NO. DOT-TSC-NHTSA-81-17

~~DOT-HS-805-892~~

WEIGHT REDUCTION POTENTIAL OF AUTOMOBILES AND LIGHT TRUCKS

1980 Summary Source Document

Hsi-sheng Hsia

U.S. DEPARTMENT OF TRANSPORTATION
RESEARCH AND SPECIAL PROGRAMS ADMINISTRATION
Transportation Systems Center
Cambridge MA 02142

JUNE 1981

FINAL REPORT

Prepared for

U.S. DEPARTMENT OF TRANSPORTATION
NATIONAL HIGHWAY TRAFFIC SAFETY ADMINISTRATION
Office of Research and Development
Washington DC 20590

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Technical Report Documentation Page

1. Report No. DOT-HS-805-892	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle WEIGHT REDUCTION POTENTIAL OF AUTOMOBILES AND LIGHT TRUCKS 1980 Summary Source Document		5. Report Date June 1981
		6. Performing Organization Code
7. Author(s) Hsi-sheng Hsia		8. Performing Organization Report No. DOT-TSC-NHTSA-81-17
9. Performing Organization Name and Address U.S. Department of Transportation Research and Special Programs Administration Transportation Systems Center Cambridge MA 02142		10. Work Unit No. (TRAIS) HS152/R1414
		11. Contract or Grant No.
12. Sponsoring Agency Name and Address U.S. Department of Transportation National Highway Traffic Safety Administration Office of Research and Development Washington DC 20590		13. Type of Report and Period Covered June 1981 Final Report
		14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

This report provides an assessment of the potential of weight reduction for passenger cars and light trucks (including pickup trucks, vans, and utility vehicles of GVWR up to 8500 pounds) in the post-1985 period. Vehicle characteristics and weight reduction methodologies, as well as methodologies for determining secondary weight reduction, are presented. Results of four weight reduction scenarios for material substitution, emphasizing high strength steels, fiberglass reinforced plastics, aluminum, and hybrid reinforced plastics, are presented for baseline vehicles.

17. Key Words Weight Reduction, Material Substitution, Light Duty Truck Passenger Car	18. Distribution Statement DOCUMENT IS AVAILABLE TO THE PUBLIC THROUGH THE NATIONAL TECHNICAL INFORMATION SERVICE, SPRINGFIELD, VIRGINIA 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	332	

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

PREFACE

This report, DOT-TSC-NHTSA-81-17, "Weight Reduction for Light Duty Vehicles, 1980 Summary Source Document," provides an assessment of the potential for weight reduction for passenger cars and light trucks in the post-1985 period.

This summary source document is a deliverable under PPA-HS-052, "Support for Research and Analysis in Automotive Fuel Economy and Related Areas -- Weight Reduction Studies."

METRIC CONVERSION FACTORS

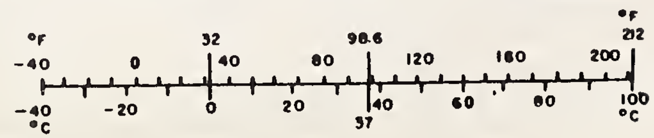
Approximate Conversions to Metric Measures

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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EXECUTIVE SUMMARY

This report presents the methodology and results of a study conducted to evaluate the potential of weight reduction for passenger cars and light trucks by material substitution. The vehicles included in this study are four-, five-, and six-passenger cars for the passenger car fleet, and pickups, vans, and utility vehicles, up to 8500 pounds CVWR, for the light truck fleet. The alternative materials considered for the substitution are high strength steels (HSS), aluminum, fiberglas reinforced plastic (FRP), and hybrid reinforced plastic (HRP), which contains 20 percent graphite and 80 percent glass.

Vehicles of weight efficient design are selected as baseline vehicles for this study. These vehicles are the 1978 Chrysler Omni, the 1980 Oldsmobile Omega and the 1977 Chevrolet Impala, representing four-, five-, and six-passenger cars, respectively, and the 1978 Chevrolet LUV, 1980 Ford F-150, the 1978 Dodge B-100, and the 1979 Dodge Ramcharger, representing compact pickups, standard pickups, vans, and utility vehicles, respectively. Detailed component material and weight data for these vehicles are obtained from vehicle tear-down studies.

For each baseline vehicle, components, which are judged to be replaceable by the material, differ only in the material selected. Four cases of material substitution were considered: the HSS dominant case, the FRP dominant case, the aluminum dominant case, and the HRP dominant case. The materials used for various components in each case are shown in the following Table E-1. In all four cases, the vehicles are assumed to have aluminum cylinder heads, stainless steel exhaust manifolds, HRP springs, aluminum bumpers and high density polyethylene (HDPE) fuel tanks.

Because of the large number of vehicle components involved, it is necessary to establish a simplified approach to classify these components by their geometrical shapes into three groups: panels, thin-walled beams, and solid sections. The components

TABLE E-1. MATERIALS USED FOR VARIOUS VEHICLE COMPONENTS FOR THE CASES CONSIDERED

VEHICLE COMPONENT	CASES CONSIDERED			
	HSS DOMINANT	FRP DOMINANT	AL DOMINANT	HRP DOMINANT
Panel member	HSS	FRP	AL	HRP
Solid section member	HSS	HSS	AL	HRP
Thin-walled beam	HSS	HSS	HSS	HRP
Cylinder head	AL	AL	AL	AL
Engine block	CI*	CI	AL	AL
Intake manifold	AL	AL	AL	AL
Exhaust manifold	SS**	SS	SS	SS
Radiator core	AL	AL	AL	AL
Fuel tank	HDPE	HDPE	HDPE	HDPE
Spring	HRP	HRP	HRP	HRP
Driveshaft	HRP	HRP	HRP	HRP
Brake disc and drum	AL	AL	AL	AL
Bumper	AL	AL	AL	AL
Wheel	AL	HRP	AL	HRP

*Cast Iron
**Stainless Steel

made of substitutional material are assumed to have the same overall dimensions and geometry as the original ones except for possible changes in thickness.

Studies show that stiffness is the most restrictive structural requirement of the total vehicle and its components for direct material substitution. Using stiffness as the component design criterion, the weight of a replacement component can be determined from the following formula:

$$W_n = W_o \left(\frac{\rho_n}{\rho_o}\right) \left(\frac{E_o}{E_n}\right)^{\frac{1}{m}}$$

where W is the weight of the component, P and E are the density and the modulus of elasticity of the material, respectively. The subscripts n and o refer to new and old material, respectively, and m is the geometric factor which is equal to 1 for thin-walled beams, 2 for panels, and 3 for solid sections.

By applying this formula, weight savings that can be achieved with direct material substitution are computed for each baseline vehicle. Since a reduction in vehicle upper body weight allows a reduction in under body weight which in turn leads to a reduction in the weight of chassis components, for every pound of primary weight reduction there is a secondary weight reduction. This secondary weight reduction ranges from a low estimate of 0.4 pounds to a high assessment of 1.6 pounds per pound of primary weight change. However, these estimates are based on statistical analyses performed on vehicle weight data for pre-1975 models. Since then, vehicle weight has been greatly reduced by resizing, material substitution, and redesign. It is doubtful that these estimates derived from pre-1975 weight data can be used to accurately project secondary weight change for present vehicles, let alone for vehicles in the future. For this reason, an alternative methodology based on component structural characteristics and change in applied load was developed at TSC. By applying TSC methodology for secondary weight reduction, total weight savings for each baseline vehicle were determined. The results are shown in Table E-2. Due to lack of detailed weight breakdown, secondary weight reduction for the baseline utility vehicle could not be determined.

TABLE E-2. ESTIMATED CURB WEIGHT FOR BASELINE VEHICLES

BASELINE VEHICLE	CURB WEIGHT									
	ORIGINAL	HSS DOMINANT		FRP DOMINANT		AL DOMINANT		HRP DOMINANT	
		A*	B**	A	B	A	B	A	B
4-Passenger Car	2092	1893	1836	1866	1801	1763	1662	1539	1362
5-Passenger Car	2702	2394	2307	2348	2241	2123	1946	1954	1724
6-Passenger Car	3708	3132	2995	3089	2932	2891	2765	2595	2264
Compact Pickup Truck	2408	2081	2001	2051	1957	1884	1730	1688	1486
Standard Pickup Truck	3687	3105	2990	3061	2929	2894	2706	2507	2225
Van	3432	2907	2715	2860	2639	2654	2334	2319	1842
Utility Truck	4277	3709	—	3668	—	3394	—	3216	—

*A — Primary weight reduction only

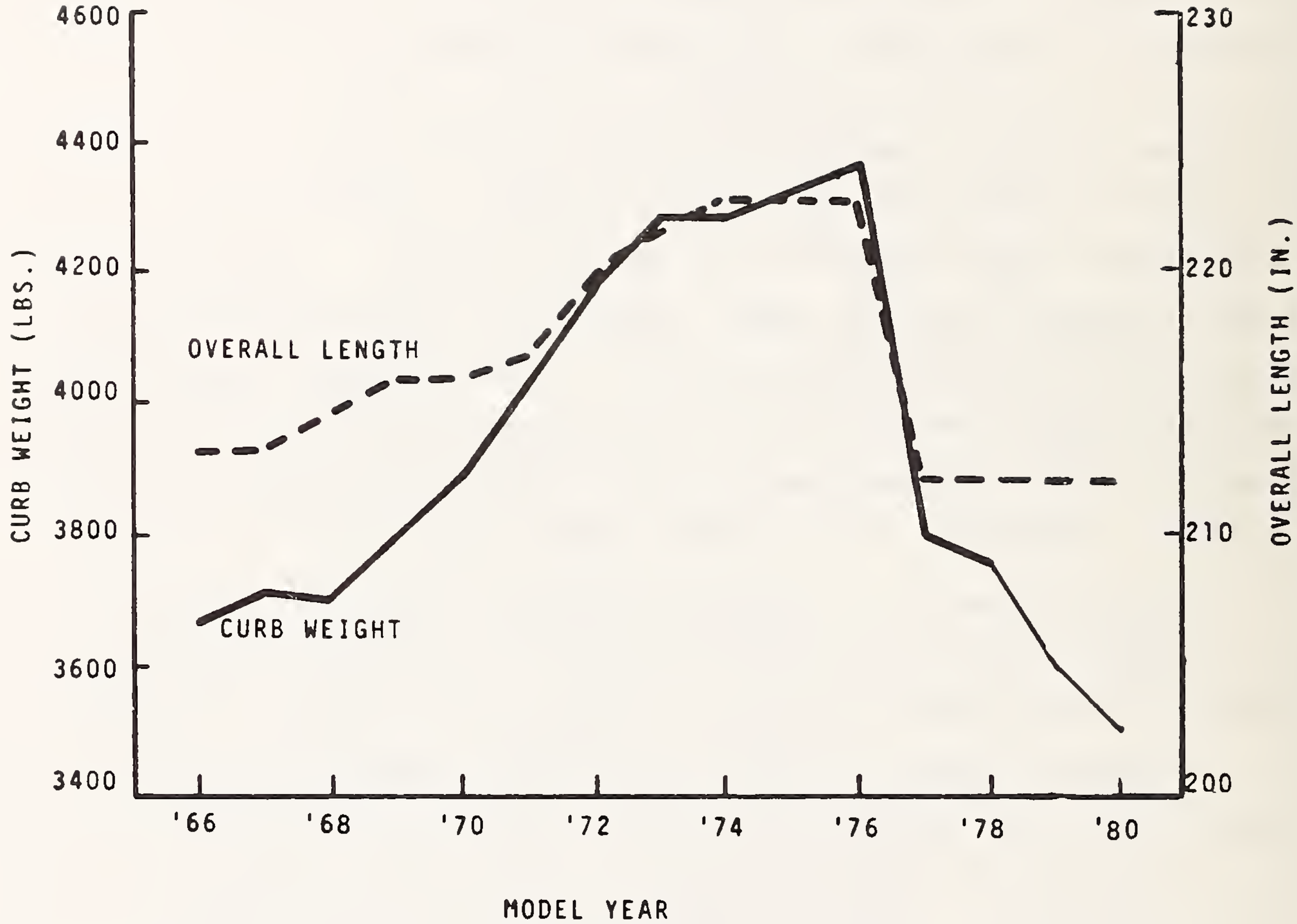
**B — With secondary weight reduction.

1. INTRODUCTION

1.1 BACKGROUND

American cars increased steadily in curb weight and overall length from the early 1950's to 1976. This trend is best represented by the best selling full-size Chevrolet which grew about 700 pounds in weight and nearly one foot in length in the period between 1967 and 1976, as shown in Figure 1-1. Since a major portion of the power required to move a vehicle is utilized to overcome vehicle inertia and rolling resistance, both of which are direct functions of vehicle weight, vehicle fuel economy deteriorates with increases in vehicle weight. Analyses show that among the many factors that influence vehicle fuel economy, vehicle weight is the most significant.[1] A ten percent reduction in vehicle weight can result in an improvement in fuel economy from a modest two to three percent to a very substantial eight to nine percent, depending on how the weight reduction is accomplished.[3,4]

In an attempt to conserve energy, Congress passed the Energy Policy and Conservation Act of 1975. This law requires each automobile manufacturer to meet or surpass a CAFE (Corporate Average Fuel Economy) value of 27.5 mpg for passenger cars and 21.0 mpg for light trucks by 1985 (Table 1-1). As a result of this mandate, the reduction of vehicle weight has become a priority in the automotive industry. General Motors was the first among the domestic automobile manufacturers to initiate a series of vehicle weight reduction programs. These programs led to the introduction of the downsized full-size cars in 1977 and the downsized mid-size cars in 1978; both were several hundred pounds lighter and about a foot shorter than the previous models. Despite the reduction in weight and exterior size, the available space for occupants remained nearly unchanged for these new models. For the 1980 model year, front-wheel drive compact-size X-body cars with transverse-mounted engines were introduced. The 1980 X-car has a base curb weight of 2450 pounds and an overall length of 177 inches as compared to 3260 pounds in weight and 200 inches in



Source: Reference 2 and MVMA Specifications

FIGURE 1-1. CURB WEIGHT AND OVERALL LENGTH OF FULL-SIZE CHEVROLET

TABLE 1-1. FLEET AVERAGE FUEL ECONOMY STANDARDS

FUEL ECONOMY STANDARDS (MPG)				
MODEL YEAR	PASSENGER CARS	LIGHT TRUCKS (up to 8500 lb GVWR)		
		2-WHEEL DRIVE	4-WHEEL DRIVE	COMBINED
1978	18.0			
1979	19.0	17.2*	15.8*	
1980	20.0	16.0	14.0	
1981	22.0	16.7	15.0	
1982	24.0	18.0	16.0	
1983	26.0	19.5	17.5	19.0
1984	27.0	20.3	18.5	20.0
1985	27.5	21.6	19.0	21.0

*For trucks up to 6000 lb GVWR only

overall length for the previous mode.

Chrysler introduced the first domestic front-wheel drive vehicle, the Omni/Horizon subcompact, in 1978. Chrysler's fullsize models were downsized in 1979. For the 1981 model year, Chrysler introduced its new front-wheel drive K-car to replace the Volare/Aspen. The K-car (Aries/Reliant) will be in competition with the X-car but is advertised to have a six-passenger capacity.

In 1978, Ford introduced its new Fairmont/Zephyr as replacements for the Maverick/Comet models. Except for a shorter wheelbase, these new cars are lighter and roomier than the previous models. Ford continued its weight reduction program by downsizing its fullsize models in 1979 and some of its mid-size models in 1980. A front-wheel drive subcompact (Escort/Lynx) was introduced as the 1981 model to replace the Pinto/Bobcat. For the 1981 model year, Ford also redesigned the Granada based on the Fairmont chassis. The new Granada is about 200 pounds lighter and 2 inches shorter than the previous model.

As a result of vehicle downsizing and the introduction of more weight efficient new models, the industry sales-weighted average vehicle test weight was drastically reduced from 4059 pounds in 1976 to an estimated 3283 pounds in 1980. Corresponding to this change in test weight was an estimated 4.9 miles/gallon increase in fleet composite fuel economy according to the EPA[5] and is shown in Table 1-2. Figure 1-2 shows the trends in fleet fuel economy and vehicle test weight for passenger cars in the period between the 1968 and 1980 model years.

Compared to passenger cars, very little progress in weight reduction has been made for light trucks of GVWR up to 8500 pounds. The primary reason is that the difference between actual size and functional size which existed in the passenger cars does not exist to the same degree in trucks. Therefore, a similar magnitude of weight reduction by downsizing does not apply to them. Besides, there are many more constraints for weight reduction for light trucks than for passenger cars. So far the only

TABLE 1-2. SALES-WEIGHTED AVERAGE VEHICLE TEST WEIGHT AND FUEL ECONOMY FOR PASSENGER CARS, PRE-CONTROL TO 1980

MODEL YEAR	TEST WEIGHT (LBS)	FUEL ECONOMY (MPG)
pre-1968	3812	14.90
1968	3863	14.69
1969	3942	14.74
1970	3877	14.85
1971	3887	14.37
1972	3942	14.48
1973	3969	14.15
1974	3968	14.21
1975	4058	15.79
1976	4059	17.46
1977	3944	18.31
1978	3587	19.90
1979*	3507	20.11
1980*	3283	22.37

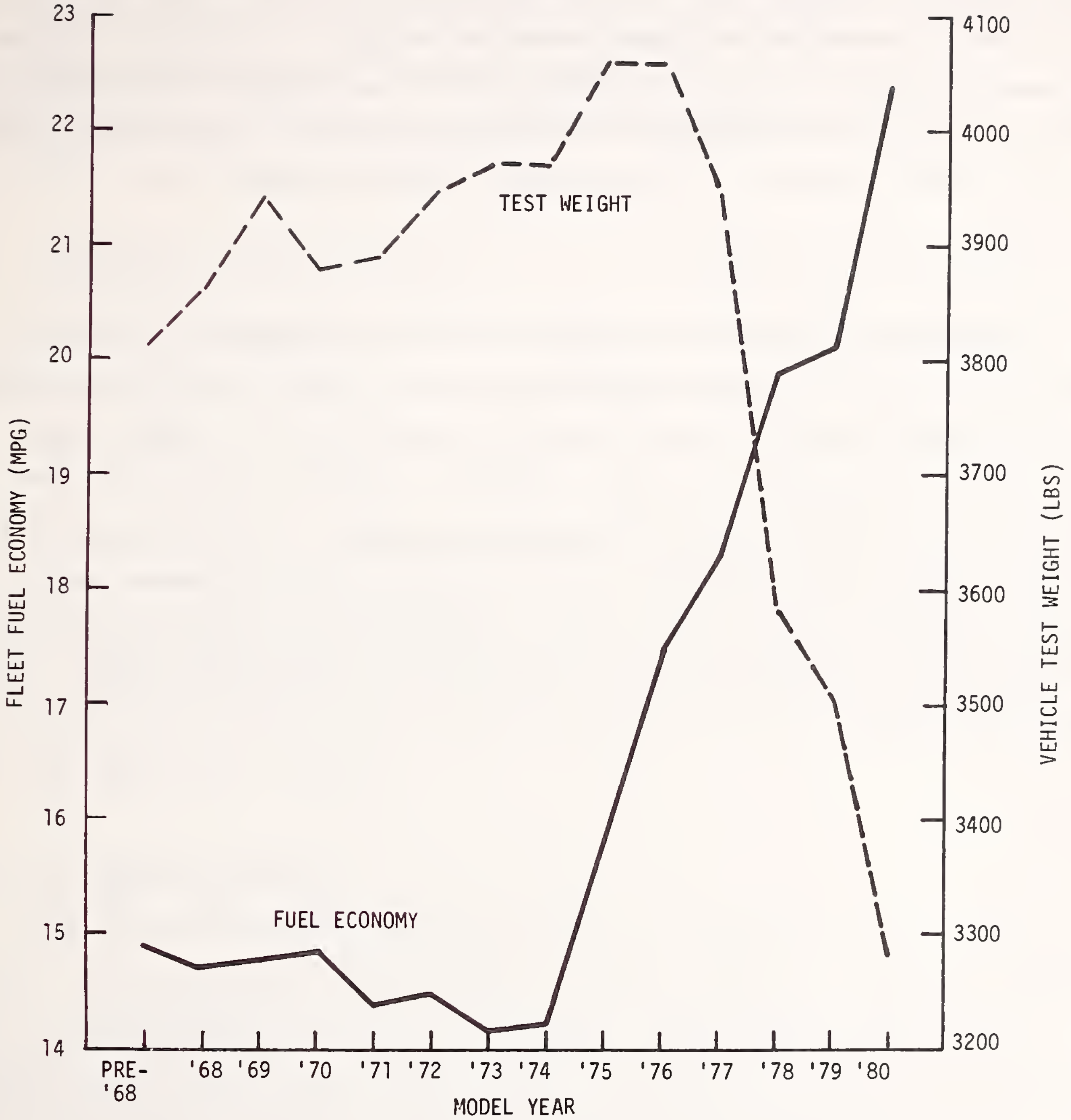
*Average vehicle test weight and fuel economy were calculated using projected sales.

Source: Reference 5

TABLE 1-3. SALES-WEIGHTED AVERAGE TEST WEIGHT AND FUEL ECONOMY FOR LIGHT DUTY TRUCKS, 1975 to 1980

MODEL YEAR	TEST WEIGHT (LBS)	FUEL ECONOMY (MPG)
1975	4222	14.59
1976	4146	16.12
1977	3878	19.13
1978	3847	18.72
1979	3796	17.53
1980	4194	17.08

Source: Reference 5



Source: Reference 5

FIGURE 1-2. TRENDS IN SALES-WEIGHTED FLEET FUEL ECONOMY AND VEHICLE TEST WEIGHT FOR PASSENGER CARS truck with substantial reduction in size is the 1980 Ford Bronco which is smaller and lighter than previous models. In the same model year, Ford also introduced its redesigned pickup trucks as "new design," weighing 200 to 360 pounds less then the previous models with comparable gross vehicle weight. Table 1-3 shows the changes in light truck sales-weighted test weight and composite fuel economy. The increase in test weight for the 1980 model year is due to the change in light truck definition.

1.2 PURPOSE OF DOCUMENT

The purpose of this document is to evaluate the potential weight reduction for passenger cars and light trucks of GVWR up to 8500 pounds in the post 1985 period. The vehicles under consideration are 2-, 4-, 5-, and 6-passenger cars for the passenger car fleet; and the pickups, vans, and utility vehicles for the light truck fleet. In addition, this document will establish methodologies for the assessment of weight reduction potential and define the relevant issues and impacts that are likely to arise.

2. VEHICLE ATTRIBUTES

Because of their distinct functional requirements, passenger cars and light trucks are characterized by different physical and performance attributes. This section presents descriptions of major vehicle attributes to provide a meaningful characterization for these two types of vehicles.

2.1 PASSENGER CAR ATTRIBUTES

In this document, passenger cars are defined as motor vehicles which have four wheels and are designed primarily for use on public streets, roads, and highways for carrying six passengers or less. Military and recreational vehicles are not included.

Vehicle attributes which concern the consumers of passenger cars include volume (passenger) capacity, fuel economy, performance, engine and transmission type, appearance, initial cost, safety, durability, etc. Of these, volume capacity and vehicle performance are two important measures of vehicle utility to the passenger car buyers.

2.1.1 Volume Capacity

The most important attribute for passenger cars is interior space. The earliest assessment of the interior space of passenger cars is the Roominess Index currently employed by Chilton's "Automotive Industries" (AI). In an annual article, since before 1974, AI ranks vehicles into classes based largely on outer size and customer perception of prestige. Within these classes, vehicles are ranked by their Roominess Index. The Roominess Index is a sum of the following measurements (in inches):

H61	Effective Head Room-Front
L34	Maximum Effective Leg Room-Accelerator
W3	Shoulder Room-Front
H30	H-point-Front to Heal (Seat Height)
H63	Effective Head Room - Second

L51 Effective Leg Room-Second

W4 Shoulder Room-Second

These dimensions are shown in Figure 2-1. Definitions of these dimensions are given in SAE procedure J-1100(a).[6]

Roominess Index for U.S. passenger cars between 1975 and 1981 model years ranges from 132.2 to 294.2 inches, as shown in Table 2-1. These values are distributed into the vehicle class as follows:

Vehicle Class	Roominess Index (inches)
Mini	254.5 - 260.8
Subcompact	248.4 - 273.4
Compact	268.3 - 276.7
Intermediate	271.5 - 288.7
Standard	280.7 - 294.2
Luxury	286.5 - 293.3
Personal Luxury	132.2 - 292.6

There is considerable overlap here which suggests either a fairly ineffective measurement or that the vehicles are misclassed. The later is suspected because the classification criterion is very subjective. Another problem with this system is that the luggage space, a definite measure of a vehicle's utility, was not taken into consideration in determining the Roominess Index.

EPA defines volume capacity for passenger cars as the interior volume of passenger and cargo compartment. Based on the measurement of this interior volume, EPA classifies passenger vehicles into five classes for sedans and three classes for station wagons, as shown in Table 2-2. Formulas for volume calculation are given in Table 2-3. Some changes in volume measurement were adopted for vehicles of 1978 and later model years to bring this classification system more in line with what consumers view as comparable grouping.[7]

This method of volume measurements also has some problems. For example, two of the linear measurements which are used for the

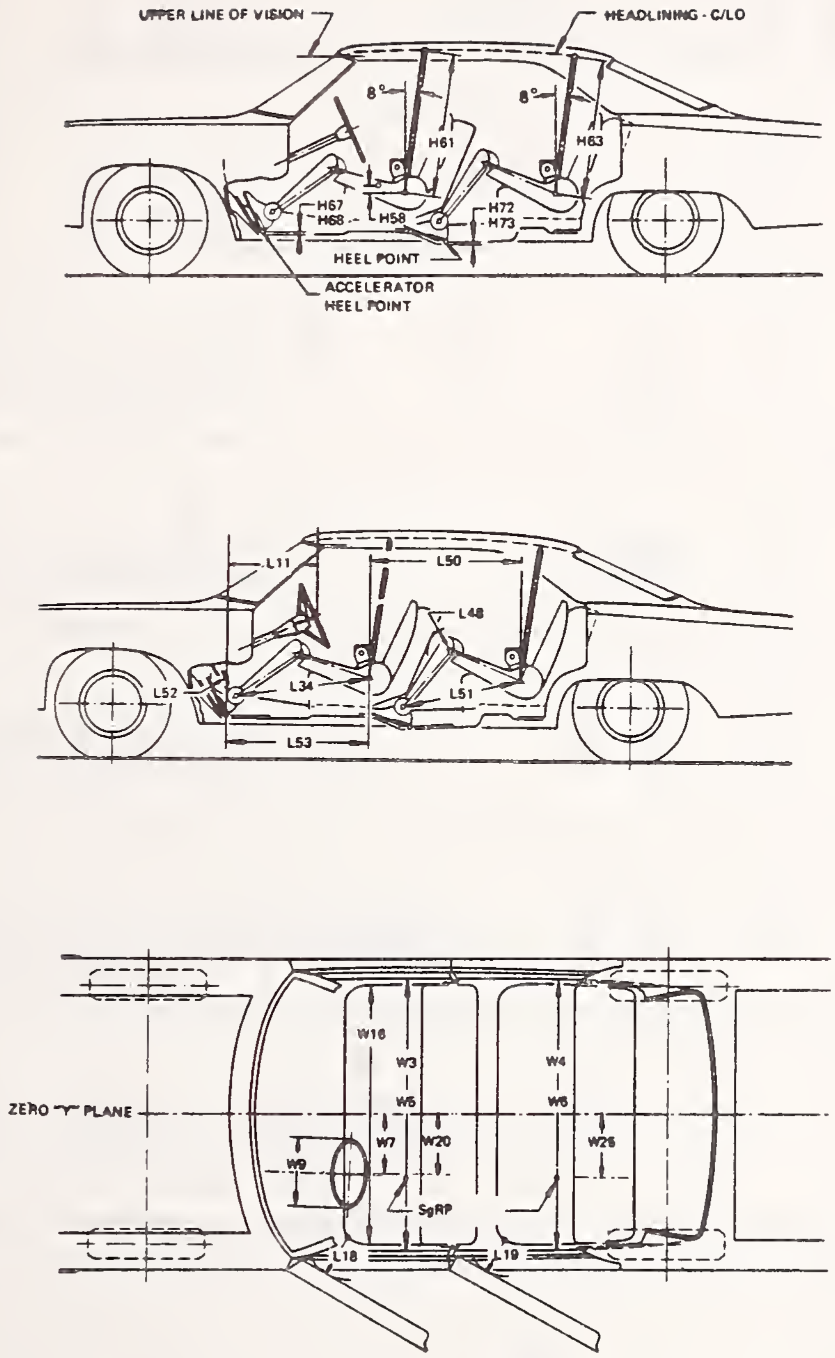


FIGURE 2-1. PASSENGER CAR INTERIOR DIMENSIONS

TABLE 2-1. ROOMINESS INDEX (INCHES) OF U.S. PASSENGER CARS, 1975-1981

MODEL	MODEL YEAR						
	'75	'76	'77	'78	'79	'80	'81
MINI							
CHEVETTE		254.9	254.5	259.9	260.4	260.8	260.6
SUBCOMPACTS							
PACER		267.5	268.4	269.8	273.4		
GREMLIN	261.1	259.4	260.9	259.8			
EAGLE-CONCORD						268.5	268.5
SPIRIT					258.6	257.8	257.7
VEGA	258.8	258.1					
ASTRE	253.8	258.1					
PINTO	257.0	255.6	252.3	254.6	254.2		
MONZA	255.3	255.5	255.5	255.8	255.8		
SUNBIRD		255.5	255.5	255.8	255.9		
STARFIRE	255.3	255.2	254.9	255.1	255.1		
SKYHAWK	255.3	254.9	254.9	255.1	255.1		
BOBCAT		253.4	254.1	253.5	252.8		
MUSTANG II	254.0	248.6	248.6	248.4	263.7	263.2	265.2
AMX					255.4		
OMNI					263.1	263.3	263.1
CAPRI					262.8	262.8	265.6
HORIZON					263.1	263.3	268.1
ESCORT							265.6
LYNX							265.6

TABLE 2-1. ROOMINESS INDEX (IN.) OF U.S. PASSENGER CARS, 1975-1981 (CONTINUED)

MODEL	MODEL YEAR						
	'75	'76	'77	'78	'79	'80	'81
COMPACTS							
ASPEN		276.7	275.9	275.9	275.9		
VOLARE		276.7	275.9	275.9	275.9		
NOVA	274.0	273.8	273.7	273.7	273.7		
OMEGA	273.5	273.6	273.7	273.7	273.7	275.5	275.5
VENTURA/PHOENIX	274.0	273.6	273.6	273.7	273.7	274.9	275.7
SKYLARK	273.5	273.5	273.7	273.7	273.7	274.3	273.6
DART	272.2	271.5					
VALIANT	272.2	271.5					
HORNET	268.3	269.2					
COMET	271.1	269.1					
MAVERICK	271.1	269.1					
FAIRMONT				275.9	275.6	274.5	275.8
ZEPHYR				275.9	275.7	275.3	274.5
CONCORD				268.6	268.6		
CITATION						276.2	276.2
RELIANT							275.7
ARIES							275.7

TABLE 2-1. ROOMINESS INDEX (IN.) OF U.S. PASSENGER CARS, 1975-1981 (CONTINUED)

MODEL	MODEL YEAR						
	'75	'76	'77	'78	'79	'80	'81
INTERMEDIATES							
MATADOR	288.0	288.7	288.7	288.7			
CENTURY	282.1	281.6	281.6	279.6	279.6	276.8	280.5
CUTLASS	282.0	281.5	281.4	279.6	279.6	280.4	280.4
LEMANS	282.0	281.5	281.5	280.1	280.1	280.1	280.4
CHEVELLE/MALIBU	282.1	281.4	281.4	280.6	280.6	280.6	280.5
MONTEGO	280.7	279.8					
TORINO	280.7	279.8					
CORONET	281.7	279.5					
FURY	281.7	279.5	278.6	279.2			
COUGAR/XR-7	272.2	271.5	279.5	278.5	279.2	272.3	273.3
LTD II			279.5	278.5	279.4		
DIPLOMAT				274.9	274.9	277.6	276.7
LEBARON				274.9	274.9	276.7	276.7
MONACO			278.6	279.2			

TABLE 2-1. ROOMINESS INDEX (IN.) OF U.S. PASSENGER CARS, 1975-1981 (CONTINUED)

MODEL	MODEL YEAR						
	'75	'76	'77	'78	'79	'80	'81
STANDARDS							
GRAN FURY	288.6	287.0					
CHECKER	280.7	280.7	280.7	280.7			
CHEVROLET	294.2	292.7	289.3	289.0	289.0	288.7	288.7
FORD	286.8	286.4	286.3	286.4	290.4	290.2	290.2
PONTIAC	293.5	292.5	287.8	289.0	289.0	288.7	289.3
BUICK	292.7	291.8	287.8	289.0	289.0	288.6	288.8
OLDSMOBILE	291.8	290.7	289.3	289.0	289.0	289.5	289.5
CHRYSLER	290.1	289.7	288.4	286.8	286.8	284.8	284.8
MERCURY	288.0	287.6	287.6	287.7	290.4	290.2	290.3
DODGE	288.6	287.0			286.7	286.8	286.8
PLYMOUTH						286.8	286.8
LUXURIES							
LINCOLN	292.3	291.6	291.6	292.0	292.0	291.8	291.9
CADILLAC	293.3	292.1	289.4	286.9	286.5	289.3	289.3

TABLE 2-1. ROOMINESS INDEX (IN.) OF U.S. PASSENGER CARS, 1975-1981 (CONTINUED)

MODEL	MODEL YEAR						
	'75	'76	'77	'78	'79	'80	'81
PERSONAL LUXURIES							
RIVIERA	289.7	289.7	288.7	289.6	278.9	279.0	278.4
TORANADO	286.1	285.4	285.1	286.7	279.0	279.0	278.5
ELDORADO	283.9	282.6	281.8	282.8	277.0	276.7	276.2
THUNDERBIRD	280.8	277.8	276.2	275.9	276.0	272.3	273.0
CHARGER SE	277.9	276.1	276.5	276.7			
CORDOBA	278.3	276.1	275.6	275.5	276.7	278.6	278.6
MARK IV	280.0	275.5					
GRAN PRIX	276.2	275.4	275.4	272.5	275.0		
MONTE CARLO	275.5	274.7	274.7	274.6	274.4	275.7	275.7
GRANADA	273.5	273.4	272.9	273.1	272.9	273.0	273.3
MONARCH/COUGAR	273.5	273.4	273.1	273.1	272.9	268.6	273.3
SEVILLE		272.8	272.4	272.7	272.7	278.7	278.4
FIREBIRD	264.9	264.9	263.3	262.6	262.7	262.7	262.8
CAMARO	264.5	264.2	262.6	262.7	262.7	262.8	262.8
CORVETTE	132.6	132.6	132.6	132.2	132.2	132.2	132.2
MAGNUM SE				276.9	276.7		
VERSAILLES				272.9	272.0		
MARK V			278.0	278.1	278.1		
REGAL					276.0	276.7	277.0
MARK VI						292.6	292.6
MIRADA						279.0	279.3
IMPERIAL							277.1

TABLE 2-2. VEHICLE CLASSIFICATION BY INTERIOR VOLUME

Vehicle Class	Interior Volume (ft^3)
Sedans	
Minicompacts	Under 85
Subcompact	85 - 100
Compact	100 - 110
Mid-size	110 - 120
Large	Over 120
Station Wagons	
Small	Under 130
Mid-size	130 - 160
Large	Over 160

TABLE 2-3. FORMULAS FOR CALCULATION OF PASSENGER CAR VOLUME

$$\text{Sedan Vol.}(ft^3) = \frac{H61 \times L34 \times W3}{1728} + \frac{H63 \times L51 \times W4}{1728} + V_1$$

-if shoulder room exceeds hip room by no more than 5 inches.

$$= \frac{H61 \times L34 \times \left(\frac{W3+W5+5}{2}\right)}{1728} + \frac{H63 \times L51 \times \left(\frac{W4+W6+5}{2}\right)}{1728}$$

-if shoulder room exceeds hip room by more than 5 inches.

$$\text{Hatchback Vol.}(ft^3) = \text{Same as Sedan} + V_3$$

$$\text{Station Wagon Vol.}(ft^3) = \text{Same as Sedan} + V_2$$

Where V_1 = Total volumes of pieces of the standard luggage set plus H-boxes as specified in J1100(a).

$$V_2 = \frac{W4 \times H201 \times L205}{1728}$$

$$V_3 = \frac{W4 \times H197 \times \left(\frac{L208 + L209}{2}\right)}{1728}$$

Note: All measurements as specified in SAE procedure J1100(a) except H197 is to top of second seat and L208 and L209 are to the back of the second seat. All measurements in inches.

computation of interior "volume" are non-perpendicular and hence this method does not produce a true volume. Another problem area is the way cargo volumes are determined, specifically those of hatchbacks and station wagons. This method uses second seat shoulder room for the width measurement of the cargo area. Few, if any, vehicles maintain this width into the cargo area due to wheel housings, spare tire and shock towers. The system used by the EPA loads station wagons to the roof while allowing hatchbacks to load only to the top of the second seat. Then it allows hatchbacks to use the rear shoulder room measurement and rectangularize the cargo compartment while the sedans must use the standard luggage sets. These inconsistancies stretch the intrinsic advantages of the vehicle types and exaggerate the differences.

Table 2-4 shows the comparison of passenger car interior measurements between AI Roominess Index and EPA passenger space for 25 1980 vehicles. As shown in Figure 2-2, the EPA volume measurement correlates amazingly well (with a correlation coefficient of 0.89) with the AI Roominess Index even through one is volume measurement while the other is linear measurement.

2.1.2 Equivalent Test Weight

Equivalent test weight is used to simulate the weight of a vehicle during acceleration and deceleration. For testing purpose, it is grouped into classes with 125, 250 and 500 pound increments. Table 2-5 shows test weight classes for vehicles up to 10,000 pounds loaded vehicle weight.

Loaded weight of a vehicle is defined by the EPA to be vehicle curb weight plus 300 pounds. Vehicle curb weight is, in turn, defined as the weight of a vehicle with maximum capacity of engine fuel, oil, and coolant and with the full weight of all items of optional equipment sold on 33 percent or more of that vehicle family.

Since the 1975 model year, domestic passenger car sales have shifted enormously to vehicles of lower test weight class. This

TABLE 2-4. COMPARISON OF PASSENGER CAR INTERIOR MEASUREMENTS, 1980 MODEL YEAR

MODEL	AI ROOMINESS INDEX (IN.)	EPA PASSENGER SPACE (FT^3)
Spirit	257.8	76
Chevette	260.8	79
Omni	263.3	81
Mustang	263.2	82
Capri	262.8	82
Concord	268.5	90
Skylark	274.3	94
Omega	275.5	94
Citation	276.2	94
Malibu	280.6	96
Century	276.8	97
Diplomat	277.6	92
Fairmont	274.5	95
Regal	276.7	98
Riviera	279.0	100
Eldorado	276.7	99
Seville	278.7	101
Cordoba	278.6	97
LeBaron	276.7	92
Camaro	262.8	85
Cougar XR-7	272.3	93
Cutlass	280.4	97
Toronado	279.0	100
Grand Prix	275.0	97
LeMans	280.1	96

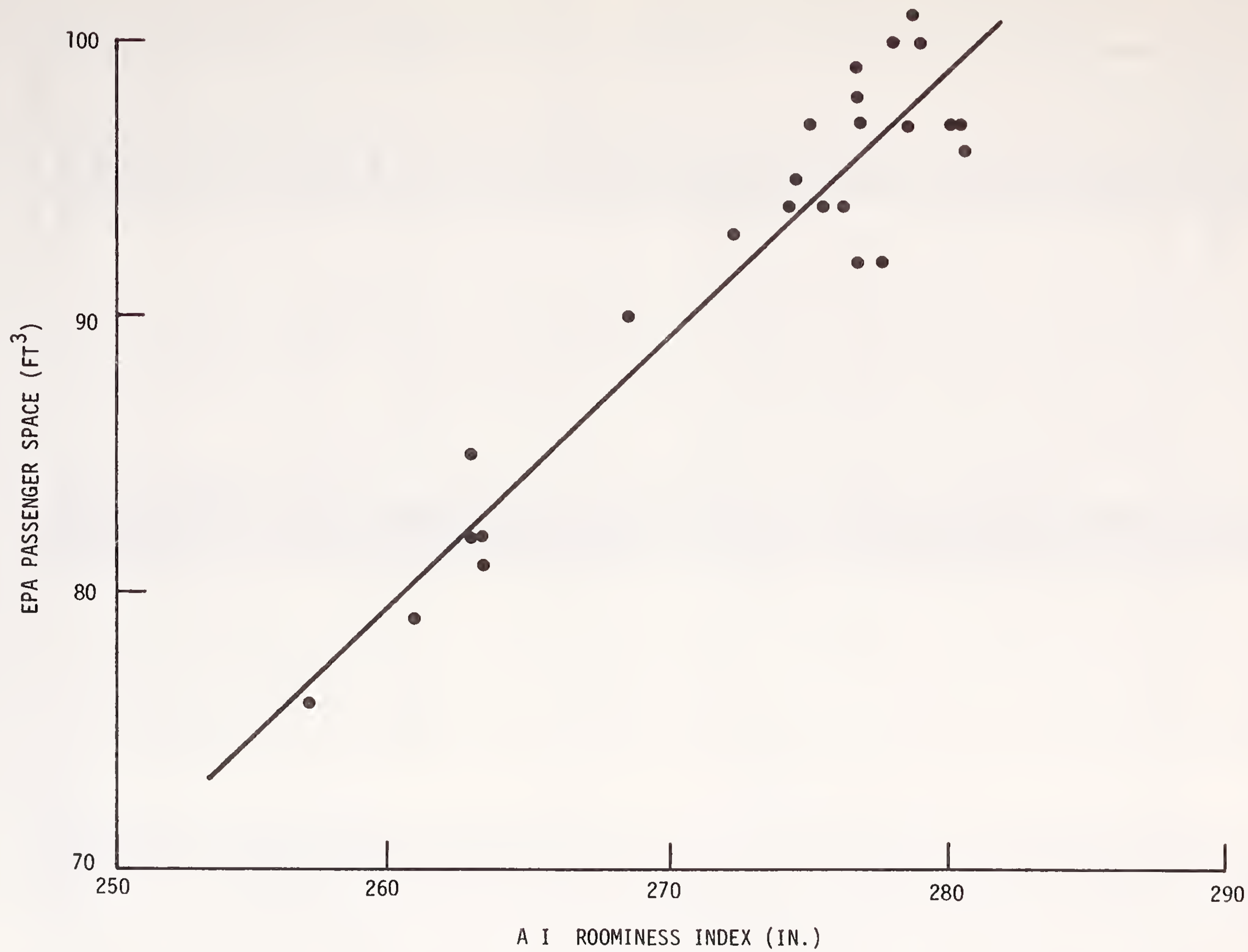


FIGURE 2-2. AI ROOMINESS INDEX VERSUS EPA PASSENGER SPACE

TABLE 2-5. TEST WEIGHT CLASSES

LOADED VEHICLE WEIGHT	TEST WEIGHT CLASS (LBS) 1979 AND EARLIER	1980 AND BEYOND
UP TO 1062	1000	1000
1063 - 1187	1000	1125
1188 - 1312	1250	1250
1313 - 1437	1250	1375
1438 - 1562	1500	1500
1563 - 1687	1500	1625
1688 - 1812	1750	1750
1813 - 1937	1750	1875
1938 - 2062	2000	2000
2063 - 2187	2000	2125
2188 - 2312	2250	2250
2313 - 2437	2250	2375
2438 - 2562	2500	2500
2563 - 2687	2500	2625
2688 - 2812	2750	2750
2813 - 2937	2750	2875
2938 - 3062	3000	3000
3063 - 3187	3000	3125
3188 - 3312	3000	3250
3313 - 3437	3500	3375
3438 - 3562	3500	3500
3563 - 3687	3500	3625
3688 - 3812	3500	3750
3813 - 3937	4000	3875
3938 - 4125	4000	4000
4126 - 4375	4000	4250
4376 - 4625	4500	4500
4626 - 4875	4500	4750
4876 - 5125	5000	5000
5126 - 5375	5000	5250
5376 - 5750	5500	5500
5751 - 6250	6000	6000
6251 - 6750	6500	6500
6751 - 7250	7000	7000
7251 - 7750	7500	7500
7751 - 8250	8000	8000
8251 - 8750	8500	8500
8751 - 9250	9000	9000
9251 - 9750	9500	9500
9751 - 10,000	10,000	10,000

trend is shown in Figure 2-3 which compares percent sales of each test weight class for 1975 and 1980 model year domestic passenger car fleets.

2.1.3 Acceleration

A simple measure of vehicle acceleration performance is the 0 to 60 mph acceleration time. The acceleration time can be related to vehicle horsepower-to-test-weight ratio (HP/TW) which is defined as the ratio of maximum engine brake horsepower to vehicle test weight. It is recognized that there are several factors affecting vehicle acceleration time besides HP/TW. Not only are engine speed-torque characteristics and drivetrain characteristics significant factors, but human reactions and test track conditions also can have appreciable affects on the measurement of acceleration time. Nevertheless, HP/TW is overwhelmingly influential and allows an adequate description of the acceleration performance.

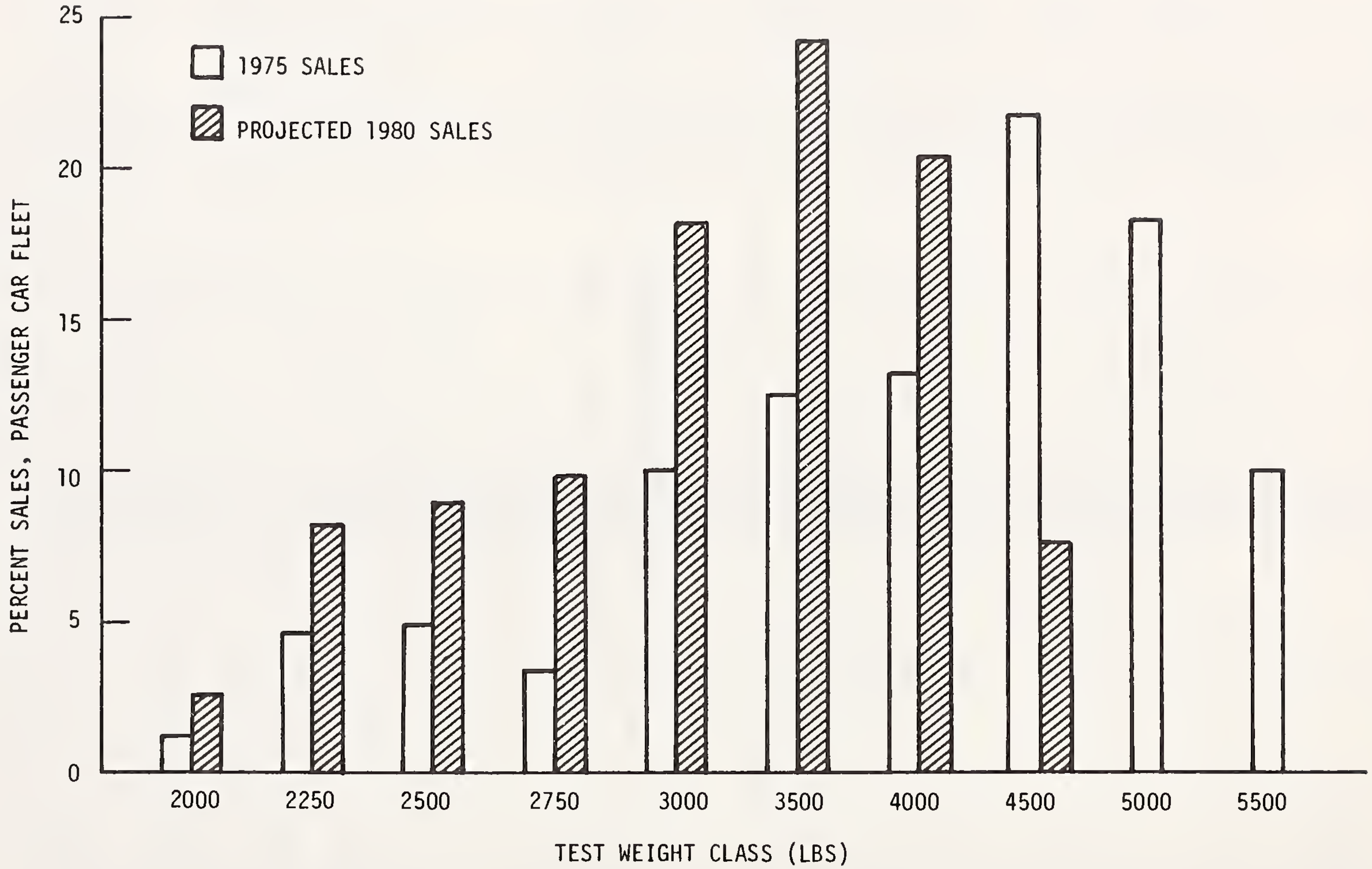
An analysis[4] using test track measurements of 1975 vehicles relates HP/TW to 0 to 60 mph acceleration time (t) as follows:

$$t = 0.829 \ (HP/TW)^{-.819}$$

where t is in seconds and HP/TW in hp/lb.
According to this formula, HP/TW values of 0.02, 0.03 and 0.04 result in a 0 to 60 mph acceleration time of 20, 15 and 12 seconds, respectively. These three levels of acceleration performance are designated as low, mid, and high, respectively, in a Federal Task Force Report on Motor Vehicle Goals Beyond 1980.[8]

Acceleration data for 110 1978 passenger cars were obtained from popular automotive literature.[9] The relationship between the 0 to 60 mph time and the HP/TW ratio for these 1978 vehicles was determined by a least-squares fit technique to be:

$$t = .681 \ (HP/TW)^{-.852}$$



Source: Reference 5

FIGURE 2-3. COMPARISON OF PERCENT SALES FOR 1975 AND 1980 PASSENGER CAR FLEETS

Acceleration data for 109 passenger vehicles of 1980 model year were collected from automobile publications. These data, together with relevant performance attributes, are tabulated in Table 2-6. Least-squares fitting of this data yielded the following relationship between the 0 to 60 mph time and the HP/TW ratio:

$$t = .800\ (HP/TW)^{-.818}$$

This fitting relation as well as the performance data are shown in Figure 2-4.

