study should be made to develop the conceptual design of a complete composite automotive door structure. This door would be designed with the anti-intrusion requirements dictated by an expanded version of the Federal Motor Vehicle Safety Standard report 214 to incorporate composite material characteristics. Finally, the weight and cost would be established*

for numerous component designs utilizing several materials and manufacturing processes.

5. *A study should be conducted to establish the cost and weight savings of applying composite materials to other automotive structures. Components such as roof beams, bumpers and axles may yield handsome weight savings with the use of composite materials. A rule of thumb guideline should be developed, based on the long term cost of operating an automobile, that would specify the worth in dollars of each pound saved from a vehicle's weight. This would act as a guideline and greatly simplify future studies.*

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