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HYBRID MATERIALS SUBSTITUTION FOR OLDSMOBILE OMEGA X-BODY COMPONENTS

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16. Abstract

This report provides an evaluation of the potential of weight savings for a 1980 General Motors X-body car through the substitution of lightweight composite materials for presently used metal materials. A total of 75 components of this vehicle are considered for substitution of lightweight materials. Based on equal stiffness for material substitution, analysis shows 495 pounds can be removed from this X-body car.

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PREFACE

The work described in this report was performed under contract P-80508 for the Department of Transportation, Transportation Systems Center, Cambridge, Massachusetts. The study was initiated to evaluate potential weight savings for passenger automobiles through the substitution of lightweight composite materials for presently used metal materials.

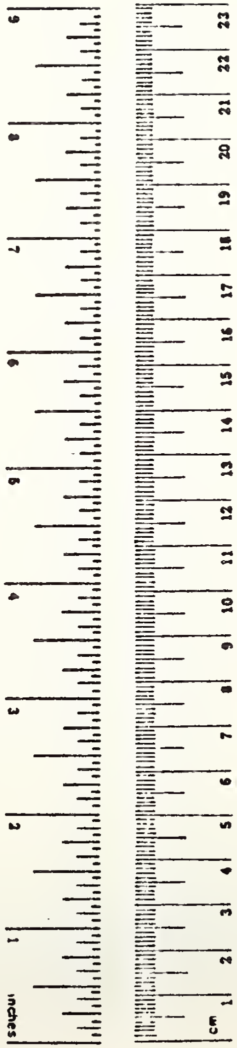
The principal contributor to the effort reprsented by this report was Mr. Stan Cross, Graphite Fiber Department, Hercules Incorporated.

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

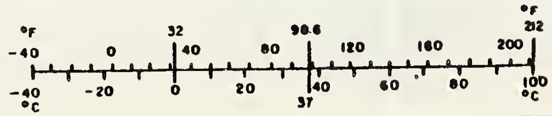
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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1. SUMMARY

Following review of the vehicle parts breakout, a total of 75 components for the 1979 Oldsmobile Omega X-Body were considered for potential substitution of lightweight materials. For the parts considered, an overall nominal weight reduction of 20% was estimated; for the 2269 pounds of current metal construction considered, 495 pounds were removed (see Table 1). The estimated weight reductions were based upon equal stiffness replacement since automotive construction is approximately 80% stiffness-dominated for structural components.

Materials selected for this study included state-of-the-art forms and processes recognized by the automotive industry as viable approaches for production such as SMC, HMC and XMC. However, the major effort was conducted in more advanced material forms such as hybrid glass/graphite SMC and thermoplastic stampable sheet. These forms were considered as representative for the 1985 to 1995 time period.

While direct tradeoffs were considered on an equal stiffness basis, it was assumed that ultimate use would require redesign of the various components to achieve maximum efficiency with the composite construction as opposed to straight materials substitution, i.e., a typical metal door beam redesigned with composite materials would consider foam sandwich core with hybrid composite face sheets or hollow beam construction of different configurations than the metal beam. Hybrid construction ratios can only be finalized through detailed analysis involving loads, attachments, environments, and service life profiles. Strength-critical designs require evaluation of operating strain levels as related to hybrid material load sharing.

Of the many materials and processes being considered today for automotive applications, the selection for the study was narrowed to seven potential candidates. These included compression molding compounds (SMC, XMC), thermoplastic stampable sheets, filament wound or pultruded composites, elastic reservoir moldings, injection molded thermoplastic composites, reaction injection molded composites, and metal/thermoplastic/metal laminates. Since there are distinct advantages, disadvantages, and limitations for each form/process, time will be required to fully assess the viability of each for high volume automotive use. Best judgement was used in matching the form/process to the specific application.

A look at possible premiums required to replace initial construction is included as a relative assessment of the different materials and variations of each. Only costs at the raw material level were considered, however, comments are offered relative to the potential cost effectiveness of the various processes.

TABLE 1. SUMMARY WEIGHT REDUCTION POTENTIAL

Totals	Actual Weight (lb)	Composite Weight (lb)	Weight Reduction (lb)	% Weight Reduction
BODY	1202	957	245	20
FRAME	35	17	18	51
FRONT SUSPENSION	108	53	55	51
REAR SUSPENSION	80	45	35	44
BRAKES	92	75	17	18
ENGINE	383	350	33	9
TRANSAXLE ASSY	173	165	8	6
STEERING SYSTEM	45	40	5	11
BUMPERS	52	33	19	37
WHEELS & WHEELCOVERS	99	39	60	61
TOTAL	2269	1774	495	22

2. INTRODUCTION

Graphite fiber-reinforced composite materials are well established as structural and functional material within the aerospace and leisure products markets. From 1976 through 1979, extensive interest was generated in the automotive industry relative to graphite fiber. This curiosity stage brought about a basic knowledge of the material capability through collection of information from other industries. The curiosity stage is now over - issues such as cost, producibility, reliability, long term durability, repair, and recycling, to note a few, must now be addressed. To approach cost constraints, over 95% of all applications using graphite fiber include hybrid fiber mixes and low cost, rapid cure resin systems.

Hybrid glass/graphite composites in thermoset and thermoplastic resin systems are being developed and characterized. Baseline costs of glass compounds are being compared with increased property/cost ratios for the improved hybrid variations. Carrythrough costs to final part production will eventually be established through limited production evaluation programs. The added value of weight savings as gasoline prices approach $4-$5/gallon will most certainly have greater impact than the current $1-$2/gallon prices.

The property/cost tradeoff for hybridization favors low end graphite fiber addition in the 5 to 15% by weight range in general. If the graphite fiber price/volume relationships as given in Figure 1 are considered and incorporated into hybrid raw material variations, the resultant price per pound can be in the $1.60 to $3.00 per pound range as shown in Figure 2. These data represent combinations of low cost E-glass, polyester resin, and graphite fiber. A family of curves is required to represent all the viable combinations of fiber and resin or matrix systems such as epoxies and thermoplastics. This provides the raw material starting point where conversion costs, tooling, and manufacturing costs are next considered. Compression molding compounds, thermoplastic sheet, injection molding compounds, etc. require a conversion cost and add-on to achieve the final form for production. Filament winding and pultrusion are the exceptions where raw material components are directly converted to finished parts - a definite cost advantage with configuration limitations.

Another factor to be considered is the long-term effect of escalation. While the percent of graphite used in the hybrid construction runs from 5 to 30 percent, graphite fiber is responsible for 20-60 percent of the cost of the part under current low-volume projections. However, allowing for higher volume and escalation of all other material and labor cost through 1985, for example, the relative cost drops to 10-40 percent. The net effect is an overall lower escalation. An example of this projection is shown in Figure 3 for the hybrid composite prop shaft compared with a two-piece, all-metal part.