The fitting relations for passenger cars of 1975, 1978 and 1980 model years are plotted in Figure 2-5 for comparison. It is interesting to see that these curves are close and are essentially parallel to each other in spite of the immense technological changes in vehicles between 1975 and 1980 model years.

Since today's legal highway speed is lower and many of todays engines are too small to give good acceleration in the 0 to 60 mph range, it has been suggested that acceleration time for speed range such as 0 to 50 mph should be the criterion for performance measurement. Chevrolet and Buick have come up with a minimum acceleration standard of 8 ft/sec^2 between 5 and 10 mph at full acceleration. This rate is equal to a 15-second 0 to 60 mph acceleration time. However, 0 to 60 mph acceleration time is still widely used in present day track measurements for vehicle performance.

2.2 LIGHT TRUCK ATTRIBUTES

Light trucks are defined in this document as pickups, vans, and utility vehicles designed primarily for the transportation of cargo and personnel with gross vehicle weight ratings of 8500 pounds or less. These vehicles are intended for both on and off highway use. Military vehicles, vehicles which are exclusively for off-road use, recreational vehicles, vehicles with a specialized body, and vehicles with a GVWR greater than 8,500 pounds are not considered in this document.

TABLE 2-6. ACCELERATION PERFORMANCE AND OTHER VEHICLE DATA FOR 1980 PASSENGER CARS

MODEL	CID	HP	TORQUE (FT-LB)	TRANSMISSION	AXLE RATIO	TEST WEIGHT (LBS)	0-60 TIME (SEC.)
LAMBORGHINI COUNTACH S	268	475	309	M5	4.09	3008	6.1
PROSCHE 911SC	183	172	189	M5	3.88	2950	6.7
MORGAN+8 TURBO	215	225	240	M5	3.31	2475	6.8
FERRARI 308 GTS	179	205	181	M5	3.71	3590	6.9
PORSCHE 928	273	219	254	M5	2.75	3600	7.4
PORSCHE 924 TURBO	121	143	147	M5	4.71	3080	7.5
CHEVROLET CORVETTE	350	190	280	M4	3.07	3630	7.6
FERRARI DINO 308	179	205	181	M5	3.71	3660	7.8
BMW 528I	170	169	170	M5	3.45	3700	7.9
TRIUMPH TR8	215	148	180	M5	3.08	2920	8.1
BMW 733I	196	174	188	M4	3.45	3910	8.2
PONTIAC FIREBIRD TURBO	302	205	310	A3	3.08	4017	8.2
VOLVO GL	130	107	114	M4	3.91	3370	8.3
LOTUS ESPIRIT S2	120	140	130	M5	4.38	2744	8.4
TRIUMPH TR8 V-8	215	133	147	M5	3.08	2962	8.5
CHEVROLET CAMARO Z28	350	190	280	M4	3.08	3960	8.5
AUDI 500T	131	130	142	A3	3.73	3280	9.4
BMW 320I	108	101	100	M5	3.91	2720	9.8
SAAB 900 TURBO	121	135	160	M4	3.89	3060	9.8
ROVER 3500	215	133	165	M5	3.08	3540	9.8
MERCEDES-BENZ 450EL	276	180	220	A3	3.06	4260	10.2
ROVER 3500 (JRT)	215	148	180	M5	3.08	3457	10.3
MAZDA RX-7	70	100	105	M5	3.91	2720	10.5
MAZDA 626	120	75	105	M5	3.63	2895	10.5
DODGE MIRADA	360	155	170	A3	2.94	3595	10.5

TABLE 2-6. ACCELERATION PERFORMANCE AND OTHER VEHICLE DATA FOR 1980 PASSENGER CARS (CONTINUED)

MODEL	CID	HP	TORQUE (FT-LB)	TRANSMISSION	AXLE RATIO	TEST WEIGHT(LBS)	0-60 TIME (SEC.)
MERCURY CAPRI TURBO RS	140	127	145	M4	3.45	2967	10.7
JAGUAR XJ6	259	176	219	A3	3.07	4420	10.7
FORD MUSTANG COBRA	140	132	142	M4	3.45	3161	10.8
HONDA CIVIC 1500GL	91	67	79	M5	3.88	2160	10.9
CHEVROLET CAPRICE	305	155	240	A3	2.41	3984	10.9
PONTIAC GRAND AM	301	155	240	A3	2.93	3770	11.0
COUGAR XR7	302	131	231	A4	3.08	3570	11.1
FORD THUNDERBIRD	302	131	231	A4	3.08	3660	11.1
PEUGEOT 604	174	133	162	M5	3.70	3720	11.1
LINCOLN CONTINENTAL IV	351	140	265	A4	3.08	4422	11.1
VOLKSWAGEN SCIROCCO	97	76	83	M5	3.17	2230	11.2
ALFA ROMERO SPIDER 2000	120	111	110	M5	4.55	2755	11.2
DATSUN 810	119	120	125	M5	3.86	3053	11.3
FORD MUSTANG COBRA	255	115	191	A3	2.26	3281	11.3
BUICK RIVIERE TYPE S	231	185	280	A3	2.93	4035	11.3
ROLLS-ROYCE SILVER SHADOW	412	190	290	A3	3.08	5140	11.3
DOVLA SHADOW	351	149	258	A3	2.47	3860	11.4
BUICK SKYLARK SEDAN	173	115	145	A3	2.84	2877	11.6
BUICK SKYLARK SPORT COUPE	173	115	145	A3	2.84	2854	11.7
VOLKSWAGEN JETTA	97	76	83	M5	3.89	2400	11.8
TOYOTA SUNCHASER(TARGA)	134	90	122	M5	3.58	2780	11.8
CHRYSLER CORDOBA	318	120	245	A3	2.45	3726	11.8
TRIUMPH TR7	122	85	105	M5	3.63	2740	11.9
CHEVROLET MONTE CARLO	231	170	265	A3	2.41	3535	11.9
TOYOTA COROLLA SR5 RWD	108	75	95	M5	3.73	2650	12.1
PONTIAC PHOENIX	151	90	134	A3	2.84	2810	12.1
FORD FIESTA	98	66	82	M4	3.58	2060	12.2

TABLE 2-6. ACCELERATION PERFORMANCE AND OTHER VEHICLE DATA FOR 1980 PASSENGER CARS (CONTINUED)

MODEL	CID	HP	TORQUE (FT-LB)	TRANSMISSION	AXLE RATIO	TEST WEIGHT (LBS)	0-60 TIME (SEC.)
TOYOTA CELICA SUPRA	156	110	136	M5	3.90	3155	12.2
FORD LTD	302	130	230	A3	2.26	3895	12.5
LANCIA ZAGATO	122	87	105	M5	4.21	3030	12.7
PLYMOUTH GRAN FURY	318	120	245	A3	2.24	4045	12.7
RABBIT L CONVERTIBLE VW	97	76	83	M5	4.17	2470	12.8
TRIUMPH TR7 CONVERTIBLE	122	85	104	M5	3.90	2701	12.8
DATSUN 510	120	92	112	M5	3.36	2360	13.0
BUICK CENTURY LIMITED	231	110	190	A3	2.41	3501	13.2
BUICK LESABRE	231	170	265	A3	2.73	3869	13.3
SUBARU DL-5	97	67	81	M5	3.70	2315	13.4
AUDI 4000	97	78	84	M4	4.11	2560	13.4
DATSUN 200-SX	119	100	112	M5	3.70	2920	13.6
CHRYSLER LEBARON 5TH AVE	318	120	245	A3	2.47	3772	13.7
HONDA CIVIC CVCC	91	63	77	M5	4.38	2097	13.8
MAZDA 626	120	80	105	M5	3.64	2865	13.8
CHEVROLET CAPRICE WAGON	305	155	240	A3	2.56	4382	13.9
PEUGEOT 505S	120	96	116	M5	4.11	3320	14.1
CHRYSLER NEW YORKER	318	120	245	A3	2.45	4182	14.1
SUBARU 1600GL-5	97	67	81	M5	3.90	2440	14.2
OLDSMOBILE CUTLASS SUP.	231	110	190	A3	2.93	3593	14.2
HONDA PRELUDE	107	72	94	M5	4.38	2406	14.3
DODGE COLT ST. WAGON	156	105	139	M5	3.03	3100	14.4
VOLKSWAGON RABBIT	97	76	83	M5	3.17	2444	14.7
CHEVROLET CITATION	151	90	128	A3	2.53	2950	14.7
MERCURY ZEPHYR ES	200	85	154	M4	3.08	2997	14.9
DATSUN 510 HATCHBACK	119	92	112	M5	2.87	2734	15.0
FORD FAIRMOUNT	200	85	154	A3	2.73	3035	15.0

TABLE 2-6. ACCELERATION PERFORMANCE AND OTHER VEHICLE DATA FOR 1980 PASSENGER CARS (CONTINUED)

MODEL	CID	HP	TORQUE (FT-LB)	TRANSMISSION	AXLE RATIO	TEST WEIGHT (LBS)	0-60 TIME (SEC.)
DODGE DIPLOMAT	225	90	160	A3	2.76	3614	15.0
TOYOTA COROLLA ST. WAGON	108	75	95	M5	3.21	2565	15.2
PLYMOUTH HORIZON	105	70	110	A3	3.67	2454	15.4
CHEVROLET CHEVETTE	98	70	82	M4	3.70	2420	15.5
TOYOTA CORONA LIFTBACK	134	90	122	M5	3.06	3011	15.5
DODGE COLT HATCHBACK	86	65	75	M5	3.47	2282	15.6
AMC CONCORD	258	120	210	A3	2.52	3116	16.0
COROLLA TERCEL SR5 TOYOTA	89	60	72	M5	3.41	2310	16.2
DATSUN 310	86	65	75	M4	3.47	2319	16.4
CITROEN CX PALLAS 2500D	151	75	111	M5	4.77	3250	16.4
MAZDA GLC	86	65	76	M5	3.73	2280	16.8
RENAULT LE CAR	85	60	70	M4	3.63	2120	17.2
AUDI 5000S DIESEL	121	67	90	M5	4.78	2270	17.6
MAZDA GLC WAGON	86	65	76	M5	3.08	2410	17.9
FORD FAIRMONT	140	88	118	A3	3.08	3170	18.1
VOLVE DIESEL	145	78	102	M4	3.54	3145	18.5
FORD FAIRMONT	200	95	152	A3	2.73	3101	18.7
DODGE ASPEN	225	90	165	A3	2.76	3681	18.7
PONTIAC BONNEVILLE DIESEL	350	125	225	A3	2.41	3980	19.1
DATSUN 210 ST. WAGON	85	65	75	M5	3.04	2410	19.2
VOLKSWAGEN DASHER	90	48	56	M4	4.11	2530	19.4
MERCEDES-BENZ 300T DIESEL	183	77	115	A4	3.46	4020	19.5
CHEV. CAPRICE WAGON DIESEL	350	105	205	A3	2.73	4433	19.6
CADILLAC SEVILLE DIESEL	350	105	205	A3	2.41	4491	19.7
AMC CONCORD	151	90	105	A3	3.08	3303	20.1

TABLE 2-6. ACCELERATION PERFORMANCE AND OTHER VEHICLE DATA FOR 1980 PASSENGER CARS (CONTINUED)

MODEL	CID	HP	TORQUE (FT-LB)	TRANSMISSION	AXLE RATIO	TEST WEIGHT (LBS)	0-60 TIME (SEC.)
CHEVROLET MALIBU	229	110	190	A3	2.73	3582	20.5
OLDS CUTLASS DIESEL	350	105	205	A3	2.29	3765	20.5
AUDI 5000 DIESEL	121	67	85	M5	4.78	3965	20.5
CHRYSLER LEBARON	225	90	160	A3	2.94	3916	20.9
PEUGEOT DIESEL	140	78	102	M4	3.78	3155	23.1

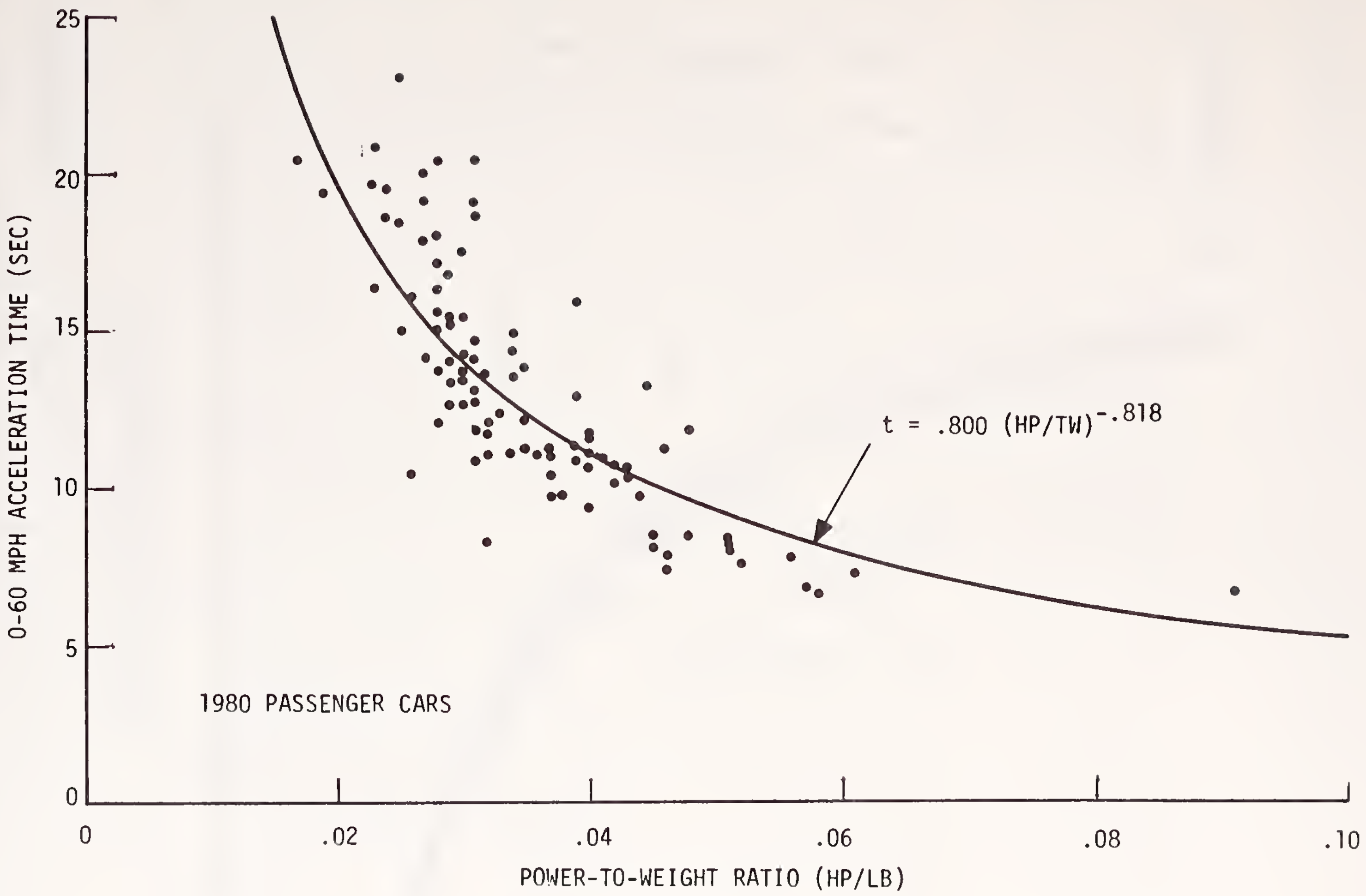


FIGURE 2-4. LEAST-SQUARES FIT OF ACCELERATION TIME VERSUS HP/TW RATIO FOR 1980 PASSENGER CARS

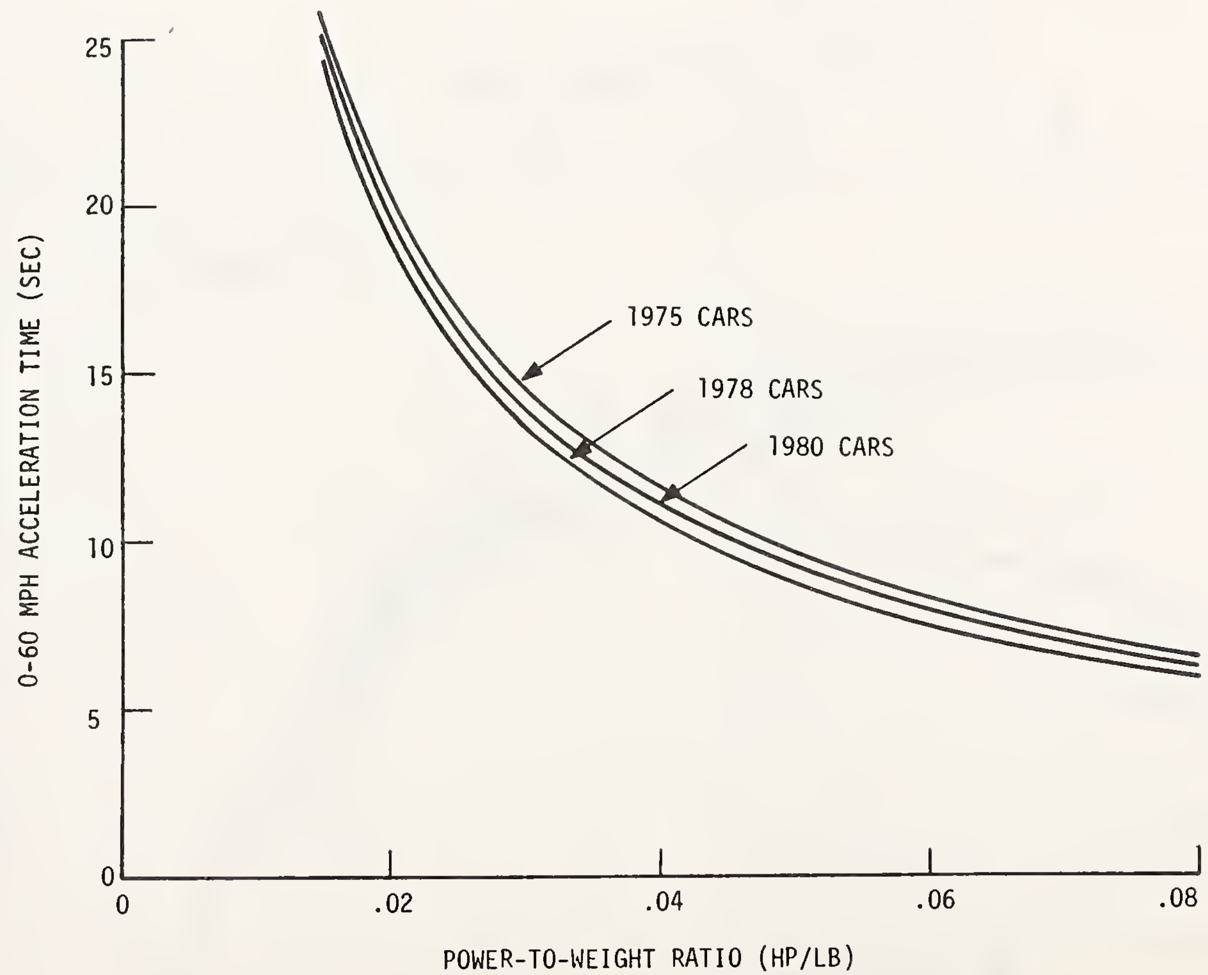


FIGURE 2-5. COMPARISON OF ACCELERATION TIME FITTING RELATIONS FOR PASSENGER CARS OF RECENT MODEL YEARS

2.2.1 Equivalent Test Weight

Equivalent test weight of light trucks is defined by EPA to be the same as for passenger cars, i.e., curb weight plus 300 pounds. It is used primarily for fuel economy labelling. Test weight classes shown in Table 2-5 also apply to light trucks.

2.2.2 GVWR and GAWR

Gross vehicle weight rating (GVWR) is defined as the maximum overall weight at which the vehicle is designed to operate. It is specified by the vehicle manufacturer and is the common measure used to classify various sizes of trucks.

Each truck also has a separate front and rear gross axle weight rating (GAWR). When fully loaded, the weight on each axle should not exceed its GAWR. On light duty trucks, the configuration of the vehicle does not usually allow the front axle to carry as much weight as its rating. For this reason, the GVWR is less than the total of the front and rear GAWR.

The GVWR and GAWR of a truck are determined by the capacity of the tires, springs and axles. The lowest load carrying capacity of these components will determine these ratings.

The GVWR and GAWR provide a guideline for vehicle selection. However, correct truck selection should include a careful study of the way the total gross weight is distributed. Weight properly distributed to front and rear axles provides proper traction at front axle for good steering control and at rear axle for good tractive ability.

2.2.3 Payload

Payload is defined as the difference between the gross vehicle weight rating and the curb weight of the truck. It includes the weight of cargo, driver, passengers, and all extra equipment not included in curb weight. It is important to note that the weight of passengers and extra equipment must be subtracted from payload to determine the true cargo load capacity.

In the weight reduction analyses for light trucks presented in this document, vehicle payload is considered to remain unchanged. Only vehicle curb weight and GVWR are subject to change. This means that vehicles with GVWR greater than 8500 pounds before weight reduction may fall to 8500 pounds GVWR or below after weight reduction.

2.2.4 Volume Capacity

Volume capacity of a truck cannot be defined as precisely as load capacity. It is considered to be the space assigned to carrying the cargo load. In a vehicle with an open cargo area, such as a pickup, volume capacity is considered to be the volume of the cargo box, although specific loads higher than the sides of the cargo box can be carried by the vehicle. In a van type vehcile, volume capacity is considered to be the interior space behind the driver's seat. Table 2-7 shows the formulas for light truck volume calculation. The dimension used in the formulas are shown in Figure 2-6.

One common requirement for cargo area is to have a minimum of four feet of clear load space between the rear wheel housings and eight feet of cargo area length. This is based on the widespread use of those dimensions as a unit size for building materials and cargo containers. These dimensions will remain unchanged in the weight reduction consideration.

2.2.5 Gradeability

Gradeability is a measure of the capability of a fully loaded truck to satisfactorily move up a specified grade from a dead stop. It is expressed in percent representing the height of the rise from level over a 100-foot distance. In general, a vehicle should provide at least 10 percent gradeability to set the vehicle in motion from a standing start on level road.[10] In addition, the vehicle should have sufficient gradeability to climb the steepest

TABLE 2-7. FORMULAS FOR LIGHT TRUCK VOLUME CALCULATION

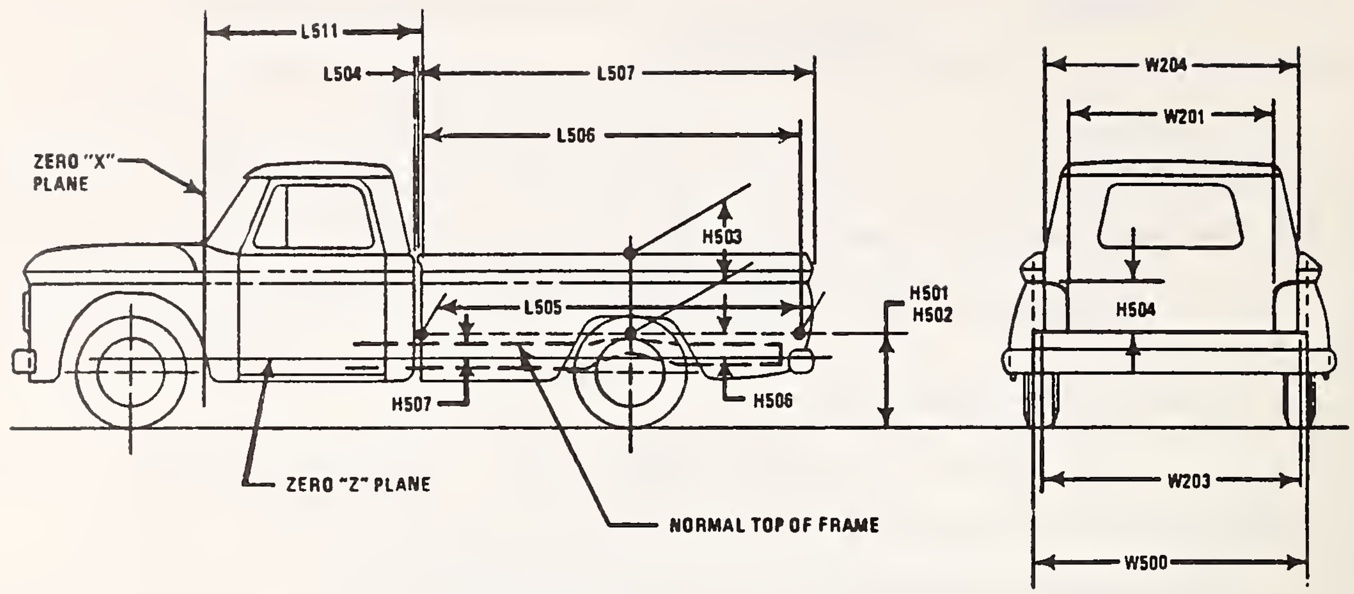
Trucks with open area

$$\text{volume (ft}^3\text{)} = \frac{L506 \times W500 \times H503}{1728}$$

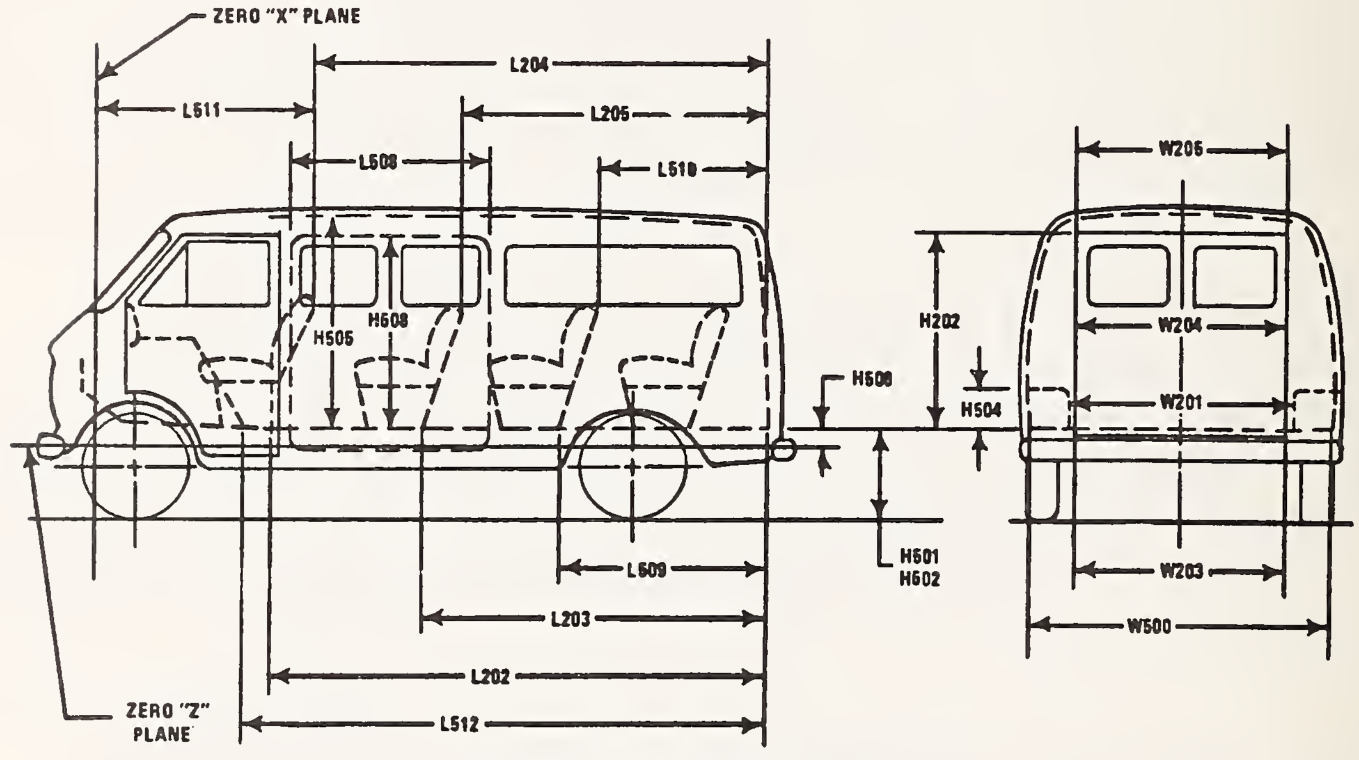
Trucks with closed area

$$\text{volume (ft}^3\text{)} = \frac{L204 \times W500 \times H505}{1728}$$

Note: All measurements in inches as specified in SAE procedure J1100(a).



TRUCK WITH OPEN CARGO AREA



TRUCK WITH CLOSED CARGO AREA

FIGURE 2-6. LIGHT TRUCK CARGO SPACE DIMENSIONS grade that will be encountered in operation. As a general rule, a maximum gradeability of 30 percent will provide satisfactory performance in the most extreme operating conditions.

In response to the Department's request, Ford and General Motors specified respectively 17 and 16 percent grade as their criteria for minimum acceptable performance.[11] GM further stated that the requirement of 16 percent grade was generally met by vehicles having a maximum theoretical tractive force equal to 46 percent and 31 percent of the vehicle gross vehicle weight (GVW) for vehicles with automatic and manual transmission, respectively. The tractive force (F_T) is computed on the basis of maximum engine torque (TQ) and maximum transmission torque multiplication ratio (TR). With appropriate algebraic manipulation, this requirement can be expressed as:

$$F_T = K_T \frac{(TQ)(TR)(N/V)}{GVW}$$

where:

K_T = .155 for automatic transmission

K_T = .230 for manual transmission

and

N/V= The quotient of engine speed in rpm divided by vehicular speed in mph measured in the highest, i.e., the lowest numerical transmission gear.

Ford suggests using the following formula for the estimation of maximum gradeability:[10]

$$\text{Gradeability (\%)} = \frac{K \times M \times R \times T}{GVW} - 1.0$$

where:

K = Constant for type of rear axle

.1011 for single axle
.099 for single-drive tandem
.095 for dual-drive tandem

M = Tire revolutions per mile

R = Max. gear reduction (1st gear main transmission ratio x 1st gear auxiliary transmission x largest rear axle ratio)

T = Engine maximum net torque

The U.S. Army uses the following formula for gradeability computation for trucks operated on concrete roads.[12]

$$\text{Gradeability (\%)} = \frac{1200 \times T \times TR \times AR \times E}{GVW \times r} - 1.2$$

where:

T = Maximum (gross) torque

TR = Transmission ratio

AR = Axle ratio

E = Gear train efficiency (.90 for direct drive, .85 for any other gear)

r = Rolling radius of tire.

2.2.6 Acceleration

The 0 to 60 mph acceleration times of 17 1980 light trucks were obtained from automotive trade publications. These data, as well as other performance related vehicle attributes are given in Table 2-8. Due to the small size of the sample, good correlation between the 0 to 60 acceleration time and the HP/TW ratio cannot be obtained.

In a study, Ford showed acceleration performance of light trucks of various power-to-weight ratios for four engines typical of those found in 1978 passenger cars and light trucks.[13] These data are shown in Table 2-9. Applying the techniques of least-

TABLE 2-8. ACCELERATION PERFORMANCE AND OTHER VEHICLE DATA FOR 1980 LIGHT TRUCKS

MODEL	CID	HP	TORQUE (FT-LB)	TRANSMISSION	AXLE RATIO	TEST WEIGHT (LBS)	0-60 TIME (SEC.)
Dodge Sportsman Maxwagon	360	170	260	A3	3.21	6700	12.2
Plymouth Arrow Sport	156	105	139	M5	3.91	2760	12.4
Ford Courier	140	82	105	M5	3.64	2600	12.5
Chevrolet K10 4x4	250	130	210	M3	2.56	5065	12.5
Toyota SR5 Longbed	132	95	122	M5	4.10	2520	13.3
GMC Caballero	229	115	175	M3	2.73	3360	13.3
Mazda B2000	122	77	109	M5	3.31	2600	14.1
Ford Bronco Ranger XLT	351	138	263	A3	3.30	5300	14.1
Toyota 4WD	134	95	122	M4	4.38	3220	14.3
Ford Courier	140	88	118	M5	3.64	3000	14.5
Datsun King Cab	122	80	107	M5	3.89	2740	15.5
Jeep Cherokee	258	118	205	M4	2.73	4510	15.6
Volkswagon Pickup	97	78	84	M4	3.90	2346	15.8
Ford F-150 4x4	300	119	243	M4	3.00	4640	16.2
Chevrolet Luv 4x4	111	80	95	M4	4.10	3080	16.3
Chevy Luv	110	80	95	A3	4.10	2640	19.0
Datsun King Cab 4x4	119	92	112	M4	4.37	3180	22.9

TABLE 2-9. ACCELERATION PERFORMANCE FOR LIGHT TRUCKS

Engine Displacement (Liter)	SAE Net Horsepower	Test Weight (LBS)	0-60 Time (Sec.)
2.3	84	4000	23
		5000	29
		7000	38
4.9	119	4000	13
		5000	17
		7000	23
5.8	162	4000	10
		5000	13
		7000	17
7.5	218	4000	8
		5000	9
		7000	12

Source: Reference 13

squares fit, the following correlation formula was obtained:

$$t = .320 \ (\frac{HP}{TW})^{-1.074}$$

A plot of the above relation is given in Figure 2-7.

Figure 2-8 compares the acceleration performance of light trucks to that of passenger cars (Figure 2-5). It can be seen that for a power-to-weight ratio between .02 and .04 HP/LB., typical of most passenger cars and light trucks, the light truck has nearly the same performance levels as that of passenger car.

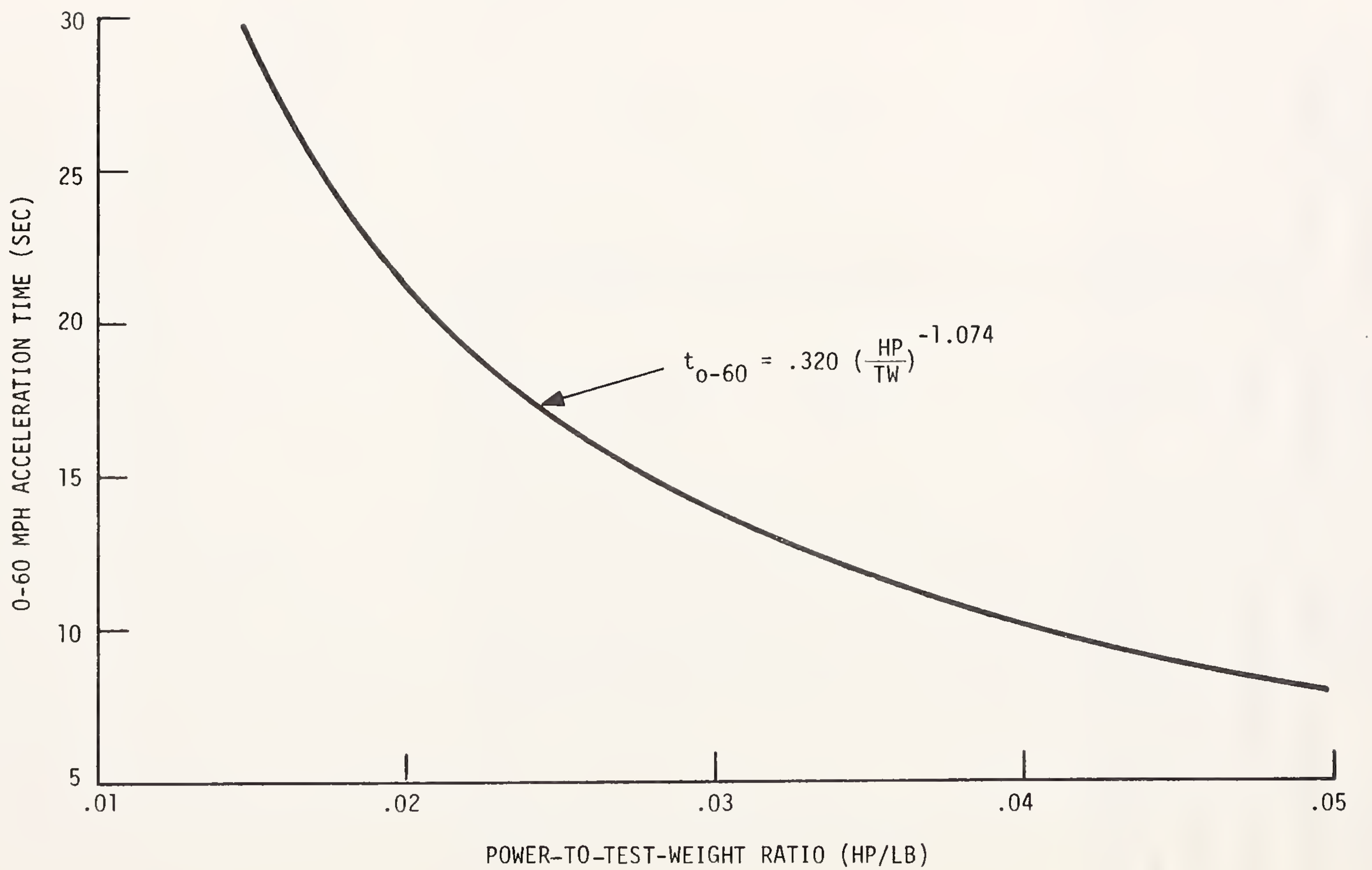


FIGURE 2-7. LIGHT TRUCK ACCELERATION PERFORMANCE

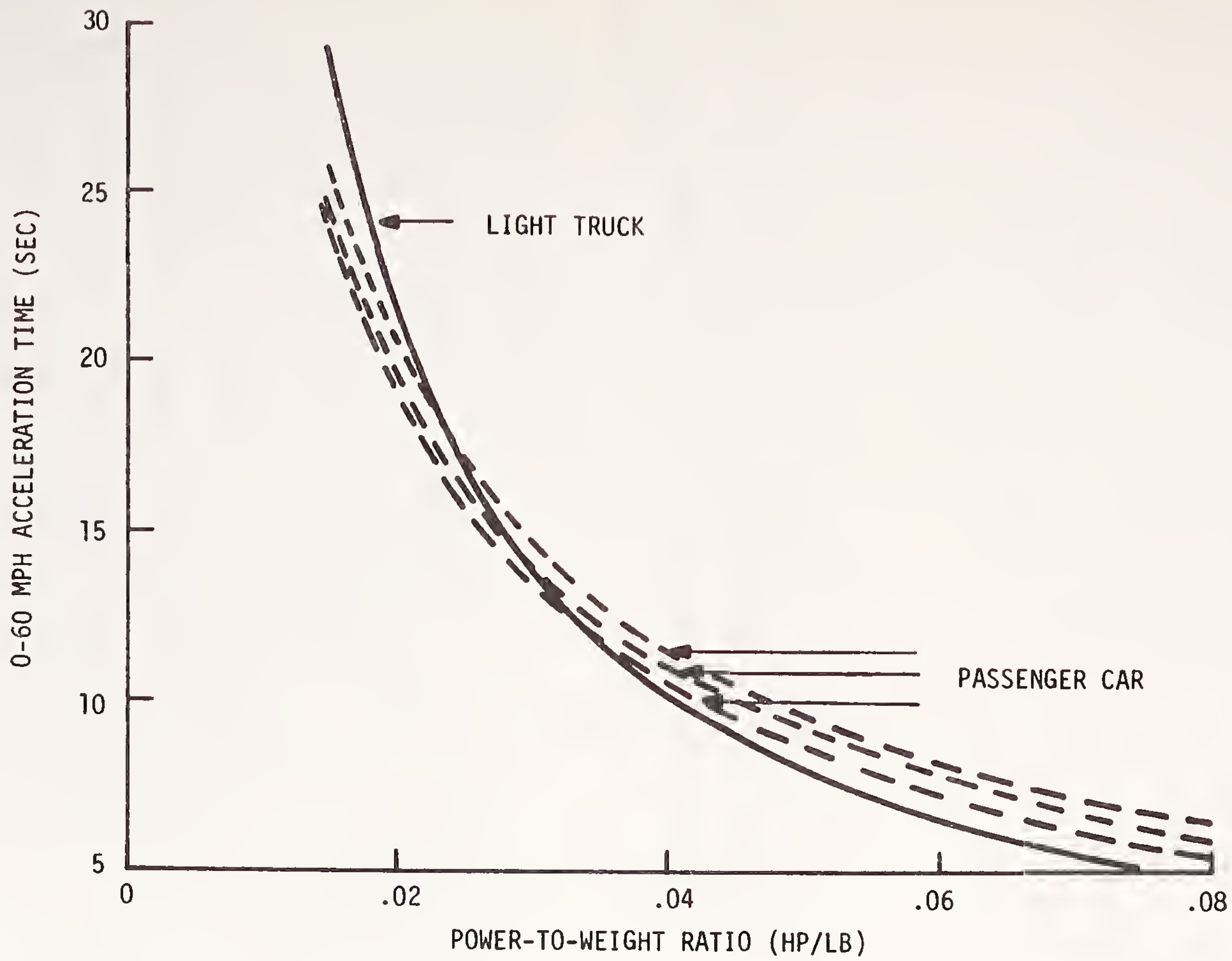


FIGURE 2-8. COMPARISON OF PASSENGER CAR AND LIGHT TRUCK ACCELERATION PERFORMANCE

3. METHODOLOGIES FOR VEHICLE WEIGHT REDUCTION

In order to improve vehicle fuel economy while meeting the demand for space and comfort in the passenger car and the demand for utility in the light truck, it is necessary to minimize vehicle exterior size and weight for maximum interior space (for passenger cars) or load and volume capacity (for light trucks). The weight of present vehicles can be substantially reduced by component and vehicle redesign and by component material substitution. These approaches can be taken separately or in combination. This section provides a discussion on the methodology for vehicle weight reduction.

3.1 VEHICLE REDESIGN

Reduction of vehicle weight can be accomplished by the total redesign of the vehicle. This involves vehicle downsize, conversion to front-wheel drive, and adoption of alternative vehicle configuration.

3.1.1 Vehicle Downsize

In the recent past, expensive passenger cars were always large in size. Therefore, besides the consideration for utility, large cars became symbols of status and prestige. Demand for large cars was high. Since it costs only a little more to build a large car than a small one, passenger cars of these early model years were made as large as possible or were styled to look as large as possible. This result was accomplished by adding large masses of metal to the vehicle, often at the extreme ends of the vehicle.

Substantial reduction of the weight of a passenger car can therefore be accomplished by reducing the non-functional size of the vehicle without reducing its interior space. This approach results in an average weight savings of 800 pounds in the case of some full-size vehicles. Table 3-1 gives a comparison of some

TABLE 3-1. A COMPARISON OF VEHICLE PARAMETERS FOR THUNDERBIRD BEFORE AND AFTER REDESIGN

VEHICLE PARAMETER	MODEL YEAR 1979	MODEL YEAR 1980
BODY TYPE	BODY/FRAME	UNITIZED
WHEELBASE (in.)	114.0	108.4
OVERALL LENGTH (in.)	215.5	200.4
HEIGHT (in.)	53.0	53.0
WIDTH (in.)	78.5	74.1
TRACK, FRONT/REAR (in.)	63.2/63.1	58.4/57.2
FRONT HEAD ROOM (in.)	37.3	37.1
FRONT LEG ROOM (in.)	42.2	41.6
FRONT HIP ROOM (in.)	55.6	55.9
REAR HEAD ROOM (in.)	36.2	36.3
REAR LEG ROOM (in.)	32.6	36.4
REAR HIP ROOM (in.)	57.2	52.0
LUGGAGE CAPACITY (cu. ft.)	15.6	18.2
BASE ENGINE (cu. in.)	302	255
CURB WEIGHT (lbs.)	4028	3275

Source: 1979 and 1980 MVMA Specifications Form major vehicle parameters for a Ford Thunderbird before and after this approach was taken. It can be seen that by reducing the exterior size, mainly the overall length of the vehicle, about 750 pounds of weight was removed without changing basic vehicle configuration.

In most cases, vehicle downsize involves reduction in wheelbase. Table 3-2 lists wheelbase and lowest model curb weight of 1980 domestic passenger cars. Least-squares fitting of these data is shown in Figure 3-1.

Small cars usually are designed near their optimum configuration. For example, the 1980 Chevrolet Chevette has a curb weight to volume (EPA definition) ratio of 24.3 lbs/ft^3, while the ratios for the already downsized 1980 Caprice and Malibu are 28.3 and 27.2 lbs/ft^3, respectively. This indicates that for full-size and intermediate cars there is still room for weight reduction through further downsizing.

Unlike passenger cars, light trucks are designed to perform a two-fold function of personal transportation and load carrying. On one hand, a truck is expected to behave like a passenger car in day to day use while, on the other hand, it is often used to haul 4 by 8 ft sheets of plywood or payloads of 1000 pounds or more. Because of the wide range of customer usage, light trucks must meet structural and performance requirements that are unique and more severe than those of passenger cars. These requirements demand heavy duty chassis and body components. Therefore, light trucks cannot be downsized to the same degree as passenger cars without major compromises in basic functional requirements.

Termed as the "New Truck of the 80's," the Ford 1980 F-series pickup trucks weigh on the average of 300 pounds less than the previous year's models. The major portion of this weight reduction was achieved by the reduction of metal and glass thickness, material substitution and component redesign. Only a very small portion of this weight reduction can be attrib-

TABLE 3-2. WHEELBASE AND LOWEST MODEL CURB WEIGHT OF 1980 DOMESTIC PASSENGER CARS

Model	Wheelbase (IN.)	Curb Weight (LBS)
Spirit	96.0	2518
Pacer	100.0	3197
Concord	108.0	2712
Omni, 2D	96.7	2198
Omni, 4D	99.2	2154
Diplomat	108.7	3310
Cordoba	112.7	3363
Gran Fury	118.5	3629
Pinto	94.5	2489
Mustang	100.4	2602
Fairmont	105.5	2661
Granada	109.9	3206
Cougar XR-7	108.4	3228
LTD	114.3	3596
Continental	117.3	4011
Chevette, 2D	94.3	2055
Chevette, 4D	97.3	2112
Sunbird	97.0	2699
Citation	104.9	2461
Camaro	108.0	3327
Firebird	108.2	3378
Malibu	108.1	3087
Bonneville	115.9	3438
DeVille	121.5	4183
Electra	118.9	3711
Toronado	114.0	3731

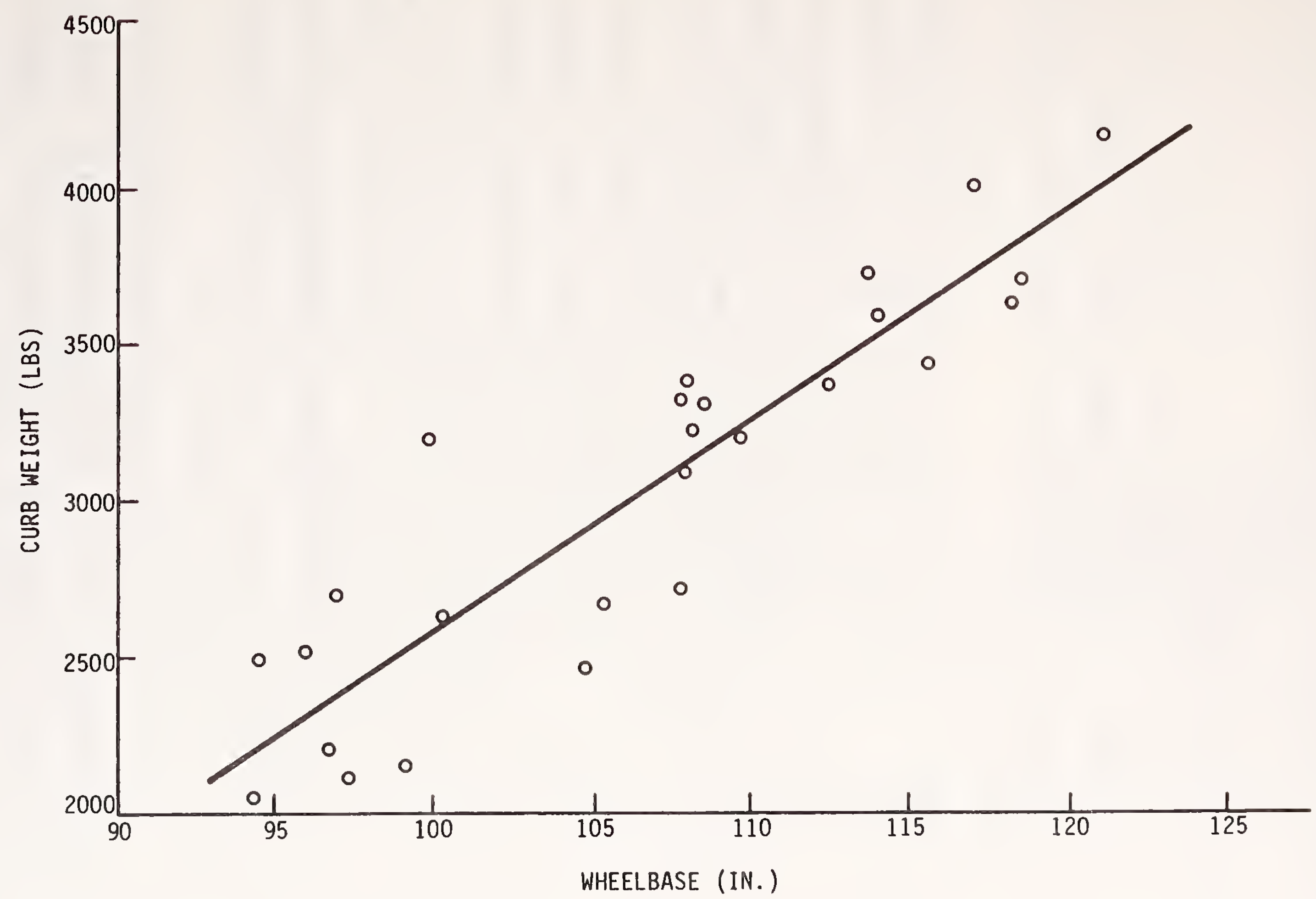


FIGURE 3-1. CURB WEIGHT VERSUS WHEELBASE, 1980 DOMESTIC PASSENGER CARS

uted to exterior size changes.[14] A comparison of vehicle parameters for 1979 and 1980 F-150 pickup trucks is given in Table 3-3. A study on light truck weight reduction shows that by reducing 4 inches in width, 2 inches in height and 6 inches in front end sheet metal, only 67 and 63 pounds can be removed from a pickup and a utility truck, respectively.[15]

3.1.2 Front-Wheel-Drive

As the exterior size of a car decreases, it becomes more difficult to reduce weight by downsizing. Under this situation, it generally requires conversion to front-wheel-drive to obtain further weight reduction.