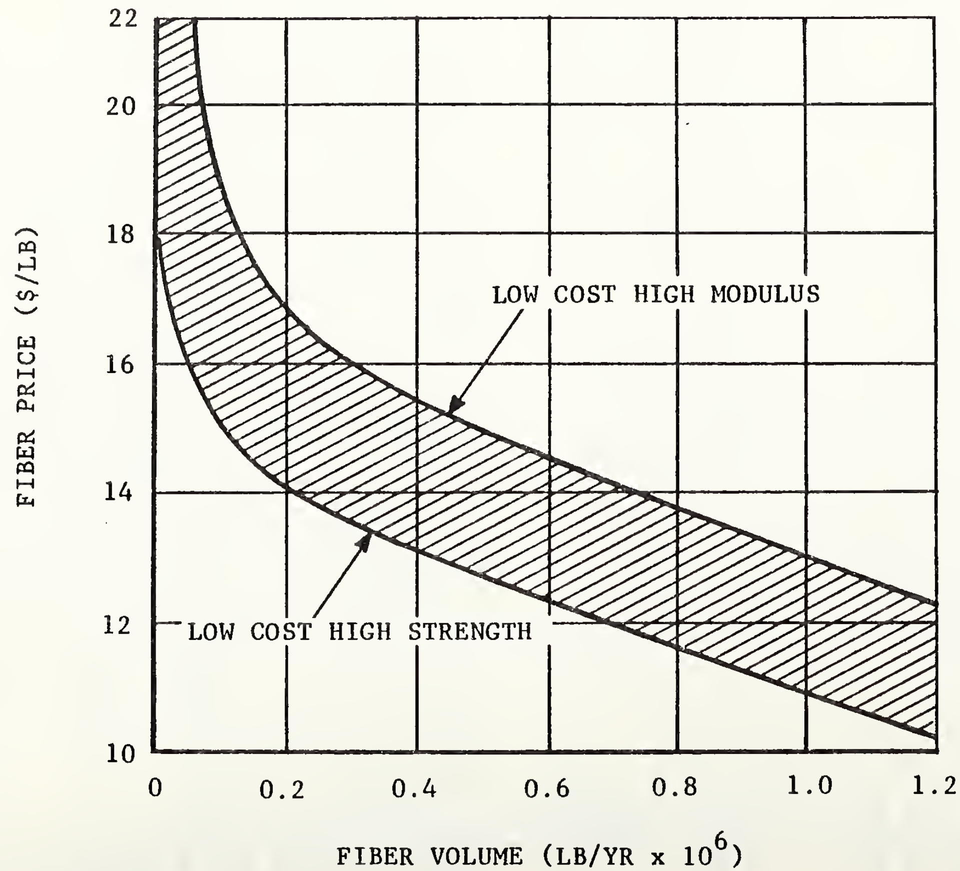

Figure 1. Fiber Price/Volume

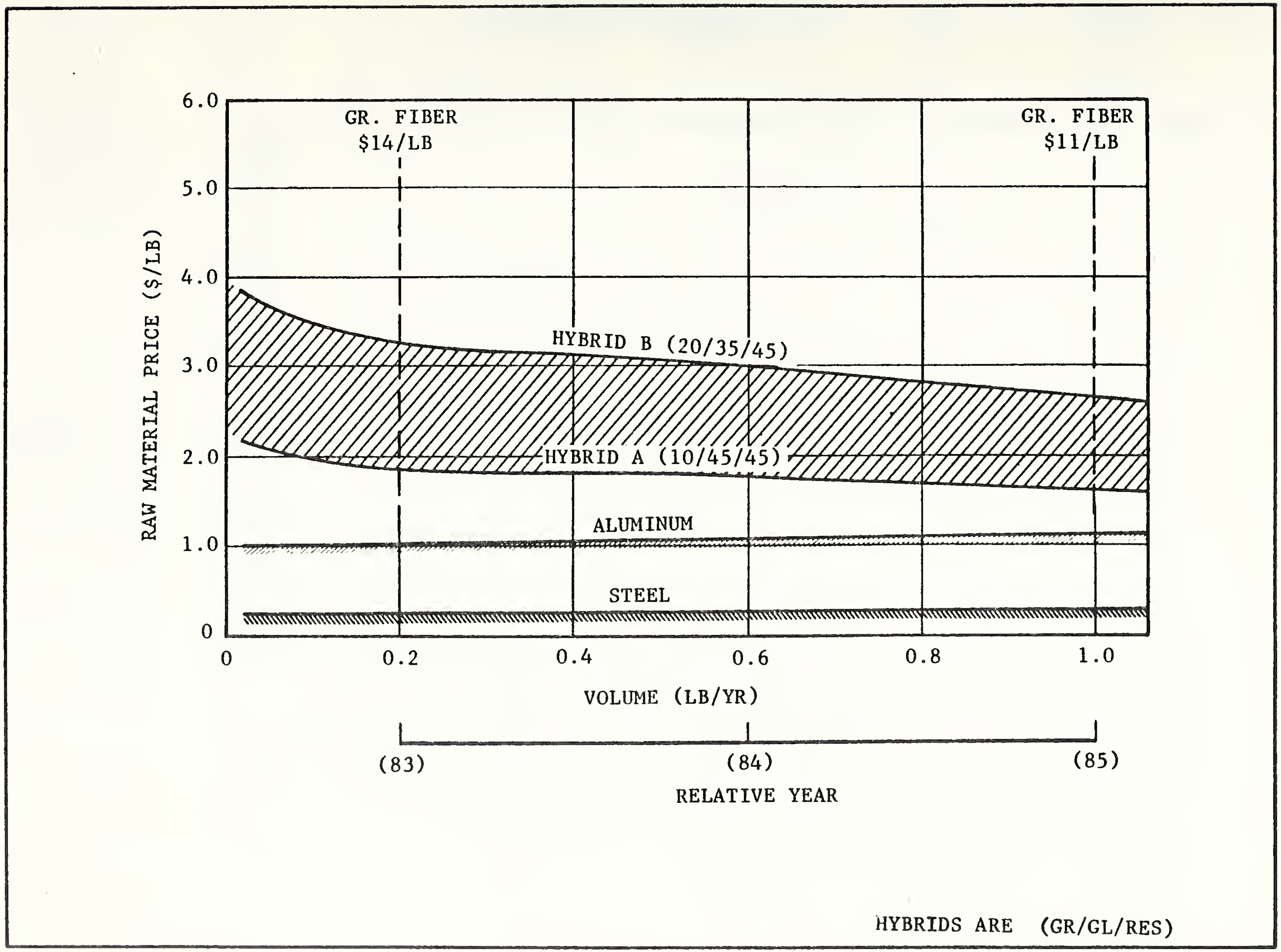

Figure 2. Raw Material Price

GRAPHITE FIBER PRICE		
1979	$18/LB	5,000 LB
1981	$16/LB	50,000 LB
1983	$14/LB	200,000 LB
1985	$11/LB	1,000,000 LB

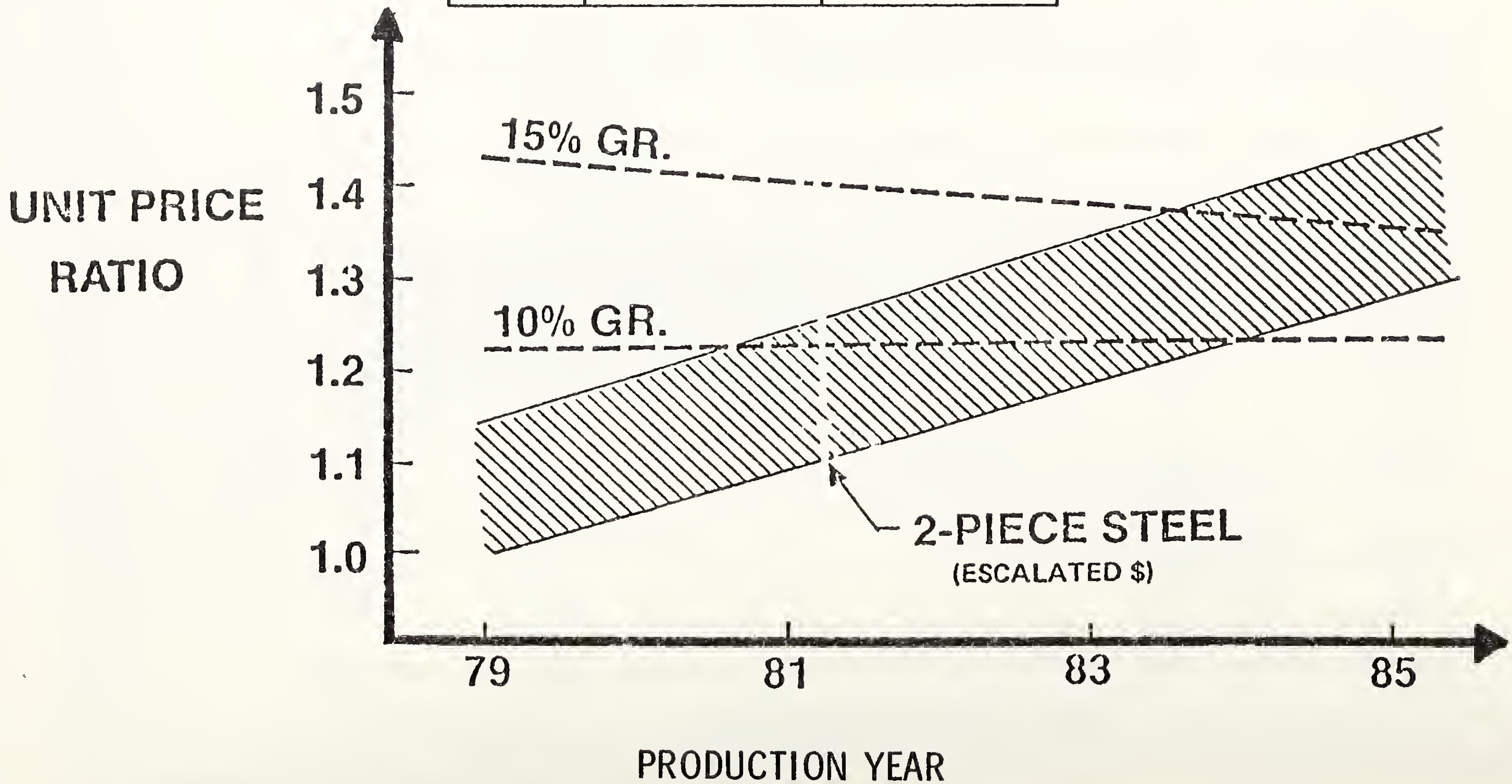

Figure 3. Prop Shaft Economy Potential

3. DISCUSSION

3.1 OBJECTIVE

The objective of this study was to evaluate the potential for weight reduction in passenger automobiles through selective substitution of lightweight composite materials for metal components. The Oldsmobile Omega X-Body vehicle was selected for the analysis to evaluate feasibility and possible extent of such substitution.

3.2 COMPONENT IDENTIFICATION

A detailed summary of existing components, materials, and weights for the 1979 Omega is given in Reference 1. Using this summary as a baseline, potential applications for lightweight material substitutions are identified in Table 1 for evaluation and discussion.

While many of the components listed have been considered for lightweight construction through design, analysis, and prototype studies, most component studies have been on an individual basis for various automobile makes and models. To realize the full potential the entire vehicle must be considered, not only for replacing materials but also for total vehicle redesign. This study attempts to satisfy the first requirement, replacement on a total vehicle basis while maintaining the basic vehicle identity.

Table 2 indicates that body components offer the greatest potential for weight reduction through material substitution (body components add up to 45% of the total vehicle weight). One might consider body components less critical than suspension, brake, and steering systems from a safety standpoint, however, body components must protect the occupants to the greatest degree under crash conditions. Body components also present an additional challenge to new materials from a finish standpoint. Most of such parts will require a class A finish which is an area new in the development chain of composite materials. Current use of in-mold coating appears feasible for surface finishes, therefore, this report assumes that by the 1985-1995 time period, the finish process will be an acceptable standard operation.

While the engine and engine accessory areas makes up the next greatest weight accumulation (around 14% per vehicle), a slightly more conservative approach was used in this area for material substitution due to the relatively lower degree of development at the present time and possible temperature limitations.

Although the combined frame and suspension systems of the automobile make up only 8% of the vehicle weight, a significant weight reduction can be achieved with composite material substitution due to the structural nature of the parts. As a consequence, over 20% of the total vehicle weight reduction can be accomplished in these areas.

TABLE 2. POTENTIAL APPICATIONS

BODY	BRAKES