Front-wheel-drive provides excellent space utilization for passenger cars. The front drive car has a flat floor since all drivetrain components and their control linkages are up front. It can also have a somewhat more spacious luggage space in the tail of the car because there is no need for a heavy rear axle which requires large free space to bounce around. However, front-wheel-drive per se does not necessarily lead to direct reduction in vehicle weight. GM's E-body cars are good examples. But front-wheel-drive coupled with a transversely mounted engine provides a more efficient and flexible arrangement of underhood space.[16,17] This can result in a shorter front end which can be translated into weight savings. A good example of this approach is the 1981 Chrysler K-car which by converting to front-wheel-drive with transverse engine is more than 1000 pounds lighter than the model it replaced (Table 3-4).

There are five types of powertrain configurations currently employed in passenger cars: transverse engine front-wheel-drive (TFWD); longitudinal engine front-wheel-drive (LFWD); front engine rear-wheel-drive (FRWD); rear engine rear-wheel-drive (RRWD); and mid-engine rear-wheel-drive (MRWD).

TABLE 3-3. A COMPARISON OF VEHICLE PARAMETERS FOR FORD F-150 PICKUP TRUCKS

Vehicle Parameter	Model Year	
	1979	1980
Model	Styleside	Styleside
Cab	Regular	Regular
GVWR (lbs.)	6050	6100
Wheelbase (in.)	133	133
Nominal Box Length (ft.)	8	8
Overall Length (in.)	208	208
Max. Width (in.)	79.1	77.2
Cab Height, Empty (in.)	72	70
Curb Weight (lbs.)	3862	3687

Source: Ford Truck Data Books and Reference 15

TABLE 3-4. A COMPARISON BETWEEN 1981 K-CAR AND 1980 VOLARE/ASPEN

Vehicle Parameters	1981 K-Car	1980 Volare/Aspen
Base Engine	2.2ℓ-4	3.7ℓ-6
Curb Weight (lbs.)	2232	3258
Overall Length (in.)	176	204.3
Overall Height (in.)	53	54.8
Overall Width (in.)	68	72.8
Wheelbase (in.)	99.6	112.7
Headroom, Front (in.)	39.2	38.5
Headroom, Rear (in.)	37.5	35.0
Legroom, Front (in.)	42.3	42.2
Legroom, Rear (in.)	37.4	35.0
Luggage Capacity (cu. ft.)	15	16.4

Source: MVMA Specifications

A comparison of the merits of these configurations is given in Table 3-5. To compare efficiency of packaging, curb weight, and EPA interior volume, some 1980 vehicles of different power-train configurations are assembled and shown in Tables 3-6 through 3-8. From data shown in these tables, it can be seen that vehicles of the TFWD configuration have lower values of weight-to-volume ratio while those of FRWD have higher levels of weight-to-volume ratios.

Figure 3-2 shows the plot of curb weight versus interior volume for those vehicles shown in Tables 3-6 and 3-8. The lines shown are least-squares fits of the data and represent vehicles of current technology. These lines could be used to aid vehicle weight projection. For example, according to the TFWD line, a full-size vehicle with an interior volume measurement of 130 ft^3 would have a curb weight of about 2700 pounds if converted to TFWD configuration.

As mentioned before, light trucks have to meet functional requirements which are much different from those of passenger cars. These requirements have traditionally been met by the front-engine-rear-wheel-drive, body-on-frame design. The major problem of converting light trucks to front-wheel-drive is traction. With front-wheel-drive, increasing the payload reduces traction on the driving wheels. Reducing rear overhang or increasing front/rear weight bias will minimize this unfavorable operating condition to some degree.

The only domestic light truck with front-wheel-drive is the 1980 VW pickup. It is of unit-body construction with solid connection between the cab and cargo box, essentially a modified VW Rabbit/Jetta. At 2046 pounds curb weight, it is the lightest truck on the domestic market. However, with a payload of 1100 pounds it does not have an exceptional payload-to-curb-weight ratio. The unloaded weight bias of this truck is 63 percent front and 37 percent rear. VW claims superior traction to conventional rear-wheel-drive pickups 93 percent of the time with two passengers and a 260-pound load. However, extreme forward weight bias

TABLE 3-5. A COMPARISON OF VEHICLE POWERTRAIN ARRANGEMENT

CONFIGURATION	ADVANTAGE	DISADVANTAGE
Transverse-Engine Front-Wheel Drive	Short front end Good directional stability Good traction No transmission tunnel	Complex suspension and drivetrain components Poor service accessability
Longitudinal-Engine Front-Wheel Drive	Good service accessability Good directional stability Good traction No transmission tunnel	Long front end Complex C-V joints
Front Engine Rear-Wheel Drive	Inexpensive suspension and drive-train components Good service accessability Inherently understeering	Long front end Poor traction
Rear Engine Rear-Wheel Drive	Good traction Reduced steering effort Compact powertrain installation	Difficult cooling Lack of luggage space Inherently oversteering Short crash zone
Mid-Engine Rear-Wheel Drive	Good weight distribution	Difficult heat and noise insulation Lack of luggage space Short crash zone Poor service accessability

TABLE 3-6. CURB WEIGHT VERSUS INTERIOR VOLUME, TRANSVERSE FRONT WHEEL DRIVE

VEHICLE	CURB WEIGHT (LBS)	EPA INTERIOR VOLUME (FT^3)	WEIGHT-VOLUME RATIO (lbs/ft^3)
DATSUN 310	2025	90	22.5
DODGE COLT	1973	88	22.4
FIAT STRADA	2080	101	20.6
FORD FIESTA	1760	86	20.5
GM X-BODY	2505	115	21.8
HONDA ACCORD	2239	91	24.6
HONDA PRELUDE	2130	81	26.3
HONDA CIVIC	1722	82	21.0
PLYMOUTH HORIZON	2100	98	21.4
VW SIROCCO	1950	86	22.7
VW RABBIT	1810	91	19.9

TABLE 3-7. CURB WEIGHT VERSUS INTERIOR VOLUME, LONGITUDINAL FRONT WHEEL DRIVE

VEHICLE	CURB WEIGHT (LBS)	EPA INTERIOR VOLUME (FT^3)	WEIGHT-VOLUME RATIO (LBS/FT^3)
AUDI 4000	2206	97	22.7
AUDI 5000	2860	105	27.2
SAAB 99	2520	106	23.8
SAAB 900	2930	112	26.2
SUBARU GLF	2035	90	22.6
TOYOTA TERCEL	1780	93	19.1
VW DASHER	2160	91	23.7
CADILLAC SEVILLE	4046	115	35.2
RENAULT LECAR	1815	84	21.6
BUICK RIVIERA	3850	116	33.2

TABLE 3-8. CURB WEIGHT VERSUS INTERIOR VOLUME, FRONT ENGINE REAR-WHEEL DRIVE

VEHICLE	CURB WEIGHT (LBS)	EPA INTERIOR VOLUME (FT^3)	WEIGHT-VOLUME RATIO (LBS/FT^3)
AMC CONCORD	2765	101	27.4
AMC PACER	3452	101	34.2
BMW 320i	2500	94	26.6
BMW 528	3210	99	32.4
BMW 630	3440	96	35.8
BUICK CENTURY	3243	113	28.7
CHEVROLET CAPRICE	3680	130	28.3
CHEVROLET MALIBU	3105	114	27.2
CHEVROLET MONZA	2824	88	32.1
FIAT BRAVA	2550	96	26.2
CHEVROLET CHEVETTE	2160	89	24.3
FORD FAIRMONT	2655	112	23.7
FORD GRANADA	3225	106	30.4
FORD LTD	3584	134	26.7
FORD PINTO	2425	83	29.2
JAGUAR XJ-6	4033	100	40.3
MAZDA GLC	1963	90	21.8
MAZDA 626	2595	94	27.6
MERCEDES 280 CE	3445	97	35.5
MERCEDES 300 SD	3120	107	29.2
MERCURY CAPRI	2640	94	28.1

TABLE 3-8. CURB WEIGHT VERSUS INTERIOR VOLUME, FRONT ENGINE REAR-WHEEL DRIVE (CONTINUED)

VEHICLE	CURB WEIGHT (LBS)	EPA INTERIOR VOLUME (FT^3)	WEIGHT-VOLUME RATIO (LBS/FT^3)
PONTIAC GP	3115	113	27.6
PONTIAC T/A	3539	92	38.5
PLYMOUTH ARROW	2250	84	26.8
PLYMOUTH GRAN FURY	3630	129	28.1
PLYMOUTH SAPPORO	2786	86	32.4
PLYMOUTH VOLARE	3415	116	29.4
PEUGEOT 504	3205	101	31.7
TOYOTA CELICA	2530	89	28.4
TOYOTA CRESSIDA	2840	91	31.2
VOLVO 242	2883	103	28.0

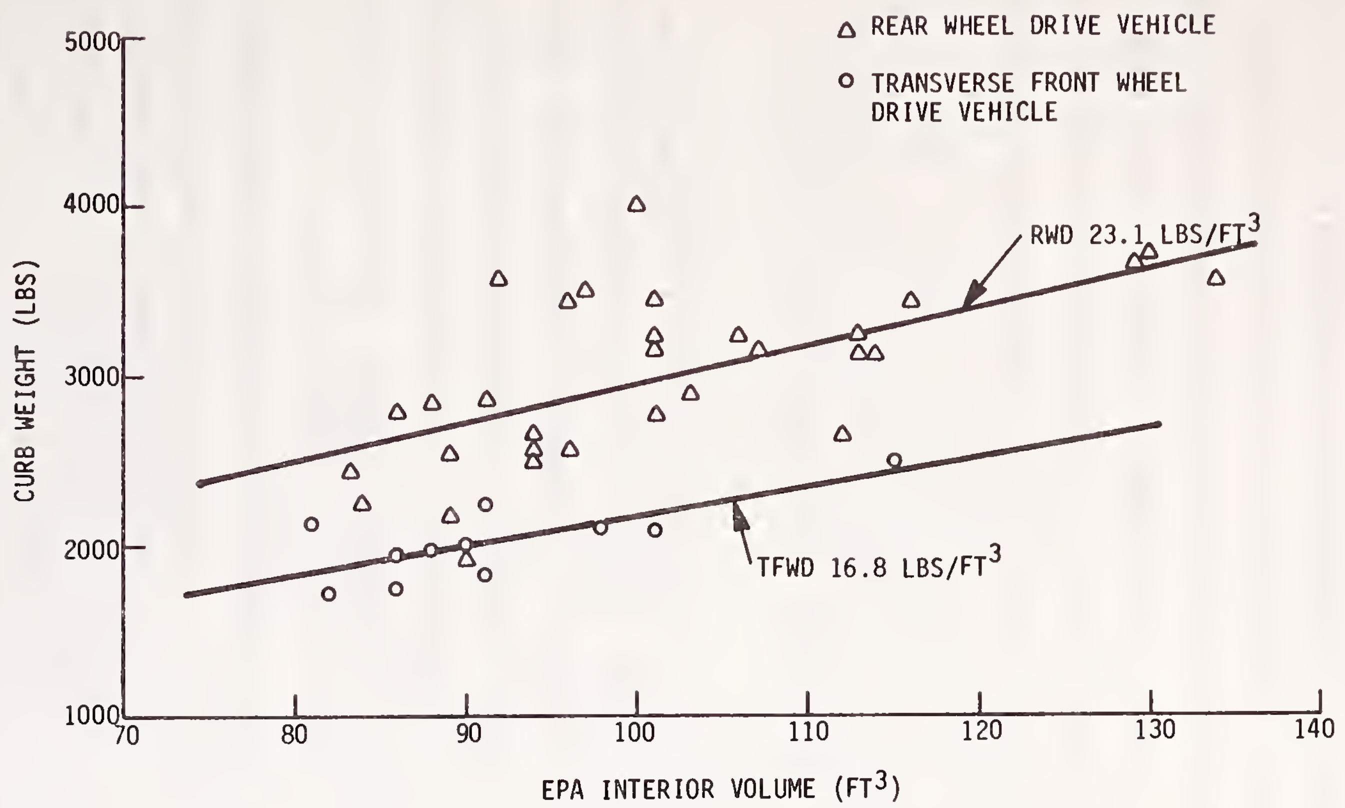


FIGURE 3-2. CURB WEIGHT VERSUS INTERIOR VOLUME FOR CONVENTIONAL REAR-WHEEL-DRIVE VEHICLES AND TRANSVERSE FRONT-WHEEL-DRIVE VEHICLES

may present some problems with the handling characteristics of the vehicle in transient conditions.

3.1.3 Alternative Configuration

A vehicle can be constructed either as a separate chassis frame and body-shell bolted together or as a combination of frame and body in a single self-supporting assembly.

A vehicle of the body-frame design has a separate frame unit of channel or box section with the body bolted to it at various points. Rubber insulators are used between the frame and the body at the attachment points to minimize the transfer of vibration. The frame must be rigid and strong because it has to support the body, engine, and suspension system and keep all units in alignment. There are three frame shapes: the X-frame, the perimeter frame, and the center X-frame. Most domestic cars of body-frame construction have perimeter type of frames which permit a low floor line.

The separate body-frame design has a strong base structure. It is easy to repair body damage and to change the body shape without extensive redesign. However, vehicles of this type of design are usually quite heavy. In recent years many domestic passenger cars have changed from the separate body-frame design to the integal design which eliminates separate chassis frame, resulting in significant weight reduction.

The most common construction in Europe and Japan is the combined body and frame type, usually called a unitary construction. Its main advantage over the separate body-frame design is that the structure can be lighter because parts of the body panels contribute to the strength of the vehicle.

Unitary construction has three variations: fully unitary, semi-unitary, and unitary with sub-frames. The fully unitary is a completely self-supporting structure with everything (suspension, engine, etc.) attached to it at various points by brackets designed to spread loads evenly into the body shell. The total structure must be as nearly as possible completely closed though openings for passengers and engine must be provided. This type of construction is frequently used in open-wheel racing vehicles of formula design because it has a very high strength-to-weight ratio.

A fully unitary structure has its disadvantages. Since body panels are structural members of the vehicle, the repair of accident damage can be very expensive. Rust in load bearing sheet metal can have devastating effect on structural integrity. There is also the risk that a major impact may cause some distortion of the structure without obvious external damage to the body panel.

The semi-unitary structure is based on a basic skeleton of unitary construction comprising the floor pan, roof, cowl panel, engine and suspension mounts, and side frames to give the necessary basic strength. The non-load-bearing panels such as doors, hood, deck lid, and fender panels are then bolted to this skeleton. Because these hang-on panels do not add to the strength of the structure, vehicles built in this way are somewhat heavier than the fully-unitary design. But as the body panels are detachable, they can be replaced more easily and cheaply if damaged. This type of design also allows the manufacturer to make minor changes to the vehicle's external shape with little difficulty.

The unitary with sub-frames design uses sub-frames to carry one or more of the main mechanical units - the engine, final drive, and suspension. These sub-frames are attached to a somewhat simplified unitary body structure. Although a vehicle with this type of design is rather heavier than the one with fully unitary construction, it has definite advantages. Because the mountings between body and sub-frames are flexible, there is no direct feedback path for noise or vibration. The mechanical parts are more accessible, making assembly and repair easier.

Current domestic passenger cars, especially the small and mid-size models, are mostly of semi-unitary construction. To achieve more weight efficient design, these vehicles either have to be changed to fully unitary construction or adopt alternative configuration for optimum packaging. One alternative is the van-type configuration. These types of vehicles have already been produced by some Japanese manufacturers for their home market. These vehicles, such as the Daihatsu Charmant models, have a wheelbase of around 90 inches, weigh less than 2500 pounds, and can accommodate six to eight occupants.[18] They may replace stationwagons in the future.

Another alternative is three rows of two passenger configuration as shown in Figure 3-3. This triplex design can result in a very short wheelbase as front and rear wheels can be moved into passenger space without infringing on useful passenger dimensions. It is an intriguing configuration which may help downsize the full-size passenger car. The problem with this design is difficulty in getting in and out of the vehicle. Gull wing doors could help to alleviate this difficulty to some extent.

Light trucks are traditionally of separate body-frame type construction because of their more severe structural requirements. Fully unitary construction is considered feasible for vans but not suitable for pickup trucks since the cargo bed of the pickup truck is essentially a shallow channel beam. Semi-unitary design has been used in some domestic vans and 1980 VW mini pickup. The problem with semi-unitary design for pickup trucks is the isolation of noise and vibration from the cab. Rusting in load bearing body panels may also become a problem for pickup trucks of semi-unitary construction as these vehicles are often used in harsh environments.

Many current European pickup trucks are of forward control design. By adopting this design, overall length of a pickup truck can be reduced without reducing the length of the cargo bed. This can result in significant weight reduction.

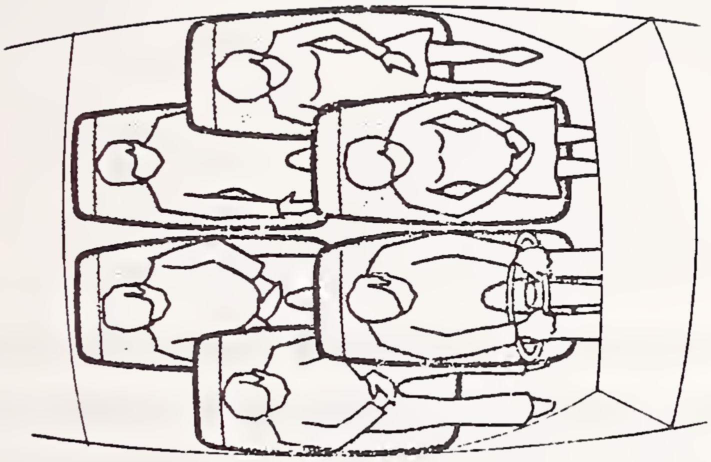


FIGURE 3-3. SEATING ARRANGEMENT FOR SIX-PASSENGER CAR

3.2 COMPONENT REDESIGN

The best way to save weight is to eliminate the component altogether. Components like spare wheel and tire can be eliminated with great weight savings. The next best way for weight saving is by component redesign. The major deterrant of component redesign has been the high cost of tooling and the risks associated with new designs. In addition, there is strong cost incentive to design components that can be used in different models. Even when components are designed specifically for a new vehicle, they are often designed with some allowance for adaptation to future models.

One obvious approach for reducing component weight is using lighter gauge material. The limitation of simple gauge reduction is the inherent reduction in flexural stiffness and buckling resistance of panels and structural members. Panels, in particular, must have adequate stiffness to resist denting, excessive deflection, and flutter. In many cases it is necessary to regain or enhance the bending stiffness of thin steel sheets.

There are several ways to improve the structural characteristics of a thin gauge design. Integrally formed reinforcing ribs can increase stiffness and prevent buckling. Adding flanges is another effective way to increase structural efficiency. The use of deeper sections, where possible, can also increase flexural stiffness.

Gauge or thickness reduction is not limited to steel sheets. In recent years, the thickness of windshield and window glass has been reduced with considerable weight reduction. Also, some engines adopted thin wall casting which resulted in significant weight savings.

Sometimes weight can be reduced by reapportioning material to the load bearing area of a component. Reinforcement plates can be used in the critical area to strengthen a thinner design.

The most effective approach for component weight reduction is to replace the current design with one of new concept. For example, U.S. Steel proposed 18 designs including stamped engine block, cone brake, and textured body panels.[19] Weight savings of these new designs were estimated to range from 12 percent to 72 percent of the original designs (Table 3-9).

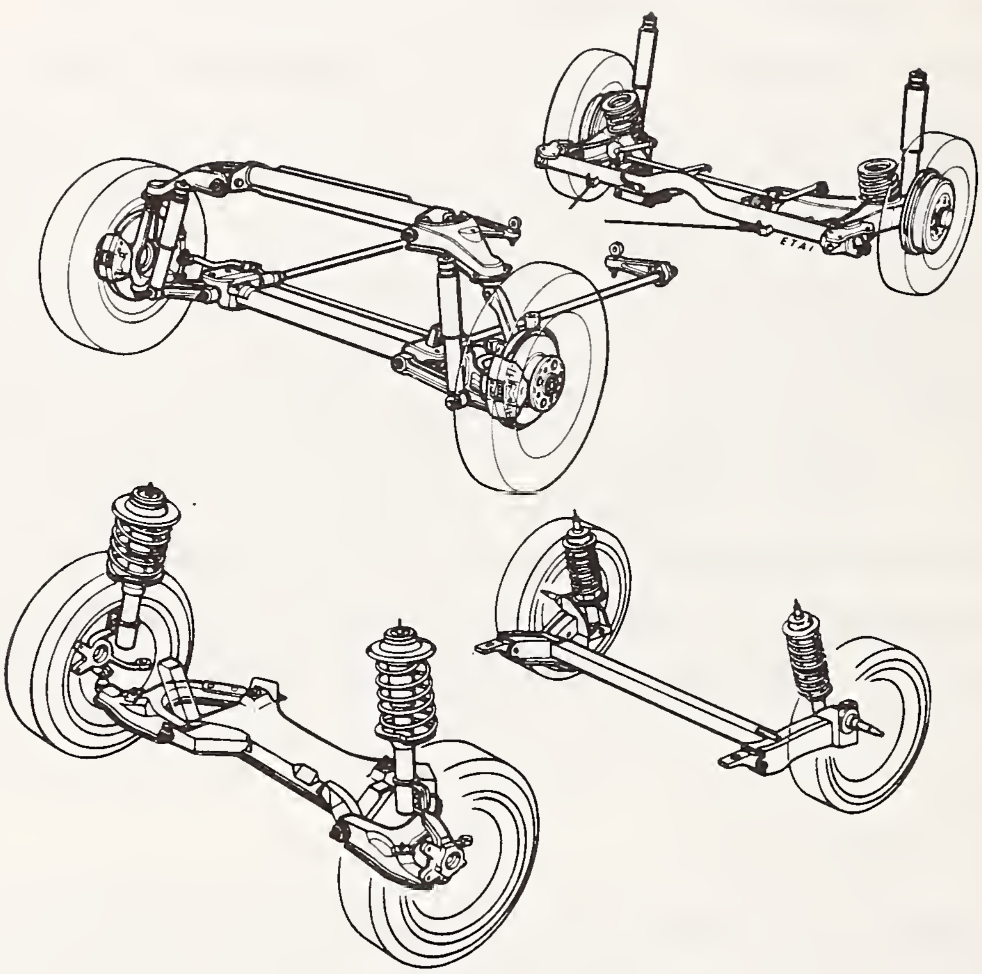
Another approach to weight reduction offered by component redesign is parts consolidation. Besides offering weight reduction, parts consolidation can often eliminate multiple manufacturing operations and extra assembly of all the separate parts making the new design more cost efficient.

A "system" approach to redesign can achieve a higher level of weight reduction than the "component-by-component" approach. The "system" approach allows the design engineer an opportunity to reduce the complexity of the original design, to take full advantage of the structural properties of the material, and to improve the manufacturing flexibility. For example, the new axle designs allow Ford to remove up to 20.6 pounds from its 8.7 in. axle and 21.2 pounds from its 9.0 in. straddle-mounted axle.[20] Another example of the "system" approach is shown in Figure 3-4 in a comparison between the suspension system on the Simca and the suspension system on the Omni/Horizon.[21] The Simca has torsion bars in front compared to MacPherson struts for the Omni/Horizon. Both cars have rear trailing arms, but the American design is much simpler.

3.3 MATERIAL SUBSTITUTION

Weight reduction becomes progressively more difficult to achieve as the size of the car decreases and the design of the components optimized. This leaves material substitution as the last measure for vehicle weight reduction.

Material substitution involves mainly the replacement of a production heavy metal component with a lighter one differing only in material and thickness. There are many materials which have great weight-saving potential. For example, magnesium is approximately one-fifth and two-thirds the weight of cast iron and aluminum, respectively, and has strength and ductility comparable to aluminum in the commonly used die cast form. It is abundant in



Source: Reference 21

FIGURE 3-4. COMPARISON OF SIMCA SUSPENSION (TOP) AND OMNI/HORIZON SUSPENSION (BOTTOM)

TABLE 3-9. ESTIMATED WEIGHT SAVINGS OF NEW COMPONENT DESIGNS

COMPONENT	WEIGHT SAVINGS	
	pounds	%
Engine block	40	33
Alternator	1	-
Air cleaner	2	55
Intake manifold, gasoline engine	40	72
Intake manifold, Diesel engine	23	60
Exhaust manifold	10	62
Rocker cover	1	53
Front drive joint	10	37
Steering housing	1.5	-
Cone brake, drum	50	47
Cone brake, disc	45	44
Brake rotor	1	13
Master cylinder	4.75	70
Wheel	2/wheel	12
Bumper	5/bumper	28
Door beam	6/door	40
Body panel	70-100	12
Roof, hatch door and pillar	14	28
Door trim panel	1.05/door	57
Seat structure	7/seat	40

Source: Reference 19

the earth's crust and is available domestically in unlimited quantities from seawater, brine, and various ores. Magnesium has been used in foreign automobiles such as the VW Bug, Fiat Dino, and Porsche 911 and 917 models. It is not used in significant quantities in domestic automobiles because of high cost, limited availability, and difficult fabrication techniques.

Ideally, substitutional materials for automotive applications should offer good structural properties, be in ample supply, have a reasonably low cost-to-weight ratio, and be adaptable to present production facilities without immense capital investment.

3.3.1 Substitutional Materials

Alternative materials most often considered for material substitution are high strength steels (HSS), aluminum, fiberglass reinforced plastics (FRP), and hybrid reinforced plastics (HRP).

Because of their exceptional strength, high strength steels have started to replace low carbon steels for body panels and structural components. For certain applications, attempts are being made to substitute them for cast iron. Many components can be designed more effectively by using high strength steel at reduced thicknesses.

The family of high strength steels includes carbon and low alloy (HSLA) steels. The yield strength of these sheet steels ranges from 33 to 80 ksi. These steels offer many of the same advantages of the low carbon steels and are completely compatible with existing manufacturing equipment. They can be formed, joined, and painted at the high production rates used in the automotive industry.

Extensive use of high strength steels can be found in the Chrysler Omni/Horizon and Aries/Reliant car lines. Table 3-10 shows the applications of high strength steels on the Omni/Horizon models.[22] High strength steels account for 200 pounds in the 1981 K-car.[24]

TABLE 3-10. HIGH STRENGTH STEELS ON THE OMNI AND HORIZON MODELS

Types of High Strength Steel	Weight/Car In kg (lbs.)	Percentage of Total High Strength Used	Typical Applications
Dent Resistant	38 kg (84 lbs.)	49	Hood Outer Panel Front Side Rails and Reinforcements, A-pillar, Various Brackets, Reinforcements for Rear Suspension, Wiper Linkage, Spare Tire Reinforcement, License Plate Frame, Gusset-Rear Rail to Rear Suspension, Various Braces in Suspension Components
Nitrogenized	6.0 kg (13 lbs.)	8	Brackets, Various Attaching Plates, Reinforcements for Suspension Parts
HSLA (310 MPa and 345 MPa Y.S.) (45 ksi and 50 ksi Y.S.)	17.0 kg (37.5 lbs.)	22	Hood Hinge, Wiper Drive and Pivot Crank, Iso-Strut Mounting Towers and Reinforcements, Exhaust Hangers, Various Reinforcements
HSLA (415 MPa Y.S.) (60 ksi Y.S.)	1.5 kg (3.5 lbs.)	2	Brake Pedal, Gussets, Reinforcement for Rear Crossmember
HSLA (550 MPa Y.S.) (80 ksi Y.S.)	6.5 kg (14.5 lbs.)	9	Rear Suspension Torsion Crossmember, Bracket for Energy Absorption Tube.
Ultra-High Strength	8.0 kg (17.5 lbs.)	10	Door Impact Beams, Shipping Tie Down Reinforcements
TOTAL	**77 kg (170.0 lbs.)**	**100 percent**	

Source: Reference 22

The use of aluminum in automobiles can represent significant weight reduction. On an equal volume basis, aluminum weighs one-third as much as steel. In addition to its light weight, the advantages of aluminum for automotive applications include the ability to be easily cast, drawn, extruded, or machined, and a high resistance to environmental corrosion.

In the past, aluminum was mainly used in castings. However, since new aluminum alloys with good strength and dent resistance were developed, more and more aluminum has been used in body panels and structural components. For 1979 model year passenger cars, approximately 60 percent of the aluminum utilized is in the form of castings. The remaining 40 percent is generally found in extruded, roll formed, or stamped components.[23] A summary of aluminum components on 1980 passenger cars produced domestically is given in Table 3-11. Many applications now existing for passenger cars can be readily transferred to light trucks. Table 3-12 shows the potential aluminum applications in future passenger cars and light trucks.

Reinforced plastics offer greater weight reduction potential in automotive applications than can be achieved with traditional materials. These composite materials combine high strength and stiffness with good fatigue and corrosion resistance. They are virtually corrosion free. They can be molded and formed into large, intricate patterns allowing consolidation of numerous parts into a single unit. They also provide excellent design flexibility, offering opportunities to tailor the material's properties through control of fiber and matrix combination and the fabrication process.

Fiberglass is the most widely used reinforcing material for plastic. FRP has already been used as lightweight substitution for steel in exterior components for automobiles. The FRP body panels in the Chevrolet Corvette are well known examples.

When two different fibers are used in combination as the reinforcing material, the composite material is called hybrid. For automotive applications, HRP generally has graphic fibers in the surface layers and glass fibers in the center core. Hybridization

TABLE 3-11. ALUMINUM APPLICATIONS IN 1980 DOMESTIC PASSENGER CARS

I. APPLICATIONS - WROUGHT

1. Bumper Systems:
   - Bumper Face Bars
   - Bumper Reinforcements & Brackets

2. Wheel:
   - Wheels
   - Hub Caps
   - Trim Rings
   - Opening Mouldings
   - Wheel Cover

3. Brakes:
   - Proportioning Valve
   - Splash Shield
   - Power Brake Booster Plate

4. Trim Mouldings:

Body	Door
Roof	Dashboard
Window	Lights
Windshield	Grille
Fender	Rocker Panel
Door Belt Trim Supports	

5. Body Applications:
   - Deck Lid - Inner and Outer
   - Deck Lid Guards
   - Hood - Inner and Outer
   - Hood - Hinges
   - Hood Latch Reinforcement
   - Rear Hinge Reinforcement
   - Head Rest Bar
   - Seat Backs
   - Seat Frame
   - Seat - Power Adjustments, Assembly
   - Arm Rest Frame
   - Tulip Panel
   - Sun Roof Hatch Frame
   - Carpet Scuff Plate
   - Door Guards
   - Instrument Panel Tie Bar
   - Luggage Rack and Air Deflector
   - Load Floor
   - Steering Wheel
   - License Plate Bracket - Front

TABLE 3-11. ALUMINUM APPLICATIONS IN 1980 DOMESTIC PASSENGER CARS (CONTINUED)

6. Engine - Powertrain and Accessories:
    - Steering Column Bracket
    - Cam Shaft Housing
    - Carburetor Overflow & Accessory Tray
    - Engine Rear Cover Plate and Alternator Bracket
    - Radiator
    - Radiator Shroud
    - Radiator Support Assembly
    - Oil Filter Cap
    - Oil Filter Base
    - Pump Mounting Brackets
    - Rear Cover Plate
    - Air Cleaner Tray & Cover
    - Heat Shields, Catalytic Converter
    - Fuel Filler Tube
    - Transmission Housing (Automatic) Cover
    - Fan Blades
    - Air Conditioning
        - Evaporators
        - Condensor Coils
        - (Plus various accessories such as Line Tubing, Muffler Suction Control Valve, Skived Fin Condenser and Compression Piston)
    - Miscellaneous Engine Components
        - Fan Spacer
        - Timing Chain Cover
        - Fuel Injectors
        - Front Wiring Harness
        - Engine Temperature Sensors
    - Miscellaneous Fasteners - Screw Machine/Upset Parts
        - Drive Pinion Gear for Power Door Lock
        - Seat Belt Actuator Pins
        - Distributor Cap Insert
        - Windshield Wiper Bolt
        - Ignition Coil Insert
        - Headlamp Adjusting Screws
        - Various Brake Valve Parts
        - Ashtray Rivets
        - Stator Rivets

II. APPLICATIONS - CAST

1. Powertrain - Chassis - Brake:
    - Brake Drums
    - Brake Silencer Pad
    - Door Lock Spacers
    - Floor Shift Housing
    - Steering Column Gear Housing
    - Windshield Wiper Housing
    - Master Cylinder

TABLE 3-11. ALUMINUM APPLICATIONS IN 1980 DOMESTIC PASSENGER CARS (CONTINUED)

1. Powertrain - Chassis - Brake (Continued):
   - MC Primary & Secondary Pistons
   - Rack & Pinion Housing
   - Front Seat Adj. Spacer
   - Wheels
   - Wheel Cylinder Piston

2. Engine - Pumps - Electrical - A/C Parts:
   - Accel. Pump Cover
   - A/C Compressor Housing
   - A/C Compressor Parts
   - A/C Mounting Brackets
   - Carburetor Air Horn
   - Air Pump Bracket
   - Air Pump Housing
   - Alternator Bracket
   - Alternator Housing
   - Cam Gear
   - Cam Shaft Housing
   - Carburetor Various Parts
   - Carburetor Spacers
   - Front Cyclinder Cover
   - Cylinder Heads
   - Distributor Base
   - Fan Spacer
   - Timing Chain Cover
   - Fuel Pump Body
   - Starter Drive Housing
   - Ignition Module
   - Intake Manifolds
   - Oil Filter Base
   - Oil Pump Body
   - Pistons
   - Power Steering Bracket
   - Power Steering Pump Housing
   - Rocker Arm Shaft Support
   - Starter Motor Housing
   - Water Inlets - Outlets
   - Water Pump Housing - Body
   - Oil Level Indicator Boss

TABLE 3-11. ALUMINUM APPLICATIONS IN 1980 DOMESTIC PASSENGER CARS (CONTINUED)

3. Transmissions:
   - Governor Body
   - Carrier - Forward/Reverse
   - Clutch Pistons
   - Converter Housing
   - Transmission Extension
   - Forks
   - Transmission Housing
   - Trans. Kickdown Servo Rod Guide
   - Clutch Housing
   - Intermediate Band Servo Cover
   - Intermediate Band Servo Piston
   - Lower & Upper Valve Body
   - Reactor Connector
   - Rear Band Servo Piston
   - Output Shaft Retainer
   - Stators
   - Transfer Body
   - Differential Housing
   - Accumulator Plate

Source: Reference 63

TABLE 3-12. POTENTIAL ALUMINUM APPLICATIONS IN FUTURE PASSENGER AUTOMOBILES AND LIGHT TRUCKS

PASSENGER CARS
Fenders
Doors
Roof Bows
Steering Bracket
Fuel Tank
Door Beams
Valve Covers
Air Conditioner Bracket
Engine Mounts
Transmission Oil Pan
Battery Tray
Engine Oil Pan
Differential Cover Plate
Heater Core
Quarter Panel
Roof
Floor Pan
Chassis
Drive Shaft
Aperture Panels
LIGHT TRUCKS
Roof
Roof Bows
Panels
Doors
Chassis
Step Bumper
Cargo Box

Source: Reference 23

in this manner results in a composite that has significantly improved flexural properties at considerably less cost than an all graphite composite. Hybrid composites that contain 20 percent graphite and 80 percent glass can be two to seven times as stiff as an all glass composite.[25]

Mechanical properties of the hybrid composite depend on the fiber length and the relative orientation of the fibers. In a unidirectional arrangement, all the fibers are parallel to each other, and are aligned in the direction of the stress. In a quasi-isentropic arrangement, the composite consists of alternate layers of parallel fibers that are arranged sequentially at relative angles of 45°. Chopped fibers can be randomly oriented in three dimensions.

3.3.2 Design Criteria

Functional requirements demand that vehicle component members meet static and dynamic load design criteria. Static load design criteria control the rigidity and/or strength of a specific component member or of the entire vehicle structure. The dynamic load design criteria require that the entire vehicle and specific component members satisfy the strength, dynamic response, and durability requirements.

Besides the static and dynamic load design criteria, there are crashworthiness load design criteria which are derived from requirements concerning front barrier impact, rollover, side door penetration, fuel tank integrity, etc. Because the relationship between various deformation modes and occupant protection is not fully understood, and design guidelines are not completely established, crash requirements will not be discussed.

From a conventional structural viewpoint, there are three types of design requirements: stiffness, strength, and vibration. The stiffness and the strength requirements govern, respectively, the maximum allowable deflection and the maximum allowable stress of a structure under a specified load. The vibration design requirement controls the desired frequency and mode response.

These structural design requirements and the related design constraints are discussed in detail by Chang and Justusson.[26]

The components made of substitutional material are acceptable only if the corresponding structural responses are equal to or better than those of the original design. It is often assumed that the substitutional component has the same overall dimensions and geometry as the original one except for possible changes in thickness.

Because of the large number of vehicle components involved, it is necessary to establish a simplified approach to calculate weight savings by material substitution. For this reason, vehicle components are classified according to their geometrical shapes into three groups: panels, thin-walled beams, and solid sections. Panel members (e.g., hood, roof panel, and door panels) and thin-walled beam members (e.g., chassis frame, pillars, and rocker panels) are made of sheet stock and account for most of the vehicle structural weight. Solid section members (e.g., various reinforcement brackets, hinges, supports and reinforcements) are used mainly as reinforcements and linkages. They contribute comparatively little weight to the vehicle structure.

By considering similar geometries for equivalent structures, the functional relationship between the structural criteria and the corresponding design variables can be simplified by eliminating many complicated geometric factors. Hence, design parameters can be reduced to a function of basic material properties: modulus of elasticity (E), Poisson's ratio (ν), yield strength (σ_y), density (ρ), and the wall thickness (t). Equations involving these parameters are given in Tables 3-13 through 3-15 for the three geometrical groups.

Chang and Justusson found that for direct material substitution, stiffness is the most restrictive structural requirement of the total vehicle and its components. Using stiffness as the design criterion, the weight of a replacement component can be determined from the following formula:

$$W_n = W_o \left(\frac{\rho_n}{\rho_o}\right) \left(\frac{E_o}{E_n}\right)^{\frac{1}{m}} \qquad (3.3.1)$$

TABLE 3-13. COMPARISON OF REQUIRED STRUCTURAL CHARACTERISTICS FOR PANEL MEMBERS -- DIRECT SUBSTITUTION OF MATERIAL

Structural Characteristic	Ratio of Structural Characteristics*	Thickness Ratio Required for Equal Structural Characteristics
Stiffness, S (Oil Canning Resistance)	$\frac{S_n}{S_o} = \frac{E_n}{E_o}\left(\frac{t_n}{t_o}\right)^2$	$\frac{t_n}{t_o} = \left(\frac{E_o}{E_n}\right)^{\frac{1}{2}}$
Denting Resistance, D	$\frac{D_n}{D_o} = \left(\frac{\sigma_{yn}(\dot{\varepsilon})t_n^2}{\sigma_{yo}(\dot{\varepsilon})t_o^2}\right)^2 \frac{S_o}{S_n}$	$\frac{t_n}{t_o} = \frac{\sigma_{yo}(\dot{\varepsilon})}{\sigma_{yn}(\dot{\varepsilon})}\left(\frac{E_n}{E_o}\right)^{\frac{1}{2}}$
Buckling Resistance, B	$\frac{B_n}{B_o} = \frac{E_n}{E_o}\frac{1-\nu_o^2}{1-\nu_n^2}\left(\frac{t_n}{t_o}\right)^3$	$\frac{t_n}{t_o} = \left(\frac{1-\nu_o^2}{1-\nu_n^2}\frac{E_o}{E_n}\right)^{\frac{1}{3}}$
Stress Yield Factor, Y	$\frac{Y_n}{Y_o} = \frac{\sigma_{yn}(\dot{\varepsilon})}{\sigma_{yo}(\dot{\varepsilon})}\frac{E_o}{E_n}\frac{\bar{S}_n}{\bar{S}_o}$	$\frac{\bar{S}_n}{\bar{S}_o} = \frac{E_n}{E_o}\frac{\sigma_{yo}(\dot{\varepsilon})}{\sigma_{yn}(\dot{\varepsilon})}$
Vibration Frequency, F	$\frac{F_n}{F_o} = \left(\frac{E_n}{E_o}\frac{t_n}{t_o}\frac{\rho_o}{\rho_n}\right)^{\frac{1}{2}}$	$\frac{t_n}{t_o} = \frac{E_o}{E_n}\frac{\rho_n}{\rho_o}$

*Subscripts n and o refer to new material and original material.

Source: Reference 26

TABLE 3-14. COMPARISON OF REQUIRED STRUCTURAL CHARACTERISTICS FOR THIN-WALLED BEAM MEMBERS -- DIRECT SUBSTITUTION OF MATERIAL

Structural Characteristic	Ratio of Structural Characteristics*	Thickness Ratio Required for Equal Structural Characteristics
Bending Stiffness, S^b	$\frac{S_n^b}{S_o^b} = \frac{E_n}{E_o}\frac{t_n}{t_o}$	$\frac{t_n}{t_o} = \frac{E_o}{E_n}$
Torsional Stiffness, S^t	$\frac{S_n^t}{S_o^t} = \frac{G_n}{G_o}\frac{t_n}{t_o}$ (closed section)	$\frac{t_n}{t_o} = \frac{G_o}{G_n}$
	$= \frac{E_n}{E_o}\frac{t_n}{t_o}$ (open section)	$\frac{t_n}{t_o} = \frac{E_o}{E_n}$
Buckling Resistance, B	$\frac{B_n}{B_o} = \frac{E_n}{E_o}\frac{t_n}{t_o}$	$\frac{t_n}{t_o} = \frac{E_n}{E_o}$
Local Buckling Resistance, L	$\frac{L_n}{L_o} = \frac{E_n}{E_o}\frac{1-\upsilon_o^2}{1-\upsilon_n^2}\left(\frac{t_n}{t_o}\right)^3$	$\frac{t_n}{t_o} = \left(\frac{1-\upsilon_n^2}{1-\upsilon_o^2}\frac{E_o}{E_n}\right)^{\frac{1}{3}}$
Crippling Resistance, C	$\frac{C_n}{C_o} = \left(\frac{E_n}{E_o}\frac{\sigma_{yn}}{\sigma_{yo}}\right)^{\frac{1}{2}}\left(\frac{t_n}{t_o}\right)^{1.75}$	$\frac{t_n}{t_o} = \left(\frac{E_o}{E_n}\frac{\sigma_{yo}}{\sigma_{yn}}\right)^{\frac{1}{3.5}}$
Stress Yield Factor, Y	$\frac{Y_n}{Y_o} = \frac{\sigma_{yn}(\dot{\varepsilon})}{\sigma_{yo}(\dot{\varepsilon})}\frac{E_o}{E_n}\frac{S_n}{S_o}$	$\frac{S_n}{S_o} = \frac{E_n}{E_o}\frac{\sigma_{yo}(\dot{\varepsilon})}{\sigma_{yn}(\dot{\varepsilon})}$
Vibration Frequency, F	$\frac{F_n}{F_o} = \left(\frac{E_n}{E_n}\frac{\rho_o}{\rho_n}\right)^{\frac{1}{2}}$	—

*Subscripts n and o refer to new material and original material.

Source: Reference 26

TABLE 3-15. COMPARISON OF REQUIRED STRUCTURAL CHARACTERISTICS FOR SOLID SECTIONS -- DIRECT SUBSTITUTION OF MATERIAL

STRUCTURAL CHARACTERISTICS	RATIO OF STRUCTURAL CHARACTERISTICS*	THICKNESS RATIO REQUIRED FOR EQUAL STRUCTURAL CHARACTERISTICS
Equal Bending Stiffness	$\frac{S_n}{S_o} = \frac{E_n}{E_o} \left(\frac{t_n}{t_o}\right)^3$	$\frac{t_n}{t_o} = \left(\frac{E_o}{E_n}\right)^{1/3}$
Equal Bending Moment Resistance	$\frac{M_n}{M_o} = \frac{\sigma_n}{\sigma_o} \left(\frac{t_n}{t_o}\right)^2$	$\frac{t_n}{t_o} = \left(\frac{\sigma_o}{\sigma_n}\right)^{1/2}$
Equal Bending Moment Resistance in Fatigue	$\frac{M^F_n}{M^F_o} = \frac{\sigma_n^F}{\sigma_o^F} \left(\frac{t_n}{t_o}\right)^2$	$\frac{t_n}{t_o} = \left(\frac{\sigma_o^F}{\sigma_n^F}\right)^{1/2}$

* Subscripts n and o refer to new material and original material

Source: Reference 25

where:

W is the weight of the component

ρ is the density of the material

E is the modulus of elasticity of the material

n and o refer to new material and original material

$m = 1$ for thin-wall beams

$m = 2$ for body panels

$m = 3$ for solid sections.

The problem in using the above formula for determining component weight is to rely on mathematical comparison of material properties without considering design changes to optimize the performance of the alternative materials. Components are not necessarily replaced on a one for one basis. Alternative materials, reinforced plastics in particular, often permit the consolidation of several separate components into a single part. Another problem of the analytical approach is that a lightweight component determined mathematically may not be fabricated or will not meet all production requirements. All materials have manufacturing and assembly limitations as well as performance limitations. Accurate component weight can only be determined with complete design and analysis for each alternative material.

4. PROPAGATED WEIGHT REDUCTION

Reduction in vehicular upper body weight allows reduction in under body weight, which leads to reduction in the weight of chassis components. As the result of this weight interaction, for every pound of primary weight reduction, there is a secondary weight change. This secondary weight reduction ranges from the rather conservative estimate of 0.4 pounds to a significant estimate of 1.6 pounds per pound of primary weight change.[27-33] A brief review of various methodologies for deriving the weight propagation factors is presented in here. Also presented is a methodology for estimating the secondary weight reduction developed at TSC.

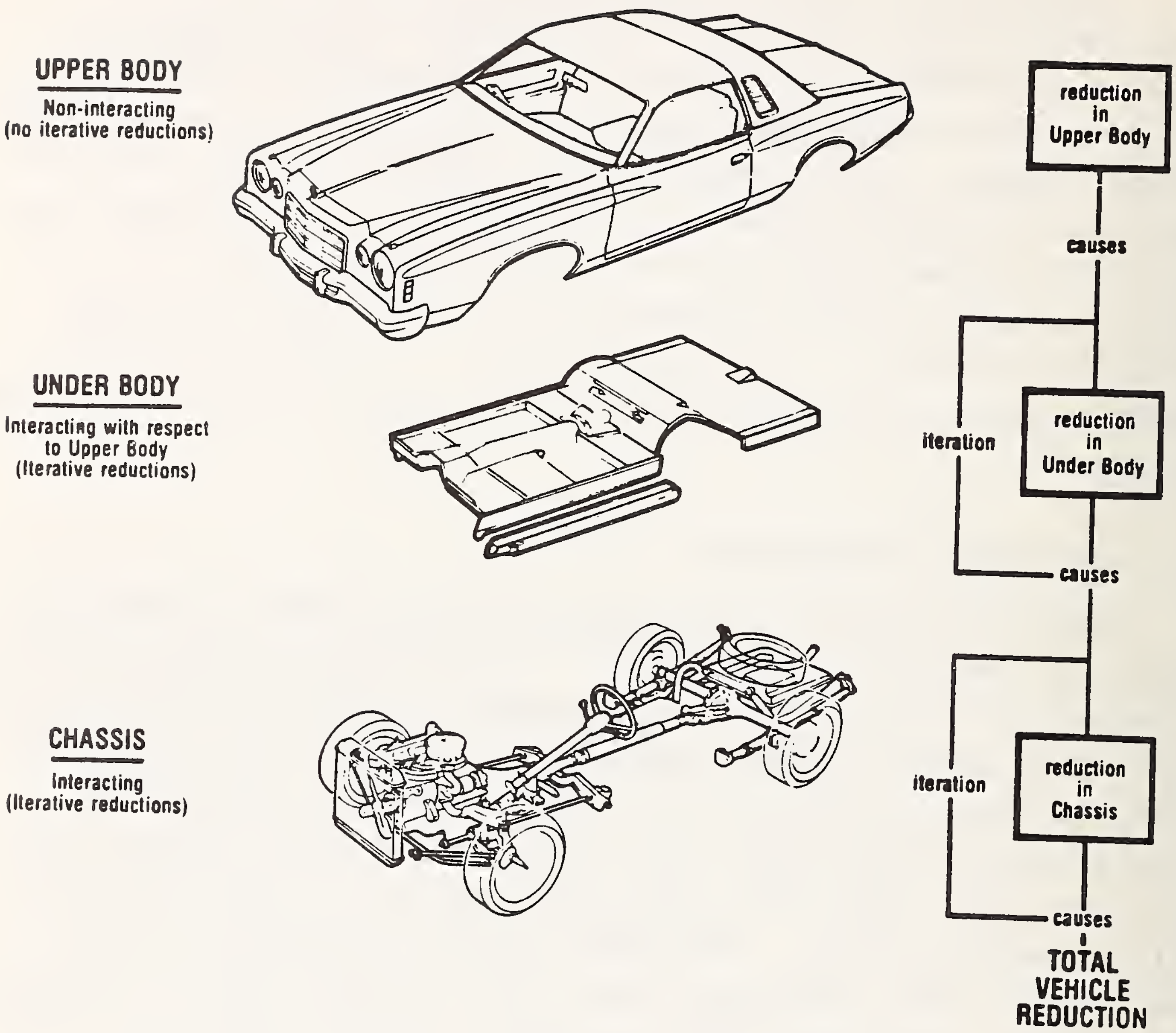
4.1 CHRYSLER'S METHODOLOGY

Chrysler proposes an interacting weight model to determine weight to weight interaction.[28,29] In the Chrysler's methodology a vehicle is divided into twelve groups: an upper body group, an under body group, and ten major chassis groups. The upper body group consists of the major body panels, interior upper body structure, the dash, the seats, the glass, and the interior and exterior trim. The under body group consists of the floor pan, rails, and side sills. The chassis groups are made up of the bumpers and those components that either propel, stop, or suspend the vehicle. The upper body components are considered non-interacting as shown in Figure 4-1.

The relationships between component groups and total vehicle weight are obtained with regression analysis for five major car lines. The simple power curve in the form of

$$y = a\ x^b$$

is used for the regression analysis. The five car lines used to obtain constants a and b are 1976 four-door models with automatic transmissions and unit body construction. The resulting relationships are given in Table 4-1.



Source: Reference 29

FIGURE 4-1. CHRYSLER'S WEIGHT INTERACTING MODEL

TABLE 4-1. VEHICLE WEIGHT-WEIGHT RELATIONSHIPS ($Y = aX^b$) (1976 DATA BASED ON VL, HN, RW, P & C*)

VEHICLE COMPONENT GROUP	CONSTANT a	CONSTANT b	CORRELATION COEFFICIENT
Chassis Groups			
Power Plant	3.702	0.65	0.91
Final Drive	0.545	0.69	0.84
Forestructure	0.002	1.34	0.83
Suspension	0.014	1.18	0.91
Steering	6×10^{-4}	1.39	0.97
Brakes	0.032	1.04	0.99
Wheels & Tires	0.005	1.29	0.99
Exhaust	5×10^{-6}	1.97	0.97
Fuel System	0.057	0.74	0.96
Bumpers	0.183	0.84	0.88
Body Groups			
Under Body	0.023	1.11	0.95
Upper Body	0.004	1.54	0.98

*Vehicle Designation

VL - Valiant, Dart
HN - Volare, Aspen
RW - Fury, Coronet
P - Gran Fury
C - Chrysler

Source: Reference 29

A computer program is used to compute the interactive weight reduction. The results show that for an intermediate size vehicle, such as the Charger SE, a 200 pound reduction in upper and under body groups can lead to an iterative chassis weight savings of 221 pounds. Thus, for a primary weight reduction of 200 pounds, total vehicle weight savings is 421 pounds, or a weight propagation factor of 2.11

4.2 FORD'S METHODOLOGY

Ford divides the vehicle components into two groups: product function weight and dependent weight.[30] The product function weight is defined as a function of vehicle packaging and configuration. It is determined by the type of product one desires as well as the materials and design used in achieving this aim. The dependent weight is defined as a function of total vehicle weight; thus, it is affected by weight decisions made elsewhere. Therefore, total vehicle weight can be expressed as:

$$W_{TOT} = W_{PF} + W_{DEP}. \tag{4.2.1}$$

The dependent weight consists of the weight of ten subsystems: engine, transmission and clutch, driveline, fuel system, exhaust, bumpers, brakes, wheels and tires, steering and suspension, and frame. The dependence of each subsystem weight on total vehicle weight (curb weight, inertia weight or gross vehicle weight) is determined by regression analysis. The following three different regression equations are used:

$$W_{SUB} = A\ W_{TOT}. \tag{4.2.2}$$

$$W_{SUB} = B + C\ W_{TOT}. \tag{4.2.3}$$

$$W_{SUB} = D\ W_{TOT}^{E}. \tag{4.2.4}$$

Ford found that the linear equation (4.2.3) generally gave higher correlation coefficients than the other two equations, and that inertia weight gave the highest degree of correlation when used as total vehicle weight. Weight data from twelve 1975 Ford production cars and from four 1975 Chrysler models were used to derive the functional dependence of the ten subsystem weights on total vehicle weight. Table 4-2 shows the results based on vehicle inertia weight.

By adding all the derived constants shown in Table 4-2, the dependent weight function becomes:

$$W_{DEP} = -115.8 + .574\ W_I.$$

When this equation is substituted into Equation 4.2.1, one obtains

$$W_I = 2.34\ W_{PF} - 271.8,$$

and, consequently one obtains

$$\frac{dW_I}{dW_{PF}} = 2.34\ .$$

This means that for every pound change in product function weight, the total vehicle weight (in this case, the vehicle inertia weight) changes by 2.34 pounds. Of this total weight change, 1.34 pounds (secondary factor) came from the dependent subsystems. The secondary weight factors for all cases as derived by Ford are summarized in Table 4-3.

The derived secondary weight factors only apply to weight changes in product function. For initial weight changes in a dependent subsystem, Ford states that it is necessary to modify that subsystem relationship and claims that the secondary weight factor would be slightly reduced.

4.3 GM'S METHODOLOGY

From teardown data of a group of vehicles, GM derives a total weight compounding factor for each functional subsystem which is considered to be affected by vehicle weight change. These functional subsystems as well as those that are considered not to

TABLE 4-2. FUNCTIONAL DEPENDENCE ON SUBSYSTEM WEIGHTS ON VEHICLE INERTIA WEIGHT ($W_{SUB} = B + CW_I$)

SUBSYSTEM	B	C	CORRELATION COEFFICIENT
Engine	-57.1	.161	.985
Transmission	-26.1	.043	.947
Driveline	11.9	.034	.983
Fuel System	46.5	.025	.830
Exhaust	6.0	.011	.914
Bumpers	-24.1	.053	.985
Brakes	1.2	.041	.996
Wheels and Tires	16.1	.052	.974
Steering	-30.5	.025	.967
Suspension, Frame	-60.0	.129	.977

Source: Reference 30

TABLE 4-3. SECONDARY WEIGHT FACTORS

ASSUMED TOTAL WEIGHT PARAMETER AND FORM OF FUNCTIONAL REPRESENTATION	2500 LB CAR: $\Sigma \frac{dW_{SUB}}{dW_{TOT}}$	2500 LB CAR: SECONDARY WT. FACTOR LBS/LB	5000 LB CAR: $\Sigma \frac{dW_{SUB}}{dW_{TOT}}$	5000 LB CAR: SECONDARY WT. FACTOR LBS/LB
1. Linear Eq. 4.2.3 with Inertia Weight	.574	1.34	.574	1.34
2. Highest Correlation Coefficient in each case	.578	1.37	.581	1.39
3. Eq. 4.2.3 with Curb Weight	.553	1.23	.553	1.23
4. Eq. 4.2.3 with Maximum Test Weight	.485	.94	.485	.94
5. Eq. 4.2.4 with Curb Weight	.578	1.37	.563	1.29
6. Eq. 4.2.4 Inertia Weight	.552	1.23	.58	1.39
7. Eq. 4.2.4 with Maximum Test Weight	.441	.79	.477	.91
8. Eq. 4.2.2 with Curb Weight	.602	1.51	.602	1.51
9. Eq. 4.2.2 with Inertia Weight	.546	1.20	.546	1.20
10. Eq. 4.2.2 with Maximum Test Weight	.426	0.74	.426	0.74

Source: Reference 30

TABLE 4-4. FUNCTIONAL SUBSYSTEMS FOR DETERMINING WEIGHT COMPOUNDING FACTORS

SUBSYSTEMS THAT ARE AFFECTED BY WEIGHT CHANGE	SUBSYSTEMS THAT ARE NOT AFFECTE BY WEIGHT CHANGE
Body Structure	Electrical System
Frame	Instrument Panel and Controls
Front Suspension	Glass
Rear Suspension	Seats
Brakes	Acoustics and insulation
- Front - Rear - Apply System	Trim
	Heating and ventilation
	Windshield washer and wiper
Powertrain	Doors
- Engine - Starting System - Transmission - Drive line - Fuel System - Exhaust - Cooling	Deck lid
	Hood
Steering	
Tires	
Wheels	
Bumpers	
- Front - Rear	
Front Sheet Metal	

Source: Reference 31

be affected by vehicle weight change are shown in Table 4-4. GM indicates that only homogeneous families of vehicles, either all transverse front-wheel drive vehicles or all rear-wheel drive vehicles, should be used for the analysis. Also, the vehicles used should comply with the same regulations.

Once teardown weights of subsystems for a group of vehicles are obtained, linear equations with gross vehicle weight (GVW) as the independent variable can be produced from a least squares fit of the weight data. The slope of the line is defined as the subsystem weight influence coefficient (WICS), while the sum of these coefficients is defined as the vehicle weight influence coefficient (WICV).

The total effect of the weight change in a vehicle consists of three parts: (R_1), the primary weight change in a subsystem, (R_2), the secondary weight change in the remainder of the vehicle as a direct result of (R_1), and (R_3), the compounded weight change as the result of R_2. If, because of a design change, the weight of subsystem A is changed by an amount R_1, the GVW of the vehicle will also be changed by R_1. The primary change in GVW allows all the remaining vehicle subsystems to be changed by an amount (R_2) depending on their weight influence coefficients. Hence,

$$R_2 = R_1 \text{ (WICV - WICA)}$$

where WICA is the weight influence coefficient of the subsystem on which the primary weight change is made. The secondary weight change then can be compounded by employing the weight influence coefficient of the total vehicle, i.e.

$$R_3 = R_2 \times \text{WICV}.$$

The total component compounded weight factor (R_T) for every unit of primary weight change becomes

$$R_T = \frac{R_2 + R_3}{R_1}$$

or, after substitutions

$$R_T = (1 + WICV)\ (WICV - WICA)$$

It should be noted that the total compounded weight factor depends on the specific subsystem on which the primary weight change is made. Using weight data from 13 1974 GM vehicles, GM derived subsystem weight influence coefficients as shown in Table 4-5.[32] Total compounded weight factors for primary weight changes made in each subsystem are also shown in Table 4-5. Therefore, for every pound of weight change in one of these subsystems, the total vehicle weight changes from a low of 1.58 pounds for the structure subsystem to a high of 2.04 pounds for the rear suspension or steering system.

4.4 HOOVEN'S METHODOLOGY

In a vehicle weight study conducted for the Department of Transportation, Hooven and Kennedy[27] grouped the vehicle subsystems into three categories: the product-dependent weight, the weight-dependent weight, and the displacement-dependent weight. Unlike the Ford study,[30] which included all chassis subsystem weights into dependent weight, Hooven divided some of the chassis subsystem weights between two of the three weight groups as shown in Table 4-6.

By defining weight per unit displacement p as

$$p = \frac{W_c + W_x}{D}$$

and the weight-dependent factor c as

$$c = \frac{W2}{W1+W3+W4}$$

Hooven derived

$$W_c = \frac{(1+c)\ (pW1 + mW_x) + cpW4}{p-m-mc}$$

TABLE 4-5. VEHICLE WEIGHT INFLUENCE COEFFICIENTS

FUNCTIONAL SUBSYSTEM	WEIGHT INFLUENCE COEFFICIENT	TOTAL COMPOUNDED WEIGHT FACTOR
Powertrain	.183	0.76
Structure	.294	0.58
Front Suspension	.021	1.02
Rear Suspension	.013	1.04
Brake System	.038	1.00
Steering System	.011	1.04
Tires	.021	1.02
Wheels	.015	1.03
Bumper System	.048	0.98

Source: Reference 32

TABLE 4-6. WEIGHT CLASSIFICATION DEFINITIONS BY HOOVEN

1. Independent variables, specified weights

Product-Dependent Weight, W1
- Body
- Frame and Tools
- Instruments and Electrical
- 80% of Battery and Alternator
- 50% of Bumpers
- 50% of Exhaust System
- 50% of Steering System
- 20% of Fuel System
- Constant, n, of powerplant weight Wp
- Heating and Ventilating

Disposable Weight, W4
- Full load of passengers (@150 lbs/passenger)
- Luggage (@25 lbs/passenger)
- All available options
- Incremental weight of heaviest available body style over that of standard model

Performance Load, Wx
- Vehicle load specified for performance evaluation = 300 lbs.

2. Dependent variables, derived weight categories

Weight-Dependent Weight, W2
- Suspension
- Wheels and Tires
- Brakes
- 80% of Final Drive
- 50% of Bumpers
- 50% of Steering System
- 50% of Transmission

Powerplant Weight, Wp
- Engine
- 80% of Fuel System
- 50% of Exhaust System
- 20% of Final Drive
- 20% of Battery and Alternator
- 50% of Transmission

Displacement-Dependent Weight, W3
- The portion of the powerplant weight that is dependent on engine power or displacement. W3 = Wp - n

Curb Weight, Wc
- The weight of the standard vehicle with liquids but without disposable weight. Wc = W1 + W2 + W3

Maximum Gross Vehicle Weight, Wg
- Curb weight plus disposable weight. Wg = W1 + W2 + W3 + W4

Source: Reference 27

where m is the slope of the line following a least-squares fit of powerplant weight (W_p) correlated with engine displacement (D):

$$W_p = n + mD.$$

The influence coefficient relating a change in W_c to a unit change in W1 was found to be:

$$Q_1 = \frac{\partial W_c}{\partial W1} = \frac{p(1+c)}{p-m-mc} .$$

Hooven calculated the influence coefficient (Q1) for seventeen vehicles produced for the U.S. market. The results of the calculations are given in Table 4-7. The mean of Q1 is 1.400 with a standard deviation of 0.067. It can be seen from Table 4-7 that the values of Q1 are nearly the same for all vehicles. Therefore, the influence coefficient (Q1) is constant and does not depend on the vehicle being studied. Thus, Hooven concluded that every decrease of one pound in the weight of a body component could lead to a total vehicle weight reduction of 1.4 pounds, assuming that the weight-dependent components are redesigned appropriately for the smaller load they must support.

4.5 NHTSA METHODOLOGY

In an attempt to establish an analytical framework to use in estimating the weight of automobiles in the 1985-1995 period, Luchter developed a methodology for determining secondary weight factors.[33] In this methodology, a vehicle is considered to be comprised of two parts, one weight sensitive and the other not weight sensitive. Then:

$$W_I = (W_{EN} + W_{BO} + W_{WS}) + W_{WN}$$

where W_I = vehicle inertia weight,

W_{EN} = engine weight,

W_{BO} = body structure weight,

TABLE 4-7. DERIVED DATA FOR SEVENTEEN ACTUAL VEHICLES

	VEHICLE 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
D (CU. IN.)	302	351	351	170	170	200	318	440	225	225	318	360	140	250	100	68	90
P (LB/CU.IN)	13.5	12.5	13.4	17.4	18.1	16.1	12.8	11.4	15.4	16.5	15.0	12.1	20.7	14.8	26.0	31.2	23.7
WEIGHTS IN POUNDS																	
W1	2386	2513	2668	1726	1774	1833	2235	2818	1974	2029	2748	2444	1722	1973	1570	1319	1253
W2	887	927	1057	614	675	772	892	1139	759	863	1076	1038	616	936	579	413	416
W3	511	653	677	317	327	324	647	752	425	515	655	587	262	491	151	90	161
CURB WEIGHT	3784	4093	4403	2657	2776	2929	3774	4709	3158	3407	4479	4069	2600	3400	2300	1823	1830
INFLUENCE COEFFICIENTS																	
Q1	1.43	1.44	1.45	1.35	1.36	1.41	1.44	1.50	1.39	1.40	1.42	1.50	1.35	1.46	1.33	1.26	1.29
Q4	0.23	0.23	0.25	0.21	0.22	0.25	0.23	0.26	0.22	0.24	0.24	0.27	0.23	0.28	0.23	0.19	0.19
QD	2.21	2.20	2.23	2.18	2.21	2.25	2.21	2.24	2.20	2.24	2.23	2.26	2.23	2.29	2.24	2.17	2.18

VEHICLES STUDIED

1. 1970 FORD CUSTOM 500
2. 1972 FORD CUSTOM 500
3. 1974 FORD GALAXIE 500
4. 1970 MAVERICK
5. 1972 MAVERICK
6. 1974 MAVERICK
7. 1974 FLYMOUTH SATELLITE
8. 1974 CHRYSLER NEW YORKER
9. 1976 VALIANT
10. 1976 FLYMOUTH VOLARE
11. 1976 FLYMOUTH GRAN FURY
12. 1976 CHARGER SE
13. 1975 VEGA
14. 1975 NOVA
15. C6
16. 1972 FIAT 128
17. 1975 VW RABBIT

Source: Reference 27

W_{WS} = other weight sensitive subsystem weights (includes transmission, driveline, brakes, wheels and tires, suspensions, starting, and exhaust system)

$= \Sigma\ (W_T + W_D + W_{BR} + W_W + W_{SU} + W_{ST} + W_{EX})$

W_{WN} = nonweight sensitive component weight

The relationship between vehicle inertia weight and weight of various subsystems is determined by regression analysis. Then the secondary weight factors for the weight sensitive and weight insensitive part are taken to be

$$\frac{dW_I}{d(W_{EN} + W_{BO} + W_{WS})}$$

and

$$\frac{dW_I}{dW_{WN}}$$

respectively.

Using weight data of vehicles from 1958 to 1978 model years, linear regression equations were obtained as shown in Table 4-8. The total weight sensitive weight was approximated by the sum of the equations in Table 4-8 and was found to be $(0.511\ W_I + 57.4)$. The weight insensitive weight was taken to be what was left, i.e., $(0.489\ W_I - 57.4)$. Thus,

$$W_I = (0.511\ W_I + 57.4) + W_{WN}$$

and

$$W_I = (0.489\ W_I - 57.4) + (W_{EN} + W_{BO} + W_{WS}).$$

Secondary weight factors for the weight sensitive part and the weight insensitive part of the vehicle were derived to be 1.96 and 2.04 respectively. These indicate that for a pound of weight removed from either the weight sensitive or the weight insensitive portions of the vehicle, the inertia weight of the vehicle will be reduced by about 2 pounds.

TABLE 4-8. WEIGHT DISTRIBUTION REGRESSION EQUATIONS

Subsystem	Equation	No. of Points	R^2
Engine	$W_{EN} = 0.163W_I - 56.4$	45	0.92
Transmission	$W_T = 0.042W_I - 17.4$	41	.89
Driveline	$W_D = 0.045W_I - 22.5$	38	.83
Brakes	$W_{BR} = 0.048W_I - 32.5$	44	.83
Wheels & Tires	$W_W = 0.047W_I + 32.8$	44	.92
Suspension	$W_{SU} = 0.042W_I + 27.7$	27	.72
Body Structure	$W_{BO} = 0.086W_I + 154.6$	14	.86
Steering	$W_{ST} = 0.023W_I - 22.7$	39	.74
Exhaust	$W_{EX} = 0.015W_I - 10.2$	26	.74

Source: Reference 33

Luchter pointed out that this magnitude of secondary weight reduction was generally not possible to achieve except in a totally new design. In most cases, only the engine and body structure undergo significant secondary weight reduction when an existing design is modified. According to results shown in Table 4-8, these two subsystems represent 24.9 percent of the total 51.1 percent, or approximately half of the total weight sensitive weight. Hence, it is concluded that any secondary weight reduction that may occur when an existing design is modified is assumed to be only half as much as in a new design; that is, instead of an additional pound, only an additional half pound of weight reduction can be expected.

4.6 TSC METHODOLOGY

The weight propagation methodologies discussed in the previous sections are essentially statistical analyses. They rely on weight data of vehicles which, in most cases, are pre-1975 models. Therefore, the results derived represent only past or, at best, present technology. Besides, the weight data used are from passenger automobiles. It is doubtful whether the results derived can be applied to light trucks.

TSC developed an alternative methodology based on the consideration of applied load, structural requirements and the properties of material. This methodology does not rely on statistical data and can be used for passenger cars as well as light trucks.

In the TSC methodology, a vehicle is considered to be comprised of three functional groups. Group 1 includes components considered as hang-on parts as shown in Table 4-9. The weight of any component in this group is not affected by weight change made anywhere in the vehicle. Group 2 consists of the structures which provide support for the hang-on parts and to which various chassis systems are attached. In the case of passenger cars and

TABLE 4-9. COMPONENTS CONSIDERED TO BE HANG-ON PARTS

Door
Hood
Deck Lid
Cab
Cargo Bed
Glass
Seats
Trim & Ornamentation
Lights
Horns
Instrument Panel & Controls
Heating & Ventilation
Seals & Weatherstrips
Insulation
Roof Covering
Floor Covering
Under Coating
Headlinings
Windshield Wiper & Washer
Electrical
Knobs & Handles
Latches & Hinges
Air Intake Grille
Sun Visors
Mirrors
Splash Guards & Stone Deflectors
Radio
Air Conditioning
Sun Roof
Luggage Racks
Tools & Jack
Wheel Covers

vans, this group is assumed to include all the structural members which form the body skeleton. In the case of pickup trucks, only frame and cross members are considered to belong to this group even though the cab and cargo bed also contribute to the torsional stiffness of the vehicle. Group 3 includes chassis systems such as engine, fuel system, transmission, driveline, suspensions, brake system, steering system, bumpers, wheels and tires. Weight change in any component in Group 1 affects the weight of components in Groups 2 and 3. Weight change in any component in Group 2 not only affects the weight of components in Group 3 but also influences the weight of components in Group 2 because in addition to supporting the components in Group 1, a component in group 2 also has to support itself and other components in the group. Weight change in any component in Group 3 only affects the weight of components in that group.

As mentioned in Section 3, stiffness is found to be the most restrictive structural requirement of the total vehicle and its components. For two structural components A and B, to have equal stiffness, the following condition must be satisfied:

$$\frac{P_A}{E_A I_A} = \frac{P_B}{E_B I_B} \tag{4.6.1}$$

where

P = applied load,

E = elastic modulus of the material, and

I = the moment of inertia of the component cross section.

If components A and B are of the same material and, except for a difference in thickness of the section, otherwise have identical cross section geometry, then Equation 4.6.1 can be reduced to

$$\frac{P_A}{t_A^m} = \frac{P_B}{t_B^m} \tag{4.6.2}$$

where

t = thickness of the section and

m = a geometric factor which has the value of 1, 2, and 3 for thin-walled beam, panel, and solid section respectively

Since the weight of the component is directly proportional to the thickness of the section, for constant material and geometrical shape, Equation 4.6.2 can be rewritten as

$$\frac{P_A}{W_A^m} = \frac{P_B}{W_B^m} \qquad (4.6.3)$$

Parameters that directly influence the design of various vehicle functional groups are listed in Table 4-10. It can be seen that the controlling parameter for the design of most functional systems is the weight of that system plus payload. Therefore the applied load on the total structure of Group 2 (P_2) is the sum of the total weight of the hang-on parts (W_1), the weight of the structure of Group 2 (W_2), and the design payload (W_p), i.e.,

$$P_2 = W_1 + W_2 + W_p$$

Let subscripts 0 and N denote the original and new design respectively. Then for the original design

$$P_{02} = W_{01} + W_{02} + W_p$$

and, for the new design

$$P_{N1} = W_{N2} + W_{N2} + W_p.$$

By applying the relationship between load and component weight as given by Equation 4.6.3, the following equation is obtained:

$$\frac{W_{N2}}{W_{02}} = \left(\frac{W_{N1} + W_{N2} + W_p}{W_{01} + W_{02} + W_p}\right)^{\frac{1}{m}} \qquad (4.6.4)$$

TABLE 4-10. INFLUENCE PARAMETERS FOR VEHICLE FUNCTIONAL GROUPS

Functional Group	Influence Parameters
Powertrain	
Engine	— Displacement, curb + 2 pass.
Starting system	— Displacement
Transmission	— Displacement, peak engine torque
Driveline	— Peak engine torque, overall width
Fuel system	— Fuel volume
Exhaust system	— Displacement, overall length
Cooling system	— Displacement, gross vehicle weight (GVW)
Structure	
Body	— GVW, gross area, gross volume, wheelbase
Sheet Metal	— Front end volume
Front Suspension	— Maximum front weight
Rear Suspension	— Maximum rear weight, overall width
Brake System	
Front brakes	— Maximum front weight
Rear brakes	— Maximum rear weight, minimum rear weight
Apply system	— GVW
Steering System	— Maximum front weight, front track
Tires	— Maximum wheel load
Wheels	— Maximum wheel load
Bumper Systems	
Front bumper	— Curb + options, overall width
Rear bumper	— Curb + options, overall width
Electrical System	— Alternator output
Instrument Panel & Controls	— Overall width
Miscellaneous	
Vehicle glass	— Gross "greenhouse" volume
Seats	— Overall width
Insulation	— Interior surface area below belt
Trim	— Interior surface area below belt
Ornamentation	— Overall width
Heating & ventilation	— Interior volume
Exterior lamps	— Overall width
Windshield wash & wipe	— Gross windshield area
Doors	— Door area below belt
Deck Lid	— Deck lid area
Hood	— Hood area
Other functional items	— GVW

Source: Reference 34

For body-frame type vehicles, the total structure of Group 2 can be considered as made up by thin-walled beams. Hence, by setting m = 1, Equation 4.6.4 becomes

$$W_{N2} = W_{02} \frac{W_{N1} + W_p}{W_{01} + W_p}$$

For vehicles of unitary construction the total structure of Group 2 can be considered as made up by panel members. Letting m = 2 in Equation 4.6.4, one obtains a quadratic equation

$$(W_{01} + W_{02} + W_p)W_{N2}^2 - W_{02}^2 W_{N2} - W_{02}^2 (W_{N1} + W_p) = 0.$$

Since W_{N2} can not have negative value, the solution of this quadratic equation is

$$W_{N2} = \frac{W_{02}^2 + [W_{02}^4 + 4W_{02}^2(W_{01} + W_{02} + W_p)(W_{N1} + W_P)]^{1/2}}{2(W_{01} + W_{02} + W_p)}$$

It is reasonable to assume that the systems in the chassis group (Group 3) are designed to handle the vehicle with maximum allowable payload. Therefore, the total weight of the systems in Group 3 can be considered to be directly proportional to gross vehicle weight, i.e.

$$\frac{W_{N3}}{W_{03}} = \frac{W_{N1} + W_{N2} + W_{N3} + W_p}{W_{01} + W_{02} + W_{03} + W_p}$$

or

$$W_{N3} = W_{03} \frac{W_{N1} + W_{N2} + W_p}{W_{01} + W_{02} + W_p}$$

The curb weight of the vehicle of new design can be written as

$$W_{NC} = W_{N1} + W_{N2} + W_{N3}$$

Then weight propagation factor relating a change in vehicle curb weight to the weight change in components in Group 1 can be determined from the following equations:

$$\frac{\partial W_{NC}}{\partial W_{N1}} = 1 + \frac{W_{02}}{W_{01} + W_p} + \frac{W_{03}}{W_{01} + W_{02} + W_p} + \left(\frac{W_{02}}{W_{01} + W_p}\right)\left(\frac{W_{03}}{W_{01} + W_{02} + W_p}\right) \tag{4.6.5}$$

for vehicle of body-frame type construction, and

$$\frac{\partial W_{NC}}{\partial W_{N1}} = 1 + \frac{W_{02}}{[W_{02}^2 + 4(W_{01} + W_{02} + W_p)(nW_{01} + W_p)]^{1/2}} + \frac{W_{03}}{W_{01} + W_{02} + W_p} + \left(\frac{W_{02}}{[W_{02}^2 + 4(W_{01} + W_{02} + W_p)(nW_{01} + W_p)]^{1/2}}\right)\left(\frac{W_{03}}{W_{01} + W_{02} + W_p}\right) \tag{4.6.6}$$

for vehicles of unitary construction. In Equation 4.6.6, a substitution $nW_{01} = W_{N1}$ is made so that the propagation factor can be expressed in terms of the original design. When weight is removed from components in Group 1, n will have a value less than 1.

In Equations 4.6.5 and 4.6.6, the first term to the right-hand side of the equation is the primary unit weight change of the hang-on parts. The second term is the weight change on the supporting structure corresponding to the weight change made on the hang-on parts. The third term represents the weight change in the chassis systems corresponding to weight change in the hang-on parts and the last term represents the weight change in the chassis systems as the result of induced weight change in the supporting structure.

Table 4-11 shows weight data on a 1978 Dodge Omni and the derived weight propagation factors for an assumed n-value of 0.8. Weight propagation factor changes from 1.74 for the original design to 1.67 for the same vehicle with lighter composite materials. Within reasonable ranges, the value of n does not have any significant effect on propagation factor, as shown in Figure 4-2. Weight data for a 1973 Ford F-100 pickup truck is shown in Table 4-12. Propagation factors are 1.98 and 1.84 for the original and the light weight designs respectively. It can be seen that the propagation factor is lower for a lighter design and that a vehicle with a more weight efficient design such as the semi-unitary body of the Omni has a lower propagation factor than a vehicle of body-frame construction such as the F-150 pickup truck.

4.7 DISCUSSION

Secondary weight savings can only be claimed if the entire vehicle is redesigned. Even in such cases weight propagation factor is used in a very broad, generalized manner. It is used primarily to establish weight goals for subsystem design at the conception of a new vehicle. Final design of a subsystem is influenced by a host of factors such as material properties, manufacturing processes, performance requirements, cost, lead time, etc. Secondary weight reduction is generally not possible each time weight is reduced from individual components.

Weight propagation analysis is often based on the assumption that the weight relationships of components in production vehicles provide acceptable levels of performance and durability. These relationships may not hold true for new vehicles designed to meet a different set of standards.

All analyses use weight data obtained from vehicles which not only differ in weight and size, but also vary in performance characteristics. However, in each analysis presented here, the variation in subsystem weight is assumed due solely to the changes in total vehicle weight. Moreover, all analyses assume that for a pound added to or removed from a component, the change in weight for the rest of the vehicle is a continuous function rather than a multiple step function. Realistically, only step-wise weight changes are feasible for nearly all subsystems, particularly for engines, transmissions, and final drives.

Another problem of these weight propagation analyses is that the results derived are affected greatly by how and what sub-systems are grouped into different weight categories. The procedure of dividing and grouping component weights into sub-systems sometimes involves more subjective judgment than objective consideration based on engineering design.

TABLE 4-11. WEIGHT DATA OF A 1978 DODGE OMNI AND THE DERIVED WEIGHT PROPAGATION FACTORS

	Weight (pounds)	
	Original*	HRP Dominant
Hang-On Parts, W_1	654.8	500.0
Supporting Structure, W_2	426.9	211.2
Chassis Systems, W_3	1010.3	828.8
Engine	340.1	281.9
Driveline & Trnasmission	117.3	102.6
Suspension	139.0	93.7
Brakes	79.9	57.0
Wheels & Tires	152.3	103.4
Steering	24.9	24.9
Exhaust	26.4	26.4
Bumpers	40.1	40.1
Fuel System	90.2	85.3
Payload, W_p	800.0	800.0
n	0.8	0.8
Propagation Factor	1.74	1.67

*Source: Reference 35

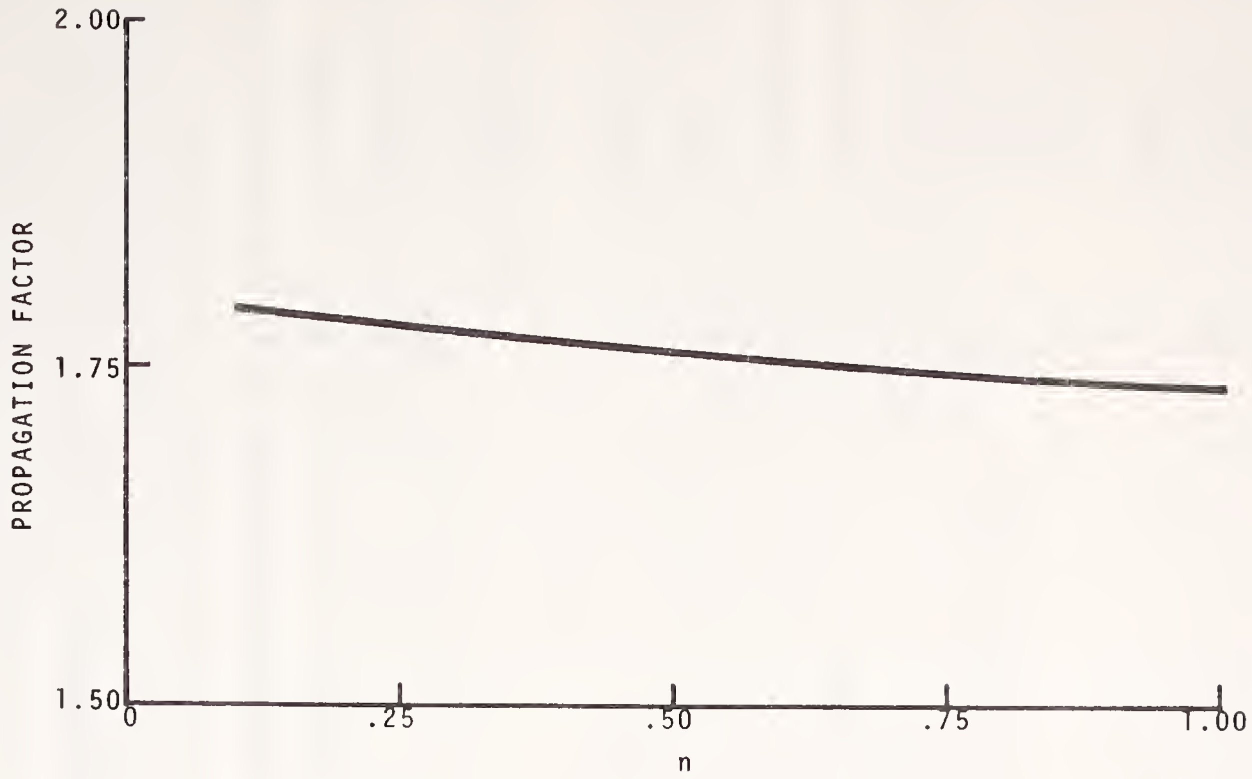


FIGURE 4-2. EFFECT OF CHANGE IN n-VALUE ON PROPAGATION FACTOR FOR 1978 OMNI

TABLE 4-12. WEIGHT DATA OF A 1973 FORD F-100 PICKUP TRUCK AND THE DERIVED WEIGHT PROPAGATION FACTORS

	Weight (pounds)	
	Original*	HRP Dominant
Hang-on Parts, W_1	1466.4	817.6
Supporting Structure, W_2	380.4	159.9
Chassis Systems, W_3	2159.6	1524.1
Engine	722.6	517.1
Transmission & Drivetrain	350.2	276.3
Suspension	271.0	123.5
Wheels & Tires	302.9	228.7
Steering	95.5	64.8
Brakes	179.4	107.5
Fuel System	169.8	153.3
Exhaust	37.7	37.7
Bumpers	30.6	15.3
Payload	1200.0	1200.0
Propagation Factor	1.98	1.84

*Source: Reference 36

5. SELECTION OF BASELINE VEHICLES

Current trends indicate that by the mid 1980's most passenger cars will have been downsized and converted to front-wheel-drive. Material substitution will eventually become necessary for achieving futher weight reduction. To evaluate the weight reduction potential of alternative materials it is necessary to select vehicles of weight efficient design as baseline vehicles for the analysis.

5.1 PASSENGER CARS

Though passenger cars can be classified by thier interior volume, a more useful measurement of the utility of a passenger car is the number of occupants it can accomodate. Currently, there are passenger cars that are designed to carry 2, 4, 5, and 6 passengers. In Reference 8, automobiles with 4-, 5-, and 6-passenger capacity are designated as small-, mid-, and large-size respectively.

5.1.1 Two-Passenger Car

Two-passenger cars of current production are of a sporty type with emphasis on performance. They are comparatively heavy for the interior size, with curb weight ranging from 2500 to 4000 pounds.

The ideal selection of a baseline vehicle for two-passenger cars is a commuter car designed for urban transportation emphasizing fuel economy. No such vehicle is available in the present market. General Motors reportedly plans to introduce a two-seater commuter car in or around 1990.[37] This car presumably will have a non-structural plastic body and a curb weight of about 1200 pounds.

5.1.2 Four-Passenger Car

With a curb weight of 1850 pounds, the VW Rabbit can be considered as one of the most weight efficient designs for a four-passenger cars. However, detailed component weight data on this vehicle is not available for this report. Among other domestic subcompacts, the Chrysler Omni/Horizon, introduced in 1978, was the first to adopt the transverse engine front-wheel-drive configuration, a design commonly used by European passenger car manufacturers in their light weight models. The Omni/Horizon was a completely new design providing the opportunity to utilize light weight materials whenever possible. Particularly, it made extensive use of high strength steels, approximately 170 pounds in 70 parts.[22] A comparison of vehicle system weight between the 1978 Dodge Omni and the 1976 VW Rabbit is given in Table 5-1.

A 1978 Dodge Omni is used as the baseline vehicle for the four-passenger car. This vehicle is a standard four-door hatchbacek with a 105 CID engine and four-speed manual transmission. Detailed component material and weight data are documented in Reference 36. Weights of the major components of this vehicle are given in Table 5-4. With a base curb weight of 2137 pounds, the 1978 Omni weighs only 15 pounds more than a 1981 four-door Ford Escort.

5.1.3 Five-Passenger Car

In a previous analysis,[9] a 1978 Ford Fairmont was chosen as the baseline vehicle for the five-passenger car class because it was a completely new design with emphasis on light weight and fuel economy.[38] In the middle of 1979, General Motors introduced its new transverse engine, front-wheel-drive X-car. The engineering goal of the design was fuel economy, with no sacrifice in interior space, riding comfort, performance, safety, and durability as compared to the models it replaced. Important design features of the X-car are shown in Table 5-2. With a curb weight of 2500 pounds, the X-car is considered the most weight efficient model among the 1980 domestic compacts.

TABLE 5-1. COMPARISON OF VEHICLE SYSTEM WEIGHT, 1978 OMNI vs. 1976 VW RABBIT

VEHICLE SYSTEM	OMNI WT(LBS)	RABBIT WT (LBS)	COMMENTS
Body	894.40	691.94	Omni body is longer (+9.4") and wider (+1.2"). Omni also has heavier body structure. A larger Omni engine requires greater space. There are more small parts on the Omni than on the Rabbit.
Exterior Ornamentation	15.82	19.49	Omni has more expensive door handles, mirrors and nameplats, wider side moldings.
Seats	92.98	111.62	Omni front seats have fixed head rests and a folding rear seat.
Instrument Panel	19.67	18.30	Omni has multi-piece panel construction (steel with plastic skirt) while Rabbit has padded fiberboard.
Bumpers	40.96	63.74	Omni has extruded aluminum bumpers while Rabbit has heavier high steel system.
Engine	287.96	265.98	Omni engine is larger (1.7 liter to 1588cc for Rabbit).
Transmission	80.37	81.28	Omni's transaxle unit is larger that the Rabbit.
Suspension	176.58	101.28	Omni front suspension is heavier and includes a sway bar. Omni also uses a sway bar in the rear.
Steering	22.51	27.66	Omni uses a heavier rack and pinion steering gear, however the system is lighter.
Brakes	75.98	70.83	Omni uses larger calipers, rotor hubs and bearings to accommodate the larger body weight.
Fuel System	18.22	21.54	Omni fuel tank is larger, is more complex and includes provisions for MVSS 301 impact (Roll over valve, etc.)
Exhaust System	26.42	42.56	Omni has a resonator and larger exhaust system
Balance of Chassis	268.11	316.99	
Total	2019.98	1833.21	

Source: Reference 35

TABLE 5-2. DESIGN FEATURES OF THE 1980 X-CARS

- Weight reduction of over 800 lbs. made possible by using smaller and lighter engines without performance sacrifice.
- Improved engine efficiency by friction and parasitic loss reduction.
- Reduced aerodynamic drag force through optimized basic body shape, styling detail tailoring and reduced frontal area.
- Electrically driven engine cooling fan which only runs during peak cooling needs.
- Aerodynamically maximized 'ram air' cooling flow, reducing the need for fan operation and reducing the weight of cooling system components.
- Tires specifically engineered to improve rolling resistance while retaining ride, handling and wear performance.
- 'Wide' gear ratio automatic and manual transmissions to achieve 'overdrive' economy with pleasing feel and performance in city traffic.
- Optimized axle gear ratios.
- Reduced brake 'drag'.
- Computer-matched engine and automatic transmission torque converter characteristics.
- Variable capacity automatic transmission oil pump to reduce pumping losses.
- Reduced transmission parasitic losses through design and lubricant improvements.
- Reduced electrical generation requirements by reduction of accessory power consumption.

Source: Reference 34

A 1980 Oldsmobile Omega is used as the baseline vehicle for five-passenger cars. This vehicle is a four-door sedan with a 173 CID V-6 engine and three-speed automatic transmission. It is also equipped with air conditioning and other convenience options resulting in a curb weight of 2702 pounds. Detailed component weights of this vehicle are documented in Reference 39. Weights of major components are given in Tabel 5-4.

The 1981 Chrysler front-wheel drive, transverse engine K-car is virtually identical to the GM X-car in size but is 273 pounds lighter, as shown in Table 5-3. The K-car is advertized as having a six passenger capacity and is designated as a mid-size car by the EPA. A K-car has been obtained and is being disassembled to document material, weight, and stock thickness of each component.

5.1.4 Six-Passenger Car

The industry's effort in vehicle weight reduction started with the General Motors 1977 downsized B-car. The 1977 B-car, as represented by the Chevrolet Impala, was made substantially lighter and shorter than the previous models with small changes in major interior dimensions.[40] Ford and Chrysler did not introduce their downsized full-size models until the 1979 model year.

A 1977 Impala is used as the baseline vehicle for six-passenger cars. This vehicle is a four-door sedan with a 305 CID engine and three-speed automatic transmission, weighing 3708 pounds with full fluid. Component weights of this vehicle were derived from References 40 and 41. Weight breakdowns of major components for this vehicle are given in Table 5-4.

5.2 LIGHT TRUCKS

The selection of baseline vehicles for light trucks is limited to vehicles of domestic manufacturers. Although some foreign models are comparatively lighter in curb weight, their load and/or volume capacity are considerably lower. Also, their

TABLE 5-3. COMPARISON OF VEHICLE PARAMETERS, 1980 X-CAR vs. 1981 K-CAR

VEHICLE PARAMETER	1980 X-CAR	1981 K-CAR
Wheelbase (in.)	104.9	99.6
Overall Length (in.)	176.7	176
Overall Width (in.)	68.3	68
Overall Height (in.)	53.1	53
Front Head Room (in.)	38.1	38.5
Rear Head Room (in.)	37.7	37.8
Front Shoulder Room (in.)	56.3	55.4
Rear Shoulder Room (in.)	56.3	55.9
Front Leg Room (in.)	42.2	42.2
Rear Leg Room (in.)	35.5	35.5
Trunk Space (cu. ft.)	12.5	15
Base Engine (CID)	151	135
Curb Weight (lbs.)	2505	2232

Source: MVMA Specification Forms

TABLE 5-4. WEIGHT BREAKDOWNS FOR IMPALA, OMEGA AND OMNI

ALL WEIGHTS GIVEN IN POUNDS

	1977 IMPALA	1980 OMEGA	1978 OMNI
CURB WEIGHT (WITHOUT FUEL)	3586.0	2618.2	2020.0
BODY AND FRAME	1813.0	1317.6	1090.0
FRONT FENDER OUTER SKIN	24.0	20.0	16.5
FRONT FENDER WHEEL HOUSING	23.0		
FRONT FENDER SUPPORT STRUCTURE	31.0		
HOOD OUTER SKIN	32.5	21.8	17.8
HOOD SUPPORT STRUCTURE	20.0	16.7	10.2
RADIATOR SUPPORT	26.5		
FRONT DOOR OUTER SKIN	24.0	21.5	18.4
FRONT DOOR GUARD BEAM	17.0	12.5	11.3
FRONT DOOR SUPPORT STRUCTURE	39.0	38.0	16.4
REAR DOOR OUTER SKIN	18.0	16.5	13.6
REAR DOOR GUARD BEAM	11.0	9.0	7.0
REAR DOOR SUPPORT STRUCTURE	36.0	23.3	12.5
DECK LID OUTER SKIN	28.5	18.3	
DECK LID SUPPORT STRUCTURE	13.5	13.7	
ROOF OUTER SKIN	35.0		24.2
ROOF SUPPORT STRUCTURE	25.5		7.7
FRAME	261.0		
SILL	55.0	32.2	44.2
A POST	45.0	23.1	8.4
B POST	25.0	19.1	12.9
C POST	18.0		4.6
FLOOR PANEL	106.0	56.4	56.8
QUARTER PANEL AND WHEEL WELL	72.0	48.4	38.8
TAIL LIGHT PANEL	11.5	6.0	
FIREWALL	51.5	7.9	
REAR SHELF	17.0	12.1	
REAR HATCH BACK			18.4
RADIATOR	15.0	15.5	
FRONT SEAT FRAME	34.5	29.5	29.4
FRONT SEAT CUSHION	10.5		9.1
FRONT SEAT BACK	10.5		5.8
FRONT SEAT TRACK	8.5	7.8	9.9
FRONT SEAT MOUNTING	5.0		
REAR SEAT FRAME	9.5	6.1	14.1
REAR SEAT CUSHION	10.5		14.4
REAR SEAT BACK	11.0	4.6	8.3
ENGINE	576.0	410.8	288.0
ENGINE BLOCK	164.0	87.0	71.9
CYLINDER HEAD	86.0	49.0	17.7
AIR CLEANER TOP	2.0		
AIR CLEANER BOTTOM	3.5	6.0	5.4
AIR FILTER ELEMENT	1.0		

TABLE 5-4. WEIGHT BREAKDOWNS FOR IMPALA, OMEGA AND OMNI (CONTINUED)

ALL WEIGHTS GIVEN IN POUNDS

	1977 IMPALA	1980 OMEGA	1978 OMNI
STARTER WITH SOLENOID	18.5	15.0	12.2
STARTER CONNECTING WIRE	1.0		
FAN BLADE	3.0		0.9
FAN PULLY	1.5	1.8	3.1
WATER PUMP	14.0	3.8	3.3
FUEL PUMP	1.0	1.1	0.7
OIL PUMP			2.4
EXHAUST MANIFOLD	31.0	12.0	8.2
EXHAUST MANIFOLD HEAD SHIELD	2.0		
INTAKE MANIFOLD	41.0	11.3	3.2
VALVE COVER	5.5	3.8	1.9
OIL PAN	6.5	5.1	5.9
BATTERY AND ALTERNATOR	44.0	47.4	39.6
BATTERY	32.0	32.3	26.7
ALTERNATOR	10.0	13.5	12.9
ALTERNATOR MOUNTING BRACKET	2.0	1.6	
EXHAUST SYSTEM	65.5	49.6	26.4
HEAD PIPE	7.0	2.8	
CATALYTIC CONVERTER	25.5	11.5	9.3
MUFFLER AND PIPE	25.0	11.8	14.3
TAIL PIPE	8.0	8.2	
FUEL SYSTEM	30.5	37.2	18.2
FUEL TANK	28.5	21.8	14.0
FILLER NECK		2.3	1.7
FILLER DOOR		1.1	
GAS LINE			2.3
CARBON CANISTER		1.9	
SUSPENSION	187.0	187.4	144.7
FRONT SPRINGS	25.0	20.0	16.9
FRONT SHOCKS	4.0	16.0	16.5
TIE RODS	6.0		
LOWER CONTROL ARM	34.0	10.5	8.2
UPPER CONTROL ARM	20.0		
SPINDLE	30.0	20.0	
SWAY BAR	16.0	9.8	10.1
REAR SPRINGS	15.0	11.0	8.7
LOWER ARM	11.0		16.9
UPPER ARM	6.0		
REAR SHOCKS	7.0	6.5	5.1

TABLE 5-4. WEIGHT BREAKDOWNS FOR IMPALA, OMEGA AND OMNI (CONTINUED)

ALL WEIGHTS GIVEN IN POUNDS

	1977 IMPALA	1980 OMEGA	1978 OMNI
BRAKE	133.5	92.4	76.0
FRONT BRAKE ROTOR	47.0	20.0	14.2
DUST COVER	1.0		0.8
CALIPER	17.0	14.0	
BRAKE PADS	3.0	3.5	
BRAKE DRUMS	30.0	14.0	21.4
REAR BRAKE BACKING PLATE	19.0	4.2	
MASTER CYLINDER	8.5	4.2	1.3
POWER BOOSTER	8.0	8.3	
PARKING BRAKE AND PADLE		6.0	
BRAKE LINE			
STEERING	51.5	47.2	22.5
STEERING BOX WITH PITMAN ARM	29.5		
DRAGLINK WITH IDLE ARM	8.5		
POWER PUMP	11.0		
MOUNTING BRACKET	2.5		
STEERING COLUMN AND WHEEL			10.5
STEERING RACK			13.3
WHEELS AND TIRES	245.0	195.6	152.3
WHEELS	105.0	82.5	81.3
TIRES	135.0	85.5	69.2
WHEEL COVERS	4.0	17.0	
TRANSMISSION & DRIVE AXLE	295.5	181.4	112.3
TORQUE CONVERTER WITH FLUID	40.5	31.8	
TRANSMISSION PAN	2.5	3.3	
DRIVE SHAFT	18.0		
U JOINTS	2.0	20.4	
AXLE SHAFT	28.0	6.4	
REAR AXLE HOUSING	64.0		
REAR AXLE GEARING	42.0		
DIFFERENTIAL COVER	2.0		
BUMPERS	144.5	51.6	50.0
FRONT BUMPER FACE	36.5	11.8	8.6
FRONT BUMPER SUPPORT STRUCTURE	23.0		
FRONT BUMPER ENERGY ABSORBER	14.0	9.0	8.4
REAR BUMPER FACE	33.0	13.5	8.3
REAR BUMPER SUPPORT STRUCTURE	23.9		
REAR BUMPER ENERGY ABSORBER	14.0	9.0	8.0

performance capabilities are considerably below the minimum established standards for domestic models.

Load and volume efficiencies are used, wherever possible, as criteria for the selection of baseline vehicles for light trucks. These efficiencies are defined as follows:

$$\text{Load efficiency} = \frac{\text{load capacity}}{\text{curb weight}}$$

$$\text{Volume efficiency} = \frac{\text{volume capacity}}{\text{curb weight}}$$

5.2.1 Compact Pickup Truck

A new Rabbit-based compact pickup truck was introduced by Volkswagen in 1980. The VW pickup is the smallest of its class and is radically different in design from all other light trucks. It is of unit-body construction which results in a solid connection between the cab and the cargo box. It has the front-wheel-drive transverse engine configuration with beam axle and leaf spring rear suspension. Because of the front-wheel-drive design, the VW pickup adopts a very high front/rear weight distribution (63/37%). With a curb weight of 2046 pounds, the VW pickup truck is the lightest among the compact pickup trucks. However, for a design payload of 1103 pounds, it has a load efficiency of 0.54, a rather low value among the compact pickup trucks.