Hood, Rear Deck Front Fender Valance Support Panel Front, Rear Door Door Hinges Front, Rear Sides Body Panels - 11 Items	Four Components ENGINE Fourteen Components
FRAME	TRANSAXLE ASSEMBLY
Frame Cradle	Three Components
FRONT SUSPENSION	STEERING SYSTEM
Nine Components	Four Components
REAR SUSPENSION	BUMPERS
Six Components	Two Components
	WHEELS
	Two Components Four Wheels and Spare Wheel Covers-Eliminated

A conservative approach was taken in the transaxle assembly area for several reasons. First, this area is a possible strength-dominated area and more detailed strength analyses would be required to comparatively assess the materials application. Second, more information is required relative to assembly part details and component operational loads and environments.

Wheels and wheel covers were also considered viable weight reduction applications. While the wheels and tires make up approximately 7% of the vehicle weight (including tires, bumper jack, and lug wrench items which are not considered for composite use) a reduction of 60 pounds in wheels and wheel covers alone appears feasible.

3.3 MATERIAL APPLICATIONS

3.3.1 State-of-the-Art

Numerous material combinations considered state-of-the-art are available for lightweight automotive construction. However, a majority of these materials are of a fairly low structural grade and are not the focus of the current study. This study includes state-of-the-art materials and forms but of a higher structural grade which, in most cases, are in various stages of development. The materials will, therefore, be considered applicable in the 1985-1995 time period. Table 3 summarizes the materials selected for the weight tradeoff study. It is noted that this summary does not cover all possibilities, however, it does cover a broad enough range to be representative of the many possible approaches.

In general, state-of-the-art materials listed in Table 3 would include only those with all-glass reinforcement (with exceptions of filament winding and injection molding where all-glass, all-graphite, and hybrid combinations are established product lines).

3.3.2 New Development

New developments generally include the higher structural grades of each material, such as all-graphite or hybrid glass/graphite reinforcements. Compression molding compound programs have been under way since early 1979 to identify and characterize potential hybrid compound products. These products, in SMC and XMC forms, should have the characterization phases complete by 1981 and be available for production validation by 1982. The hybrid versions include chopped glass as well as continuous glass and continuous graphite reinforcements.

The primary thermoplastic stampable/heat formable sheet stock products presently available include the PPG-Azdel product and the Allied Chemical STX product. Both are of the lower structural grade where reinforcement includes only glass mats. Some development is under way with continuous fiber-reinforced Torlon (poly(amidimide)) where sheet stock is

TABLE 3. MATERIALS APPLICATION

	Density (g/cc)	Strength (MPA)	Strength (Ksi)	Modulus (MPA)	Modulus (Msi)	Glass/Graphite/Resin Percentage			Comment
Compression	1.99	480	70	40	5.6	60	--	40	Standard and hybrid
	1.55	1300	190	110	16.0	--	60	40	forms of SMC, XMC
	1.91	550	80	52	7.5	50	10	40	chopped continuous
Compounds	1.85	760	110	70	10.0	40	20	40	fiber
Thermoplastic Stampable/	1.35	345	50	28	4.0	30	--	70	Torlon, Nylon,
	1.24	690	100	85	12.0	--	30	70	Pet
Thermoformable Sheet	1.57	415	60	42	6.0	30	10	60	Continuous fiber
	1.51	580	84	56	8.0	20	20	60	and fiber reinforcement
Filament Wound and Pultruded Composites	1.99	1100	160	40	5.6	60	--	40	Continuous glass
	1.55	1380	200	130	19.0	--	60	40	and graphite
	1.91	623	90	65	8.0	50	10	40	fiber, thermoset
	1.85	800	115	70	10.0	40	20	40	resin
Steel/Plastic/Steel Stampable Laminate	2.99	125	18.0	70	10.0	7 PP/30 Steel			Steel Polypropylene
Plastic Reservoir Molding Compound	1.45	173	25	16	2.3	40 Glass/60 Foam			Glass Fabric
	1.26	345	50	54	7.7	20 Gr/80 Foam			Graphite Fabric
	1.38	207	30	34	4.9	10 Gr/10 Gl/80 Foam			Foam
Thermoplastic Injection Molding Compound	1.37	220	32	11	3.6	30	--	70	Nylon 616
	1.28	248	36	24	3.4	--	30	70	Torlon
	1.60	138	20	10	1.5	30	10	60	PPS
	1.54	193	28	14	2.0	20	20	60	Chopped Fiber
Reaction Injection and Resin Transfer Molding	1.10	130	18.6	7	1.0	30	--	70	Continuous
	1.02	145	20.9	14	2.0	--	30	70	fiber reinforcement,
	1.29	125	18.0	11	1.5	30	10	60	epoxy matrix
	1.24	132	19.0	13	1.8	20	20	60	glass, graphite fabric

produced for subsequent stamping or hot forming. Other thermoplastic systems are being considered for continuous and woven fiber reinforcement to provide a generally upgraded structural class of formable sheet stock. The properties shown for graphite and hybrid reinforced thermoplastic were calculated. It is noted that only a 30 to 40% total reinforcement level was considered and this is based on initial results. If reinforcement levels can achieve 60% and above, as with thermoset molding compounds, much higher properties will be achieved.

Filament winding has long been an established process for composite manufacture. Properties achieved by this method are excellent by virtue of the controlled fiber placement and potentially high fiber content. While the process is limited to certain structural shapes, it offers an approach involving minimum conversion costs from fiber to finished part.

A more recent development, the steel/plastic/steel laminate looks very promising, especially for high visibilty body components. While the weight saving potential is not as high as fiberglass or hybrid glass/graphite construction, tradeoffs relative to cost premium and weight reduction appear favorable for the laminate. Current stamping equipment could be used and surface finish would not be a concern. While many versions are proposed, this report includes only one. This report does not consider the counterpart aluminum/plastic/aluminum laminate currently under development.

Elastic reservoir molding material with glass and hybrid glass/graphite reinforcement has been produced and characterized to some degree. The material has shown great promise for potential use in large auto body panel structures. Since this is basically a foam core sandwich material with optional possibilities for skin reinforcements, it should provide a valuable approach to total vehicle redesign relative to safety, performance, and noise reduction.

Chopped fiber reinforced injection molded thermoplastic compounds are standard products at this time. While general structural properties are on the low side, certain applications involving complicated shapes, low stresses, and envelope freedom can use injection molded thermoplastics to realize significant weight reductions. Parts consolidation can lead to favorable economic potential for this approach.

To date, reinforced reaction injection molding has used primarily urethanes with finely milled fiber to achieve dispersion. The resultant properties are low. More recently epoxy reaction injection moldings (RIM) injected into continuous strand mat have shown promise for higher structural grades. This study involves the more structural grade of reinforced reaction injection moldings (RRIM), including glass and hybrid glass/graphite mat, fabric, or continuous fiber reinforcement. On this basis, RRIM will then attain competitive properties with mat and fabric reinforced resin transfer moldings. In fact, the properties shown under this study may well increase as the products are further developed.

3.4 WEIGHT REDUCTION POTENTIAL AND COST COMPARISON

This study includes weight comparisons based on equal stiffness criteria. No attempt was made to redesign configurations to best suit composite construction nor have stresses been evaluated to determine if strength-critical conditions exist on certain components. It is noted, however, that equal stiffness comparisons generally yield overdesigned composite parts for strength-dominated cases. Configuration redesign best fitting composite construction, such as one-piece sandwich hoods or deck lids, would no doubt lead to additional weight savings.

Stiffness comparisons were based on the Reference 2 relationship

$$Wc/Wm = (\rho c/\rho m) \ [Em/Ec]^{R} \qquad (1)$$

where the factor R depends on part configuration, i.e. solid section, panel, or thin wall beam. Comparative thickness for equal stiffness was based upon this relationship and includes

$$tc = tm \ (Em/Ec)^{R} \qquad (2)$$

As shown in Table 2, most materials selected for evaluation include variations of all-glass, all-graphite, to hybrid glass/graphite. Current per pound prices were estimated, then escalated 6% per year to 1985 and 1995 to evaluate potential raw material cost premiums over metal construction. Based on these estimated premiums, material selections were made from the variations listed. It is recognized that the values are approximate and that they only consider raw material costs. The final analysis would require evaluation of overall producibility factors.

For the compression molding compounds, estimated material premiums (dollars per pound of weight saved) includes values of $1.00/lb, $3.00/lb, $1.20/lb, and $1.50/lb for all-glass, all-graphite, Hybrid A, and Hybrid B, respectively, for 1985. While graphite price is decreasing, thermoplastic resin prices play a larger part in final price compared to the lower cost thermosets such as polyester and vinylesters. Therefore, 1995 premiums were estimated at $2.50/lb, $3.00/lb, $2.80/lb, and $2.50/lb, respectively.

The other hybrid materials used for the weight study include elastic reservoir molding at $1.80/lb premium in 1985 to $2.20/lb in 1995; injection molding compounds at $3.00/lb premium throughout the 1985 to 1995 period; filament wound composites at $.60/lb in 1985 down to $.30/lb in 1995; and the steel/plastic/steel laminate at $.20/lb in 1985 to $.30/lb in 1995.

With the ground rules noted above, a summary of individual part weight reduction potentials was prepared and is given in Table 4.

TABLE 4. WEIGHT REDUCTION POETENTIALS

	Qty	Total Wt. (lb)	Mat-erial	Fab	Thick-ness (in.)	Attach-ment	Alternate Material	Wt. (lb)	Fab	Thick-ness (in.)	Attach-ment	Weight Reduction (lb)
1. BODY												
A HOOD												
Outer Panel	1	21.75	Steel	Stamp	0.034	Spot weld	M/PP/M	14.27	Stamp	0.058	Flange/Bond	7.50
Inner Panel	1	16.75	Steel	Stamp	0.031	Spot weld	H-CMC	8.00	Comp Mold	0.061	Flange/Bond	8.80
B REAR DECK LID												
Outer Panel	1	18.25	Steel	Stamp	0.037	Hem Flange	M/PP/M	11.97	Stamp	0.064	Flange/Bond	6.30
Inner Panel	1	13.75	Steel	Stamp	0.031	Hem Flange	H-CMC	6.50	Comp Mold	0.061	Flange/Bond	7.30
C FRONT FENDER												
Fender Panel	2	20.00	Steel	Stamp	0.034	Screw	H-TPSS	9.00	Hot Form	0.075	Screw	11.10
D BODY VALANCE & DAM												
Support Panel	1	0.59	Steel	Stamp	0.036	Screw	H-TPSS	0.26	Hot Form	0.080	Screw	0.33
E FRONT DOOR												
Inner Panel	2	38.00	Steel	Stamp	0.042	H. Flange Spot Weld	H-CMC	18.24	Comp Mold	0.083	Flange/Bond	19.76
Outer Panel	2	21.50	Steel	Stamp	0.035	H. Flange Spot Weld	M/PP/M	13.98	Stamp	0.060	Flange/Bond	7.52
Hinges	2	2.75	Steel	Stamp	0.194	Weld	H-TPSS	0.94	Hot Form	0.330	Ultrasonic Weld	1.81
Safety Door Beam	2	12.50	Steel	Stamp	0.092	Weld	H-CMC	8.75	Comp Mold	0.182	Weld/Metal Fitting	3.75

NOTE: Abbreviations in the Alternate Material column are as follows:

H-CMC = Hybrid Compression Molding
M/PP/M = Metal Polypropylene Metal
H-TPSS = Hybrid Thermoplastic Stampable Sheet
H-FWC = Hybrid Filament Wound Composite
GR-IMC = Graphite Reinforced Injection Molding Compound
H-ERM = Hybrid Elastic Reservoir Molding

TABLE. 4. WEIGHT REDUCTION POTENTIALS (CONT.)