The captive models carried by Chrysler, Ford, and General Motors are of conventional body-on-frame, rear-wheel-drive configuration. They have considerably higher load capacity than the VW pickup. Table 5-5 shows the comparison of major vehicle parameters for compact pickup trucks of comparable wheelbase.

A 1978 Chevrolet LUV is used as the baseline vehicle for the compact pickup truck because detailed component teardown data for that vehicle is readily available. This LUV pickup truck is equipped with a 111 CID 4-cylinder engine and a 4-speed manual transmission. Curb weight of this vehicle is 2408 pounds with a gross vehicle weight rating of 3550 pounds. Detailed component weights of this vehicle are given in Reference 42.

TABLE 5-5. COMPARISON OF 1980 COMPACT PICKUP TRUCKS

VEHICLE PARAMETER	VW PICKUP	CHRYSLER D50	FORD COURIER	CHEVROLET LUV
GVWR (lbs.)	3149	4045	4100	3550
Wheelbase (in.)	103.3	109.4	106.9	102.4
Curb Weight (lbs.)	2046	2520	2515	2230
Load Capacity (lbs.)	1103	1525	1585	1320
Box Length (in.)	—	81.5	74.6	73.0
Box Width (in.)	—	64.2	56.5	57.5
Box Height (in.)	—	—	16.1	15.6
Volume Capacity (ft^3)	—	—	39.3	37.9
Load Efficiency (lbs/lb)	0.54	0.61	0.63	0.59
Volume Efficiency (ft^3/lb.)	—	—	0.016	0.017

Source: Truck Data Books

Weight breakdowns of vehicle systems are presented in Table 5-8.

5.2.2 Standard Pickup Truck

Ford's 1980 F-series pickup trucks were introduced as "new design", weighing around 300 pounds less than previous models without loss of payload capacity. The reduction in the weight of the 1980 F-series pickup trucks is basically the result of sheet metal gauge reduction.[43] Table 5-6 shows the comparison of pickup models of comparative wheelbase and GVWR. Among the models shown, the Ford F150 not only has the highest payload capacity, but also has the highest load and volume efficiencies.

A 1980 Ford F150 regular Styleside pickup truck is selected as the baseline vehicle for standard pickup trucks. This vehicle has a curb weight of 3687 pounds and is equipped with a 302 CID V-8 engine and C6 three-speed automatic transmission. Weight breakdowns of major systems of this vehicle are given in Table 5-8. Detailed component weights of this F150 pickup truck are given in Reference 43.

5.2.3 Van

Compared to other types of vehicles, vans offer more interior space in relationship to outside dimensions. The enclosed body provides many advantages for personal use or for cargo delivery.

Among domestic models, Ford vans have separate body and frame while Chrysler and General Motors vans are of unitized construction. A comparison of load and volume efficiencies for three 1980 domestic vans of comparable wheelbase is given in Table 5-7. The Dodge B100 van appears to have excellent load and volume efficiencies.

A 1978 Dodge B100 cargo van is selected as the baseline vehicle for vans. This vehicle, equipped with a 318 CID engine and a three-speed automatic transmission, has an acutal curb

TABLE 5-6. COMPARISON OF 1980 STANDARD PICKUP TRUCKS

VEHICLE PARAMETER	DODGE D150	FORD F150	CHEVROLET C10
GVWR (lbs.)	6050	6100	6000
Wheelbase (in.)	133	133	131.5
Curb Weight (lbs.)	3755	3567	3993
Load Capacity (lbs.)	2295	2533	2007
Box Length (in.)	96.9	98.2	98.1
Box Width (in.)	70.0	70.0	72.0
Box Height (in.)	19.1	19.5	19.3
Volume Capacity (ft^3)	76.6	75.8	74.3
Load Efficiency (lbs/lb)	0.61	0.71	0.50
Volume Efficiency (ft^3/lb)	0.020	0.021	0.019

Source: Truck Data Books

TABLE 5-7. COMPARISON OF 1980 DOMESTIC VANS

VEHICLE PARAMETER	DODGE B100	FORD E100	CHEVROLET C10
GVWR (lbs.)	4700	5200	4900
Wheelbase (in.)	127.6	138.0	125.0
Curb Weight (lbs.)	3465	3938	3869
Load Capacity (lbs.)	1235	1262	1031
Volume Capacity (ft^3)	246.5	247.3	278.8
Load Efficiency (lbs./lb)	0.36	0.32	0.27
Volume Efficiency (ft^3/lb)	0.071	0.063	0.072

Source: 1980 Truck Data Books

TABLE 5-8. WEIGHT BREAKDOWNS FOR LUV, F150, AND B100

	1978 LUV	1980 F150	1978 B100
Curb Weight	2408.0	3687.0	3432.0
Body Total	780.1	1239.8	
Hood	32.7	59.1	17.5
Cab	238.2	262.5	
Cargo Bed	195.0	324.0	
Van Body			972.5
Doors	50.0	71.0	185.0
Tailgate	37.5	48.0	
Seat	47.5	64.9	40.3
Frame	224.8	329.0	
Engine	342.2	549.0	586.0
Transmission	71.9	188.0	88.5
Axle & Driveshaft	151.0	184.0	172.0
Front Suspension	87.9	143.9	140.0
Rear Suspension	75.5	128.6	80.1
Steering	47.8	93.0	73.4
Brakes	120.7	173.7	158.7
Fuel System	24.2	31.1	30.0
Exhaust System	46.9	58.7	45.0
Wheels & Tires	222.5	299.1	215.0
Bumpers	20.0	82.8	62.5
Fluids and Gasoline	102.1	186.3	185.0

weight of 3432 pounds. Weight breakdowns of major systems of this vehicle are given in Table 5-8. More detailed component weights can be found in Reference 15.

5.2.4 Utility Vehicle

Utility vehicles are designed for rugged service. They must be capable of operating in extreme off-road situations. This demands four-wheel-drive and high ground clearance. They must also meet criteria for on-highway operation.

Table 5-9 shows a comparison of three 1980 domestic four-wheel-drive utility vehicles. The Ford U150 Bronco is a new design in 1980, about three inches shorter and 450 pounds lighter than the 1979 model.

Component teardown data for utility vehicles is not available for this report. However, since utility vehicles usually use a high percentage of components from the pickup truck, many component weights can be found if component weight breakdowns of an equivalent pickup model are known. From the weight data of a 1978 Dodge D100 pickup truck,[15] component weights for an AW100 Ramcharger were derived and are given in Table 5-10. This vehicle is used as the baseline vehicle for the utility vehicles.

TABLE 5-9. COMPARISON OF 1980 DOMESTIC UTILITY VEHICLES (FOUR-WHEEL DRIVE)

VEHICLE PARAMETER	DODGE AW100	FORD U150	CHEVROLET K10
GVWR (lbs.)	5850	5450	6200
Wheelbase (in.)	106.0	104.7	106.5
Curb Weight (lbs.)	4275	4265	4460
Load Capacity (lbs.)	1575	1185	1740
Overall length (in.)	184.6	177.6	184.4
Ground Clearance, Front/Rear (in.)	8.1/8.5	7.5/7.8	7.0/7.0

Source: Truck Data Books

TABLE 5-10. COMPONENT WEIGHTS FOR A 1978 DODGE AW100 RAMCHARGER

COMPONENT	WEIGHT (lbs.)
Body Top	175.0
Dash	32.0
Floor	97.0
Hood	55.0
Radiator Support	40.0
Grille Lower Panel	4.0
Cowl Side	22.0
Cowl Vent Panel	4.0
Side Panel	79.5
Fender	52.0
Wheelhouse	24.0
Doors	80.0
Tailgate	44.0
Frame	300.0
Engine Rear Support	20.5
Seat Frame	12.0
Hood Hinge Bracket	10.0
Engine Mounting Bracket	8.5
Front Leaf Spring	75.0
Rear Leaf Spring	80.0
Battery Tray	3.0
Radiator	14.0
Heater Core	5.0
Rear Spring Shackle	3.0
Axle U-Bolt Plate	10.0
Steering Gear Case	15.5
Master Cylinder	10.2
Brake & Clutch Pedals	6.0
Parking Brake Pedal & Bracket	4.0
Front Bumper	29.0
Rear Bumper	23.0
Front Bumper Mounting Bracket	4.0
Rear Bumper Mounting Bracket	5.0
Fuel Tank	24.0
Wheels	107.5

Source: Reference 15

6. MATERIAL SUBSTITUTION FOR BASELINE VEHICLES

Applying equal stiffness as the structural requirement, primary and secondary weight reductions for each selected baseline vehicle are determined. Four cases of materials substitution are considered in this report: the high strength steel dominant case, the aluminum dominant case, the FRP dominant case, and the HRP dominant case.

6.1 SUBSTITUTIONAL MATERIALS CONSIDERED

The substitutional materials considered in this report include high strength steels (HSS), aluminum alloys, fiberglass reinforced plastics (FRP), and hybrid reinforced plastics (HRP).

Many automotive components which are made of low carbon steel can be designed more weight efficiently by using high strength steels at reduced thickness. The average weight reduction with high strength steels varies from 15 to 30 percent depending upon the individual parts.[22,44] The wide range of qualities of high strength steels also permits optimization of selection in terms of formability, weldability, and cost. Typical applications of high strength steels are body panels, brackets, reinforcements, and thin walled beam type components.

Aluminum has a specific weight about one third that of steel. Substitution at a gage to gage level is possible only for cases requiring equal strength. Aluminum alloys such as 6009-T4 and 6010-T4 can have a yield strength which matches that of low carbon steel. However, because of its low modulus of elasticity, a thickness increase is generally required for aluminum to provide the equivalent stiffness of a steel component. Weight savings by aluminum substitution are generally in the 50 percent level. Major areas of aluminum application are body panels, castings, bumpers, wheels, heat exchangers, and a variety of interior components such as brackets, cover plates, and seat frames.

Most automotive FRP uses E glass for reinforcement. The content of the glass ranges from 10 to 80 percent depending on the application. The FRP considered in this report are standard and hybrid forms of SMC and XMC. Weight reduction with FRP depends on the mechanical properties of the material and the specific part. For example, on the 1981 Chevrolet Corvette, the FRP single leaf spring weighing eight pounds has replaced a 41 pound 10-leaf spring in the rear suspension system.

The HRP considered in this report has two graphite epoxy face sheets and a fiberglass epoxy core. Two types of fiber lay-up are selected here: the quasi-isotropic graphite fiber/random chopped E glass fiber to be used for panel members and solid section members; and the unidirectional graphite fiber/random chopped E glass fiber to be used for thin walled beam members.

Densities and modulus of elasticity of the selected substitutional materials as well as those of low carbon steel are given in Table 6-1.

6.2 PRIMARY WEIGHT REDUCTION

By applying the formula for equal stiffness (Equation 3.3.1) and using the material properties listed in Table 6-1, weight savings that can be achieved with the substitutional materials can be computed. Table 6-2 lists the weight savings for components of various geometrical shapes. Weight savings by HSS substitution is the result of gauge reduction.

Four cases of material substitution for weight reduction are considered: the HSS dominant case, the FRP dominant case, the aluminum dominant case, and the HRP dominant case. These cases represent different levels of material substitution technology. The materials used for various components in each case are listed in Table 6-3. In all four cases, the vehicles are assumed to have aluminum cylinder heads, stainless steel exhaust manifolds, HRP springs, aluminum bumpers, and a high density polyethylene (HDPE) fuel tank. Aluminum and FRP are not used in thin-walled beam members.

TABLE 6-1. PROPERTIES OF SUBSTITUTING MATERIALS

MATERIAL	DENSITY (g/cm^3)	MODULUS (GPa)
Low Carbon Steel	7.83	207
HSS	7.83	207
Aluminum	2.70	72
FRP	1.80	18
HRP		
Quasi-isotropic HM graphite fiber/random chopped E glass fiber	1.76	43
Unidirectional HM graphite fiber/random chopped E glass fiber	1.76	116

Source: Reference 25

TABLE 6-2. WEIGHT SAVINGS FOR COMPONENTS OF VARIOUS GEOMETRICAL SHAPES

GEOMETRICAL SHAPE	PERCENT OF WEIGHT SAVINGS			
	HSS	ALUMINUM	FRP	HRP
Panel	17	42	22	50
Thin-Walled Beam	20	0	0	60
Solid Section	20	50	48	60

TABLE 6-3. SUBSTITUTIONAL MATERIAL FOR AUTOMOTIVE COMPONENTS

VEHICLE COMPONENT	CASES CONSIDERED			
	HSS DOMINANT	FRP DOMINANT	AL DOMINANT	HRP DOMINANT
Panel member	HSS	FRP	AL	HRP
Solid section member	HSS	HSS	AL	HRP
Thin-walled beam	HSS	HSS	HSS	HRP
Cylinder head	AL	AL	AL	AL
Engine block	CI*	CI	AL	AL
Intake manifold	AL	AL	AL	AL
Exhaust manifold	SS**	SS	SS	SS
Radiator core	AL	AL	AL	AL
Fuel tank	HDPE	HDPE	HDPE	HDPE
Spring	HRP	HRP	HRP	HRP
Driveshaft	HRP	HRP	HRP	HRP
Brake disc and drum	AL	AL	AL	AL
Bumper	AL	AL	AL	AL
Wheel	AL	HRP	AL	HRP

*Cast Iron
**Stainless Steel

From each baseline vehicle, components which are considered to have potential for weight savings by material substitution were selected and the weight for replacement components was determined by applying the percent weight savings listed in Table 6-2. Results of the computation for all four cases of material substitution of three baseline passenger cars and four baseline light trucks are given in Appendix A. From these results, total weight savings for each case was calculated and a new curb weight for each baseline vehicle was determined. The resulting percent distribution of material, as well as curb weight, for baseline passenger cars and pickup trucks are summarized in Tables 6-4 through 6-8. Table 6-9 summarizes the resultant curb weights for the baseline van and utility vehicle. Since the original materials summaries for the baseline van and utility vehicle are not available, distribution of materials for these vehicles can not be determined at this time.

Under contract with the Department of Transportation, ALCOA (Aluminum Company of America), Hercules, Incorporated, and Armco Inc. performed independent studies to evaluate the potential of weight savings for the five-passenger baseline vehicles by the substitution of aluminum, reinforced composite materials, and high strength steels respectively.[45,46,64] ALCOA estimated that the substitution of aluminum, primarily 6XXX and 5XXX series aluminum alloys, could save 776 pounds from the baseline vehicle (Table 6-10). Candidate components and materials of ALCOA's study are given in Table 6-11. Hercules estimated a weight reduction of 495 pounds for the same baseline vehicle by the substitution of thermoplastic stampable sheet and hybrid glass/graphite SMC. Weight savings by the substitution of composite materials are summarized in Table 6-12. Weights and materials of the components considered in the Hercules' study are given in Table 6-13. Armco estimated that through the optimization of plain carbon steel and the substitution of high strength steels, 74 pounds could be removed from the baseline vehicle using current steel technology. An additional 100 pound weight savings was judged to be possible in a time span to 1990. Table 6-14 shows the components suggested for weight savings by ARMCO.

TABLE 6-4. PERCENT DISTRIBUTION OF MATERIAL FOR BASELINE FOUR-PASSENGER CAR

MATERIAL	CASE				
	ORIGINAL	HSS	FRP	ALUMINUM	HRP
Steel	54.0	18.7	18.9	20.1	22.8
HSS	8.1	37.3	20.6	21.8	0.6
Cast Iron	9.6	8.3	8.4	4.7	5.4
Aluminum	2.8	6.3	4.1	21.8	6.4
Copper	1.0	1.2	1.2	1.2	1.4
Lead	1.2	1.4	1.4	1.5	1.7
Zinc	0.6	0.7	0.7	0.7	0.8
Glass	3.5	3.8	3.9	4.2	4.8
Rubber	5.5	6.1	6.2	6.6	7.6
NRP*	4.0	4.4	4.5	4.8	5.5
FRP	0	0.5	16.8	0.5	0.6
HRP	0	0.6	2.4	0.6	29.1
Other	9.7	10.7	10.9	11.5	13.3
Curb Weight Less Fuel (lbs.)	2020	1821	1794	1691	1467

*Non-reinforced plastics

TABLE 6-5. PERCENT DISTRIBUTION OF MATERIAL FOR BASELINE FIVE-PASSENGER CAR

MATERIAL	CASE				
	ORIGINAL	HSS	FRP	ALUMINUM	HRP
Steel	53.7	12.0	12.2	13.5	14.8
HSS	2.1	39.4	13.7	9.1	0
Cast Iron	9.3	4.8	4.9	1.2	1.3
Aluminum	5.1	9.4	8.1	37.2	12.1
Copper	1.2	0.7	0.7	0.8	0.8
Lead	1.2	1.3	1.4	1.5	1.7
Zinc	0.1	0.1	0.1	0.1	0.1
Glass	2.6	2.9	3.0	3.3	3.6
Rubber	4.5	5.1	5.2	5.8	6.3
NRP	7.9	9.0	9.2	10.2	11.1
FRP	0	0.6	25.4	0.7	0.8
HRP	0	0.7	1.9	0.8	30.2
Other	12.3	14.0	14.2	15.8	17.2
Curb Weight Less Fuel (lbs.)	2618	2310	2264	2039	1870

TABLE 6-6. PERCENT DISTRIBUTION OF MATERIAL FOR BASELINE SIX-PASSENGER CAR

MATERIAL	CASE				
	ORIGINAL	HSS	FRP	ALUMINUM	HRP
Steel	64.5	22.2	22.5	24.1	27.1
HSS	0	36.5	19.0	20.4	0
Cast Iron	16.9	11.9	12.1	7.3	8.3
Aluminum	2.9	8.3	6.6	25.4	11.4
Copper/Brass	0.8	0.4	0.4	0.4	0.5
Lead	0.5	0.6	0.6	0.6	0.7
Zinc	0.4	0.4	0.5	0.5	0.6
Glass	2.5	3.0	3.0	3.2	3.7
Rubber	2.6	3.1	3.2	3.4	3.9
NRP	4.8	5.7	5.8	6.2	7.1
FRP	0	0.6	17.5	0.6	0.7
HRP	0	0.8	2.2	0.8	27.9
Other	4.1	6.5	6.6	7.1	8.1
Curb Weight Less Fuel (lbs.)	3586	3010	2967	2769	2417

TABLE 6-7. PERCENT DISTRIBUTION OF MATERIAL FOR BASELINE COMPACT PICKUP TRUCK

MATERIAL	CASE				
	ORIGINAL	HSS	FRP	ALUMINUM	HRP
Steel	74.7	28.6	29.0	31.7	35.6
HSS	0	39.6	15.6	16.0	0
Cast Iron	8.5	5.9	6.0	2.6	2.9
Aluminum	1.8	6.8	6.9	28.5	7.6
Copper	0.5	0.1	0.1	0.1	0.1
Glass	2.0	2.4	2.4	2.6	2.9
Rubber	5.8	6.8	6.9	7.5	8.4
NRP	1.9	2.2	2.3	2.5	2.8
FRP	0	0.5	23.6	0.6	0.7
HRP	0	1.5	1.5	1.6	32.0
Other	4.8	5.6	5.7	6.3	7.0
Curb Weight Less Fuel (lbs.)	2330	2003	1973	1806	1610

TABLE 6-8. PERCENT DISTRIBUTION OF MATERIAL FOR BASELINE STANDARD PICKUP TRUCK

MATERIAL	CASE				
	ORIGINAL	HSS	FRP	ALUMINUM	HRP
Steel	64.2	22.8	23.2	24.6	28.5
HSS	3.4	38.6	21.7	22.4	0
Cast Iron	11.6	4.1	4.1	0.1	0.2
Aluminum	1.7	9.8	7.7	26.2	9.5
Copper	0.5	0.1	0.1	0.1	0.1
Zinc	0.2	0.1	0.2	0.2	0.2
Glass	1.5	1.8	1.9	2.0	2.3
Rubber	5.6	6.7	6.8	7.2	8.3
NRP	2.6	3.1	3.1	3.3	3.9
FRP	0	0.5	16.9	0.6	0.6
HRP	0	2.0	3.8	2.2	33.4
Other	8.7	10.4	10.5	11.1	13.0
Curb Weight Less Fuel (lbs.)	3573	2991	2947	2780	2393

TABLE 6-9. CURB WEIGHT FOR BASELINE VAN AND UTILITY VEHICLE (LBS)

TYPE OF VEHICLE	CASE				
	ORIGINAL	HSS	FRP	ALUMINUM	HRP
Van	3432	2907	2860	2654	2319
Utility Vehicle	4277	3709	3668	3394	3216

TABLE 6-10. ALCOA'S ESTIMATION OF WEIGHT SAVING BY ALUMINUM SUBSTITUTION FOR THE BASELINE FIVE-PASSENGER CAR

VEHICLE SYSTEM	WEIGHT OF PARTS CONSIDERED (LBS)		
	STEEL & IRON	ALUMINUM	WEIGHT SAVED
Body	846.0	337.0	469.0
Frame	35.0	17.5	17.5
Front Suspension	45.3	26.3	19.0
Rear Suspension	51.2	27.4	23.8
Brakes	46.2	26.0	20.2
Engine	218.0	108.0	110.0
Transaxle	41.1	17.8	23.5
Fuel/Exhaust	29.9	12.5	17.4
Steering	11.9	5.5	6.4
Wheels/Tires	107.0	52.9	54.1
Cooling System	15.5	9.3	6.2
Bumpers	18.0	9.0	9.0
TOTALS	1,465	689	776

TABLE 6-11. WEIGHT REDUCTION BY ALUMINUM SUBSTITUTION FOR BASELINE FIVE-PASSENGER CAR

	Qty. per car	Total Weight per car (lbs.)	Material to be Replaced	FAB	Thickness (in.)	Aluminum Alloy	Thickness (in.)	FAB	Total Weight per car (lbs.)	Weight Saving (lbs.)	% Weight Saving	Comments
1. Body												
A. Hood											69	
Outer Panel	1	21.75	steel	stamp	0.034	6010	0.028	stamp	6.16	15.59		
Inner Panel	1	16.75	steel	stamp	0.031	6009	0.031	stamp	5.76	10.99		Redesign Required
Hinges	2	1.38	steel	stamp	0.156	6XXX	0.156	stamp	0.47	0.91		
Latch	1	2.00	steel	stamp	0.109	6XXX	0.109	stamp	0.69	1.31		
B. Rear Deck Lid											69	
Outer Panel	1	18.25	steel	stamp	0.037	6009	0.028	stamp	4.75	13.50		
Inner Panel	1	13.75	steel	stamp	0.031	6010	0.031	stamp	4.73	9.02		Redesign Required
Latch & Lock	1	1.38	steel	stamp		6XXX		stamp	0.69	0.69		
C. Front Fender											65	
Fender Panel	2	20.00	steel	stamp	0.034	6010	0.034	stamp	6.88	13.12		
Trim	2	1.12	s.steel	stamp		5252			0.56	0.56		
D. Body Valence & Dam											66	
Support Panel	1	0.59	steel	stamp	0.036	6XXX	0.036	stamp	0.20	0.39		
E. Front Door											61	
Inner Panel	2	38.00	steel	stamp	0.042	6009	0.042	stamp	13.07	24.93		
Outer Panel	2	21.50	steel	stamp	0.035	6010	0.035	stamp	7.40	14.10		
Lock & Latch	2	5.12	steel	stamp		6XXX		stamp	2.47	2.65		
Hinges	2	2.75	steel	stamp	0.194	6XXX	0.270	stamp	1.32	1.43		
Safety Beam	2	12.50	steel	stamp	0.092	6010	0.125	stamp	5.84	6.66		
Lower Molding	2	1.12	s.steel	stamp	0.029	5252		stamp	0.54	0.58		
F. Rear Door											61	
Inner Panel	2	23.30	steel	stamp	0.031	6009	0.031	stamp	8.02	15.28		
Outer Panel	2	16.50	steel	stamp	0.036	6010	0.036	stamp	5.68	10.82		
Lock & Latch	2	4.30	steel	stamp		6XXX		stamp	2.07	2.27		
Hinges	2	2.19	steel	stamp	0.179	6XXX	0.250	stamp	1.05	1.14		
Safety Beam	2	9.00	steel	stamp	0.061/0.043	6010		stamp	4.50	4.50		
Lower Molding	2	0.88	s.steel	stamp	0.029	5252		stamp	0.43	0.45		
G. Pillar Hinges											52	
Front	2	3.25	steel	stamp	0.213	6XXX	0.300	stamp	1.57	1.68		
Rear	2	2.62	steel	stamp	0.179	6XXX	0.250	stamp	1.26	1.36		

TABLE 6-11. WEIGHT REDUCTION BY ALUMINUM SUBSTITUTION FOR BASELINE FIVE-PASSENGER CAR (CONTINUED)

	Qty. per car	Total Weight per car (lbs.)	Material to be Replaced	FAB	Thickness (in.)	Aluminum Alloy	Thickness (in.)	FAB	Total Weight per car (lbs.)	Weight Saving (lbs)	% Weight Savings	Comments
1. Body (cont.)												
H. Exterior Trim											62	
Air-Intake Grille	1	4.31	steel	stamp	0.036	6010	0.036	stamp	1.48	2.83		
Wind. Wip. Links	1	2.09	steel	stamp		6X.X		stamp	1.01	1.08		
Pr. End Panel Supp.	1	0.72	steel	stamp	0.060	6XXX	0.084	stamp	0.35	0.37		
Roller Panel Mldg.	2	4.00	s.steel	stamp	0.025	5252	0.025	stamp	1.38	2.62		
Panel, Rear Comp Top	1	1.00	steel	stamp	0.028	6XXX	0.050	stamp	0.49	0.51		
Rear Wheel Mold	2	1.25	s.steel	stamp	0.030	5252	0.028	stamp	0.43	0.82		
I. Front Seat											50	Design modification probable. Casting may be feasible.
Frame	1	29.50	steel	stamp	0.030	6009		stamp	14.75	14.75		
J. Rear Seat											52	
Base	1	(5.00)[a]	steel	stamp		6XXX		stamp	2.38	2.62		
Back	1	(4.00)[a]	steel	stamp		6XXX		stamp	1.90	2.10		
K. Body Panels											52	
Radiator Brace	2	2.31	steel	stamp/weld	0.080	6XXX	0.080	stamp/weld	0.79	1.52		
Quarter Panel Outer	2	26.94	steel	stamp/weld	0.032	6010	0.044	stamp/weld	12.74	14.20		
Rear Wheel Well	2	21.50	steel	stamp/weld	0.032	6009	0.044	stamp/weld	10.17	11.33		
Tail Light Panel	1	6.00	steel	stamp/weld	0.035	6XXX	0.049	stamp/weld	2.89	3.11		
Roof Outer Panel	1	33.31	steel	stamp/weld	0.035	6010	0.049	stamp/weld	16.04	17.27		
Roof Inner Ribs	Lot	16.75	steel	stamp/weld	0.032/0.035	6010	0.045/0.035	stamp/weld	8.00	8.75		Cross-rib redesign probable
Firewall	1	7.94	steel	stamp/weld	0.035	6009	0.049	stamp/weld	3.82	4.12		
Sill	2	32.19	steel/HSLA	stamp/weld	0.040	6010	0.044	stamp/weld	12.30	19.89		
Floor Panel	1	56.44	steel	stamp/weld	0.032	6009	0.045	stamp/weld	27.30	29.14		
"A" Post, Pillar	2	23.06	steel/HSLA	stamp/weld	0.040/0.048	6009	0.053/0.069	stamp/weld	11.33	11.73		
"B" Post, Pillar	2	19.12	steel	stamp/weld	0.032/0.048	6009	0.037/0.058	stamp/weld	6.58	12.54		
Rear Shelf	1	12.06	steel	stamp	0.035	6009	0.049	stamp	6.35	5.71		
Center Support (fr.)	1	1.62	steel	stamp	0.050	6010	0.070	stamp	0.78	0.84		
Remaining Body Panels		294.87	steel	stamp	various	6XXX		stamp	147.44	147.43		50% weight savings probable
2. Frame											50	
A. Cradle	1	35.00	steel	stamp/weld	0.080/0.095	5454		stamp/weld	17.50	17.50		
3. Front Suspension											43	
Lower Control Arm	2	10.50	steel	stamp	0.110	5454	0.165	stamp	5.42	5.58		
Steering Stop Bracket	2	1.44	steel	stamp	0.125	6XXX	0.125	stamp	0.50	0.94		
Knuckle (Upright)	2	20.00	iron	cast		6061		forge	12.00	8.00		Permanent mold casting also feasible
Spring Seat	2	2.62	steel	stamp	0.077	6XXX	0.108	stamp	1.26	1.36		
Stabilizer Bar	1	9.75	steel	drawn	0.8700	6061	1.220	rod	6.60	3.15		
Brake Rotor Shield	2	1.00	steel	stamp	0.037	5454	0.052	stamp	0.48	0.52		

TABLE 6-11. WEIGHT REDUCTION BY ALUMINUM SUBSTITUTION FOR BASELINE FIVE-PASSENGER CAR (CONTINUED)

	Qty. per car	Total Weight per car (lbs.)	Material to be Replaced	FAB	Thickness (in.)	Aluminum Alloy	Thickness (in.)	FAB	Total Weight per car (lbs.)	Weight Saving (lbs)	% Weight Savings	Comments
4. Rear Suspension											46	
Axle Beam	1	27.12	steel	stamp	0.175	5454		stamp	13.56	13.56		
Control Arm	2	6.06	steel	stamp	0.165	5454	0.330	stamp	4.17	1.89		
Spring Perch	2	4.25	steel	stamp	0.125	5454	0.175	stamp	2.05	2.20		
Anti-Roll Bar	1	8.22	steel	drawn	0.812Ø	6061	1.07Ø	rod	4.93	3.29		
Track Bar	1	3.81	steel	stamp	0.093	6XXX	0.130	stamp	1.90	1.91		
Trailing Arm Brkt.	2	1.75	steel	stamp	0.092	6XXX	0.125	stamp	0.82	0.93		
5. Brakes											44	
Calipers	2	14.00	iron	cast		6061		forge	7.60	6.40		
Drums	2	14.00	iron	cast		355		cast	9.60	4.40		Iron insert required
Backing Plate	2	4.19	steel	stamp	0.100	6009	0.140	stamp	2.02	2.17		
Park Brake Pedal & Lock	1	2.50	steel	stamp	0.090	6009	0.126	stamp	1.20	1.30		
Brake Power Assist	1	8.25	steel	stamp	0.055	5182	0.077	stamp	3.97	4.28		
Pedal Assembly	1	1.90	steel	stamp	0.375	6XXX		stamp	0.95	0.95		
Pedal Mount-Brkt	1	1.38	steel	stamp	0.093	6XXX	0.093	stamp	0.69	0.69		
6. Engine											50	
Cylinder Head	2	49.00	iron	cast		355		cast	23.00	26.00		Ferrous guides and seats
Air Cleaner Assy	1	6.00	steel	stamp		5182		stamp	2.03	3.97		
Valve Cover	2	3.75	steel	stamp	0.045	5182		stamp	1.27	2.48		
Oil Pan	1	5.06	steel	stamp	0.045	5182	0.063	stamp	2.40	2.66		Special forming reqd
Engine Block	1	(125.00)[a]	iron	cast		355		cast	65.00	60.00		Iron sleeves and bearing caps.
P. Steering Pump	1	(8.00)[a]	steel	stamp		5182		stamp	4.00	4.00		
P. Steering Brkt	2	3.38	steel	stamp	0.200	5454	0.280	stamp	1.60	1.78		
Air Cond. Brkt	3	5.06	steel	stamp	0.193	5454	0.270	stamp	2.40	2.66		Forging possible
Fuel Pump Ht. Sh.	2	0.59	steel	stamp	0.027/0.090	5182	0.027/0.090	stamp	0.20	0.39		
Engine, Transmission Mounting Brkt	Lot	6.50	steel	stamp	various	5454		stamp	3.25	3.25		
Engine Vibration Mt.	3	(4.60)[a]	steel	stamp	various	5454		stamp	2.30	2.30		
Throttle Bracket	1	0.88	steel	stamp	0.078	5XXX		stamp	0.44	0.44		
7. Transaxle											57	
Valve Body	1	13.00	iron	cast		380		die cast	4.33	8.67		Spool valves of 6262
Valve Body Cover	1	2.44	steel	stamp	0.050	5182	0.050	stamp	0.83	1.61		
Fluid Pan	1	(2.64)[a]	steel	stamp/mold	0.047	5182	0.047	stamp	0.90	1.74		
Torque Converter	1	23.00	steel	stamp/mold	various	6009		stamp	11.50	11.50		Efficient fab procedure needed.

TABLE 6-11. WEIGHT REDUCTION BY ALUMINUM SUBSTITUTION FOR BASELINE FIVE-PASSENGER CAR (CONTINUED)

	Qty. per car	Total Weight per car (lbs.)	Material to be Replaced	FAB	Thickness (in.)	Aluminum Alloy	Thickness (in.)	FAB	Total Weight per car (lbs.)	Weight Saving (lbs.)	% Weight Savings	Comments
8. Fuel and Exhaust System											58	
Gas Tank	1	21.75	steel	stamp	0.036	5182	0.040	stamp	8.20	13.55		Form flanged and use adhesive bonds
Filler Neck, Vent	1	2.28	steel	drawn	1.250	3102		drawn	1.55	0.73		
Tank Straps	2	2.12	steel	stamp	0.090	6XXX	0.090	stamp	0.73	1.39		
Shields	3	3.75	steel	stamp	0.020	5454	0.040	stamp	2.00	1.75		
9. Steering											54	
Steering Wheel	1	(4.10)[a]	steel	stamp		6XXX		rod/sheet	2.05	2.05		Design modification probable
Pad	1	(0.53)[a]	steel	stamp/mold		6XXX		stamp/mold	0.18	0.35		
Jacket Assembly	1	2.56	steel	drawn		5182		stamp	0.88	1.68		
Shift Tube	1	1.20	steel	drawn		6XXX		rod	0.60	0.60		
Brackets	6	3.50	steel	stamp	various	5454		stamp	1.75	1.75		
10. Wheels/Tires											51	
Wheels	4	69.00	steel	stamp	0.100	5454		sheet	41.00	28.00		Forged wheels est. at 34 lbs.
Wheel Covers	4	17.00	steel	stamp	0.034	---	No Cover - Finished Wheel Surfaces -					
Spare Wheel	1	(14.00)[a]	steel	stamp		5454		stamp	8.40	5.60		
Bumper Jack Assy	1	7.00	steel	stamp	0.095/0.115	6XXX		stamp	3.50	3.50		
11. Cooling											40	
Radiator	1	15.50	brass	stamp/solder					9.30	6.20		Requires several different alloys
12. Bumpers											50	
E-A Units	4	18.00	steel	stamp/drawn		6009		stamp/drawn	9.00	9.00		

a Weight in ( ) is estimated steel or iron weight to be replaced

Source: Reference 45

TABLE 6-12. HERCULES' ESTIMATE OF WEIGHT SAVINGS BY COMPOSITE MATERIALS SUBSTITUTION FOR THE BASELINE FIVE-PASSENGER CAR

Vehicle System	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
WHEEL & WHEELCOVERS	99	39	60	61
TOTAL	2269	1774	495	22

Source: Reference 46

TABLE 6-13. WEIGHT REDUCTION BY COMPOSITE MATERIALS SUBSTITUTION FOR BASELINE FIVE-PASSENGER CAR

	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 6-13. WEIGHT REDUCTION BY COMPOSITE MATERIALS SUBSTITUTION FOR BASELINE FIVE-PASSENGER CAR (CONTINUED)

	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 6-13. WEIGHT REDUCTION BY COMPOSITE MATERIALS SUBSTITUTION FOR BASELINE FIVE-PASSENGER CAR (CONTINUED)

	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 6-13. WEIGHT REDUCTION BY COMPOSITE MATERIALS SUBSTITUTION FOR BASELINE FIVE-PASSENGER CAR (CONTINUED)

	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 6-13. WEIGHT REDUCTION BY COMPOSITE MATERIALS SUBSTITUTION FOR BASELINE FIVE-PASSENGER CAR (CONTINUED)

	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 6-13. WEIGHT REDUCTION BY COMPOSITE MATERIALS SUBSTITUTION FOR BASELINE FIVE-PASSENGER CAR (CONTINUED)

	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 6-13. WEIGHT REDUCTION BY COMPOSITE MATERIALS SUBSTITUTION FOR BASELINE FIVE-PASSENGER CAR (CONTINUED)

	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

Source: Reference 46

TABLE 6-14. COMPONENTS SUGGESTED FOR WEIGHT SAVINGS THROUGH STEEL OPTIMIZATION AND SUBSTITUTION

Part	Item	Present Weight lbs.	Present Thickness (in) Gage	Proposed Thickness (in) Gage	Proposed Weight lbs.	Weight Savings lbs.	Change
Hood	Inner Panel	16.7	.031	.026	14.7	2.0	HS
Rear Deck	Outer Panel	18.2	.037	.032	15.8	2.4	HS
" "	Inner Panel	13.7	.031	.029	11.9	1.8	HS
Valance	Support Panel	0.6	.036	.028	0.4	0.2	
Front Door	Outer Panel	21.5	.035	.030	18.4	3.1	HS
	Hinges	2.7	.194	.150	2.1	0.6	
Rear Door	Safety Beam	9.0	.061	.040	7.7	1.3	HS
Door Hinges	Front Pillar	3.2	.213	.200	2.8	0.4	HS
	Rear Pillar	2.6	.179	.160	2.3	0.3	HS
Grille	Air Intake	4.3	.036	.032	3.8	0.5	
Front Seat	Frame	29.5	.030	.024	23.6	5.9	HS
	Tracks	7.8	.085	.060	6.5	1.3	HS
Body Panels	Trail Light	6.0	.035	.032	5.4	0.6	
	Roof Outer	33.3	.035	.032	30.5	2.8	
	Rear Shelf	12.1	.035	.032	11.0	1.1	
Front Suspension	Lower Arm	10.5	.110	.094	8.5	2.0	HS
	Steering Stop	1.4	.125	Holes	1.0	0.4	
	Knuckle	20.0	Cast Iron	Steel	16.0	4.0	
	Hub Assembly	9.1		Holes	8.8	0.3	
Rear Suspension	Control Arm	6.1	.165	.140	5.2	0.9	HS
	Spring Perch	4.2	.125	.100	3.3	0.9	HS
	Track Bar	3.8	.093	.083	3.3	0.5	HS
	Hub Assembly	10.5	3/8	Holes	10.0	0.5	
Wheels	Rim & Spider	69.0	.120	.105	61.0	8.0	HS
			.150	.135			HS

TABLE 6-14. COMPONENTS SUGGESTED FOR WEIGHT SAVINGS THROUGH STEEL OPTIMIZATION AND SUBSTITUTION (CONTINUED)

Part	Item	Present Weight lbs.	Present Thickness (in) Gage	Proposed Thickness (in) Gage	Proposed Weight lbs.	Weight Savings lbs.	Change
Brakes	Calipers	14.0	Iron......>	Steel	13.0	1.0	
	Rotors	20.0	Iron......>	Steel	16.0	4.0	
	Drum	14.0	Iron......>	Steel	10.0	4.0	
	Backing Plate	4.2	.100	.080	3.6	0.6	HS
	Shoes	3.1		Holes	2.4	0.7	
	Parking Pedal	2.5	.090	.081	2.0	0.5	HS
	Master Cylr.	4.2	Al ......>	Steel	3.5	0.7	
	Power Asst.	8.2	.055	.045	7.0	1.2	HS
Engine	Air Cleaner	6.0	.028	.024	5.3	0.7	S/P/S
	Valve Cover	3.7	.045	.036	3.3	0.4	DDQ
	Oil Pan	5.1	.045	.040	4.6	0.5	HS
	Air Cond. Brkt.	5.0	.193	Holes	4.3	0.7	
	Throttle Arm	0.5	.375	Tube	0.3	0.2	
Trans Axle	Valve Cover	2.4	0.50	.045	2.2	0.2	DDQ
Fuel	Tank	21.8	.036	.030	18.0	3.8	HS
	Filler Neck	2.3			2.0	0.3	
	Tank Door	1.1	.035	.032	0.9	0.2	
	Straps	2.1	.090	.050	1.2	0.9	HS
Exhaust	Muffler	11.8			9.8	2.0	HS
	Tail Pipe	8.2			6.8	1.4	HS
	Hangers	3.6			2.8	0.8	HS
	Pulsair Valve	3.4			2.9	0.5	S/P/S
Steering	Wheel	5.1		Tube	4.2	0.9	
	Rack & Pinion	18.0		Tube	15.0	3.0	
	Shaft PRI	2.7	.125	.110	2.0	0.7	
	Jacket Assy.	2.6	.072	.050	1.8	0.8	HS
	Shift Tube	1.2	.060	.040	0.8	0.4	HS
	Shaft Assy.	3.7	Steel	Tube	2.9	0.8	HS
		496.3			422.6	73.7	

Source: Reference 64

TABLE 6-15. COMPARISON OF CURB WEIGHT (LBS) ESTIMATION FOR THE BASELINE FIVE-PASSENGER CAR (1980 OMEGA)

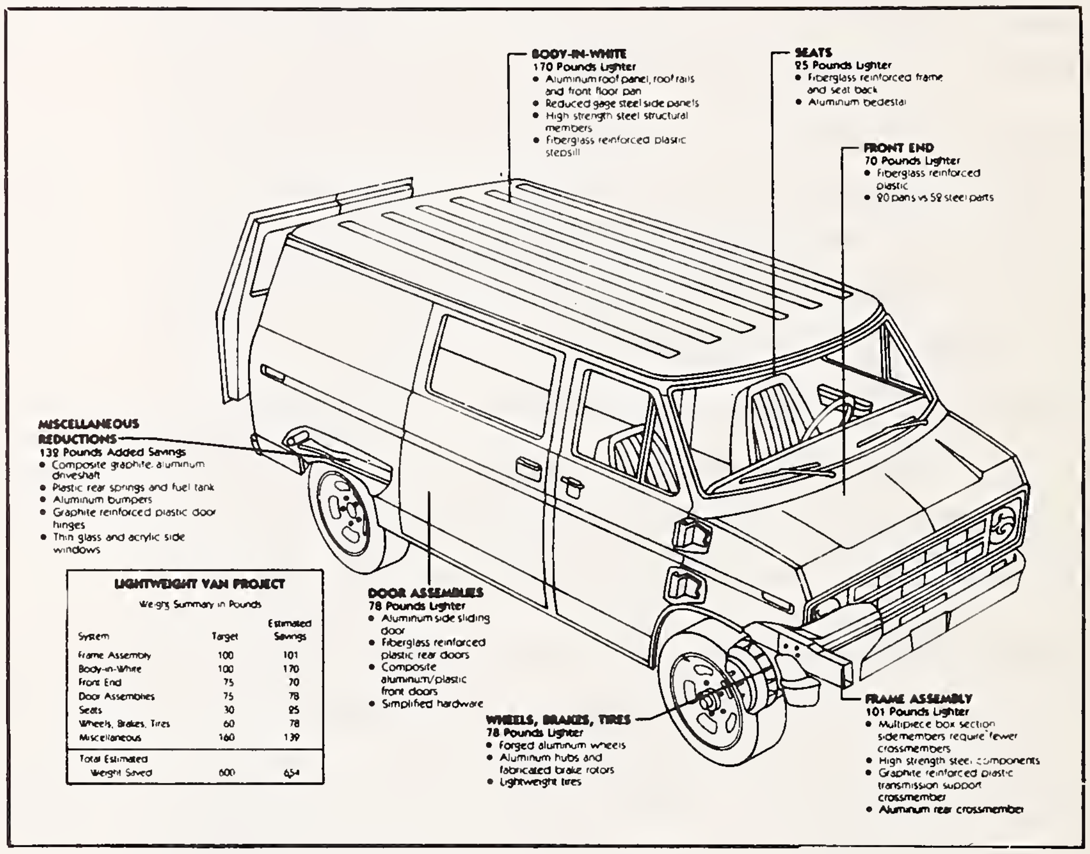
	TSC's ESTIMATE				CONTRACTOR's ESTIMATE		
PRODUCTION	HSS	FRP	ALUMINUM	HRP	ALUMINUM	COMPOSITE	STEEL
2702	2394	2348	2123	1954	1926	2207	2528

Table 6-15 provides a comparison of the curb weight estimations for the baseline five-passenger car. ALCOA's estimate is about 200 pounds lower than that of TSC for the aluminum case even though both are based on a one for one replacement. The differences are believes due to: 1) ALCOA used aluminum in thin-walled beam structural members; 2) in some cases, ALCOA applied equal strength as the criteria for substitution; and 3) ALCOA assumed that optimum designs, processes, and alloy properties could be achieved. The composite materials used in the Hercules study included FRP and HRP. Therefore, the Hercules estimate falls between the TSC's estimate for FRP and HRP cases. The Armco's estimate of 174 pounds weight reduction, primarily through the substitution of high strength steels, is lower than the TSC's estimate. Armco's estimate is based on a different assumption of component material usage. Besides, in addition to material properties, Armco also considered factors relevant to performance and manufacturing in their analysis.

One independent study on material substitution for light trucks is the development of an experimental van by the Budd Company. The Budd LWV features FRP doors, seats, and front end, aluminum roof and bumpers, HRP door hinges and transmission support, and HSS body and frame structural components.[47] These substitutions reduce the total curb weight of the experimental van by 654 pounds, as shown in Figure 6-1. This level of weight reduction by material substitution is within the TSC estimates for the baseline van as shown in Table 6-9.

6.3 SECONDARY WEIGHT REDUCTION

Applying TSC methodology, secondary weight reduction for the baseline vehicles were determined. The resultant curb weight for these baseline vehicles are given in Tables 6-16 through 6-21. Due to lack of detailed weight breakdown, secondary weight reduction for the baseline utility vehicle can not be determined.



LIGHTWEIGHT VAN PROJECT

Weight Summary in Pounds

System	Target	Estimated Savings
Frame Assembly	100	101
Body-in-White	100	170
Front End	75	70
Door Assemblies	75	78
Seats	30	25
Wheels, Brakes, Tires	60	78
Miscellaneous	160	132
Total Estimated Weight Saved	600	654

Source: Reference 47

FIGURE 6-1. THE BUDD LWV (LIGHT WEIGHT VAN)

TABLE 6-16. ESTIMATED CURB WEIGHT FOR THE BASELINE FOUR-PASSENGER CAR

WEIGHT	CASE (ALL WEIGHTS IN POUNDS)				
	ORIGINAL	HSS	FRP	ALUMINUM	HRP
Hang-on Parts	663	619	613	581	516
Supporting Structures	427	367	355	314	201
Chassis Systems	1002	907	898	868	822
Payload	800	800	800	800	800
Curb Weight					
No Wt. Propagation	2092	1893	1866	1763	1539
With Wt. Propagation		1836	1801	1662	1362

TABLE 6-17. ESTIMATED CURB WEIGHT FOR THE BASELINE FIVE-PASSENGER CAR

WEIGHT	CASE (ALL WEIGHTS IN POUNDS)				
	ORIGINAL	HSS	FRP	ALUMINUM	HRP
Hang-on Parts	729	677	662	611	575
Supporting Structures	589	496	474	381	291
Chassis Systems	1384	1221	1212	1131	1088
Payload	1000	1000	1000	1000	1000
Curb Weight					
No Wt. Propagation	2702	2394	2348	2123	1954
With Wt. Propagation		2307	2241	1946	1724

TABLE 6-18. ESTIMATED CURB WEIGHT FOR THE BASELINE SIX-PASSENGER CAR

WEIGHT	CASE (ALL WEIGHTS IN POUNDS)				
	ORIGINAL	HSS	FRP	ALUMINUM	HRP
Hang-on Parts	1530	1360	1328	1203	1027
Supporting Structures	283	227	227	227	170
Chassis Systems	1895	1545	1534	1461	1398
Payload	1200	1200	1200	1200	1200
Curb Weight					
No Wt. Propagation	3708	3132	3089	2891	2595
With Wt. Propagation		2995	2932	2765	2264

TABLE 6-19. ESTIMATED CURB WEIGHT FOR THE BASE-LINE COMPACT PICKUP TRUCK

WEIGHT	CASE (ALL WEIGHTS IN POUNDS)				
	ORIGINAL	HSS	FRP	ALUMINUM	HRP
Hang-on Parts	828	722	694	579	517
Supporting Structures	225	181	181	181	92
Chassis Systems	1355	1178	1177	1124	1079
Payload	1540	1540	1540	1540	1540
Curb Weight					
No Wt. Propagation	2408	2081	2051	1884	1688
With Wt. Propagation		2001	1957	1730	1486

TABLE 6-20. ESTIMATED CURB WEIGHT FOR THE BASE-LINE STANDARD PICKUP TRUCK

WEIGHT	CASE (ALL WEIGHTS IN POUNDS)				
	ORIGINAL	HSS	FRP	ALUMINUM	HRP
Hang-on Parts	1240	1082	1052	937	787
Supporting Structures	329	263	263	263	132
Chassis Systems	2118	1760	1746	1694	1588
Payload	2413	2413	2413	2413	2413
Curb Weight					
No Wt. Propagation	3687	3105	3061	2894	2507
With Wt. Propagation		2990	2929	2706	2225

TABLE 6-21. ESTIMATED CURB WEIGHT FOR THE BASE-LINE VAN

WEIGHT	CASE (ALL WEIGHTS IN POUNDS				
	ORIGINAL	HSS	FRP	ALUMINUM	HRP
Hang-on Parts	375	315	303	258	229
Supporting Structures	973	794	771	677	441
Chassis Systems	2084	1798	1786	1719	1649
Payload	1160	1160	1160	1160	1160
Curb Weight					
No Wt. Propagation	3432	2907	2860	2654	2319
With Wt. Propagation		2715	2639	2334	1842

6.4 WEIGHT/COST OPTIMIZATION

The four material substitution cases presented in this report are hypothetical. The objective of this study is to show the weight saving potential of the alternative materials. Realistically, no vehicle will be made emphasizing only one substitutional material. The selection of the substitutional material for each component will have to be made by optimizing the cost and weight of the total vehicle.