	Qty	Total Wt. (lb)	Mat-erial	Fab	Thick-ness (in.)	Attach-ment	Alternate Material	Wt. (lb)	Fab	Thick-ness (in.)	Attach-ment	Weight Reduction (lb)
1. BODY (CONT.)												
F REAR DOOR												
Inner Panel	2	23.30	Steel	Stamp	0.031	Hem Flange	H-CMC	11.18	Comp Mold	0.061	Flange/Bond	12.12
Outer Panel	2	16.50	Steel	Stamp	0.036	Hem Flange	M/PP/M	10.73	Stamp	0.062	Flange/Bond	5.77
Hinges	2	2.19	Steel	Stamp	0.179	Weld	H-TPSS	0.74	Hot Form	0.304	Ultrasonic Weld	1.45
Safty Door Beam	2	9.00	Steel	Stamp	0.061/ 0.043	Weld	H-CMC	6.30	Comp Mold	0.240/ 0.169	Weld/Fittings	2.70
G DOOR HINGES												
Front Pillar Hinges	2	3.25	Steel	Stamp	0.213	Weld	H-TPSS	1.11	Hot Form	0.362	Ultrasonic Weld	2.14
Rear Pillar Hinges	2	2.62	Steel	Stamp	0.179	Weld	H-TPSS	.89	Hot Form	0.304	Ultrasonic Weld	1.73
H FRONT SEAT												
Frame	1	29.50	Steel	Stamp	0.030	Screw	H-TPSS	21.24	Hot Form	0.148	Bolt	8.26
Seat Track Assy-LH	1	4.16	Steel	Stamp	0.085	Screw	H-TPSS	1.41	Hot Form	0.145	Bolt	2.75
Seat Track Assy-RH	1	3.59	Steel	Samp	0.085	Screw	H-TPSS	1.22	Hot Form	0.145	Bolt	2.37
I REAR SEAT												
Base & Spring	1	6.12	Steel	Stamp		Screw	H-TPSS	4.41	Hot Form		Bolt	1.71
Back & Spring	1	4.63	Steel	Stamp		Screw	H-TPSS	3.33	Hot Form		Bolt	1.30

TABLE 4. WEIGHT REDUCTION POTENTIALS (CONT.)

	Qty	Total Wt. (lb)	Mat-erial	Fab	Thick-ness (in.)	Attach-ment	Alternate Material	Wt. (lb)	Fab	Thick-ness (in.)	Attach-ment	Weight Reduction (lb)
1. BODY (CONT.)												
J BODY PANELS												
Radiator Brace	2	2.31	Steel	Stamp/ Weld	0.080	Bolt	H-CMC	1.10	Comp Mold	0.159	Bolt/Bond	1.21
Quarter Panel Outer	2	26.94	Steel	Stamp/ Weld	0.032	Weld	M/PP/M	17.51	Stamp	0.055	Weld	9.43
Rear Wheel Well	2	21.50	Steel	Stamp/ Weld	0.032	Weld	H-ERM	9.25	El Res Mold	0.078	Bolt/Bond	12.25
Roof Outer Panel	1	33.31	Steel	Stamp/ Weld	0.035	Weld	M/PP/M	21.65	Stamp	0.060	Weld	11.66
Roof Inner Ribs	Lot	16.75	Steel	Stamp/ Weld	0.032/ 0.035	Weld	H-TPSS	7.54	Hot Form	0.071/ 0.078	Ultrasonic Weld	9.21
Firewall	1	7.94	Steel	Stamp/ Weld	0.035	Weld	H-ERM	3.41	El Res Mold	0.086	Bolt/Bond	4.53
Sill	2	32.19	St/HSLA	Stamp/ Weld	0.040	Weld	H-CMC	15.45	Comp Mold	0.079	Bolt/Bond	16.74
Floor Panel	1	56.44	Steel	Stamp/ Weld	0.032	Weld	H-ERM	24.27	El Res Mold	0.078	Bolt/Bond	32.17
'A' Post & Pillar	2	23.06	St/HSLA	Stamp/ Weld	0.040/ 0.068	Weld	H-CMC	8.76	Comp Mold	0.063/ 0.107	Bolt/Bond	14.30
'B' Post & Pillar	2	19.12	Steel	Stamp/ Weld	0.032/ 0.048	Weld	H-CMC	7.27	Comp Mold	0.050/ 0.075	Bolt/Bond	11.85
Rear Shelf	1	12.06	Steel	Stamp	0.035	Weld	H-TPSS	5.43	Hot Form	0.078	Ultrasonic Weld	6.63
2. FRAME												
A FRAME CRADLE	1	35.00	Steel	Stamp/ Weld	0.080/ 0.095	Bolt	H-CMC	16.80	Comp Mold	0.159/ 0.188	Bolt/Bond	18.20

TABLE 4. WEIGHT REDUCTION POTENTIALS (CONT.)

	Qty	Total Wt. (lb)	Mat-erial	Fab	Thick-ness (in.)	Attach-ment	Alternate Material	Wt. (lb)	Fab	Thick-ness (in.)	Attach-ment	Weight Reduction (lb)
3. FRONT SUSPENSION												
Lower Control Arm	2	10.50	Steel	Stamp	0.110	Screw	H-CMC	3.99	Comp Mold	0.173	Bolt	6.51
Knuckle	2	20.00	Iron	Cast		Screw	GR-IMC	6.60	Inj Mold		Bolt	13.40
Strut/Damper	2	16.00	Steel	Stamp		Screw	H-TPSS	5.44	Hot Form		Bolt	10.56
Coil Spring	2	20.00	Steel	Wound	0.570	Captive	H-FWC	7.60	Fil Wind			12.40
Spring Seat	2	2.62	Steel	Stamp	0.077	Captive	H-TPSS	1.18	Hot Form	0.171		1.44
Strut Mtg Assy	2	6.38	Steel	Stamp		Screw	H-TPSS	2.87	Hot Form		Bolt	3.51
Stabilizer Bar	1	9.75	Steel	Drawn	0.870	Clamp	H-FWC	3.71	Fil Wind		Clamp	6.04
Brackets	4	1.50	Steel	Stamp	0.096/ 0.118	Screw	H-CMC	0.57	Comp Mold	0.151/ 0.185	Bolt	0.93
Plates	2	1.19	Steel	Stamp	0.038	Screw	H-CMC	0.57	Comp Mold	0.075	Bolt	0.62
4. REAR SUSPENSION												
Axle Beam	1	27.12	Steel	Stamp	0.175	Screw	H-CMC	10.31	Comp Mold	0.275	Bolt	16.81
Control Arm	2	6.06	Steel	Stamp	0.165	Weld	H-CMC	2.91	Comp Mold	0.327	Bolt/Bond	3.15
Anti-Roll Bar	1	8.22	Steel	Drawn	0.812	Weld	H-FWC	3.12	Fil Wind		Bolt/Bond	5.10
Track Bar	1	3.81	Steel	Stamp	0.093	Screw	H-CMC	1.45	Comp Mold	0.146	Bolt	2.36
Coil Spring	2	11.00	Steel	Wound	0.490	Captive	H-FWC	4.18	Fil Wind			6.82
Bracket, Trailing Arm	2	1.75	Steel	Stamp	0.092	Screw	H-TPSS	0.79	Hot Form	0.204	Bolt	0.96

TABLE 4. WEIGHT REDUCTION POTENTIALS (CONT.)