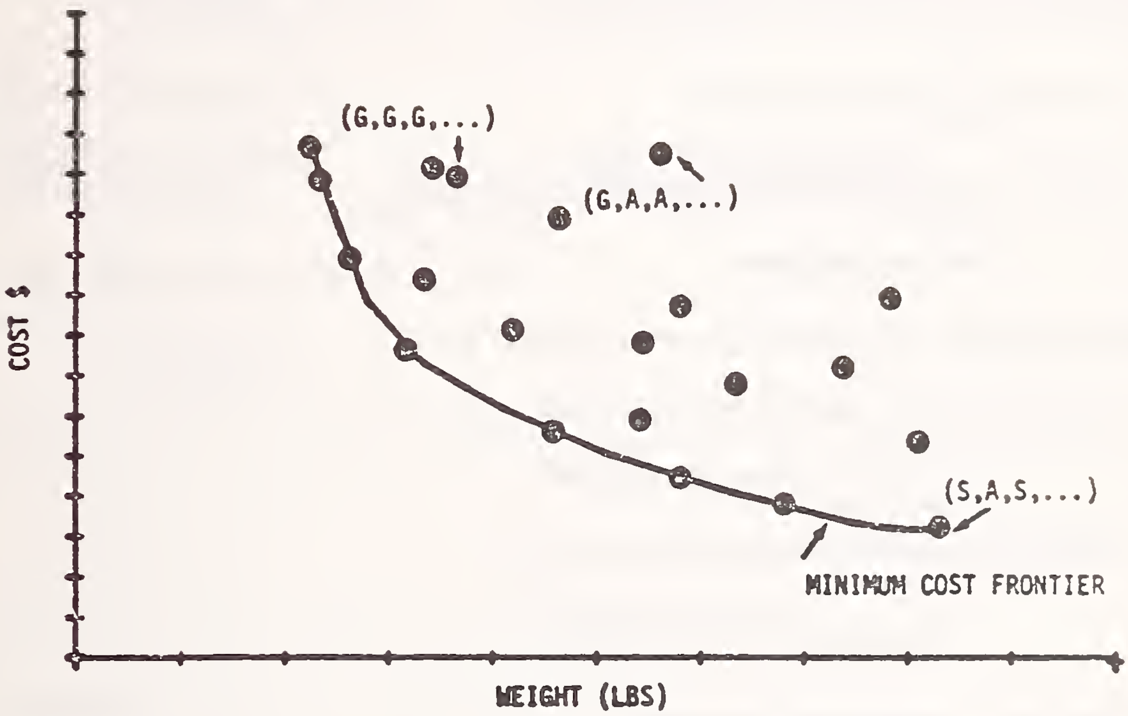
Under a contract with the Department of Transportation, ECON, Incorporated developed a computerized mathematical programming tool to be used to determine weight and cost tradeoffs for passenger cars and light trucks.[48] The algorithm developed is capable of determining the optimal materials mix by component over a wide range of component and material selection and deriving the relationship between total weight and cost of a given vehicle. The algorithm also accounts for the effects of weight propagation.

For any feasible mix of materials for each component of the automobile, there is a directly calculated weight and associated cost. Figure 6-2 demonstrates the situation where each possible combination of materials is evaluated in terms of weight and cost. The letters in parentheses indicate typical material mixes for each component. For example, (G,G,G...) indicates that components 1, 2, and 3 are all made of graphite, while (S,A,S,...) indicates that components 1 and 3 are made of steel and component 2 is made of aluminum.

While every combination has an associated level of interest, the points which have the most economic significance are those which represent the minimum cost for a specified weight. The algorithm is designed to efficiently trace the minimum cost frontier beginning with the minimum weight vehicle. Table 6-22 shows the equations used in the algorithm.

The algorithm was run on a test case of the 1980 X-body Oldsmobile Omega with 118 components and 6 principal materials.

Figure 6-3 shows the trace of the minimum cost frontier for this test case. Figure 6-4 shows the material usage as a function of the percent of weight reduction from the vehicle of minimum cost. It should be noted that this test case was used to try out the algorithm and to demonstrate the type of output the algorithm is capable of producing. An actual case will be tried when reliable component costs can be obtained.



Source: Reference 48

FIGURE 6-2. WEIGHT/COST TRADEOFF OF MATERIALS MIX

TABLE 6-22. MATHEMATICAL STATEMENT OF THE ALGORITHM

Variables

I	- Component
J	- Material
CURRENT(I)	- Current material for component I
BASELINE(I)	- Baseline material for component I
LEVEL(I)	- Weight propogation level for component I (1 = upper body, 2 = underbody, 3 = chassis)
WEIGHT(I,J)	- Baseline propogatable weight for component I when made from material J
FIXED(I,J)	- Fixed costs for component I when made from material J
VARIABLE(I,J)	- Variable (weight dependent) costs for component I when made from material J

The total weight and total cost of the baseline vehicle are as follows:

$$\text{BWEIGHT} = \sum_{I=1}^{I} \text{WEIGHT(I, BASELINE(I))}$$

$$\text{BCOST} = \sum_{I=1}^{I} \text{(FIXED(I, BASELINE(I)) + VARIABLE(I, BASELINE(I))} \\ * \text{WEIGHT(I, BASELINE(I)))}$$

For any other configuration, weight propogation effection are as follows: Let

BASEWGT(L) - Baseline weight for weight propogation Level L =

$$\sum_{I:\text{LEVEL(I)}=L} \text{WEIGHT(I,BASELINE(I))}$$

CURWGT(L) - Current (unpropogated weight for Level L =

$$\sum_{I:\text{LEVEL(I)}=L} \text{WEIGHT(I, CURRENT(I))}$$

PAYLOAD	- Payload weight of the vehicle
WTPROP(1)	- Weight propogation factor for Level 1 = 1
WTPROP(2)	- Weight propogation factor for Level 2 =

$$\frac{\text{BASEWGT(2)} + [\text{BASEWGT(2)} + 8(\text{BASEWGT(1)} + \text{BASEWGT(2)} + \text{PAYLOAD})(\text{CURWGT(1)} + \text{PAYLOAD})]^{\frac{1}{2}}}{2(\text{BASEWGT(1)} + \text{BASEWGT(2)} + \text{PAYLOAD})}$$

The total weight and the total cost of the current vehicle are as follows:

$$\text{CWEIGHT} = \sum_{I=1}^{I} \text{WEIGHT(I, CURRENT(I))} * \text{WTPROP(LEVEL(I))}$$

$$\text{CCOST} = \sum_{I=1}^{I} [\text{FIXED(I, CURENT(I))} + \text{VARIABLE(I, CURRENT(I))} * \text{WEIGHT(I, CURRENT(I))} * \text{WTPROP(LEVLE(J))}]$$

TABLE 6-22. MATHEMATICAL STATEMENT OF THE ALGORITHM (CONTINUED)

The algorithm procedes as follows:

Step 1: Set

$K = 0$

$CURRENT(I) = \hat{J}$ where $\hat{J}$ is the minimum weight material for component I

Step 2: Calculate

$CWEIGHT_K, CCOST_K$

Step 3: Set

$K = K + 1$

For each I calculate

$CWEIGHT_{I,J,K}, CCOST_{I,J,K}$ for $J \notin CURRENT(I)$

Step 4: Select $\hat{I}, \hat{J}$ according to

$$\frac{CWEIGHT_{\hat{I},\hat{J},K} - CWEIGHT_K}{CCOST_{\hat{I},\hat{J},K} - CCOST_K} = \max_{\substack{I,J \\ CCOST_{I,J,K} < CCOST_K}} \left(\frac{CWEIGHT_{I,J,K} - CWEIGHT_K}{CCOST_{I,J,K} - CCOST_K} \right)$$

Step 5: If $\hat{I}, \hat{J}$ not selected, normal termination

Step 6: Set

$CURRENT(\hat{I}) = \hat{J}$

Go to Step 2

Source: Reference 48

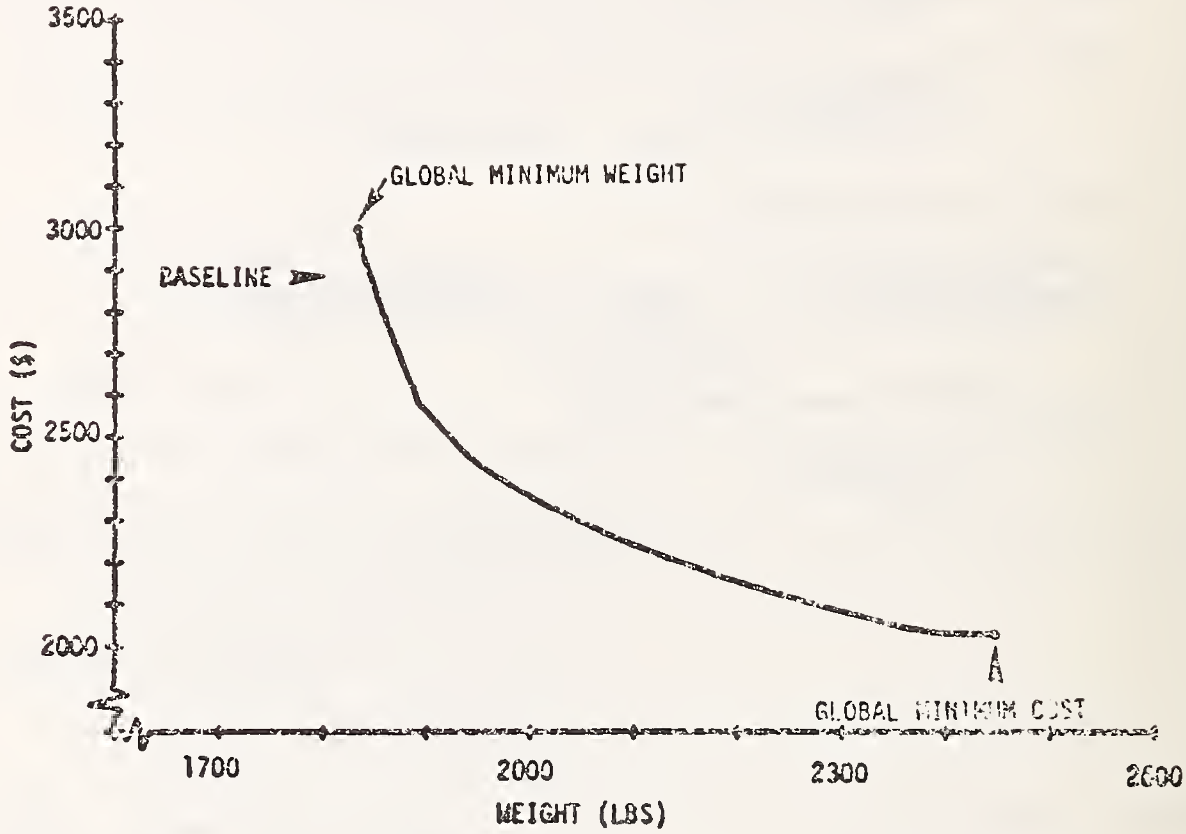


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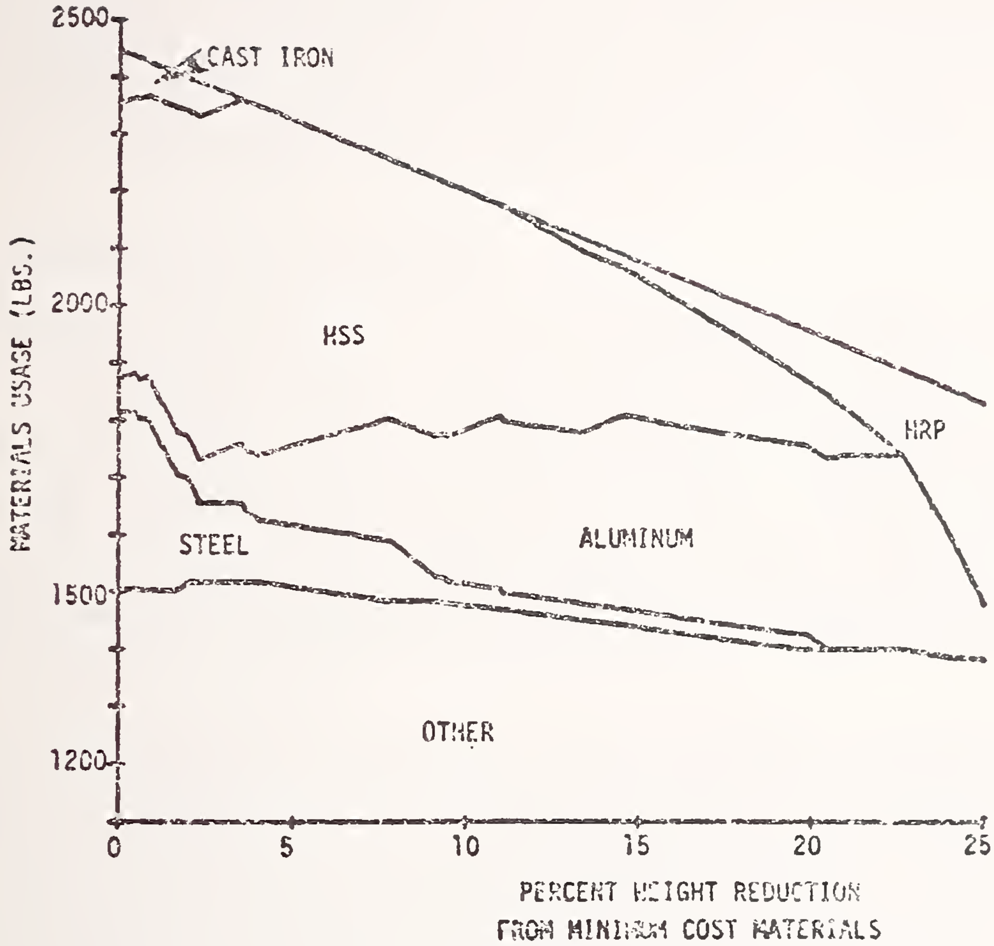
FIGURE 6-3. MINIMUM COST FRONTIER



Source: Reference 48

FIGURE 6-4. MATERIAL USAGE AS A FUNCTION OF PERCENT WEIGHT REDUCTION

7. EFFECTS OF WEIGHT REDUCTION

The constraint for vehicle weight reduction is to maintain constant vehicle quality. However, any change in vehicle curb weight or weight distribution affects the dynamic behavior and safety of the vehicle. The use of alternative materials for weight reduction also brings up questions concerning durability, repairability, etc. The following sections present brief discussions on some effects of vehicle weight reduction.

7.1 ACCELERATION PERFORMANCE

There are currently two performance parameters in use that provide a measure of the acceleration capability of a motor vehicle. These are: 1) the time period required to attain the speed of 60 mph from the position of rest; and 2) the time required to increase the speed from 40 mph to 60 mph. The second parameter is characteristic of the vehicle's potential of passing another vehicle.

Both parameters depend on the available engine thrust at the wheels to accelerate the vehicle and to overcome the rolling resistance of tires and the aerodynamic drag. Study indicates a nearly linear relationship between speed and time.[49] Assuming equal thrust is available to both vehicles at curb weight, the reduced weight vehicle requires a fraction of a second more time to reach 60 mph than the original weight vehicle when starting from the position of rest because the weight reduction diminishes the useful thrust force exerted at the wheels due to tire slip. However, once the vehicle reaches 15 to 20 mph, the reduced rolling resistance allows greater acceleration even though that advantage is negligible in comparison to aerodynamic drag which is identical for both vehicles with assumed identical body styles. On the other hand, assuming that equal tractive force at the driving wheels can be maintained, then a light vehicle has a higher rate of acceleration.

7.2 VEHICLE HANDLING AND RIDE QUALITY

Handling is concerned with the way a vehicle responds to driver commands in terms of directional control. It is the roll, pitch, and yaw motions of the vehicle as produced either by driver-applied steering inputs or by outside disturbances such as sidewinds or road profile. Ride quality is a measure of how well the vehicle occupants are insulated from dynamic forces originated by the road surface. It is largely governed by vehicle balance, static deflections, and frequencies.

Aside from the critical cornering characteristics of pneumatic tires, vehicle handling is affected by axle load distribution or location of vehicle sprung mass center of gravity, and the length of the radius of gyration. The latter depends on distribution of the sprung masses and their density. Unsprung weights include axles, wheels, and linkages. Reduction in unsprung weight improves vehicle handling and ride quality. The sprung-to-unsprung weight ratio should be as high as possible for the best combination of ride and handling, especially in a lighter car.

Study shows that lateral acceleration and the amount of understeering are not affected by change in vehicle weight. However, yaw rate and roll deflection increase while side slip velocity decreases as the vehicle weight is reduced.[49] Recent research in the field of human factors seems to indicate a higher sensitivity of the vehicle occupants relative to yaw than to side slip. Drive simulation also reveals that the response time to changes in the steer angle is reduced as the vehicle weight is reduced.

Downsizing for weight reduction reduces vehicle overhangs. This, in turn, reduces the radius of gyration in yaw and pitch relative to the wheelbase.[50] The downsized vehicle, therefore, possesses a significant amount of inertial coupling between bounce and pitch motions and has a higher pitching acceleration.

As vehicles become lighter, the ratio of payload to curb weight increases. There will be a larger shift in the longitudinal location of the center of the mass over the full range of loading. The change in the understeering level is likely to be greater for a lighter car when it goes from the driver-only case to the fully-loaded case. This shift in the longitudinal location of the center of mass also affects braking performance.

A lighter and smaller vehicle also has higher ratios between the height of center of gravity to wheelbase and track width. The fore/aft and right/left transfers of wheel loads will be a greater percentage of the static loading than is the case for a larger and heavier vehicle. This adversely affects the braking and cornering efficiencies.

7.3 NOISE AND VIBRATION

Occupants of automotive vehicles are submitted to noise surrounding the vehicle and to noise and vibrations generated by the vehicle itself. Noises coming from the surrounding are attenuated more or less by the body panels. Noises and vibrations generated by the vehicle are coming from the powertrain, aerodynamic turbulence, tire-road contact, suspension vibration, etc. In general, passenger compartment noise is inversely proportional to vehicle size and weight. The relationship exists for several reasons:

1. Replacing smooth running, low rpm eight and six cylinder engines with vibration prone, higher rpm four cylinder engines increases under-hood noise.

2. Replacing conventional steel with high strength steel with commensurate structural properties, but thinner gauge, allows more noise to be transmitted through the body.

3. To save weight, there is an increasing tendency to employ unit body construction and eliminate the frame. This practice exacerbates the problem of isolating the passenger compartment from road noise and suspension vibration.

4. Small diameter, low-volume tires tend to produce a rougher ride than larger, high-volume tires. Also, increasing the tire pressure to reduce rolling resistance and improve fuel economy, reduces tire shock absorption characteristics. These factors translate into increased suspension vibration.

5. In an effort to save weight, manufacturers are generally using thinner carpets, which have reduced noise absorption capacity. This allows increased levels of road noise to be transmitted into the passenger compartment.

6. For weight reduction, windshield glass often is reduced in thickness by approximately 20 percent; other automotive glass is usually reduced by approximately 33 percent. These decreases permit more aerodynamic noise to enter the interior sections.

To reduce noises and vibrations generated by the vehicle, one needs more efficient intake and exhaust silencers, stiffer sheet metal parts, better gears, less noisy tires, more powerful cooling system, slower but larger fans, more sound deafening materials, etc. All these measures add weight to the vehicle.

7.4 CORROSION

The use of light gauge steel sheet stock for weight reduction requires better corrosion protection for lower body panels and under-vehicle components. Coating of a thin layer of dissimilar metal on one or both sides of the steel proved to be the most economical method in protecting steel parts from corrosion in a vehicle. Insulating gaskets can be used to prevent galvanic corrosion where two dissimilar metals are in contact. Redesign of component by avoiding entrapment areas is another effective way to control corrosion.[51] Other design changes can be adopted to minimize corrosion attack in welded joints and eliminate standing seams.

Aluminum alloys in general have good resistance to corrosion in the environment of streets and highways. Depending on the application, they can be used bare or painted. If bright finished products are required, anodizing can enhance corrosion resistance.

Galvanic corrosion may be encountered where aluminum is in contact with steel or other metals in continuously wet conditions. Corrosion of this type usually can be reduced or eliminated by applying protective barriers between the two metals.

Reinforced plastics for automotive application are resistant to corrosion and chemically stable. As a result, reinforced plastic parts are more durable and can be expected to last for the life of the vehicle. Moisture absorption in exposed fiber can cause degradation of mechanical properties at elevated temperatures, but no significant degradation has been reported in the ambient temperature range. Continuous exposure to strong sunlight can result in surface degradation in reinforced plastics. However, this type of degradation is usually cosmetic and does not have significant effect on the mechanical properties.

7.5 SAFETY

Study shows that increased mass contributes to a substantial reduction in acceleration transmissibility for the heavier vehicle if two vehicles of unequal weight are involved in accidents.[52] This means that lighter vehicles would be at a greater disadvantage relative to the heavier vehicles in vehicle to vehicle impact. However, there are many ways to improve vehicle crashworthiness. For example, by increasing the displacement of bumpers, a light vehicle can have crashworthiness equal to that of a heavy vehicle.

A study on structural response of materials indicates that alternative materials such as HSLA steels, aluminum alloys, and reinforced composites can be used in the automotive structure without degrading the structural response to a collision.[53] However, this can not be done on a gage to gage or shape for shape basis. New concepts in component design will be required for the structure to obtain the greatest benefit in crashworthiness.

8. A REVIEW OF AUTOMOTIVE COMPOSITE MATERIALS

There are many definitions for composite materials. In this report a composite material is defined as a combination of two or more man-made materials with an interface between them. By this definition, fiber-reinforced composites and metal-plastic laminates are considered composite materials.

Interest in weight reduction has resulted in increasing use of fiber-reinforced composites in automotive applications. Depending on the fibers used, reinforced composites can be structured to provide high strength and stiffness at low weight compared to other conventional automotive materials. They also offer excellent design flexibility. Recent development has extended the use of reinforced composites to load-bearing components such as springs and driveshafts.

Metal-plastic laminates have recently attracted considerable attention within the automotive industry as possible alternatives to conventional sheet metals. Because of their high stiffness-to-weight ratio, use of metal-plastic laminates could result in significant weight reduction. These laminates are likely to be used in stiffness-limited body panel applications.

8.1 FIBER-REINFORCED COMPOSITES

Fiber-reinforced composites offer many advantages over conventional automotive materials. They offer high strength and stiffness at low weight, fatigue and corrosion resistance, damage tolerance, design flexibility, and life-cycle cost reduction. The reinforcing fibers can be metallic, ceramic (glass fibers), polymeric (aramid), graphitic, or a combination of these fibers. Combinations of fibers make it possible to create hybrid composites in which the best properties of each fiber is used. For example, by combining the low cost glass fibers of excellent impact resistance but low modulus with graphite fibers having low impact resistance but high modulus, the resulting hybrid composite would have good impact resistance and high modulus.

8.1.1 Properties of Fiber-Reinforced Composites

Mechanical properties of fiber-reinforced composites depend largely on the type of reinforcing fibers used, the orientation of the fibers, and the fiber content. Glass fiber and graphite (carbon) fiber are the most commonly used reinforcing materials in composite materials for automotive applications. Glass fibers are made of molten glass drawn down from holes in bushings or cisterns made of platinum. The bushings are electrically heated by low voltage alternative current at several thousand amperes. The glass streams are collected as they draw down naturally, passed over a lubricating pad and wound up at speeds on the order of 40 M/s. Fiber diameter is controlled between 5 and 10 micrometers.

There are three types of glass fibers: type E, type C, and type S. Type E glass fiber has superior electrical characteristics, excellent mechanical properties, and high heat resistance. It is widely used in electrical application. Type C glass fiber has superior resistance to corrosive action of acids and is used for containers, pipes, and other similar applications where good chemical resistance is required. Type S glass fiber has high strength-to-weight ratio and is used for structural components. The S glass fiber is more expensive than E glass fiber because of differences in composition and processing.

Carbon fibers are made by heating rayon or polyacrylonitrile precursor in inert gas first at low temperature (~300°C) to remove water and carbon dioxide and then at high temperature (~1000°C) to eliminate hydrogen. By proper control of temperature and atmosphere, strong carbon fibers are formed. The random microcystalline structure of the carbon fibers can be converted to an oriented graphite structure by drawing it at a very high temperature (~2000°C). This produces a family of carbon fibers of high modulus. A new technology for making graphite fibers using pitch as the precursor material is under development. The pitch process has the potential for significantly reducing the cost of graphite fibers.

Table 8-1 lists the principal physical properties of the glass and graphite fibers that are currently commercially available. The properties of aramid and boron/tungsten fibers are also included in Table 8-1 for comparison. The very high modulus graphite fibers and the boron/tungsten fibers are considered too expensive for anything but aerospace and military applications. The principal physical properties of high performance fibers presently under development are presented in Table 8-2.

The reinforcing fibers can have many different forms depending upon the application and manufacturing process of the composite. They can be continuous, chopped, in continuous or woven roving, or in a chopped strand mat. Since tensile strength of the composite depends to a great degree on fiber orientation, as shown in Figure 8-1 for a unidirectional graphite-epoxy composite, the fibers can be arranged in many different patterns to satisfy different strength requirements. In general, fibers can be arranged in the following patterns.

a. Unidirectional - In this arrangement all fibers are aligned in one direction (0^{o} orientation). More fiber can be packed into a given volume in this manner and results in higher directional strength.

b. Bidirectional - In this arrangement continuous fibers are at right angles to each other either as in woven roving or as in a crossply of alternating perpendicular layers of parallel fibers. Strengths will be highest in the directions of the fibers (0^{o}, 90^{o}). Strength in any one direction will be lower than in the unidirectional case.

c. Multidirectional (isotropic) - In this arrangement the composite consists of alternate layers of parallel continuous fibers that are arranged at relative angles of 45^{o} or chopped fibers oriented randomly. Strengths are isotropic in this arrangement.

TABLE 8-1. PHYSICAL PROPERTIES OF COMMERCIALLY AVAILABLE REINFORCING FIBERS

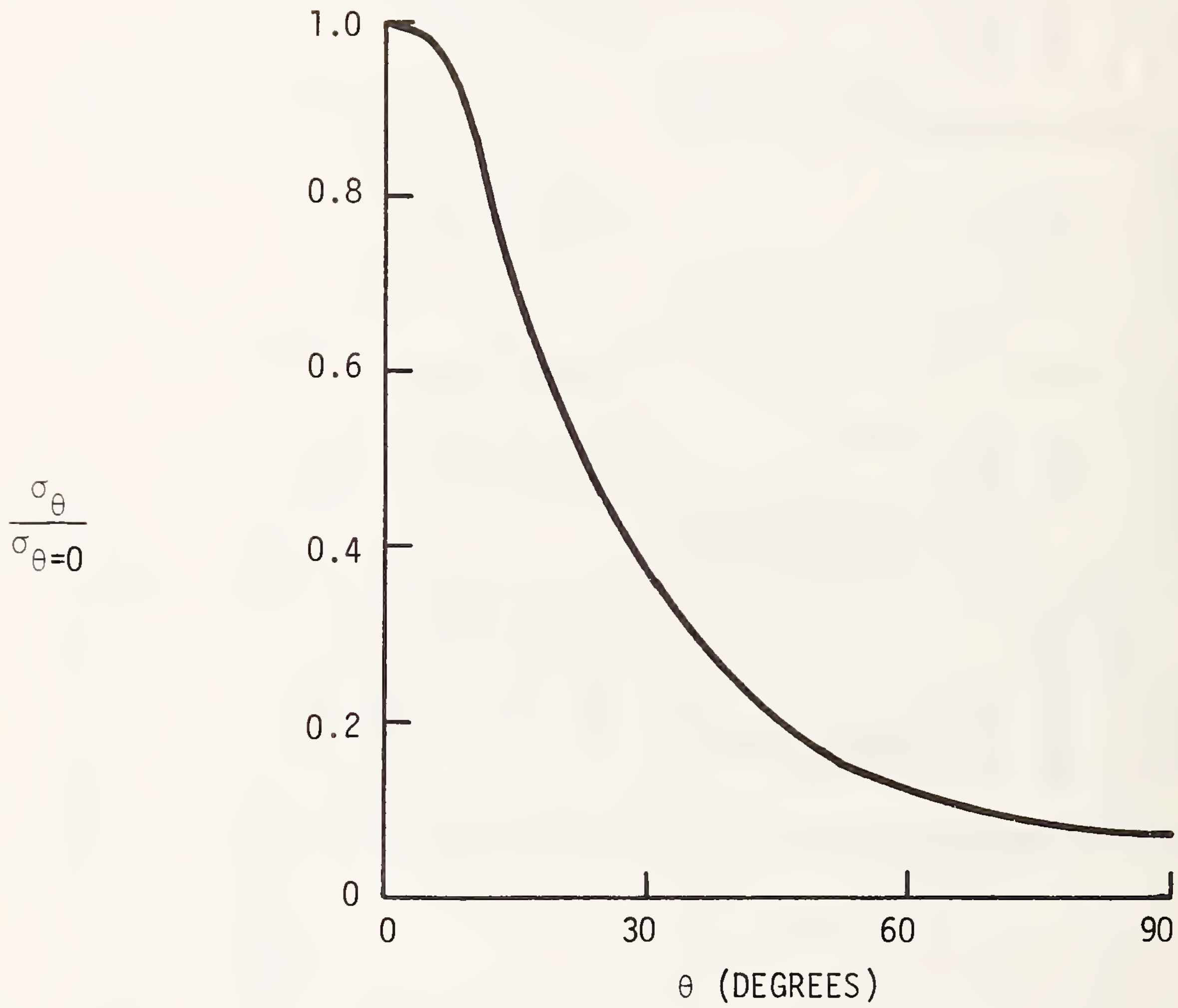
					Graphite Filaments		
Material	E-Glass Fiber	S-Glass Fiber	Aramid Fiber	Boron/Tungsten Fiber	High Strength Fiber	High Modulus Fiber	Very High Modulus Fiber
Product	(Roving)	(Roving)	Kevlar 49	5.6 mil Diam.	Thornel 300 (WYP 15-1/0)	Magnamite HMS	Celion GY-70
Supplier			Dupont	Avco/CTI	Union Carbide	Hercules	Celanese
Density lbs/in^3	0.092	0.090	0.052	0.090	0.062	0.067	0.071
g/cm^3	2.54	2.48	1.44	2.48	1.72	1.86	1.96
Tensil Strength 10^3 psi	372	550	400	500	360	340	270
MPa	2500	3700	2800	3400	2600	2300	1900
Tensil Modulus 10^6 psi	10.5	12.4	18.0	58.0	32.5	50	75
GPa	73	86	124	406	225	350	520
Ultimate Elongation, %	4.8	5.4	2.5	0.8	1.1	0.58	0.38
Specific Strength, in	$4.0x10^6$	$6.0x10^6$	$7.9x10^6$	$5.6x10^6$	$6.1x10^6$	$5.0x10^6$	$3.8x10^6$
cm	$9.8x10^6$	$1.5x10^7$	$1.9x10^7$	$1.4x10^7$	$1.5x10^7$	$1.2x10^9$	$9.7x10^6$
Specific Modulus, in	$1.1x10^8$	$1.4x10^8$	$3.6x10^8$	$6.4x10^8$	$5.2x10^8$	$7.5x10^8$	$1.1x10^9$
cm	$2.9x10^8$	$3.5x10^8$	$8.6x10^8$	$1.6x10^9$	$1.3x10^8$	$1.9x10^9$	$2.7x10^9$
Filament Diameter, mils	0.20-0.55	0.35-0.40	0.47	5.6	0.3	0.3	0.33
cm	0.0005-0.014	0.0009	0.0012	0.014	0.0007	0.00075	0.00084
Thermal Conductivity BTU-ft/hr (ft^2) (^oF)	0.56				12	70	
W/m ^oK	0.97				20.8	121	
Electrical Resistivity Ω mil ft					9000	4500	3900
$\mu\Omega$cm					1500	750	650
Current Price, $/lb	0.49	2.00	8-10 & up to 27 for fine denier fiber	200	20-32	70	140-250

Source: Reference 25

TABLE 8-2. PHYSICAL PROPERTIES OF DEVELOPMENTAL HIGH STRENGTH FIBERS

Material	Pitchbase Graphite	Boron/Carbon	Silicon Carbide/Carbon	Alumina	Boron Nitride
Product	Thornel P-VSB-32			FP	
Manufacturer	Union Carbide	AVCO	AVCO	DuPont	Carborundum
Density lbs/in^3	0.073	0.082	0.113	0.143	0.065-0.069
g/cm^3	2.02	2.26	3.11	3.95	1.8-1.9
Tensils Strength 10^3psi	200	475	450	200	120 (ave.)
MPa	1380	3300	3100		830
Tensile Modulus 10^6psi	50	53	62	55	30 (ave.)
GPa	345	363	425	377	210
Ultimate Elongation, %	0.4			0.4	
Specific Strength, in	2.8×10^6	5.8×10^6	4.0×10^6	1.4×10^6	1.8×10^6 (ave.)
cm	6.8×10^6	1.5×10^7	1.0×10^7	3.6×10^6	4.7×10^6
Specific Modulus, in	6.8×10^8	6.4×10^8	5.5×10^8	3.5×10^8	4.6×10^8 (ave.)
cm	1.7×10^9	1.6×10^9	1.4×10^9	8.9×10^8	1.2×10^9
Filament Diameter, mils	0.44	5.6	5,6	1.0	0.24
cm	0.0011	0.014	0.014	0.002	0.0006
Thermal Conductivity BTU ft/hr (ft^2) (^{o}F)	48			0.074	1.7
W/m^{o}K	83			0.13	3.0
Electrical Resistivity, ohm-cm					10^{14}
Current Price $/lb	20	250	450	200	

Source: Reference 25



Source: Reference 54

FIGURE 8-1. VARIATION IN TENSILE STRENGTH IN A UNIDIRECTIONAL GRAPHITE-EPOXY COMPOSITE (Θ IS THE ANGLE WITH THE FIBER ORIENTATION)

The effects of fiber orientation on the mechanical properties of various fibrous composites are presented in Table 8-3. Included are fibers of A type (high strength) graphite, HM type (high modulus) graphite, and UHM type (ultra high modulus) graphite, E-glass, S-glass, and Kevlar 49. Unless otherwise specified, the nominal fiber loading is 60 percent by volume. Mechanical properties of aluminum and cold rolled steel are also presented for comparison.

8.1.2 Manufacturing of Fiber-Reinforced Composites

Many processes have been developed for the fabrication of the reinforced composites. These processes can be grouped into open molding and compression molding. Open (contact) molding is the major process for the fabrication of reinforced composites. In general, it applies a combination of plastic resin and reinforcing material to a form, mold, or die. Heat is occasionally used to complete the polymerization process to achieve the desired properties in the final fabrication part. Compression molding is also called press or closed molding. In this method a combination of plastic resin and reinforcing material is either placed between matched dies and compressed into the shape of the mold, or injected into a closed cavity where it is polymerized. Four different types of materials may be charged to a molding press: 1) sheet molding compound (SMC), 2) bulk molding compound (BMC), 3) reinforcing mat or chopped fiber preform saturated with resin, and 4) preimpregnated. Processes included in the open and compression molding groups are shown in Table 8-4 and described briefly in the following:

a. Centrifugal Casting - In this process chopped strand mat or fabric is positioned inside a hollow mandrel which can be rotated. Resin mix is added to the rotating mandrel and is distributed uniformly throughout the reinforcement by centrifugal force. External heat may be applied through the wall of the mandrel. Cylinderical structures such as tubing can be formed by this process.

TABLE 8-3. MECHANICAL PROPERTIES OF VARIOUS FIBER-REINFORCED EPOXY COMPOSITES AND OF METALS OF INTEREST

Material	Fiber Lay UP Geometry	Density gr/cm^3	Elastic Moduli, GPa Longitudinal Ex	Elastic Moduli, GPa Transverse, Ey	Elastic Moduli, GPa Shear Gxy	Ultimate Strength, MPa Longitudinal σ_x	Ultimate Strength, MPa Transverse, σ_y	Ultimate Strength, MPa Shear τ_{xy}	Yield Strength as Percent Ultimate Strength	Fatigue Strength as Percent Ultimate Strength
A Type Graphite/Epoxy	Unidirectional (0°)	1.57	138	6.9	4.5	1517	41	97		70
	Crossply (0°, 90°)	1.57	74	74	4.5	838	838	97		59
	Crossply (±45°)	1.57	17.2	17.2	31.0	138	138	345		
	Isotropic (0°, 90°, ±45°)	1.57	48	48	17.8	604	604	221		78
	Harness Satin Weave Cloth (Warp)	1.57	62	62		462	476			
HM Type Graphite/Epoxy	Unidirectional (0°)	1.60	221	6.9	4.8	1206	34	69		
	Crossply (0°, 90°)	1.60			4.8			59		
	Crossply (±-45°)	1.60	17.2	17.2	44.8	124	124	290		
	Isotropic (0°, 90°, ±45°)	1.60	73	73	24.8	345	345	179		
UHM Type Graphite/Epoxy	Unidirectional (0°)	1.68	303	6.9	6.6	758	28	48		
	Crossply (0°, 90°)	1.68	159	159	6.6	402	402	48		
	Crossply (±45°)	1.68	20.7	20.7	79.3	96.5	96.5	207		
	Isotropic (0°, 90°, ±45°)	1.68	103	103	42.8	242	242	128		
Kevlar 49/Epoxy	Unidirectional (0°)	1.38	86(tens) 41(comp)	5.5	2.1	1517(tens) 276(comp)	28	41		70
	Crossply (±90°)	1.38								
	Crossply (±45°)		7.6	7.6	20.7	207	207	221		
	Isotropic (0°, 90°, ±45°)									
	181 Fabric (Warp)(50v/o)	1.33	31	31	2.0	517(tens) 172(comp)	517(tens) 172(comp)	110		
	Chopped Fiber (50v/o)	1.32	20	20		196	196			
S-Glass/Epoxy	Unidirectional (0°)	1.88	48	6.9	3.4	1730	40	10		
	Crossply (0°, 90°)	1.88	31	31		980	980			
	Crossply (±45°)	1.88	16	16		170	170			
	Isotropic (0°, 90°, ±45°)	1.88	25	25		730	730			
E-Glass/Epoxy	Unidirectional(0°)	1.80	39	9.6	2.1	1104	20			23
	Crossply (0°, 90°)	1.80	25	25		518	518		32	22
	Crossply (±45°)	1.80	11	11		152	152			
	Isotropic (0°, 90°, ±45°)	1.80	18	18		330	330		42	25
	Chopped Fiber (47% glass)	1.86	15	15		99	99			
Aluminum 6061-T-6		2,70	72	72	26.2	310	310	207	88	31
Steel, Cold Rolled (0.2% Carbon)		7.85	207	207	83	552	552	414	75(Tension) 60(Shear)	40-45

Source: Reference 25

TABLE 8-4. MANUFACTURING PROCESSES FOR THE FABRICATION OF FIBER-REINFORCED COMPOSITES

- Production Processes
  - Open Molding
    - Centrifugal Casting
    - Spray-up
    - Filament Winding
    - Hand Lay-up
    - Vacuum Bag
    - Pressure Bag
    - Pultrusion
    - Continuous Laminating
  - Compression Molding
    - Sheet Molding
    - Bulk Molding
    - Mat or Preform Molding
    - Injection Molding

b. Spray-Up - In this process chopped fibers and resin are simultaneously deposited in a mold. The fiber rovings are fed through a chopper and ejected into a resin stream which is directed at the mold by either one of two spray systems: 1) a spray gun ejects resin premixed with catalyst or catalyst alone, while another gun ejects resins premixed with accelerator; or 2) resin ingredients are fed into a single gun mixing chamber ahead of the spray nozzle. By either method, the resin mix precoats the fiber strands and the merged spray is directed into the mold by the operator.

c. Filament Winding - This process is applicable only to surface of rotation. Fiber strands are fed through a resin bath and wound on a mandrel. Dry winding using preimpregnated roving may also be employed. Thickness is dependent on the number of complete layers uniformly placed on the mandrel. After it has reached the desired thickness, the wound mandrel is cured in an oven and the mandrel is then removed from the laminate. Soluble mandrels may be used to permit winding of closed-end structures.

d. Hand Lay-Up - In this process reinforcement material and resin are placed manually against the surface of the mold. The resin is worked into the layered reinforcement by brushes, squeegees, and rollers. Thickness is controlled by the layers of materials placed against the mold.

e. Vacuum Bag Molding - In this process a film is placed over the lay-up and is drawn against the lay-up by a vacuum. This method is used when manual roll-out is not used or is insufficient to remove entrapped air and excess resin from the lay-up

f. Pressure Bag Molding - This process is similar to the vacuum bag molding process except that an inflatable rubber bag is pressurized inside a "clam shell" mold to remove ontrapped air and excess resin.

g. Pultrusion - In this process continuous fiber strands are fed through a resin bath and then drawn through a die which determines the cross-section geometry and controls the resin content. Final cure is accomplished in a heated section of the die.

h. Continuous Laminating - In this process fabric or mat is fed from rolls, passed through a resin bath, and brought together to form the composite layer between two cellophane covering sheets. Thickness and resin content is controlled by exerting pressure on the squeeze rolls through which the laminate passes. The laminate is drawn through a heating zone for curing.

i. Sheet Molding - In this process sheet molding compound (SMC) is made by first blending the resin, pigment, filler, and catalyst into a paste and then combining with reinforcing fibers on a conveyor which rolls the combination out between two sheets of plastic film. These films are then removed when the SMC has thickened sufficiently and is ready for molding.

j. Bulk Molding - In this process bulk molding compound (BMC) is made by blending reinforcing materials with resin, pigment, filler, and catalyst into a premixed bulk material. The premix may be used in lump form or extruded into logs or rope to ease charge preparation.

k. Mat or Preform Molding - In this process the resin, fillers, pigment, and other required additives are blended in a charge prep area. The preform or mat may be saturated with the resin mix either outside or on the mold by a process similar to hand lay-up.

1. Injection Molding - In this process a mixture of resin and chopped fibers is forced by a piston through an orifice into the cavity of a closed matched mold. The charge then takes shape and is hardened to solid form before removal from the mold.

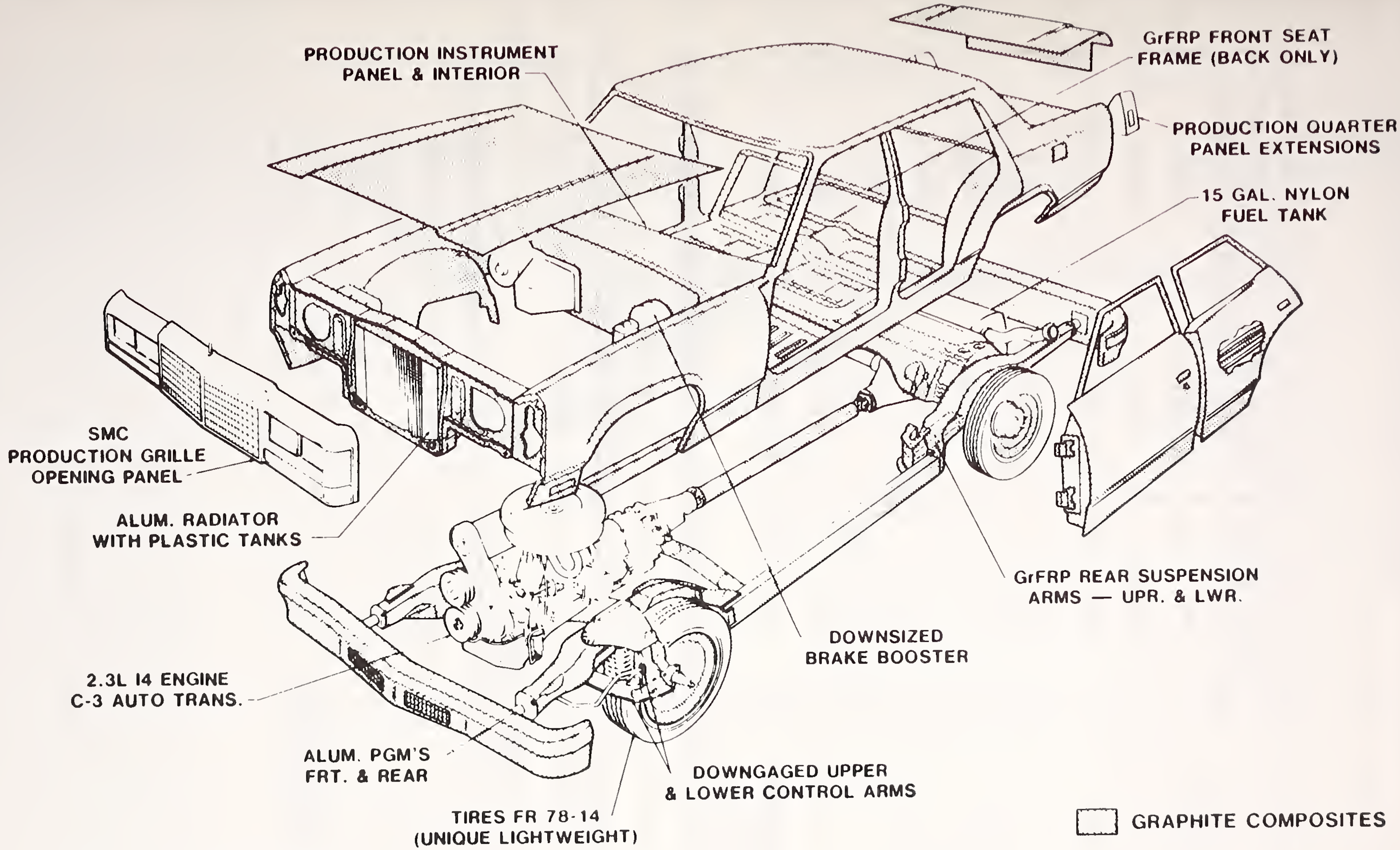
8.1.3 Application of Fiber-Reinforced Composites

Because of their great weight reduction potential, advanced composites are considered to be important alternatives in cars and trucks. However, large scale use of advanced composites will be dictated by the development of rapid and automated processing, the reliability of mass-produced structures, material cost, and more efficient design.

Material feasibility of the advanced composites is demonstrates by the development of two experimental vehicles. These vehicles are the Ford graphite concept car and the Budd Company light weight prototype van.

The Ford lightweight concept vehicle was a 1979 Ford LTD sedan in which all body panels, doors, wheels, the floor pan, frame, bumpers and certain hardware items, totaling 160 components, were molded from graphite composite. For practical reasons, some of these components were not redesigned for graphite composite, but essentially duplicated the steel design. The experimental LTD weighed 2504 pounds as compared with a proudction 1979 LTD which weighed 3740 pounds.[55] Figure 8-2 shows the applications of graphite composite in the lightweight concept vehicle. Component weights in steel and graphite composite are summarized in Table 8-5.

The Budd lightweight prototype van made material substitutions that included high strength low alloy steel, aluminum, and reinforced composites in place of steel, and plycarbonate in place of glass. In the largest single application, the entire front end assembly of the van (fender, fender skirt, and grill opening panel) was converted to SMC. In addition to weight savings, the



Source: Reference 56

FIGURE 8-2. APPLICATION OF GRAPHITE COMPOSITE IN THE FORD LIGHTWEIGHT CONCEPT VEHICLE

TABLE 8-5. COMPONENTS WEIGHT SUMMARY FOR FORD LIGHTWEIGHT CONCEPT VEHICLE

	WT. IN STEEL (LB.)	WT. IN GRAPHITE (LB.)	WEIGHT SAVINGS (LB.)
BODY-IN-WHITE	461.0	208.0	253.0
FRAME	282.8	207.2	75.6
FRONT END	96.0	29.3	66.7
HOOD	49.0	16.7	32.3
DECK LID	42.8	13.9	28.9
BUMPERS	123.1	44.4	78.7
WHEELS	92.0	49.3	42.7
DOORS	155.6	61.1	94.5
MISCELLANEOUS (BRACKETRY, SEAT FRAME, ETC.)	69.3	35.8	33.3

	VEHICLE WEIGHT
FORD LTD 1979	3740
LIGHTWEIGHT CONCEPT VEHICLE	2504

Source: Reference 56

number of parts in the assembly was reduced from 52 to 10 by taking advantage of the molding process for part consolidation.[57] Structural type of applications were represented by the transmission cross member and leaf springs. The original two-piece steel cross member was replaced by a composite assembly molded from graphite-epoxy and aramid-epoxy. The two single piece composite springs were 67 percent lighter than the four-leaf springs they replaced, yet provided a superior ride quality and lower noise transmisson. Table 8-6 gives a comparison on component weights for the Budd lightweight van.

Composites of the future will include hybrids of glass and graphite fibers. Developments over the coming years will focus on manufacturing technology and testing of selected components in actual service. Table 8-7 shows automotive components which are being investigated for use in graphite composites. As the volume of fiber usage goes up, the cost of the graphite fiber will come down, making graphite composites cost competitive.