	Qty	Total Wt. (lb)	Mat-erial	Fab	Thick-ness (in.)	Attach-ment	Alternate Material	Wt. (lb)	Fab	Thick-ness (in.)	Attach-ment	Weight Reduction (lb)
5. BRAKES												
A FRONT BRAKES												
Calipers	2	14.00	Iron	Cast		Bolts	H-CMC	5.32	Comp Mold		Bolt	8.68
B REAR BRAKES												
Backing Plate	2	4.19	Steel	Stamp	0.100	Screw	M/PP/M	2.72	Stamp	0.172	Bolt	1.47
C PARKING BRAKES												
Pedal & Lock	1	2.50	Steel	Stamp	0.090	Screw	H-TPSS	0.85	Hot Form	0.153	Bolt	1.65
D BRAKE CONTROLS												
Power Assit Unit	1	8.25	Steel	Stamp	0.055	Screw	H-CMC	3.96	Comp Mold	0.109	Bolt	4.29
6. ENGINE												
A ENGINE												
Air Cleaner Assy	1	6.00	Steel	Stamp		Screw	M/PP/M	3.90	Stamp		Bolt	2.10
Valve Cover	2	3.75	Steel	Stamp	0.045	Screw	M/PP/M	2.44	Stamp	0.077	Bolt	1.31
Oil Pan	1	5.06	Steel	Stamp	0.045	Screw	H-TPSS	2.28	Hot Form	0.100	Bolt	2.78
Conn. Rod	6	7.56	Steel	Forged		Captive	H-FWC	2.87	Mold			4.69
Push Rod	12	1.06	Steel	Drawn	0.315	Captive	H-FWC	0.40	Pultrude			0.66

TABLE 4. WEIGHT REDUCTION POTENTIAL (CONT.)

	Qty	Total Wt. (lb)	Mat-erial	Fab	Thick-ness (in.)	Attach-ment	Alternate Material	Wt. (lb)	Fab	Thick-ness (in.)	Attach-ment	Weight Reduction (lb)
6. ENGINE (CONT.)												
A ENGINE (Cont)												
Pulley, Water Pump	1	1.75	Steel	Stamp		Screw	H-TPSS	0.60	Hot Form		Bolt	1.15
Piston	6	6.12	Alum	Cast		Pin	GR IMC	3.98	Inj Mold		Pin	2.14
Rocker Arms	12	2.44	Steel	Stamp	0.125	Stud	H-TPSS	0.83	Hot Form	0.213	Stud	1.61
Valve Spring	12	2.12	Steel	Wound	0.175	Captive	H-FWG	0.81	Fil Wind	0.269		1.31
Crank Pulley	1	3.25	Steel	Stamp		Screw	H-TPSS	1.11	Hot Form		Bolt	2.14
Brackets, Power Steering	2	3.38	Steel	Stamp	0.200	Screw	H-CMC	1.62	Comp Mold	0.396	Bolt	1.76
Brackets, Air Cond	3	5.06	Steel	Stamp	0.193	Screw	H-CMC	2.43	Comp Mold	0.383	Bolt	2.63
B ENGINE & TRANS MOUNTS												
Brackets	Lot	6.50	Steel	Stamp	Various	Screw	H-TPSS	2.93	Hot Form		Bolt	3.57
Vib. Mounts	3	5.75	St/ Rubber	Stamp/ Mold		Screw	H-TPSS	2.59	Hot Form		Bolt	3.16
7. TRANSAXLE ASSEMBLY												
Cover, Main Case	1	9.00	Alum	Cast		Screw	H-TPSS	4.05	Hot Form		Bolt	4.95
Cover Valve Body	1	2.44	Steel	Stamp	0.050	Screw	H-TPSS	1.10	Hot Form	0.111	Bolt	1.34
Fluid Pan	1	3.30	St/Plas	Stamp/ Mold	0.047	Screw	H-TPSS	1.49	Hot Form	0.104	Bolt	1.81

TABLE 4. WEIGHT REDUCTION POTENTIALS (CONT.)

	Qty	Total Wt. (lb)	Mat-erial	Fab	Thick-ness (in.)	Attach-ment	Alternate Material	Wt. (lb)	Fab	Thick-ness (in.)	Attach-ment	Weight Reduction (lb)
8. STEERING SYSTEM												
Steering Shaft PRI	1	2.75	Steel	Drawn		Nut	H-FWC	1.05	Fil Wind		Bolt	1.70
Jacket Assy	1	2.56	Steel	Drawn		Screw	H-FWC	1.20	Fil Wind		Bolt	1.36
Bracket, Col Mtg	1	1.06	Steel	Stamp	0.133	Screw	H-CMC	0.40	Comp Mold	0.209	Bolt	0.66
Bracket, Rack Mtg	4	1.50	Steel	Stamp	0.148/ 0.172	Screw	H-TPSS	0.51	Hot Form	0.252/ 0.292	Bolt	0.99
9. BUMPERS, MISC												
Front Bumper	1	11.75	Alum	Stamp	0.130	Screw	H-TPSS	5.29	Hot Form	0.289	Bolt	6.46
Rear Bumper	1	13.50	Alum	Stamp	0.130	Screw	H-TPSS	6.08	Hot Form	0.289	Bolt	7.42
10. WHEELS & TIRES												
Wheels	4	69.0	Steel	Stamp	0.100	Nut	H-CMC	34.0	Comp Mold		Nut	35.0
Wheel Covers	1	17.0	Steel	Stamp	0.034	Captive	Eliminate					7.0
Spare Tire Wheel	1	13.0	Steel	Stamp	0.100	Screw	H-CMC	5.00	Comp Mold		Nut	8.0

NOTE: Abbreviations in the Alternate Material column are as follows:

H-CMC = Hybrid Compression Molding
M/PP/M = Metal Polypropylene Metal
H-TPSS = Hybrid Thermoplastic Stampable Sheet
H-FWC = Hybrid Filament Wound Composite
GR-IMC = Graphite Reinforced Injection Molding Compound
H-ERM = Hybrid Elastic Reservoir Molding

The Omega body items A and B (hood and rear deck, Table 4) include a combintion of metal laminate for outer surfaces and hybrid compression molding compound inner panels. They are both considered viable approaches and yield appreciable weight reductions. A second general approach could utilize such sandwich construction as elastic reservoir molding or honeycomb core/laminate face sheet molding. This second approach would involve one-piece construction.

The front fenders include hybrid thermoplastic stampable sheets for ease of processing and to provide the capability of tailoring the designs with directional properties. Other processes might include reinforced RIM (epoxy base, fabric reinforced) or resin transfer molded parts using continuous fiber reinforcement.

The front and rear door panels include material combinations similar to the hood which, again, offer the capability for stamped outer surfaces with a good finish and inside panels which can be structurally tailored to meet load and stiffness requirements. One part sandwich construction with elastic reservoir molding also presents a viable approach to door construction with a slightly lower weight reduction potential.

The remainder of the body parts include various material selections as they appear to be suited for an application. Final selections would most certainly reflect the overall cost and producibility aspects noted previously.

The frame cradle and front and rear suspension parts are candidate applications which are more likely to require refinement due to details and interactions involved. Safety factors and factors accounting for environmental conditions will have greater significance in these areas. Many of these parts will require metal interface fittings which have not been included. Additional details may also yield more potential items for low cost filament winding, pultrusion, and resin transfer molding.

Several experimental programs have considered brake components for composite construction (backing plate, brake pedal, and brake booster shell). Weight savings are significant and prelimnary testing successful. The parts summarized in Table III are similar to those previously prototyped. One application not included is the brake pads which are currently being considered for use of filler materials such as chopped graphite fiber to replace asbestos.

Many engine components are candidates for lightweight construction, however, much has to be learned about long term temperature effects on the materials. Many of the parts listed are small, therefore, multiple pieces are required for each engine thus requiring very high production rates. These are two major concerns related to engine component applications. With engine downsize, however, lighter weight components are important for reduced vibration and potentially higher rpm's. These factors have been very significant in pushing the development of lightweight components for engines.

The transaxle assembly includes many parts not considered for material replacement in this study due to insufficient amount of detail about design, operating conditions, environment, and interface attachments. While this study considered only three components for a weight reduction of 8 pounds, it is estimated that total weight reduction in this area would exceed 40 pounds if a more detailed analysis were made.

A considerable amount of work is under way to develop light-weight, impact resistant bumper systems. Replacement on an equal stiffness basis is a starting point. More important, however is the satisfaction of 5 mph impact. This requires consideration of energy-absorbing means such as foam cores, semiflexible face sheets, backup beams of selected stiffness, and other factors. The marriage of these functional and structural components into a single assembly obviously requires a considerable amount of testing and analysis. For this comparative weight evaluation, however, the conservative 50% weight reduction estimated on an equal stiffness basis should be sufficiently close. The weight summary is shown in Table 1.

3.5 EFFECTS OF SUBSTITUTION

The introduction of new materials into the automotive industry raises many issues that must be resolved in a given time to achieve acceptability. Many of the issues relate directly or indirectly to end item cost compared to the current baseline material. With current trends in fuel costs and the ultimate demands of energy conservation, a new factor has entered into the assessment of materials substitution, added value of weight reduction. While this report does not project added value, it is understood that vehicle redesign for composite construction would yield additional weight reductions and the value added through reduced fuel consumption would significantly reduce or eliminate the premiums estimated in paragraph 3.4.

This paragraph offers comments relative to tooling requirements, manufacturing processes, vehicle durability and repairiability, painting and joining, recycling and material availability and uncontrolled fiber release.

3.5.1 <u>Tooling Requirements</u>

In general, tooling requirements for these new materials and processes are well established and could already be introduced into a production line system. Raw material form implies a specific manufacturing process which, in turn, generally establishes the type of tooling required.

The tooling costs are related to the material used, temperature and pressure requirements, and quantity of parts to be produced. Lower cost epoxy, spray metal, and Kirksite tooling ($10,000-$14,000 for small plate stock) can be used at lower mold pressures of 50 to 100 psi and for smaller production runs of 100 to 5,000 units. High volume, high pressure tooling such as P-20 steel for producing plate stock can run over $30,000 (for production quantities of 30,000 to 40,000 parts). The hybrid compression molding compounds and thermoplastic stampable sheet stock will require tooling for pressures from 900 to 1500 psi depending on part configuration and thickness. The lower pressure molding of elastic reservoir molding materials, resin transfer molded materials, and vacuum injection molded materials can be accomplished with the lower cost tooling noted above.

A second consideration involves the capital investment required to support the process and tooling. A significant factor involves the molding pressure. For the lower molding pressures of 50 to 100 psi, a 450 ton press can be used which can cost $150,000. In contrast, a 1,000 psi mold pressure requires a 2,500 ton press costing approximately $700,000 (5 by 9 foot bed).

Introduction of nonmetal materials will therefore require new tooling. However, most existing facilities for metal forming and stamping will apply with some modification. Since the transition to composite materials will most likely occur on an evolutionary basis, the required changes should not create severe problems.

3.5.2 Manufacturing Processes

Producibility related to the new materials will present one of the greatest challenges in achieving composite component acceptability. In general, the processes available today for manufacturing with composite materials have not been through the full rigors of automotive part production.

High pressure compression molding of structural grade sheet molding compound requires in-mold times of 2 to 3 minutes. To achieve required production rates, multiple cavity molds and multiple molds are required. Production lines will require initial blanking stations where the molding charge is cut from sheet stock and placed on conveyor systems for delivery to the mold. These lines would ultimtely be positioned in line with the sheet molding compound machine. A similar arrangement would apply for thermoplastic stampable sheet and elastic reservoir molding (with the exception of a premold heating stage added to the thermoplastic stamping line to soften the material prior to forming).

Filament winding is a very old manufacturing process of composite materials and recently has gained much attention for potential use in automotive parts manufacture. New concepts are available for high speed winding of simple and complicated configurations. It is estimated that a single machine will produce 360 ft/hr of drive shaft tubing. Multiple machines could satisfy total automotive requirements. This process will lend itself to drive shafts, frame components, stabilizer bars, and many more parts of similar configuration.

Other manufacturing processes, such as screw machine injection molding and reaction type injection molding, provide excellent means for achieving high volume production rates. In general, these materials are of a lower structural grade compared to continuous fiber reinforced materials; however, lightly loaded components where parts consolidation can be achieved are being considered.

The impact of new material substitution on the overall vehicle manufacturing processes will be one of significant change. New manufacturing technologies and skills will be required of those now familiar with metal working techniques. There will almost certainly be a resistance to these processing changes as well as to reinvestment in new tooling and equipment. However, the challenge must be met if energy conservation is to be achieved. The impact on manufacturing processes is, therefore, not one of inventing and developing totally new processes, but one of adjustment to and scaleup of existing processes. In fact, this change is taking place now at the major automotive companies as well as at established parts suppliers.

3.5.3 Vehicle Durability and Repairability

Long term durability and repairability associated with new lightweight materials are certainly on the list of issues to be studied and resolved. These particular sujects will not be quickly answered. While several fleet service programs will be completed during 1980 and fleet durability tests during 1981, these are relatiely short term tests when one considers total vehicle life. Obviously the first step is to qualify parts for vehicles (laboratory screening tests, fleet service exposure, crash test response, and fleet durability exposure) so that limited production runs are accomplished and parts installed on vehicles. An example would be the composite drive shafts. To date, many such assemblies have successfully completed laboratory screening tests which, in fact, are much more severe than actual service life. These same lightweight shafts are now in fleet service evaluation (1980) and have undergone successful crash test safety demonstrations. Vehicle durability will not be conducted until 1981 and will only be conducted if and when the shafts are accepted for production (initial evaluation began in 1975). To satisfactorily characterize a wide range of parts manufactured with new lightweight materials for vehicle durability, continuing interest and programs are required from the automotive companies. To date, long term programs conducted by aerospace corporations and government agencies relative to durability of composite materials have not been accepted by the auto industry. Therefore, demonstration of vehicle durability with new lightweight materials will take time. Test data obtained on noise vibration harshness (NVH), fatigue, impact, environmental sensitivity, and other tests have been evaluated on selected components during the past several years (1978-1980). These tests certainly represent a start and have yielded very positive results thus far.

Part repairability will depend upon construction, configuration, structural load constraints, material, extent of damage, location of damage, and various other factors. There is no question that damaged parts manufactured with composite materials can be repaired. Tradeoff studies will be required to establish the damage level at which part replacement will be more economical. Unlike metal construction, composite materials are basically unyielding. Therefore, impact levels typically causing dents in steel or aluminum (plastic deformation or elastic buckling) may cause no visible or permanent damage to a composite. If the impact is severe enough, however, permanent damage such as a crack or hole could occur. Material at the damage site and immediately surrounding the site would then be removed by sanding, grinding, or drilling techniques and new material inserted and bonded in place. In some cases, impacts may simply cause bruises or localized resin crazing. This would normally be more of a cosmetic than structural nature and could be repaired by a simple external resin application or by vacuum-injected internal application of resin. It is noted that a large percentage of parts damaged on vehicles today are replaced rather than straightened or repaired.