8.1.4 Problems and Issues

A number of problems and issues have to be addressed and solved in order for advanced composite materials to be considered as construction materials for production automobiles. These include:

a. Cost of Raw Materials - At current prices, advanced composites are prohibitively expensive for nearly all automotive uses. Even though the price of graphite fiber could be reduced with increased production, relative direct material costs of the alternative materials are expected to remain at the same ratio in the near future.

b. Manufacturing - Most of the experimental advanced composite automotive components have been made with all graphite composites formed by aerospace fabrication techniques that are too expensive and too slow to be

TABLE 8-6. PART-WEIGHT COMPARISONS IN BUDD LIGHTWEIGHT VAN

Component	Steel	Composite	Weight Saving
Front end (SMC)	117 lb	53 lb	54%
Tailgate (SMC)	45	28	62
Transmission support (graphite-epoxy/aramid-epoxy)	13.5	4.1	76
Leaf spring (unidirectional glass)	79	26	67
Door (SMC)	51	38	25
Hinges (graphite-epoxy)	2	0.55	72

Source: Reference 57

TABLE 8-7. CARBON FIBER AUTOMOTIVE COMPONENTS BEING INVESTIGATED

LEAF SPRINGS
DRIVESHAFT
DOOR INTRUSION BEAM
ENGINE MOUNTING BRACKETS
TRANSMISSION SUPPORT
RADIATOR SUPPORT
BUMPERS
SUSPENSION ARM
HOOD, DECK ASEMBLIES
DOOR ASSEMBLY
FRONT HINGE PILLAR
WHEEL
FRAME
PUSH ROD
WRIST PIN
CONNECTING ROD
DOOR HINGE
FRAME CROSSMEMBER
OTHERS

Source: Reference 56

considered for high volume automotive applications. It will be necessary to adapt, and improve upon, existing fiberglass reinforced plastic manufacturing technology to the manufacture of hybrid composites. The conductivity of graphite filaments will require that provisions be made for containing these fibers during shipping, storage, and manufacture of composite structures.

c. Durability - To date, long term programs conducted by aerospace corporations relative to durability of composite materials have not been accepted by the auto industry. Therefore, demonstration of vehicle durability with composites will take time.

d. Damageability and Crashworthiness - The failure mode of fibrous composites, which are brittle materials, is very different from the failure of metals which can yield. Composites are less likely to deform under light loads than metals, but could shatter and form jagged edges upon severe impact in some cases, or simply delaminate in other instances.

e. Repair upon Damage - The ability to repair major structural components made of any reinforced plastic is an open issue. Part repairability will depend upon construction, configuration, structural load constraints, extent of damage, location of damage, and various other factors. Tradeoff studies will be required to establish the damage level at which part replacement will be more economical.

f. Recycling - Reinforced thermosetting resins can not be economically recycled at the moment. Land fill of scrap advanced composite parts is the only current available option.

g. Graphite Fiber Release - The uncontrolled release of graphite fibers of lint from burning graphite-organic matrix composites is a problem of current concern.

Graphite fibers are less flammable than organic matrices, such as an epoxy resin. The matrix can be preferentially consumed in a burning composite resulting in the formation of an uncontained graphite fiber skeleton from which fibers can break off and diffuse. This diffusion problem can be compounded if the fire is accompanied by an explosion.

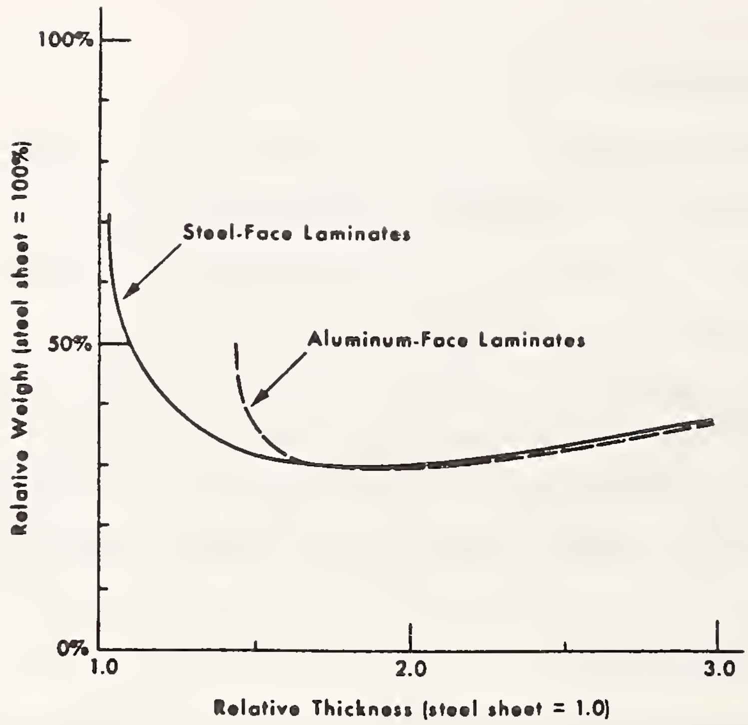
8.2 METAL-PLASTIC LAMINATES

Metal-plastic laminates are sandwich structures with two thin metal face sheets, typically aluminum or steel, bonded to a thermoplastic core. Because of their high stiffness-to-weight ratio relative to steel and aluminum, metal-plastic laminates can provide significant weight savings at potentially lower costs in stiffness-limited automotive applications. Figure 8-3 shows relative weight and thickness of steel-plastic and aluminum-plastic laminates for equal stiffness replacement of steel sheet.

8.2.1 Laminate Properties

Mechanical properties of metal-plastic laminates depend on the relative thickness and properties of the face sheets and core and the geometrical arrangement of the laminate. A sandwich panel is analogous to an I beam with facings and core corresponding to the flanges and web. The facings carry axial compressive and tensile forces while the core sustains shear stress. When thick facings are used, they may be subjected to significant shear stresses.

National Steel Corporation and Hercules, Incorporated jointly developed a steel-polypropylene-steel (S-P-S) laminate.[59] The facings on this laminate can be coated or uncoated and varied in strength to provide a number of combinations for specific applications. A laminate consisting of annealed low carbon steel facings with 60 percent polypropylene core was developed for general automotive applications. Mechanical properties of several S-P-S laminates are given in Table 8-8. Table 8-9 shows mechanical properties of steel laminates with polyionomer core.



Source: Reference 58

FIGURE 8-3. COMPARISON OF LAMINATE WEIGHT AND THICKNESS NORMALIZED TO THE WEIGHT AND THICKNESS OF STEEL SHEET BASED ON EQUAL STIFFNESS

Dent resistance is an important requisite for any material to be used in automotive body panels. For a laminate to be effectively applicable for body panels, it should have a dent resistance equivalent to that of current materials. Results of impact tests indicate that the dent resistance of S-P-S laminates compares favorably with that of AK steel. As shown in Figure 8-4, a 0.04 in. thick S-P-S laminate has a dent resistance comparable to that of a 0.03 in. thick AK steel. If 0.04 in. laminates were to replace a thicker steel, either the laminate thickness or the strength of the face sheets must be increased to maintain equivalent dent resistance.

The formability of the S-P-S laminate is found to be slightly less than that of steel. The S-P-S laminate has a springback angle equivalent to that of steel and less than that of high strength steel and aluminum.

Monsanto Plastics and Resins Company recently developed aluminum-nylon-aluminum laminates for automotive body panel applications.[61] Nylon was used for the core because of its high strength and modulus, high melting point, and its good low temperature properties relative to other candidate polymers. It has excellent resistance to chemicals, especially hydrocarbons, and provides very strong bonds in the laminate. The nylon/aluminum bond is found to be very resistant to moisture, salts, and forming stresses. Table 8-10 shows mechanical properties of two aluminum-nylon-aluminum laminates. Properties of a laminate with steel face sheets and nylon core and that of a reference hood steel are also presented for comparison.

Per unit area, aluminum laminates weigh about one-third the weight of steel sheet and three-quarters that of aluminum sheet at equivalent stiffness. As shown in Figure 8-5, aluminum/nylon laminates show good load bearing performance as compared to the reference hood steel (SAE 1005 steel). In Table 8-10, aluminum laminates are shown to have better dent resistance than a steel/nylon laminate weighing 2.84 Kg/m^2. However, if it were allowed to be optimized, the steel/nylon laminate would have higher dent resistance.

TABLE 8-8. MECHANICAL PROPERTIES OF STEEL-POLYPROPYLENE-STEEL LAMINATES

LAMINATE THICKNESS, mm	1.02	1.73	3.81	8.26
FACE SHEET THICKNESS, mm	0.20	0.34	0.76	1.57
CORE THICKNESS, mm	0.61	1.02	2.29	5.11
CORE VOLUME RATIO, PERCENT	60	60	60	60
WEIGHT PER UNIT AREA, Kg/m^2	3.77	6.41	14.1	30.6
FLEXURAL MODULUS, GPA	145	145	145	145
FLEXURAL STRENGTH, MPA	325	228		
FLEXURAL FATIGUE STRENGTH, MPA	138	138	152	131
TENSILE MODULUS, GPA	83	83	83	83
TENSILE YIELD STRENGTH, MPA	101	115	77	70
TENSILE STRENGTH, MPA	163	143	143	132
PERCENT TOTAL ELONGATION	35	37	43	47
TENSILE FATIGUE STRENGTH, MPA	95	97	97	97

Source: Reference 60

TABLE 8-9. MECHANICAL PROPERTIES OF SELECTED STEEL-POLYIONOMER LAMINATES

FACE SHEET / CORE	STEEL / POLYIONOMER			
TOTAL LAMINATE THICKNESS, mm	0.69	0.78	0.94	1.03
FACE SHEET THICKNESS, mm	0.22	0.26	0.22	0.26
CORE THICKNESS, mm	0.25	0.25	0.50	0.51
CORE VOLUME RATIO, PERCENT	37.0	32.7	54.1	49.3
WEIGHT PER UNIT AREA, Kg/m^2	3.627	4.345	3.867	4.585
DEFLECTION PER UNIT LOAD PER UNIT WIDTH, cm/N PER cm WIDTH (over a 8.9 cm span)	0.0135	0.0085	0.0062	0.0057
EFFECTIVE FLEXURAL STIFFNESS, EI, KPa per cm WIDTH	253	410	570	595
APPARENT FLEXURAL MODULUS E_a, GPA	92	104	82	65
TENSILE MODULUS, GPA	113	131	48	110
TENSILE YIELD STRENGTH, MPA	256	195	180	143
TENSILE STRENGTH, MPA	269	222	193	168
TOTAL ELONGATION, PERCENT	17.7	32.4	19.2	32.9
YIELD POINT ELONGATION, PERCENT	2.2	1.5	3.7	1.3

Source: Reference 60

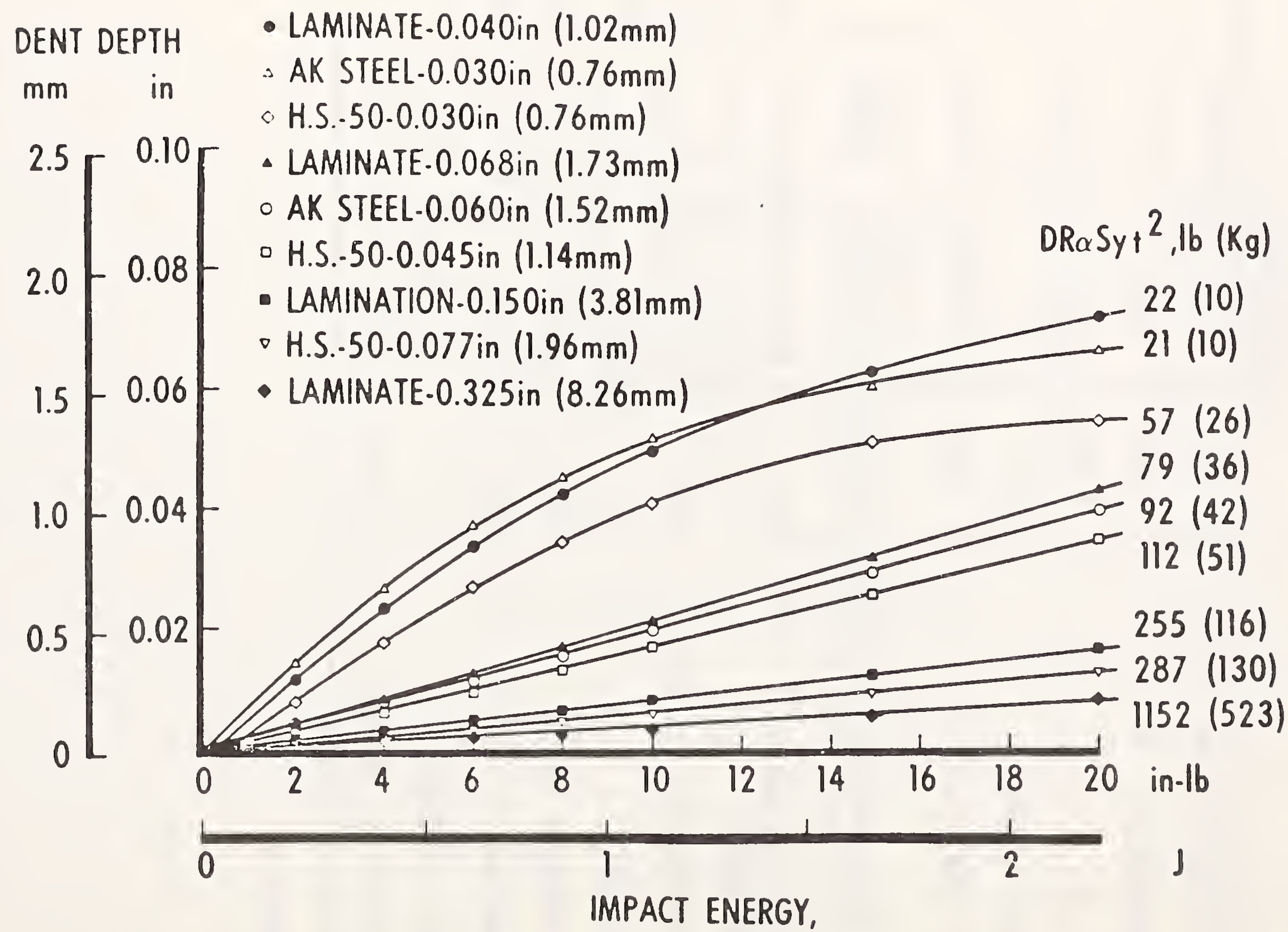


FIGURE 8-4. DENT RESISTANCE OF STEELS AND STEEL LAMINATES

TABLE 8-10. MECHANICAL PROPERTIES OF SELECTED METAL-PLASTIC LAMINATES WITH NYLON 6-6 CORES

FACE SHEET	ALUMINUM 3004-H19	ALUMINUM 6061-T4	STEEL C1005	REFERENCE HOOD STEEL
CORE	NYLON 6-6	NYLON 6-6	NYLON 6-6	
TOTAL LAMINATE THICKNESS, mm	1.60	1.53	1.00	0.84
FACE SHEET THICKNESS, mm	0.15	0.13	0.13	
CORE THICKNESS, mm	1.30	1.27	0.74	
CORE VOLUME RATIO, PERCENT	81.2	83.0	74.0	
WEIGHT PER UNIT AREA, Kg/m^2	2.33	2.15	2.84	6.60
FLEXURAL STIFFNESS*, N/cm per cm of WIDTH	1854	1830	1860	1860
BENDING MOMENT CAPACITY, N-m per cm of WIDTH	0.168	0.240	0.343	.165
DENT DEPTH, mm		1.40	1.55	1.27

*Flexural Stiffness = Force required to obtain a given deflection per unit sample width in a three point bending test with a 2.54 cm span

Source: References 60, 61

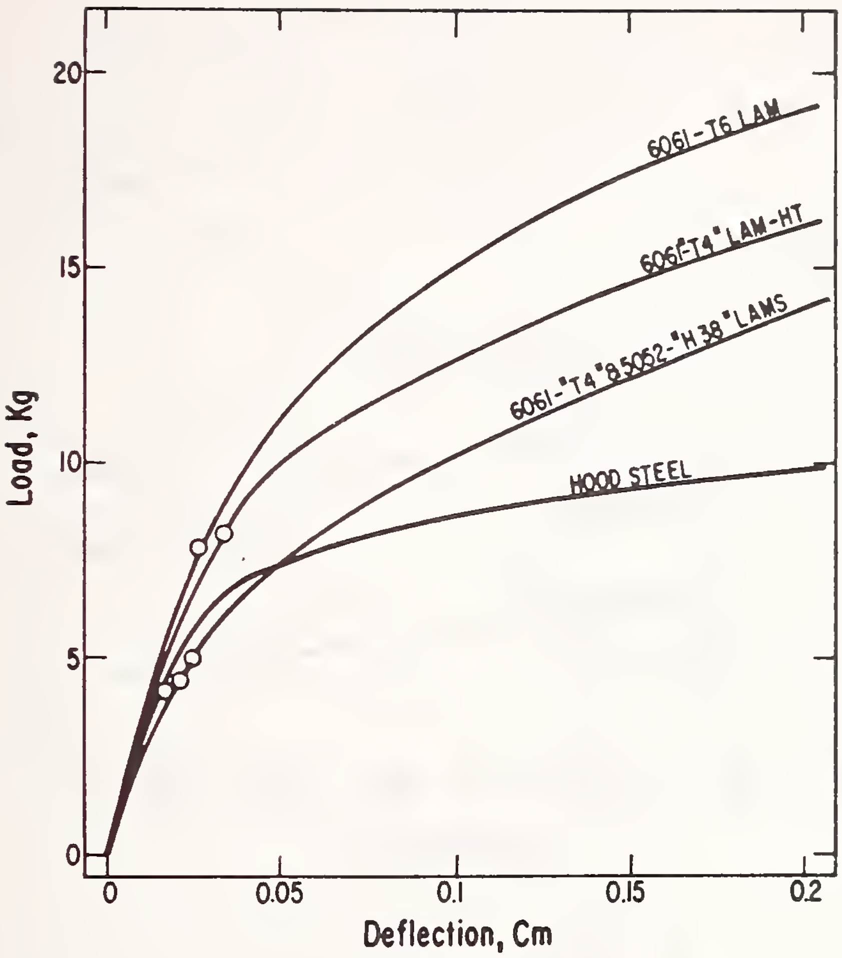
Temperature has an influential effect on the properties of aluminum laminates. The dent resistance decreases with increases in temperature. Olsen cup stretch-forming ratio also varies with temperature as shown in Figure 8-6. Test data suggest that optimum forming for the aluminum/nylon laminates is best done at temperatures in the range of 66-107^{o}C.

Finite element analyses have been performed to determine the interlaminar stresses in a aluminum/nylon laminate due to changes in temperature and axial stress.[62] Figure 8-7 shows theoretical stresses at the laminate interface and at midplane for a uniform temperature change of 1^{o}F. Maximum shear stress (2.25 psi) is found to occur at a distance about 0.015 in. from the free edge. The face at about 1 inch from the free-edge is essentially stress free.

Stresses in the aluminum/nylon laminate under uniform axial load were also calculated. Figure 8-8 shows the distribution of shear and normal stress in the laminate for an applied axial stress of 1 psi. As in the previous case, the face at about 1 inch from the free edge is again stress free.

8.2.2 Application of Metal-Plastic Laminates

Metal-plastic laminates are a formable, lightweight sheet material for stiffness-limited automotive applications. Steel-plastic laminates offer weight savings potential of 30 to 50 percent and aluminum-plastic laminates have weight savings potential of 50 to 70 percent. Laminates can be tailored to meet specific requirements. They have good acoustic properties which can lead to further possible weight reduction through elimination of sound deadening materials. They require low forming load and can be formed into most part shapes with the same fabrication processes used for sheet steel components.



Source: Reference 61

FIGURE 8-5. FLEXURAL LOAD-DEFLECTION CURVES FOR SEVERAL ALUMINUM/NYLON LAMINATES AND 0.84 mm-THICK HOOD STEEL

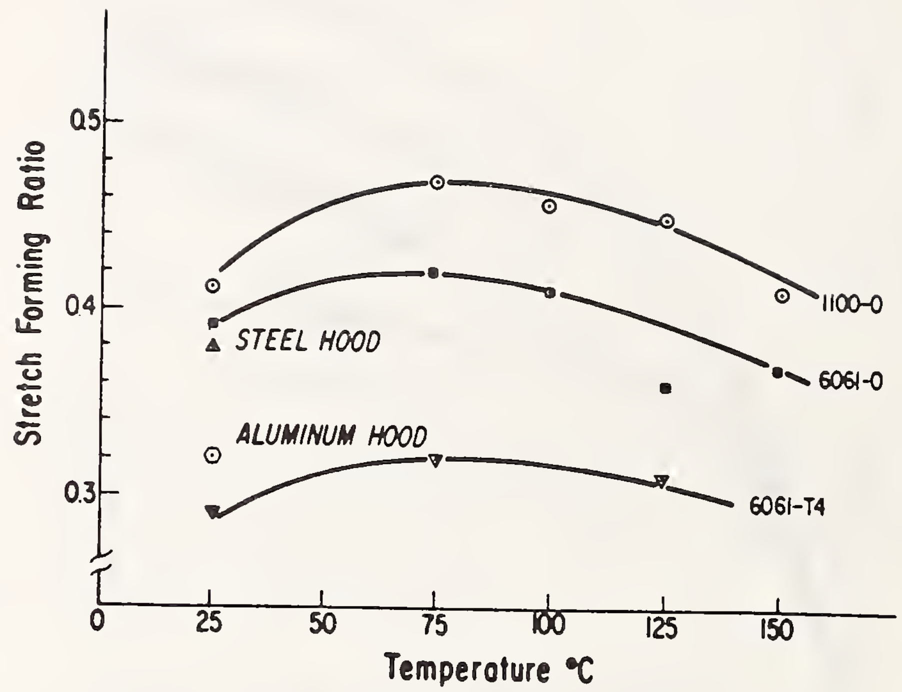


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FIGURE 8-6. OLSEN CUP STRETCH-FORMING RATIO VERSUS TEMPERATURE FOR SEVERAL ALUMINUM/NYLON LAMINATES

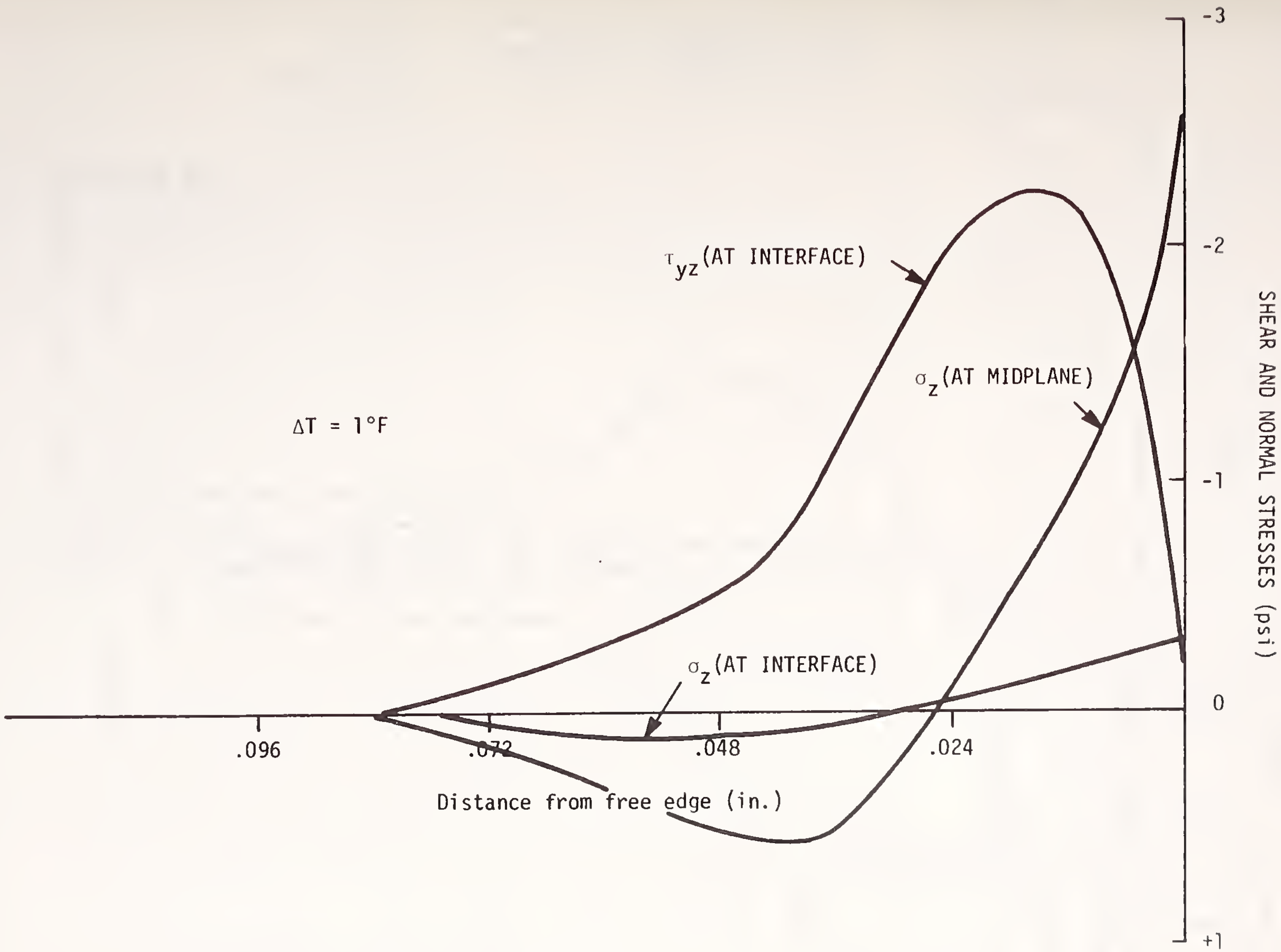

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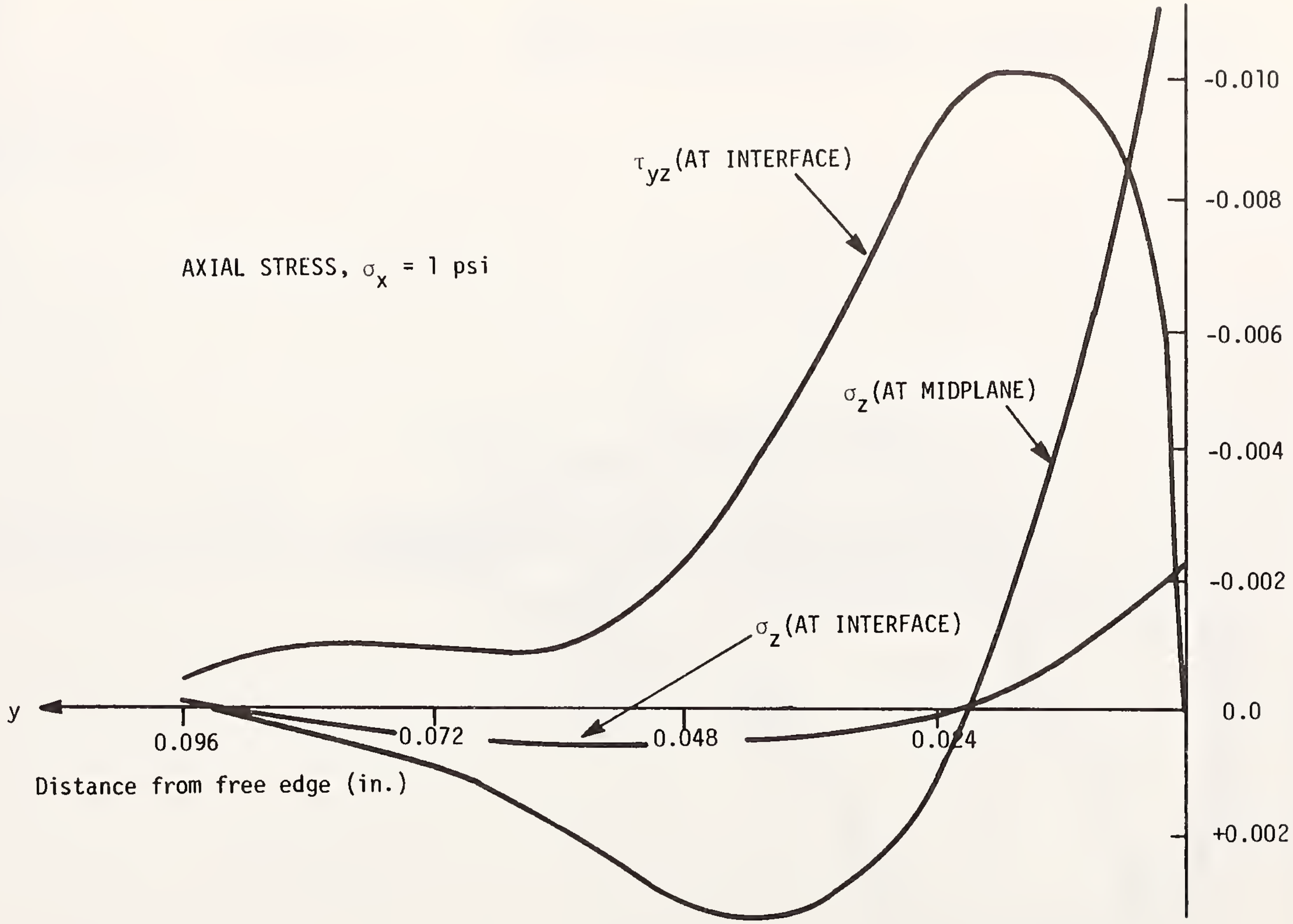
FIGURE 8-7. STRESS DISTRIBUTION IN ALUMINUM/NYLON LAMINATE UNDER THERMAL LOADING



Source: Reference 62

FIGURE 8-8. STRESS DISTRIBUTION IN ALUMINUM/NYLON LAMINATE UNDER TENSION

At the present, no production automotive part is made of laminate even though trial parts have been fabricated. In the near term, metal-plastics laminates could be used in small, non-appearance, low risk applications. Future applications would include seat backs, load floors, narrow body panels, truck trailer sides, covers and pans, and interior trims.

Analyses were conducted to determine weight and cost of selected vehicle components using laminates with aluminum and steel face sheets.[60] Five parts from a 1979 Omni and nine parts form a 1980 Ford F-150 pickup truck were selected for the analysis. These parts are all non-appearance with relatively low levels of loadings. Results of the analysis are shown in Tables 8-11 and 8-12.

As shown in these tables, the cost penalty for most parts considered is higher than the $0.50/lb criterion adopted currently by the automotive industry. Those components with cost penalty below $0.50/lb are considered to be probable candidates for laminate application. Unless the laminates can be made more cost competitive relative to steel, application on a large scale is not considered to be likely in the near future.

8.2.3 Potential Limitation of Metal-Plastic Laminates

Besides the cost constraint, some characteristics of metal-plastic laminates will also limit their use in certain automotive applications. Potential limitations of the laminates include:

a. Corrosion - The corrosion of the face sheets, particularly for steel faced laminates, is of greater concern with a laminate than the corrosion of a homogenious sheet. For a given level of corrosion penetration, the laminates will sufrer a significantly greater loss in mechanical properties.

TABLE 8-11. LAMINATE STUDY CANDIDATE PART COST/WEIGHT ANALYSIS - 1978 OMNI

	CURRENT PART						LAMINATE SUBSTITUTE					PER VEHICLE		
PART DESCRIPTION	FIN. WGT. (lb.)	MATL. (1)	BLANK COST ($)	BLANK WGT. (lb.)	VARI. PIECE COST ($)	USAGE	FIN. WGT. (lb.)	MATL. (2)	BLANK COST ($)	BLANK WGT. (lb.)	VARI. PIECE COST ($)	Δ WT $ -	Δ $ +	COST/LB SAVED
OMNI PARTS														
RR SEAT BACK PNL	15.22	.035 CRS	4.46	17.44	7.80	1	9.07	.040 SPS	8.54	14.00	12.83	6.15	5.03	.82
HOOD PANEL INNER	15.25	.035 CRS	7.63	30.5	10.43	1	7.74	.040 SNS	11.15	15.48	13.92	7.51	3.49	.46
LIFTGATE INNER	5.20	.033 CRS	6.45	25.8	10.50	1	2.9	.040 SNS	10.37	14.4	14.63	2.3	4.13	1.80
DOOR PANEL INNER-FT	6.94	.030 CRS	2.89	11.56	6.86	2	4.23	.040 SNS	5.14	7.05	9.14	5.42	4.56	.84
DOOR PANEL INNER-RR	4.46	.030 CRS	2.25	8.92	6.22	2	2.73	.040 SNS	3.92	5.45	7.92	3.46	3.40	.98

(1) CRS = Cold Rolled Steel
(2) SPS = Steel Polypropylene Steel
SNS = Steel Nylon Steel

Source: Reference 60

TABLE 8-12. LAMINATE STUDY CANDIDATE PART COST/WEIGHT ANALYSIS - 1980 F-150 PICKUP TRUCK

	CURRENT PART						LAMINATE SUBSTITUTE					PER VEHICLE		
PART DESCRIPTION	FIN. WGT. (lb.)	MATL. (1)	BLANK COST ($)	BLANK WGT. (lb.)	VARI. PIECE COST ($)	USAGE	FIN. WGT. (lb.)	MATL. (2)	BLANK COST ($)	BLANK WGT. (lb.)	VARI. PIECE COST ($)	Δ WT $ -	Δ $ +	COST/LB SAVED
F-150 PARTS		.030 AL	2.34	2.34				.035 ANA	3.20	1.84		.88		
ENG. AIR CLNR.	3.28	.030 CRS	.44	1.74	See Laminate	1	2.40	.040 SNS	.82	1.13	Δ +1.24		1.24	1.41
GRILLE BRKT-RT&LT	1.07	.032 CRS	.34	1.34	See Laminate	1	.62	.040 SPS	.48	.78	Δ + .14	.45	.14	.31
TORQUE CONV ACCESS PLT	.46	.037 CRS	.13	.51	See Laminate	1	.23	.040 SPS	.15	.25	Δ + .03	.23	.03	.13
FRONT SEAT FRAME	19.17	.044/ .053 HRS	5.33	21.31	22.97	1	9.59	.060 SPS	5.12	10.66	24.32	9.59	1.35	.14
FLOOR PAN ACCESS HOLE COVER	.27	.036 CRS	.07	.28	See Laminate	2	.14	.040 SPS	.09	.15	Δ + .02	.26	.04	.15
FRONT BRAKE DUSTSHIELD	1.06	.028 CRS	.44	1.74	See Laminate	2	.71	.040 SPS	.71	1.16	Δ + .27	.70	.54	.77
HUB CAP	.49	.025 AL	.63	.63	See Laminate	4	.33	.030 ANA	.78	.43	Δ + .16	.64	.61	.95

*48x62 SHEETS REQUIRED

(1) Al = Aluminum, CRS = Cold Rolled Steel, HRS = Hot Rolled Steel
(2) SPS = Steel-Polypropylene-Steel, ANA=Aluminum-Nylon-Aluminum, SNS = Steel-Nylon-Steel

Source: Reference 60

b. Joining - Joining of laminate parts to each other or to other components is complicated by the heterogeneity of the metal-plastic laminates. The presence of plastic core restricted the use of conventional resistance and fusion welding. Adhesive bonding appears to be the most suitable method for laminate joining. However, the strength of such joining is limited by the strength of skin and skin-polymer bond. Moreover, the time and temperature needed for cure also complicates the use of adhesive bonding.

c. Damage Repair - Metal-plastic laminates are not compatible with current finishing practice. The filing and grinding would remove all, or a significant portion, of the face sheet, thereby greatly weakening the laminate. The use of lead solders to fill indentations and joints will cause melting of the plastic core and is likely to result in local distortion.

d. Strength in Tension and Compression - Due to the low strength of the plastic core and the thinness of the metal skins, laminates have very low in-plane strength. This limits the use of laminates to components in which bending will be the major loading.

e. Laminate Width - The width of laminates is restricted by the width of the thin metal sheets commercially available. This limits the automotive use of laminates to applications for which the blank dimension is less than the maximum width of the laminate.

f. Recyling - There are three conceptual options for recycling laminate scrap: granulation of the laminates to reclaim a metal filled molding power; separation of the metal sheets from the plastic core with subsequent re-use of each material and; reclamation of the laminate for its scrap metal content. Only the last approach appears to be the most feasible. Difficulties which may result with this approach, other than for the low metal content per unit volume, would derive from the decomposition of the polymer core in the smelting furnace into particulates and noxious fumes, thereby increasing the duty requirements of the environmental control systems.

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APPENDIX A

PASSENGER CAR MATERIAL SUBSTITUTION

This appendix summarizes original material and weight of selected vehicular components and the weight of replacement components for the three baseline passenger vehicles. For each baseline vehicle, four alternative material dominant cases are presented. Tables A-1 through A-4, A-5 through A-8, and A-9 through A-12 tabulate component data for the 4-, 5-, and 6-passenger baseline vehicles respectively.

TABLE A-1 CHRYSLER OMNI 4-DOOR HATCHBACK
EQUIPPED WITH 105 CID ENGINE,
HSS DOMINANT CASE

PART NAME	CURRENT		ALTERNATIVE	
	MATERIAL	WT.(LBS)	MATERIAL	WT.(LBS)
FRONT FENDER PANEL	STEEL	27.6	HSS	22.9
FENDER EXTENSION & MOUNTING	STEEL	2.4	HSS	1.9
HOOD OUTER PANEL	HSS	17.8	HSS	17.8
HOOD INNER PANEL	STEEL	11.0	HSS	9.1
HOOD HINGE	HSS	2.3	HSS	2.3
RADIATOR CROSSMEMBER	STEEL	2.5	HSS	2.0
HOOD LAMP PANEL	STEEL	10.4	HSS	8.6
FRONT DOOR OUTER PANEL	STEEL	18.4	HSS	15.3
FRONT DOOR INNER PANEL	STEEL	16.4	HSS	13.6
FRONT DOOR HINGE & BRACKET	STEEL	9.2	HSS	7.4
FRONT DOOR GUARD BEAM	HSS	11.3	HSS	11.3
FRONT DOOR WINDOW FRAME	STEEL	7.5	HSS	6.0
REAR DOOR OUTER PANEL	STEEL	13.6	HSS	11.3
REAR DOOR INNER PANEL	STEEL	12.5	HSS	10.4
REAR DOOR PILLAR	HSS	5.9	HSS	5.9
REAR DOOR GUARD BEAM	HSS	7.0	HSS	7.0
REAR DOOR WINDOW FRAME	STEEL	7.8	HSS	6.2
REAR DOOR HINGE & BRACKET	STEEL	3.6	HSS	2.9
SIDE SILL PANEL	STEEL	40.1	HSS	33.3
BODY PILLAR	HSS	12.5	HSS	12.5
QUARTER PANEL & WHEEL WELL	STEEL	29.6	HSS	24.6
LIFT GATE TROUGH & SUPPORT	STEEL	9.2	HSS	7.4
SHOCK ABSORBER REINFORCEMENT	HSS	4.5	HSS	4.5
LIFT GATE OUTER PANEL	STEEL	10.1	HSS	8.4
LIFT GATE INNER PANEL	STEEL	8.4	HSS	7.0
LIFT GATE HINGE & SUPPORT	STEEL	3.9	HSS	3.1
DECK OPENING PANEL	STEEL	9.6	HSS	8.0
DECK OPENING SUPPORT	STEEL	2.9	HSS	2.3

*ESTIMATED WEIGHT

TABLE A-1 (CONT'D)

PART NAME	CURRENT		ALTERNATIVE	
	MATERIAL	WT.(LBS)	MATERIAL	WT.(LBS)
ROOF OUTER PANEL	STEEL	24.2	HSS	20.1
ROOF RAIL, BOW, & SUPPORT	STEEL	10.8	HSS	8.6
DASH PANEL	STEEL	12.4	HSS	10.3
DASH PANEL FRAME	STEEL	7.9	HSS	6.3
COWL TOP & SIDE PANEL	STEEL	19.7	HSS	16.4
COWL SUPPORT & FRAME	STEEL	14.9	HSS	11.9
BODY FRONT PILLAR & SUPPORT	HSS	10.7	HSS	10.7
FLOOR PAN	STEEL	59.7	HSS	49.6
SPARE TIRE WELL	STEEL	10.1	HSS	8.4
FLOOR PAN CROSSMEMBER	STEEL	10.4	HSS	8.3
SIDE RAIL & SILL	STEEL	27.3	HSS	21.8
UNDER BODY BRACKET & BRACE	STEEL	19.2	HSS	15.4
INSTRUMENT PANEL COVER	STEEL	2.9	HSS	2.4
FRONT FRAME	HSS	53.9	HSS	53.9
CROSSMEMBER & STRUT	STEEL	21.2	HSS	17.0
FRONT TOWER	STEEL	5.1	HSS	4.1
TOWER REINFORCEMENT	HSS	4.1	HSS	4.1
BATTERY TRAY	STEEL	3.0	HSS	2.5
FRONT SEAT TRACK	STEEL	9.9	HSS	7.9
FRONT SEAT FRAME	STEEL	29.4	HSS	23.5
REAR SEAT FRAME	STEEL	14.1	HSS	11.3
REAR SEAT PIN & BRACKET	STEEL	1.2	HSS	1.0
FRONT BUMPER	AL	8.6	AL	8.6
REAR BUMPER	AL	8.3	AL	8.3
FRONT COIL SPRING	STEEL	16.9	HRP	6.8
FRONT CONTROL ARM	STEEL	8.2	HSS	6.6
SWAYBAR	STEEL	10.1	HSS	8.1
REAR COIL SPRING	STEEL	8.7	HRP	3.5

*ESTIMATED WEIGHT

TABLE A-1 (CONT'D)

PART NAME	CURRENT		ALTERNATIVE	
	MATERIAL	WT.(LBS)	MATERIAL	WT.(LBS)
REAR CONTROL ARM	STEEL	16.9*	HSS	13.5
REAR SUSPENSION "X" MEMBER	HSS	20.0*	HSS	20.0
ENGINE BLOCK	IRON	71.9	IRON	71.9
CYLINDER HEAD	AL	17.7	AL	17.7
CONNECTING ROD	STEEL	5.0	STEEL	5.0
VALVE COVER	STEEL	1.9	HSS	1.6
OIL PAN	STEEL	5.9	HSS	4.9
AIR CLEANER	STEEL	3.5*	HSS	2.9
INTAKE MANIFOLD	AL	3.2	AL	3.2
EXHAUST MANIFOLD	IRON	8.2	STAINLESS STEEL	3.1
ENGINE MOUNT	STEEL	6.6*	HSS	5.3
CLUTCH DUST COVER	STEEL	1.0	HSS	0.8
FUEL TANK	TERNE	14.0	HDPE	9.1
FRONT BRAKE DISC	IRON	14.2	AL	7.1
FRONT BRAKE SPLASH SHIELD	STEEL	0.8	HSS	0.7
REAR BRAKE DRUM	IRON	21.4	AL	10.7
BRAKE PEDAL	HSS	2.9	HSS	2.9
PARKING BRAKE LEVEL	STEEL	2.8	HSS	2.2
GEAR SHIFT BRACKET	HSS	2.1	HSS	2.1
WHEEL	STEEL	81.3	AL	40.7
MISC. BRACKET & SUPPORT	STEEL	14.3	HSS	11.4

*ESTIMATED WEIGHT

TABLE A-2 1978 CHRYSLER ONMI 4-DOOR HATCHBACK
EQUIPPED WITH 105 CID ENGINE
FRP DOMINANT CASE

PART NAME	CURRENT		ALTERNATIVE	
	MATERIAL	WT.(LBS)	MATERIAL	WT.(LBS)
FRONT FENDER PANEL	STEEL	27.6	FRP	21.5
FENDER EXTENSION & MOUNTING	STEEL	2.4	HSS	1.9
HOOD OUTER PANEL	HSS	17.8	FRP	16.7
HOOD INNER PANEL	STEEL	11.0	FRP	8.6
HOOD HINGE	HSS	2.3	HSS	2.3
RADIATOR CROSSMEMBER	STEEL	2.5	HSS	2.0
HOOD LAMP PANEL	STEEL	10.4	FRP	8.1
FRONT DOOR OUTER PANEL	STEEL	18.4	FRP	14.4
FRONT DOOR INNER PANEL	STEEL	16.4	FRP	12.8
FRONT DOOR HINGE & BRACKET	STEEL	9.2	HSS	7.4
FRONT DOOR GUARD BEAM	HSS	11.3	HSS	11.3
FRONT DOOR WINDOW FRAME	STEEL	7.5	HSS	6.0
REAR DOOR OUTER PANEL	STEEL	13.6	FRP	10.6
REAR DOOR INNER PANEL	STEEL	12.5	FRP	9.8
REAR DOOR PILLAR	HSS	5.9	HSS	5.9
REAR DOOR GUARD BEAM	HSS	7.0	HSS	7.0
REAR DOOR WINDOW FRAME	STEEL	7.8	HSS	6.2
REAR DOOR HINGE & BRACKET	STEEL	3.6	HSS	2.9
SIDE SILL PANEL	STEEL	40.1	FRP	31.3
BODY PILLAR	HSS	12.5	HSS	12.5
QUARTER PANEL & WHEEL WELL	STEEL	29.6	FRP	23.1
LIFT GATE TROUGH & SUPPORT	STEEL	9.2	HSS	7.4
SHOCK ABSORBER REINFORCEMENT	HSS	4.5	HSS	4.5
LIFT GATE OUTER PANEL	STEEL	10.1	FRP	7.9
LIFT GATE INNER PANEL	STEEL	8.4	FRP	6.6
LIFT GATE HINGE & SUPPORT	STEEL	3.9	HSS	3.1
DECK OPENING PANEL	STEEL	9.6	FRP	7.5
DECK OPENING SUPPORT	STEEL	2.9	HSS	2.3

*ESTIMATED WEIGHT

TABLE A-2 (CONT'D)

PART NAME	CURRENT		ALTERNATIVE	
	MATERIAL	WT.(LBS)	MATERIAL	WT.(LBS)
ROOF OUTER PANEL	STEEL	24.2	FRP	18.9
ROOF RAIL, BOW, & SUPPORT	STEEL	10.8	HSS	8.6
DASH PANEL	STEEL	12.4	FRP	9.7
DASH PANEL FRAME	STEEL	7.9	HSS	6.3
COWL TOP & SIDE PANEL	STEEL	19.7	FRP	15.4
COWL SUPPORT & FRAME	STEEL	14.9	HSS	11.9
BODY FRONT PILLAR & SUPPORT	HSS	10.7	HSS	10.7
FLOOR PAN	STEEL	59.7	FRP	46.6
SPARE TIRE WELL	STEEL	10.1	FRP	7.9
FLOOR PAN CROSSMEMBER	STEEL	10.4	HSS	8.3
SIDE RAIL & SILL	STEEL	27.3	HSS	21.8
UNDER BODY BRACKET & BRACE	STEEL	19.2	HSS	15.4
INSTRUMENT PANEL COVER	STEEL	2.9	FRP	2.3
FRONT FRAME	HSS	53.9	HSS	53.9
CROSSMEMBER & STRUT	STEEL	21.2	HSS	17.0
FRONT TOWER	STEEL	5.1	HSS	4.1
TOWER REINFORCEMENT	HSS	4.1	HSS	4.1
BATTERY TRAY	STEEL	3.0	FRP	2.3
FRONT SEAT TRACK	STEEL	9.9	HSS	7.9
FRONT SEAT FRAME	STEEL	29.4	HSS	23.5
REAR SEAT FRAME	STEEL	14.1	HSS	11.3
REAR SEAT PIN & BRACKET	STEEL	1.2	HSS	1.0
FRONT BUMPER	AL	8.6	AL	8.6
REAR BUMPER	AL	8.3	AL	8.3
FRONT COIL SPRING	STEEL	16.9	HRP	6.8
FRONT CONTROL ARM	STEEL	8.2	HSS	6.6
SWAYBAR	STEEL	10.1	HSS	8.1
REAR COIL SPRING	STEEL	8.7	HRP	3.5

*ESTIMATED WEIGHT

TABLE A-2 (CONT'D)

PART NAME	CURRENT		ALTERNATIVE	
	MATERIAL	WT.(LBS)	MATERIAL	WT.(LBS)
REAR CONTROL ARM	STEEL	16.9*	HSS	13.5
REAR SUSPENSION "X" MEMBER	HSS	20.0*	HSS	20.0
ENGINE BLOCK	IRON	71.9	IRON	71.9
CYLINDER HEAD	AL	17.7	AL	17.7
CONNECTING ROD	STEEL	5.0	STEEL	5.0
VALVE COVER	STEEL	1.9	FRP	1.5
OIL PAN	STEEL	5.9	FRP	4.6
AIR CLEANER	STEEL	3.5*	FRP	2.7
INTAKE MANIFOLD	AL	3.2	AL	3.2
EXHAUST MANIFOLD	IRON	8.2	STAINLESS STEEL	3.1
ENGINE MOUNT	STEEL	6.6*	HSS	5.3
CLUTCH DUST COVER	STEEL	1.0	FRP	0.8
FUEL TANK	TERNE	14.0	HDPE	9.1
FRONT BRAKE DISC	IRON	14.2	AL	7.1
FRONT BRAKE SPLASH SHIELD	STEEL	0.8	FRP	0.6
REAR BRAKE DRUM	IRON	21.4	AL	10.7
BRAKE PEDAL	HSS	2.9	HSS	2.9
PARKING BRAKE LEVEL	STEEL	2.8	HSS	2.2
GEAR SHIFT BRACKET	HSS	2.1	HSS	2.1
WHEEL	STEEL	81.3	HRP	32.5
MISC. BRACKET & SUPPORT	STEEL	14.3	HSS	11.4

*ESTIMATED WEIGHT

TABLE A-3 CHRYSLER OMNI 4-DOOR HATCHBACK
EQUIPPED WITH 105 CID ENGINE
ALUMINUM DOMINANT CASE

PART NAME	CURRENT		ALTERNATIVE	
	MATERIAL	WT.(LBS)	MATERIAL	WT.(LBS)
FRONT FENDER PANEL	STEEL	27.6	AL	16.0
FENDER EXTENSION & MOUNTING	STEEL	2.4	HSS	1.9
HOOD OUTER PANEL	HSS	17.8	AL	12.4
HOOD INNER PANEL	STEEL	11.0	AL	6.4
HOOD HINGE	HSS	2.3	HSS	2.3
RADIATOR CROSSMEMBER	STEEL	2.5	HSS	2.0
HOOD LAMP PANEL	STEEL	10.4	AL	6.0
FRONT DOOR OUTER PANEL	STEEL	18.4	AL	10.7
FRONT DOOR INNER PANEL	STEEL	16.4	AL	9.5
FRONT DOOR HINGE & BRACKET	STEEL	9.2	HSS	7.4
FRONT DOOR GUARD BEAM	HSS	11.3	HSS	11.3
FRONT DOOR WINDOW FRAME	STEEL	7.5	HSS	6.0
REAR DOOR OUTER PANEL	STEEL	13.6	AL	7.9
REAR DOOR INNER PANEL	STEEL	12.5	AL	7.3
REAR DOOR PILLAR	HSS	5.9	HSS	5.9
REAR DOOR GUARD BEAM	HSS	7.0	HSS	7.0
REAR DOOR WINDOW FRAME	STEEL	7.8	HSS	6.2
REAR DOOR HINGE & BRACKET	STEEL	3.6	HSS	2.9
SIDE SILL PANEL	STEEL	40.1	AL	23.3
BODY PILLAR	HSS	12.5	HSS	12.5
QUARTER PANEL & WHEEL WELL	STEEL	29.6	AL	17.2
LIFT GATE TROUGH & SUPPORT	STEEL	9.2	HSS	7.4
SHOCK ABSORBER REINFORCEMENT	HSS	4.5	HSS	4.5
LIFT GATE OUTER PANEL	STEEL	10.1	AL	5.9
LIFT GATE INNER PANEL	STEEL	8.4	AL	4.9
LIFT GATE HINGE & SUPPORT	STEEL	3.9	HSS	3.1
DECK OPENING PANEL	STEEL	9.6	AL	5.6
DECK OPENING SUPPORT	STEEL	2.9	HSS	2.3