3.5.4 Painting and Joining

Most thermoset and thermoplastic systems being developed for low cost, high rate automotive parts production have temperature limitations of from 250 to 300°F. In many cases, these temperatures are exceeded during primer and final paint drying operations. New primers and paints are being developed for lower temperature drying operations to prevent damage to body parts manufactured with either plastics or reinforced plastics/composites.

In joining or bonding composites, proper design of attachments and joints is essential to ensure that imposed loads do not involve failures due to stress concentrations at such sites. Unnecessary weight increases resulting from unduly conservative design must be avoided. The two basic methods for joining laminates are by adhesive bonding and by mechanical fasteners.

To obtain maximum efficiency from adhesives, joints should be specifically designed for adhesive bonding. Some general design principles include the bond areas as large as possible within allowable geometry and weight constraints, and stressing of the adhesive in the direction of maximum strength. The two basic types of adhesives are thermosetting and rubber-based.

Thermosetting adhesives are relatively rigid and exhibit high tensile and shear strength independent of dynamic or static loading. These adhesives also demonstrate good fatigue characteristics. However, rigid adhesives have relatively poor bonding qualities when stressed in peel or cleavage.

The rubber-based adhesives develop high peel or cleavage strength because of the effects of film elasticity, but have low tensile or shear strengths.

Good design practice generally requires the avoidance of types of loads and joints which concentrate stresses in small areas or on component edges. Since adhesives generally possess great strength under shear loading, joints which stress the adhesive in shear are preferable.

Although many assembly problems can be solved with adhesive bonding techniques, there are many instances where only mechanical joints are capable of meeting design requirements. Examples include parts requiring replacement or removal for ease of fabrication or repair, access covers, and joints subjected to complex loadings.

Mechanical fasteners display some obvious advantages over adhesive bonding. Some of these advantages include utilization of conventional metal-working tools and techniques, ease of inspection, and assurance of strucural reliability. Offsetting the advantages are some disadvantages which include the necessity of additional loose parts (fasteners) for assembly, strength degradation of the basic laminate and resultant weight penalty, and need for more careful design than used for conventional metals due to the unequal directional properties of the laminate.

Some loading conditions may call for a combination of bonding and mechanical joining to meet the design allowables. In general, the problems associated with joining composites will require all of the ingenuity of the designers.

3.5.5 Recycling and Material Availability

Recycling fiber-reinforced composites presents an interesting area for speculation. The recycling process depends upon resin type, thermoplastic or thermoset, and whether manufacturing scrap or the end product is being recycled.

At the present, recycling scrap material is the easiest solution. This is particularly true when using thermoplastic resins. Thermoplastic scrap may be ground and used in injection molded parts. When using thermoset resins, it is feasible to grind the uncured scrap and use it in some sort of low grade compression molding compound. The cured scrap would have to be disposed of properly.

Recycling of the end product will require a large amount of development effort. This would include product life studies to determine if thermoplastics could be reground after a service life, and a study of the nature of facilities to do the recycling efficiently. It appears that thermoset products would have to be buried in a landfill for disposal. It is assumed that by the 1985-1995 time frame the technology could be developed to solve these problems, and that the energy saved by using the products would greatly off-set the disposal problems.

Fiber manufacturers expect that carbon fiber usage will grow very rapidly with good visibility for production planning. Since 1974, industry capacity has remained at about twice the market demand and forecasts through 1984 indicate it will remain that way. The three major U. S. fiber manufactures will have installed capacities of three million pounds by 1983. Generally, one million pounds of capacity, (or increments thereof) can be added in 18 to 24 months. Therefore in the time that it takes to bring a particular automotive model with a certain amount of carbon fiber into production, fiber manufacturers could install the capacity to meet production needs.

3.5.6 Uncontrolled Fiber Release

As graphite fibers are electrically conductive and have a low free fall rate of 2.5 cm/sec, there has been some concern about contamination of electronic equipment and electrical systems through the accidental release of these materials.

Uncontrolled fiber release has been a topic of government-funded programs for the past several years. The specific program, dealing with the commercial application of graphite fiber, has been a NASA-funded project to determine the risk potential through 1995.

Some conclusions from the NASA risk study are:

(a) The number or release incidents and number of carbon fibers released each year was estimated for each of 3000 counties in the U.S.

(b) The amount of equipment, along with associated vulnerabilities and failure costs, was tabulated for these counties.

(c) The losses for the individual counties have been calculated and summed to determine the national risk.

(d) The result of this calculation was a projected annual national dollar loss associated with the use of carbon fibers in surface transportation on the order of $6,000 per year.

(e) The vulnerability of surface transportation to airborne carbon fibers is very low. The risk of failure is less than one a year at the carbon fiber hazard level predicted for the year 1995. Similarly, the national risk due to this hazard is very low.

With increasing use of graphite fiber predicted, the risk of potential contamination will increase. However the conclusions presented in NASA Report 2119, Assessment of Carbon Fiber Electrical Effects, considered 1995 fiber predicted usage when evaluating data.

In summary, plants that manufacture or process carbon fibers have experienced minor fiber release problems but have solved them easily by protection or modifying the equipment involved. This, combined with the low probability of accidental release, emphasizes the need to pursue graphite fiber as a major structural material for weight reduction in the automotive industry.

4. CONCLUSIONS

Based on this study, it appears feasible that a 400 to 700 pound weight reduction could be achieved on the 1979 Omega X-Body and similar types of vehicles through hybrid material substitution. The lower pound value would reflect a conservative approach, while a higher pound value could be achieved through systems redesign for composite materials. The latter case would include primary and secondary weight reductions.

Current materials development programs will advance the state-of-the-art for higher structural grades of reinforced molding comounds and thermoplastic sheet by 1985. Production methods being developed today for the generally lower grades of reinforced materials will have direct application for the more advanced versions. The anticipated cost premiums of composites over metal construction relative to weight reduction will effectively become less and less by virtue of the greater added value due to fuel cost increases.

Much work is yet to be completed relative to long term composite part durability. Uncertainties must be eliminated through fleet service and durability programs. Testing on parts such as drive shafts, brackets, leaf springs, engine parts, and similar components has yielded generally positive results related to durability of composite materials.

5. RECOMMENDATIONS

Material substitution studies provide a basis for judging potentially viable applications for lightweight materials. Many more such studies are required before committing to part manufacture.

In support of a study of this nature, it is recommended that a detailed systems evaluation be conducted specifically for composite construction. Structural loads, systems handling and NVH response, vehicle safety, and all other requirements for total vehicle acceptance should be included in the design, analysis, and selection of parts and materials.

In support of the systems analysis approach to material selection, extensive test programs should be conducted. A parallel effort of testing and characterizing the lightweight materials prior to prototyping is recommended to verify baseline design characteristics. Much of this type of testing is being done today and, as more advanced materials are developed, additional characterization will be required.

6. REFERENCES

(1) Andon, J. and Falk, R., Oldsmobile Omega X-Body Baseline Weight Data, South Coast Technology, Inc., Santa Barbara, CA, Contract DOT HS-9-02111, 1979.

(2) Kaiser Robert, "Automotive Applications of Composite Material", Argos Associates Incorporated, Report No. DOT-HS-804-745, July 1978.

APPENDIX

Report of New Technology

No invention has been made during the preformance of work under this contract. This study establishes the weight reduction potential of light weight composite materials for a 1980 General Motor X-body car. Total weight savings is summaried in Table 1 (page 2). A summary of individual part weight reduction is given in Table 3 (pages 12 through 18).

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