*ESTIMATED WEIGHT

TABLE A-3 (CONT'D)

PART NAME	CURRENT		ALTERNATIVE	
	MATERIAL	WT. (LBS)	MATERIAL	WT. (LBS)
ROOF OUTER PANEL	STEEL	24.2	AL	14.0
ROOF RAIL, BOW, & SUPPORT	STEEL	10.8	HSS	8.6
DASH PANEL	STEEL	12.4	AL	7.2
DASH PANEL FRAME	STEEL	7.9	HSS	6.3
COWL TOP & SIDE PANEL	STEEL	19.7	AL	11.4
COWL SUPPORT & FRAME	STEEL	14.9	HSS	11.9
BODY FRONT PILLAR & SUPPORT	HSS	10.7	HSS	10.7
FLOOR PAN	STEEL	59.7	AL	34.6
SPARE TIRE WELL	STEEL	10.1	AL	5.9
FLOOR PAN CROSSMEMBER	STEEL	10.4	HSS	8.3
SIDE RAIL & SILL	STEEL	27.3	HSS	21.8
UNDER BODY BRACKET & BRACE	STEEL	19.2	HSS	15.4
INSTRUMENT PANEL COVER	STEEL	2.9	AL	1.7
FRONT FRAME	HSS	53.9	HSS	53.9
CROSSMEMBER & STRUT	STEEL	21.2	HSS	17.0
FRONT TOWER	STEEL	5.1	HSS	4.1
TOWER REINFORCEMENT	HSS	4.1	HSS	4.1
BATTERY TRAY	STEEL	3.0	AL	1.7
FRONT SEAT TRACK	STEEL	9.9	HSS	7.9
FRONT SEAT FRAME	STEEL	29.4	HSS	23.5
REAR SEAT FRAME	STEEL	14.1	HSS	11.3
REAR SEAT PIN & BRACKET	STEEL	1.2	HSS	1.0
FRONT BUMPER	AL	8.6	AL	8.6
REAR BUMPER	AL	8.3	AL	8.3
FRONT COIL SPRING	STEEL	16.9	HRP	6.8
FRONT CONTROL ARM	STEEL	8.2	HSS	6.6
SWAYBAR	STEEL	10.1	HSS	8.1
REAR COIL SPRING	STEEL	8.7	HRP	3.5

*ESTIMATED WEIGHT

TABLE A-3 (CONT'D)

PART NAME	CURRENT		ALTERNATIVE	
	MATERIAL	WT.(LBS)	MATERIAL	WT.(LBS)
REAR CONTROL ARM	STEEL	16.9*	HSS	13.5
REAR SUSPENSION "X" MEMBER	HSS	20.0*	HSS	20.0
ENGINE BLOCK	IRON	71.9	AL	36.0
CYLINDER HEAD	AL	17.7	AL	17.7
CONNECTING ROD	STEEL	5.0	STEEL	5.0
VALVE COVER	STEEL	1.9	AL	1.1
OIL PAN	STEEL	5.9	AL	3.4
AIR CLEANER	STEEL	3.5*	AL	2.0
INTAKE MANIFOLD	AL	3.2	AL	3.2
EXHAUST MANIFOLD	IRON	8.2	STAINLESS STEEL	3.1
ENGINE MOUNT	STEEL	6.6*	HSS	5.3
CLUTCH DUST COVER	STEEL	1.0	AL	0.6
FUEL TANK	TERNE	14.0	HDPE	9.1
FRONT BRAKE DISC	IRON	14.2	AL	7.1
FRONT BRAKE SPLASH SHIELD	STEEL	0.8	AL	0.5
REAR BRAKE DRUM	IRON	21.4	AL	10.7
BRAKE PEDAL	HSS	2.9	HSS	2.9
PARKING BRAKE LEVEL	STEEL	2.8	HSS	2.2
GEAR SHIFT BRACKET	HSS	2.1	HSS	2.1
WHEEL	STEEL	81.3	AL	40.7
MISC. BRACKET & SUPPORT	STEEL	14.3	HSS	11.4

*ESTIMATED WEIGHT

TABLE A-4 1978 CHRYSLER OMNI 4-DOOR HATCHBACK
EQUIPPED WITH 105 CID ENGINE
HRP DOMINANT CASE

PART NAME	CURRENT		ALTERNATIVE	
	MATERIAL	WT.(LBS)	MATERIAL	WT.(LBS)
FRONT FENDER PANEL	STEEL	27.6	HRP	13.8
FENDER EXTENSION & MOUNTING	STEEL	2.4	HRP	1.0
HOOD OUTER PANEL	HSS	17.8	HRP	10.7
HOOD INNER PANEL	STEEL	11.0	HRP	5.5
HOOD HINGE	HSS	2.3	HRP	1.2
RADIATOR CROSSMEMBER	STEEL	2.5	HRP	1.0
HOOD LAMP PANEL	STEEL	10.4	HRP	5.2
FRONT DOOR OUTER PANEL	STEEL	18.4	HRP	9.2
FRONT DOOR INNER PANEL	STEEL	16.4	HRP	8.2
FRONT DOOR HINGE & BRACKET	STEEL	9.2	HRP	3.7
FRONT DOOR GUARD BEAM	HSS	11.3	HRP	5.7
FRONT DOOR WINDOW FRAME	STEEL	7.5	HRP	3.0
REAR DOOR OUTER PANEL	STEEL	13.6	HRP	6.8
REAR DOOR INNER PANEL	STEEL	12.5	HRP	6.3
REAR DOOR PILLAR	HSS	5.9	HRP	3.0
REAR DOOR GUARD BEAM	HSS	7.0	HRP	3.5
REAR DOOR WINDOW FRAME	STEEL	7.8	HRP	3.1
REAR DOOR HINGE & BRACKET	STEEL	3.6	HRP	1.4
SIDE SILL PANEL	STEEL	40.1	HRP	20.1
BODY PILLAR	HSS	12.5	HRP	6.3
QUARTER PANEL & WHEEL WELL	STEEL	29.6	HRP	14.8
LIFT GATE TROUGH & SUPPORT	STEEL	9.2	HRP	3.7
SHOCK ABSORBER REINFORCEMENT	HSS	4.5	HRP	2.3
LIFT GATE OUTER PANEL	STEEL	10.1	HRP	5.1
LIFT GATE INNER PANEL	STEEL	8.4	HRP	4.2
LIFT GATE HINGE & SUPPORT	STEEL	3.9	HRP	1.6
DECK OPENING PANEL	STEEL	9.6	HRP	4.8
DECK OPENING SUPPORT	STEEL	2.9	HRP	1.2

*ESTIMATED WEIGHT

TABLE A-4 (CONT'D)

PART NAME	CURRENT		ALTERNATIVE	
	MATERIAL	WT.(LBS)	MATERIAL	WT.(LBS)
ROOF OUTER PANEL	STEEL	24.2	HRP	12.1
ROOF RAIL, BOW, & SUPPORT	STEEL	10.8	HRP	4.3
DASH PANEL	STEEL	12.4	HRP	6.2
DASH PANEL FRAME	STEEL	7.9	HRP	3.2
COWL TOP & SIDE PANEL	STEEL	19.7	HRP	9.9
COWL SUPPORT & FRAME	STEEL	14.9	HRP	6.0
BODY FRONT PILLAR & SUPPORT	HSS	10.7	HRP	5.4
FLOOR PAN	STEEL	59.7	HRP	29.9
SPARE TIRE WELL	STEEL	10.1	HRP	5.1
FLOOR PAN CROSSMEMBER	STEEL	10.4	HRP	4.2
SIDE RAIL & SILL	STEEL	27.3	HRP	10.9
UNDER BODY BRACKET & BRACE	STEEL	19.2	HRP	7.7
INSTRUMENT PANEL COVER	STEEL	2.9	HRP	1.5
FRONT FRAME	HSS	53.9	HRP	27.0
CROSSMEMBER & STRUT	STEEL	21.2	HRP	8.5
FRONT TOWER	STEEL	5.1	HRP	2.0
TOWER REINFORCEMENT	HSS	4.1	HRP	2.1
BATTERY TRAY	STEEL	3.0	HRP	1.5
FRONT SEAT TRACK	STEEL	9.9	HRP	4.0
FRONT SEAT FRAME	STEEL	29.4	HRP	11.8
REAR SEAT FRAME	STEEL	14.1	HRP	5.6
REAR SEAT PIN & BRACKET	STEEL	1.2	HRP	0.5
FRONT BUMPER	AL	8.6	HRP	6.9
REAR BUMPER	AL	8.3	HRP	6.6
FRONT COIL SPRING	STEEL	16.9	HRP	6.8
FRONT CONTROL ARM	STEEL	8.2	HRP	3.3
SWAYBAR	STEEL	10.1	HRP	4.0
REAR COIL SPRING	STEEL	8.7	HRP	3.5

*ESTIMATED WEIGHT

TABLE A-4 (CONT'D)

PART NAME	CURRENT		ALTERNATIVE	
	MATERIAL	WT. (LBS)	MATERIAL	WT. (LBS)
REAR CONTROL ARM	STEEL	16.9*	HRP	6.8
REAR SUSPENSION "X" MEMBER	HSS	20.0*	HRP	10.0
ENGINE BLOCK	IRON	71.9	AL	36.0
CYLINDER HEAD	AL	17.7	AL	17.7
CONNECTING ROD	STEEL	5.0	HRP	2.0
VALVE COVER	STEEL	1.9	HRP	1.0
OIL PAN	STEEL	5.9	HRP	3.0
AIR CLEANER	STEEL	3.5*	HRP	1.8
INTAKE MANIFOLD	AL	3.2	AL	3.2
EXHAUST MANIFOLD	IRON	8.2	STAINLESS STEEL	3.1
ENGINE MOUNT	STEEL	6.6*	HRP	2.6
CLUTCH DUST COVER	STEEL	1.0	HRP	0.5
FUEL TANK	TERNE	14.0	HDPE	9.1
FRONT BRAKE DISC	IRON	14.2	AL	7.1
FRONT BRAKE SPLASH SHIELD	STEEL	0.8	HRP	0.4
REAR BRAKE DRUM	IRON	21.4	AL	10.7
BRAKE PEDAL	HSS	2.9	HRP	1.5
PARKING BRAKE LEVEL	STEEL	2.8	HRP	1.1
GEAR SHIFT BRACKET	HSS	2.1	HRP	1.1
WHEEL	STEEL	81.3	HRP	32.5
MISC. BRACKET & SUPPORT	STEEL	14.3	HRP	5.7

*ESTIMATED WEIGHT

TABLE A-5 1980 OLDSMOBILE OMEGA
FOUR DOOR X-BODY SEDAN
HSS DOMINANT CASE

PART NAME	CURRENT		ALTERNATIVE	
	MATERIAL	WT. (LBS)	MATERIAL	WT. (LBS)
HOOD OUTER PANEL	STEEL	21.75	HSS	18.05
HOOD INNER PANEL	STEEL	16.75	HSS	13.90
HOOD HINGES	STEEL	1.38	HSS	1.10
HOOD LATCH	STEEL	2.00	HSS	1.60
HOOD HOLDUP	STEEL	0.75	HSS	0.60
DECK LID OUTER PANEL	STEEL	18.25	HSS	15.15
DECK LID INNER PANEL	STEEL	13.75	HSS	11.41
DECK LID LATCH & LOCK	STEEL	1.38	HSS	1.10
FRONT FENDER PANEL	STEEL	20.00	HSS	16.60
BUMPER VALENCE PANEL	STEEL	0.59	HSS	0.49
FRONT DOOR INNER PANEL	STEEL	38.00	HSS	31.54
FRONT DOOR OUTER PANEL	STEEL	21.50	HSS	17.85
FRONT DOOR LATCH & LOCK	STEEL	5.50	HSS	4.40
FRONT DOOR HINGES	STEEL	2.75	HSS	2.20
FRONT DOOR SAFETY BEAM	STEEL	12.50	HSS	10.00
REAR DOOR INNER PANEL	STEEL	23.30	HSS	19.34
REAR DOOR OUTER PANEL	STEEL	16.50	HSS	13.70
ROOF DOOR LOCK & LATCH	STEEL	4.68	HSS	3.74
REAR DOOR HINGES	STEEL	2.19	HSS	1.75
REAR DOOR SAFETY BEAM	STEEL	9.00	HSS	7.20
FRONT DOOR PILLAR HINGE	STEEL	3.25	HSS	2.60
FRONT DOOR HINGE PINS & SPRING	STEEL	1.06	HSS	0.85
REAR DOOR PILLAR HINGE	STEEL	2.87	HSS	2.30
COWL PANEL	STEEL	4.31	HSS	3.58
WINDSHIELD WIPER LINKS	STEEL	2.09	HSS	1.67
FRONT END PANEL SUPPORT	STEEL	0.72	HSS	0.88
REAR COMPARTMENT TOP PANEL	STEEL	1.00	HSS	0.83
ASH TRAY & RADIO BRACKET	STEEL	0.53	HSS	0.42

*ESTIMATED WEIGHT

TABLE A-5 (CONT'D)

PART NAME	CURRENT		ALTERNATIVE	
	MATERIAL	WT. (LBS)	MATERIAL	WT. (LBS)
FRONT SEAT FRAME	STEEL	29.50	HSS	24.49
LEFT SEAT TRACK ASSEMBLY	STEEL	4.16	HSS	3.33
RIGHT SEAT TRACK ASSEMBLY	STEEL	3.59	HSS	2.87
REAR SEAT BASE	STEEL	4.90*	HSS	3.92
REAR SEAT BACK	STEEL	3.70*	HSS	2.96
RADIATOR BRACE	STEEL	2.31	HSS	1.85
OUTER QUARTER PANEL	STEEL	26.94	HSS	22.36
REAR WHEEL WELL	STEEL	21.50	HSS	17.85
TAIL LIGHT PANEL	STEEL	6.00	HSS	4.98
OUTER ROOF PANEL	STEEL	33.31	HSS	27.65
ROOF RIBS	STEEL	16.75	HSS	13.40
FIREWALL	STEEL	7.94	HSS	6.59
SILL	HSS	32.19	HSS	32.19
FLOOR PANEL	STEEL	56.44	HSS	46.85
A-POST	HSS	23.06	HSS	23.06
B-POST	STEEL	19.12	HSS	15.30
REAR SHELF	STEEL	12.06	HSS	10.01
FRONT CENTER SUPPORT	STEEL	1.62	HSS	1.30
FRAME CRADLE	STEEL	35.00	HSS	28.00
REMAINING BODY PANEL	STEEL	294.87	HSS	244.74
LOWER CONTROL ARM	STEEL	10.50	HSS	8.40
STEERING STOP BRACKET	STEEL	1.44	HSS	1.15
KNUCKLE	CI	20.00	HSS	16.00
FRONT COIL SPRING	STEEL	20.00	HRP	8.00
SPRING SEAT	STEEL	2.62	HSS	2.17
STRUT MOUNTING ASSEMBLY	STEEL	6.38	HSS	5.10
STABILIZER BAR	STEEL	9.75	HSS	7.80
FRONT SUSPENSION BRACKET	STEEL	1.50	HSS	1.20

*ESTIMATED WEIGHT

TABLE A-5 (CONT'D)

PART NAME	CURRENT		ALTERNATIVE	
	MATERIAL	WT.(LBS)	MATERIAL	WT.(LBS)
FRONT SUSPENSION PLATE	STEEL	1.19	HSS	0.99
ROTOR SHIELD	STEEL	1.00	HSS	0.83
AXLE BEAM	STEEL	27.12	HSS	21.70
REAR CONTROL ARM	STEEL	6.06	HSS	4.85
SPRING PERCH	STEEL	4.25	HSS	3.53
ANTI-ROLL BAR	STEEL	8.22	HSS	6.58
TRACTION BAR	STEEL	3.81	HSS	3.05
REAR COIL SPRING	STEEL	11.00	HRP	4.40
TRAILING ARM BRACKET	STEEL	1.75	HSS	1.40
BRAKE CALIPER	CI	14.00	HSS	11.20
BRAKE ROTOR	CI	20.00	AL	10.00
BRAKE DRUM	CI	14.00	AL	7.00
BRAKE BACKING PLATE	STEEL	4.19	HSS	3.48
WHEEL CYLINDER	CI	1.31	HSS	1.05
PARKING BRAKE PEDAL & LOCK	STEEL	2.50	HSS	2.00
BRAKE PEDAL ASSEMBLY	STEEL	2.06	HSS	1.65
BRAKE PEDAL MOUNTING BRACKET	STEEL	1.38	HSS	1.10
CYLINDER HEAD	CI	49.00	AL	24.50
CYLINDER BLOCK	CI	87.00	CI	87.00
EXHAUST MANIFOLD	CI	12.00	SS	4.55
AIR CLEANER ASSEMBLY	STEEL	6.00	HSS	4.98
VALVE COVER	STEEL	3.75	HSS	3.11
OIL PAN	STEEL	5.06	HSS	4.20
PUSHROD	STEEL	1.06	HSS	0.85
CONNECTING ROD & CAP	STEEL	7.56	HSS	6.05
WATER PUMP PULLEY	STEEL	1.75	HSS	1.40
ROCKER ARM	STEEL	2.44	HSS	1.95
CRANK PULLEY	STEEL	3.25	HSS	2.60

*ESTIMATED WEIGHT

TABLE A-5 (CONT'D)

PART NAME	CURRENT		ALTERNATIVE	
	MATERIAL	WT.(LBS)	MATERIAL	WT.(LBS)
STEERING BRACKET	STEEL	3.38	HSS	2.70
AIR CONDITIONING BRACKET	STEEL	5.06	HSS	4.05
BRAKE BRACKET	STEEL	1.00	HSS	0.80
FUEL PUMP HEAT SHIELD	STEEL	0.59	HSS	0.49
ENGINE MOUNTING BRACKET	STEEL	6.50	HSS	5.20
THROTTLE ARM & BRACKET	STEEL	1.38	HSS	1.10
TRANSAXLE VALVE BODY COVER	STEEL	2.44	HSS	2.03
LEFT AXLE SHAFT	STEEL	2.81	HRP	1.12
RIGHT AXLE SHAFT	STEEL	3.62	HRP	1.44
FUEL TANK	STEEL	21.75	HDPE	14.14
FILLER NECK WITH VENT PIPE	STEEL	2.28	HSS	1.82
FUEL TANK FILLER DOOR	STEEL	1.09	HSS	0.90
FUEL TANK MOUNTING STRAP	STEEL	2.12	HSS	1.75
CONVERTER HEAT SHIELD	STEEL	3.75	HSS	3.11
STEERING SHAFT	STEEL	2.75	HSS	2.20
STEERING COLUMN JACKET	STEEL	2.56	HSS	2.05
SHIFT TUBE	STEEL	1.20	HSS	0.96
STEERING COLUMN MOUNTING BKT.	STEEL	1.06	HSS	0.85
RACK MOUNTING BRACKETS	STEEL	1.50	HSS	1.20
SHAFT SUPPORT BRACKET	STEEL	0.94	HSS	0.75
INTERMEDIATE SHAFT	STEEL	3.68	HSS	2.94
WHEELS	STEEL	69.00	AL	34.50
RADIATOR	CU/BRASS	15.50	AL	7.75
JACK & LUG WRENCH	STEEL	8.96	HSS	7.17
WHEEL CAPS	STEEL	17.00		
SPARE TIRE & WHEEL	ST/RUBBER	27.00		

*ESTIMATED WEIGHT

TABLE A-6 1980 OLDSMOBILE OMEGA
FOUR DOOR X-BODY SEDAN
FRP DOMINANT CASE

PART NAME	CURRENT		ALTERNATIVE	
	MATERIAL	WT.(LBS)	MATERIAL	WT.(LBS)
HOOD OUTER PANEL	STEEL	21.75	FRP	16.97
HOOD INNER PANEL	STEEL	16.75	FRP	13.07
HOOD HINGES	STEEL	1.38	HSS	1.10
HOOD LATCH	STEEL	2.00	HSS	1.60
HOOD HOLDUP	STEEL	0.75	HSS	0.60
DECK LID OUTER PANEL	STEEL	18.25	FRP	12.57
DECK LID INNER PANEL	STEEL	13.75	FRP	10.73
DECK LID LATCH & LOCK	STEEL	1.38	HSS	1.10
FRONT FENDER PANEL	STEEL	20.00	FRP	13.78
BUMPER VALENCE PANEL	STEEL	0.59	FRP	0.41
FRONT DOOR INNER PANEL	STEEL	38.00	FRP	29.64
FRONT DOOR OUTER PANEL	STEEL	21.50	FRP	16.77
FRONT DOOR LATCH & LOCK	STEEL	5.50	HSS	4.40
FRONT DOOR HINGES	STEEL	2.75	HSS	2.20
FRONT DOOR SAFETY BEAM	STEEL	12.50	HSS	10.00
REAR DOOR INNER PANEL	STEEL	23.30	FRP	18.17
REAR DOOR OUTER PANEL	STEEL	16.50	FRP	12.87
ROOF DOOR LOCK & LATCH	STEEL	4.68	HSS	3.74
REAR DOOR HINGES	STEEL	2.19	HSS	1.75
REAR DOOR SAFETY BEAM	STEEL	9.00	HSS	7.20
FRONT DOOR PILLAR HINGE	STEEL	3.25	HSS	2.60
FRONT DOOR HINGE PINS & SPRING	STEEL	1.06	HSS	0.85
REAR DOOR PILLAR HINGE	STEEL	2.87	HSS	2.30
COWL PANEL	STEEL	4.31	FRP	3.36
WINDSHIELD WIPER LINKS	STEEL	2.09	HSS	1.67
FRONT END PANEL SUPPORT	STEEL	0.72	HSS	0.58
REAR COMPARTMENT TOP PANEL	STEEL	1.00	FRP	0.78
ASH TRAY & RADIO BRACKET	STEEL	0.53	HSS	0.42

*ESTIMATED WEIGHT

TABLE A-6 (CONT'D)

PART NAME	CURRENT		ALTERNATIVE	
	MATERIAL	WT. (LBS)	MATERIAL	WT. (LBS)
FRONT SEAT FRAME	STEEL	29.50	FRP	23.01
LEFT SEAT TRACK ASSEMBLY	STEEL	4.16	HSS	3.33
RIGHT SEAT TRACK ASSEMBLY	STEEL	3.59	HSS	2.87
REAR SEAT BASE	STEEL	4.90*	HSS	3.92
REAR SEAT BACK	STEEL	3.70*	HSS	2.96
RADIATOR BRACE	STEEL	2.31	HSS	1.85
OUTER QUARTER PANEL	STEEL	26.94	FRP	21.01
REAR WHEEL WELL	STEEL	21.50	FRP	16.77
TAIL LIGHT PANEL	STEEL	6.00	FRP	4.68
OUTER ROOF PANEL	STEEL	33.31	FRP	25.98
ROOF RIBS	STEEL	16.75	HSS	13.40
FIREWALL	STEEL	7.94	FRP	6.19
SILL	HSS	32.19	HSS	32.19
FLOOR PANEL	STEEL	56.44	FRP	44.02
A-POST	HSS	23.06	HSS	23.06
B-POST	STEEL	19.12	HSS	15.30
REAR SHELF	STEEL	12.06	FRP	9.41
FRONT CENTER SUPPORT	STEEL	1.62	HSS	1.30
FRAME CRADLE	STEEL	35.00	HSS	28.00
REMAINING BODY PANEL	STEEL	294.87	FRP	230.00
LOWER CONTROL ARM	STEEL	10.50	HSS	8.40
STEERING STOP BRACKET	STEEL	1.44	HSS	1.15
KNUCKLE	CI	1.44	HSS	16.00
FRONT COIL SPRING	STEEL	20.00	HRP	8.00
SPRING SEAT	STEEL	2.62	FRP	2.04
STRUT MOUNTING ASSEMBLY	STEEL	6.38	HSS	5.10
STABILIZER BAR	STEEL	9.75	HSS	7.80
FRONT SUSPENSION BRACKET	STEEL	1.50	HSS	1.20

*ESTIMATED WEIGHT

TABLE A-6 (CONT'D)

PART NAME	CURRENT		ALTERNATIVE	
	MATERIAL	WT.(LBS)	MATERIAL	WT.(LBS)
FRONT SUSPENSION PLATE	STEEL	1.19	FRP	0.93
ROTOR SHIELD	STEEL	1.00	FRP	0.78
AXLE BEAM	STEEL	27.12	HSS	21.70
REAR CONTROL ARM	STEEL	6.06	HSS	4.85
SPRING PERCH	STEEL	4.25	FRP	3.32
ANTI-ROLL BAR	STEEL	8.22	HSS	6.58
TRACTION BAR	STEEL	3.81	HSS	3.05
REAR COIL SPRING	STEEL	11.00	HRP	4.40
TRAILING ARM BRACKET	STEEL	1.75	HSS	1.40
BRAKE CALIPER	CI	14.00	HSS	11.20
BRAKE ROTOR	CI	20.00	AL	10.00
BRAKE DRUM	CI	14.00	AL	7.00
BRAKE BACKING PLATE	STEEL	4.19	FRP	3.27
WHEEL CYLINDER	CI	1.31	HSS	1.05
PARKING BRAKE PEDAL & LOCK	STEEL	2.50	HSS	2.00
BRAKE PEDAL ASSEMBLY	STEEL	2.60	HSS	1.65
BRAKE PEDAL MOUNTING BRACKET	STEEL	1.38	HSS	1.10
CYLINDER HEAD	CI	49.00	AL	24.50
CYLINDER BLOCK	CI	87.00*	CI	87.00*
EXHAUST MANIFOLD	CI	12.00	SS	4.55
AIR CLEANER ASSEMBLY	STEEL	6.00	FRP	4.68
VALVE COVER	STEEL	3.75	FRP	2.93
OIL PAN	STEEL	5.06	FRP	3.95
PUSHROD	STEEL	1.06	HSS	0.85
CONNECTING ROD & CAP	STEEL	7.56	HSS	6.05
WATER PUMP PULLEY	STEEL	1.75	HSS	1.40
ROCKER ARM	STEEL	2.44	HSS	1.95
CRANK PULLEY	STEEL	3.25	HSS	2.60

*ESTIMATED WEIGHT

TABLE A-6 (CONT'D)

PART NAME	CURRENT		ALTERNATIVE	
	MATERIAL	WT. (LBS)	MATERIAL	WT. (LBS)
STEERING BRACKET	STEEL	3.38	HSS	2.70
AIR CONDITIONING BRACKET	STEEL	5.06	HSS	4.05
BRAKE BRACKET	STEEL	1.00	HSS	0.80
FUEL PUMP HEAT SHIELD	STEEL	0.59	FRP	0.46
ENGINE MOUNTING BRACKET	STEEL	6.50	HSS	5.20
THROTTLE ARM & BRACKET	STEEL	1.38	HSS	1.10
TRANSAXLE VALVE BODY COVER	STEEL	2.44	FRP	1.90
LEFT AXLE SHAFT	STEEL	2.81	HRP	1.12
RIGHT AXLE SHAFT	STEEL	3.62	HRP	1.44
FUEL TANK	STEEL	21.75	HDPE	14.14
FILLER NECK WITH VENT PIPE	STEEL	2.28	HSS	1.82
FUEL TANK FILLER DOOR	STEEL	1.09	FRP	0.85
FUEL TANK MOUNTING STRAP	STEEL	2.12	FRP	1.65
CONVERTER HEAT SHIELD	STEEL	3.75	FRP	2.93
STEERING SHAFT	STEEL	2.75	HSS	2.20
STEERING COLUMN JACKET	STEEL	2.56	HSS	2.05
SHIFT TUBE	STEEL	1.20	HSS	0.96
STEERING COLUMN MOUNTING BKT.	STEEL	1.06	HSS	0.85
RACK MOUNTING BRACKETS	STEEL	1.50	HSS	1.20
SHAFT SUPPORT BRACKET	STEEL	0.94	HSS	0.75
INTERMEDIATE SHAFT	STEEL	3.68	HSS	2.94
WHEELS	STEEL	69.00	HRP	27.60
RADIATOR	CU/BRASS	15.50	AL	7.75
JACK & LUG WRENCH	STEEL	8.96	HSS	7.17
WHEEL CAPS				
SPARE TIRE & WHEEL				

*ESTIMATED WEIGHT

TABLE A-7 1980 OLDSMOBILE OMEGA
FOUR DOOR X-BODY SEDAN
ALUMINUM DOMINANT CASE

PART NAME	CURRENT		ALTERNATIVE	
	MATERIAL	WT.(LBS)	MATERIAL	WT.(LBS)
HOOD OUTER PANEL	STEEL	21.75	AL	12.62
HOOD INNER PANEL	STEEL	16.75	AL	9.75
HOOD HINGES	STEEL	1.38	AL	0.69
HOOD LATCH	STEEL	2.00	AL	1.00
HOOD HOLDUP	STEEL	0.75	AL	0.38
DECK LID OUTER PANEL	STEEL	18.25	AL	10.44
DECK LID INNER PANEL	STEEL	13.75	AL	7.98
DECK LID LATCH & LOCK	STEEL	1.38	AL	0.69
FRONT FENDER PANEL	STEEL	20.00	AL	11.44
BUMPER VALENCE PANEL	STEEL	0.59	AL	0.34
FRONT DOOR INNER PANEL	STEEL	38.00	AL	22.04
FRONT DOOR OUTER PANEL	STEEL	21.50	AL	12.47
FRONT DOOR LATCH & LOCK	STEEL	5.50	AL	3.19
FRONT DOOR HINGES	STEEL	2.75	AL	1.38
FRONT DOOR SAFETY BEAM	STEEL	12.50	HSS	10.00
REAR DOOR INNER PANEL	STEEL	23.30	AL	13.51
REAR DOOR OUTER PANEL	STEEL	16.50	AL	9.57
ROOF DOOR LOCK & LATCH	STEEL	4.68	AL	2.34
REAR DOOR HINGES	STEEL	2.19	AL	1.10
REAR DOOR SAFETY BEAM	STEEL	9.00	HSS	7.20
FRONT DOOR PILLAR HINGE	STEEL	3.25	AL	1.63
FRONT DOOR HINGE PINS & SPRING	STEEL	1.06	AL	0.53
REAR DOOR PILLAR HINGE	STEEL	2.87	AL	1.44
COWL PANEL	STEEL	4.31	AL	2.50
WINDSHIELD WIPER LINKS	STEEL	2.09	AL	1.05
FRONT END PANEL SUPPORT	STEEL	0.72	AL	0.36
REAR COMPARTMENT TOP PANEL	STEEL	1.00	AL	0.58
ASH TRAY & RADIO BRACKET	STEEL	0.53	AL	0.27

*ESTIMATED WEIGHT

TABLE A-7 (CONT'D)

PART NAME	CURRENT		ALTERNATIVE	
	MATERIAL	WT. (LBS)	MATERIAL	WT. (LBS)
FRONT SEAT FRAME	STEEL	29.50	AL	17.11
LEFT SEAT TRACK ASSEMBLY	STEEL	4.16	HSS	3.33
RIGHT SEAT TRACK ASSEMBLY	STEEL	3.59	HSS	2.87
REAR SEAT BASE	STEEL	4.90*	HSS	3.92
REAR SEAT BACK	STEEL	3.70*	HSS	2.96
RADIATOR BRACE	STEEL	2.31	HSS	1.85
OUTER QUARTER PANEL	STEEL	26.94	AL	15.63
REAR WHEEL WELL	STEEL	21.50	AL	12.47
TAIL LIGHT PANEL	STEEL	6.00	AL	3.48
OUTER ROOF PANEL	STEEL	33.31	AL	19.32
ROOF RIBS	STEEL	16.75	HSS	13.40
FIREWALL	STEEL	7.94	AL	4.61
SILL	HSS	32.19	HSS	32.19
FLOOR PANEL	STEEL	56.44	AL	32.74
A-POST	HSS	23.06	HSS	23.06
B-POST	STEEL	19.12	HSS	15.30
REAR SHELF	STEEL	12.06	AL	6.99
FRONT CENTER SUPPORT	STEEL	1.62	AL	0.81
FRAME CRADLE	STEEL	35.00	HSS	28.00
REMAINING BODY PANEL	STEEL	294.87	AL	171.02
LOWER CONTROL ARM	STEEL	10.50	HSS	8.40
STEERING STOP BRACKET	STEEL	1.44	AL	0.72
KNUCKLE	CI	20.00	AL	10.00
FRONT COIL SPRING	STEEL	20.00	HRP	8.00
SPRING SEAT	STEEL	2.62	AL	1.52
STRUT MOUNTING ASSEMBLY	STEEL	6.38	AL	3.19
STABILIZER BAR	STEEL	9.75	AL	4.88
FRONT SUSPENSION BRACKET	STEEL	1.50	AL	0.75

*ESTIMATED WEIGHT

TABLE A-7 (CONT'D)

PART NAME	CURRENT		ALTERNATIVE	
	MATERIAL	WT. (LBS)	MATERIAL	WT. (LBS)
FRONT SUSPENSION PLATE	STEEL	1.19	AL	0.69
ROTOR SHIELD	STEEL	1.00	AL	0.58
AXLE BEAM	STEEL	27.12	HSS	21.70
REAR CONTROL ARM	STEEL	6.06	HSS	4.85
SPRING PERCH	STEEL	4.25	AL	2.47
ANTI-ROLL BAR	STEEL	8.22	AL	4.11
TRACTION BAR	STEEL	3.81	AL	1.91
REAR COIL SPRING	STEEL	11.00	HRP	4.40
TRAILING ARM BRACKET	STEEL	1.75	AL	0.88
BRAKE CALIPER	CI	14.00	AL	7.00
BRAKE ROTOR	CI	20.00	AL	10.00
BRAKE DRUM	CI	14.00	AL	7.00
BRAKE BACKING PLATE	STEEL	4.19	AL	2.43
WHEEL CYLINDER	CI	1.31	AL	0.66
PARKING BRAKE PEDAL & LOCK	STEEL	2.50	AL	1.25
BRAKE PEDAL ASSEMBLY	STEEL	2.06	AL	1.03
BRAKE PEDAL MOUNTING BRACKET	STEEL	1.38	AL	0.69
CYLINDER HEAD	CI	49.00	AL	24.50
CYLINDER BLOCK	CI	87.00*	AL	43.50
EXHAUST MANIFOLD	CI	12.00	SS	4.55
AIR CLEANER ASSEMBLY	STEEL	6.00	AL	3.48
VALVE COVER	STEEL	3.75	AL	2.18
OIL PAN	STEEL	5.06	AL	2.93
PUSHROD	STEEL	1.06	AL	0.53
CONNECTING ROD & CAP	STEEL	7.56	AL	3.78
WATER PUMP PULLEY	STEEL	1.75	AL	0.88
ROCKER ARM	STEEL	2.44	AL	1.22
CRANK PULLEY	STEEL	3.25	AL	1.63

*ESTIMATED WEIGHT

TABLE A-7 (CONT'D)

PART NAME	CURRENT		ALTERNATIVE	
	MATERIAL	WT. (LBS)	MATERIAL	WT. (LBS)
STEERING BRACKET	STEEL	3.38	AL	1.69
AIR CONDITIONING BRACKET	STEEL	5.06	AL	2.53
BRAKE BRACKET	STEEL	1.00	AL	0.50
FUEL PUMP HEAT SHIELD	STEEL	0.59	AL	0.34
ENGINE MOUNTING BRACKET	STEEL	6.50	AL	3.25
THROTTLE ARM & BRACKET	STEEL	1.38	AL	0.69
TRANSAXLE VALVE BODY COVER	STEEL	2.44	AL	1.42
LEFT AXLE SHAFT	STEEL	2.81	HRP	1.12
RIGHT AXLE SHAFT	STEEL	3.62	HRP	1.44
FUEL TANK	STEEL	21.75	HDPE	14.14
FILLER NECK WITH VENT PIPE	STEEL	2.28	HSS	1.82
FUEL TANK FILLER DOOR	STEEL	1.09	AL	0.63
FUEL TANK MOUNTING STRAP	STEEL	2.12	AL	1.23
CONVERTER HEAT SHIELD	STEEL	3.75	AL	2.18
STEERING SHAFT	STEEL	2.75	HSS	2.20
STEERING COLUMN JACKET	STEEL	2.56	HSS	2.05
SHIFT TUBE	STEEL	1.20	AL	0.60
STEERING COLUMN MOUNTING BKT.	STEEL	1.06	AL	0.53
RACK MOUNTING BRACKETS	STEEL	1.50	AL	0.75
SHAFT SUPPORT BRACKET	STEEL	0.94	AL	0.47
INTERMEDIATE SHAFT	STEEL	3.68	AL	1.84
WHEELS	STEEL	69.00	AL	34.50
RADIATOR	CU/BRASS	15.50	AL	7.75
JACK & LUG WRENCH	STEEL	8.96	AL	4.48
WHEEL CAPS	STEEL	17.00		
SPARE TIRE & WHEEL	ST/RUBBER	27.00		

*ESTIMATED WEIGHT

TABLE A-8 1980 OLDSMOBILE OMEGA
FOUR DOOR X-BODY SEDAN
HRP DOMIANT CASE

PART NAME	CURRENT		ALTERNATIVE	
	MATERIAL	WT.(LBS)	MATERIAL	WT.(LBS)
HOOD OUTER PANEL	STEEL	21.75	HRP	10.88
HOOD INNER PANEL	STEEL	16.75	HRP	8.38
HOOD HINGES	STEEL	1.38	HRP	0.55
HOOD LATCH	STEEL	2.00	HRP	0.80
HOOD HOLDUP	STEEL	0.75	HRP	0.38
DECK LID OUTER PANEL	STEEL	18.25	HRP	9.13
DECK LID INNER PANEL	STEEL	13.75	HRP	6.88
DECK LID LATCH & LOCK	STEEL	1.38	HRP	0.54
FRONT FENDER PANEL	STEEL	20.00	HRP	10.00
BUMPER VALENCE PANEL	STEEL	0.59	HRP	0.30
FRONT DOOR INNER PANEL	STEEL	38.00	HRP	19.00
FRONT DOOR OUTER PANEL	STEEL	21.50	HRP	10.75
FRONT DOOR LATCH & LOCK	STEEL	5.50	HRP	2.20
FRONT DOOR HINGES	STEEL	2.75	HRP	1.10
FRONT DOOR SAFETY BEAM	STEEL	12.50	HRP	5.00
REAR DOOR INNER PANEL	STEEL	23.30	HRP	11.65
REAR DOOR OUTER PANEL	STEEL	16.50	HRP	8.25
ROOF DOOR LOCK & LATCH	STEEL	4.68	HRP	1.87
REAR DOOR HINGES	STEEL	2.19	HRP	0.88
REAR DOOR SAFETY BEAM	STEEL	9.00	HRP	3.60
FRONT DOOR PILLAR HINGE	STEEL	3.25	HRP	1.30
FRONT DOOR HINGE PINS & SPRING	STEEL	1.06	HRP	0.42
REAR DOOR PILLAR HINGE	STEEL	2.87	HRP	1.15
COWL PANEL	STEEL	4.31	HRP	2.16
WINDSHIELD WIPER LINKS	STEEL	2.09	HRP	0.84
FRONT END PANEL SUPPORT	STEEL	0.72	HRP	0.29
REAR COMPARTMENT TOP PANEL	STEEL	1.00	HRP	0.50
ASH TRAY & RADIO BRACKET	STEEL	0.53	HRP	0.21

*ESTIMATED WEIGHT

TABLE A-8 (CONT'D)

PART NAME	CURRENT		ALTERNATIVE	
	MATERIAL	WT. (LBS)	MATERIAL	WT. (LBS)
FRONT SEAT FRAME	STEEL	29.50	HRP	14.75
LEFT SEAT TRACK ASSEMBLY	STEEL	4.16	HRP	1.66
RIGHT SEAT TRACK ASSEMBLY	STEEL	3.59	HRP	1.44
REAR SEAT BASE	STEEL	4.90*	HRP	1.96
REAR SEAT BACK	STEEL	3.70*	HRP	1.48
RADIATOR BRACE	STEEL	2.31	HRP	0.92
OUTER QUARTER PANEL	STEEL	26.94	HRP	13.47
REAR WHEEL WELL	STEEL	21.50	HRP	10.75
TAIL LIGHT PANEL	STEEL	6.00	HRP	3.00
OUTER ROOF PANEL	STEEL	33.31	HRP	16.66
ROOF RIBS	STEEL	16.75	HRP	6.70
FIREWALL	STEEL	7.94	HRP	3.97
SILL	HSS	32.19	HRP	16.10
FLOOR PANEL	STEEL	56.44	HRP	28.22
A-POST	HSS	23.06	HRP	11.80
B-POST	STEEL	19.12	HRP	7.65
REAR SHELF	STEEL	12.06	HRP	6.03
FRONT CENTER SUPPORT	STEEL	1.62	HRP	0.65
FRAME CRADLE	STEEL	35.00	HRP	17.50
REMAINING BODY PANEL	STEEL	294.87	HRP	147.44
LOWER CONTROL ARM	STEEL	10.50	HRP	4.20
STEERING STOP BRACKET	STEEL	1.44	HRP	0.58
KNUCKLE	CI	20.00	HRP	8.00
FRONT COIL SPRING	STEEL	20.00	HRP	8.00
SPRING SEAT	STEEL	2.62	HRP	1.31
STRUT MOUNTING ASSEMBLY	STEEL	6.38	HRP	2.55
STABILIZER BAR	STEEL	9.75	HRP	3.90
FRONT SUSPENSION BRACKET	STEEL	1.50	HRP	0.60

*ESTIMATED WEIGHT

TABLE A-8 (CONT'D)

PART NAME	CURRENT		ALTERNATIVE	
	MATERIAL	WT.(LBS)	MATERIAL	WT.(LBS)
FRONT SUSPENSION PLATE	STEEL	1.19	HRP	0.60
ROTOR SHIELD	STEEL	1.00	HRP	0.50
AXLE BEAM	STEEL	27.12	HRP	10.85
REAR CONTROL ARM	STEEL	6.06	HRP	2.42
SPRING PERCH	STEEL	4.25	HRP	2.13
ANTI-ROLL BAR	STEEL	8.22	HRP	4.11
TRACTION BAR	STEEL	3.81	HRP	1.52
REAR COIL SPRING	STEEL	11.00	HRP	4.40
TRAILING ARM BRACKET	STEEL	1.75	HRP	0.70
BRAKE CALIPER	CI	14.00	HRP	5.60
BRAKE ROTOR	CI	20.00	AL	10.00
BRAKE DRUM	CI	14.00	AL	7.00
BRAKE BACKING PLATE	STEEL	4.19	HRP	2.10
WHEEL CYLINDER	CI	1.31	HRP	0.52
PARKING BRAKE PEDAL & LOCK	STEEL	2.50	HRP	1.00
BRAKE PEDAL ASSEMBLY	STEEL	2.06	HRP	0.82
BRAKE PEDAL MOUNTING BRACKET	STEEL	1.38	HRP	0.55
CYLINDER HEAD	CI	49.00	AL	24.50
CYLINDER BLOCK	CI	87.00*	AL	43.50
EXHAUST MANIFOLD	CI	12.00	SS	4.55
AIR CLEANER ASSEMBLY	STEEL	6.00	HRP	3.00
VALVE COVER	STEEL	3.75	HRP	1.88
OIL PAN	STEEL	5.06	HRP	2.53
PUSHROD	STEEL	1.06	HRP	0.42
CONNECTING ROD & CAP	STEEL	7.56	HRP	3.02
WATER PUMP PULLEY	STEEL	1.75	HRP	0.70
ROCKER ARM	STEEL	2.44	HRP	0.98
CRANK PULLEY	STEEL	3.25	HRP	1.30

*ESTIMATED WEIGHT

TABLE A-8 (CONT'D)

PART NAME	CURRENT		ALTERNATIVE	
	MATERIAL	WT. (LBS)	MATERIAL	WT. (LBS)
STEERING BRACKET	STEEL	3.38	HRP	1.35
AIR CONDITIONING BRACKET	STEEL	5.06	HRP	2.02
BRAKE BRACKET	STEEL	1.00	HRP	0.40
FUEL PUMP HEAT SHIELD	STEEL	0.59	HRP	0.30
ENGINE MOUNTING BRACKET	STEEL	6.50	HRP	2.60
THROTTLE ARM & BRACKET	STEEL	1.38	HRP	0.55
TRANSAXLE VALVE BODY COVER	STEEL	2.44	HRP	1.22
LEFT AXLE SHAFT	STEEL	2.81	HRP	1.12
RIGHT AXLE SHAFT	STEEL	3.62	HRP	1.44
FUEL TANK	STEEL	21.75	HDPE	14.14
FILLER NECK WITH VENT PIPE	STEEL	2.28	HRP	0.91
FUEL TANK FILLER DOOR	STEEL	1.09	HRP	0.55
FUEL TANK MOUNTING STRAP	STEEL	2.12	HRP	1.06
CONVERTER HEAT SHIELD	STEEL	3.75	HRP	1.88
STEERING SHAFT	STEEL	2.75	HRP	1.10
STEERING COLUMN JACKET	STEEL	2.56	HRP	1.02
SHIFT TUBE	STEEL	1.20	HRP	0.48
STEERING COLUMN MOUNTING BKT.	STEEL	1.06	HRP	0.42
RACK MOUNTING BRACKETS	STEEL	1.50	HRP	0.60
SHAFT SUPPORT BRACKET	STEEL	0.94	HRP	0.38
INTERMEDIATE SHAFT	STEEL	3.68	HRP	1.47
WHEELS	STEEL	69.00	HRP	27.60
RADIATOR	CU/BRASS	15.50	AL	7.75
JACK & LUG WRENCH	STEEL	8.96	HRP	3.58
WHEEL CAPS	STEEL	17.00		
SPARE TIRE & WHEEL	ST/RUBBER	27.00		

*ESTIMATED WEIGHT

TABLE A-9 1977 CHEVROLET IMPALA 4-DOOR SEDAN
EQUIPPED WITH 305 CID ENGINE
HSS DOMINANT CASE

PART NAME	CURRENT		ALTERNATIVE	
	MATERIAL	WT.(LBS)	MATERIAL	WT.(LBS)
FRONT FENDER OUTER PANEL	STEEL	31.0	HSS	25.7
FRONT FENDER INNER PANEL	STEEL	24.0	HSS	19.9
FRONT WHEEL HOUSING	STEEL	23.0	HSS	19.1
HOOD OUTER PANEL	STEEL	32.5	HSS	27.0
HOOD INNER PANEL	STEEL	20.0	HSS	16.6
HOOD HINGE	STEEL	12.0	HSS	9.6
RADIATOR SUPPORT	STEEL	26.5	HSS	21.2
FRONT DOOR OUTER PANEL	STEEL	24.0	HSS	19.9
FRONT DOOR INNER PANEL	STEEL	39.0	HSS	32.4
FRONT DOOR GUARD BEAM	STEEL	17.0	HSS	13.6
FRONT DOOR HINGE & LATCH PLATE	STEEL	23.4	HSS	18.7
REAR DOOR OUTER PANEL	STEEL	9.0	HSS	7.5
REAR DOOR INNER PANEL	STEEL	36.0	HSS	29.9
REAR DOOR GUARD BEAM	STEEL	11.0	HSS	8.8
DECK LID OUTER PANEL	STEEL	28.5	HSS	23.7
DECK LID INNER PANEL	STEEL	13.5	HSS	11.2
DECK LID HINGE	STEEL	6.0	HSS	4.8
QUARTER PANEL & WHEEL WELL	STEEL	72.0	HSS	59.8
TAIL LIGHT PANEL	STEEL	11.5	HSS	9.5
FIREWALL	STEEL	51.5	HSS	42.7
ROOF OUTER PANEL	STEEL	35.0	HSS	29.1
ROOF INNER PANEL	STEEL	25.5	HSS	21.2
FRAME	STEEL	261.0	HSS	208.8
SILL	STEEL	55.0	HSS	44.0
A POST	STEEL	45.0	HSS	36.0
B POST	STEEL	25.0	HSS	20.0
C POST	STEEL	18.0	HSS	14.4

*ESTIMATED WEIGHT

TABLE A-9 (CONT'D)

PART NAME	CURRENT		ALTERNATIVE	
	MATERIAL	WT.(LBS)	MATERIAL	WT.(LBS)
FLOOR PANEL	STEEL	106.0	HSS	88.0
REAR SHELF	STEEL	17.0	HSS	14.1
LOWER INSTRUMENT PANEL	STEEL	5.5	HSS	4.6
BATTERY TRAY	STEEL	2.4	HSS	2.0
WINDOW CHANNEL, RAIL & FRAME	STEEL	10.4	HSS	8.3
WINDOW CONTROL MECHANISM	STEEL	13.5	HSS	10.8
FRONT SEAT TRACK	STEEL	8.5	HSS	6.8
FRONT SEAT FRAME	STEEL	34.5	HSS	27.6
FRONT SEAT BACK	STEEL	10.5	HSS	8.7
REAR SEAT FRAME	STEEL	9.5	HSS	7.6
REAR SEAT BACK	STEEL	11.0	HSS	9.1
FRONT BUMPER & ENERGY ABSORBER	VARIOUS	73.5	FOAM	27.0
REAR BUMPER & ENERGY ABSORBER	VARIOUS	70.9	FOAM	27.0
FRONT COIL SPRING	STEEL	25.0	HRP	10.0
FRONT CONTROL ARM	STEEL	35.6	HSS	28.5
SWAY BAR & TIE ROD	STEEL	22.0	HSS	17.6
REAR LEAF SPRING	STEEL	15.0	HRP	6.0
REAR CONTROL ARM	STEEL	13.0	HSS	10.4
DRIVE SHAFT	STEEL	18.1	HRP	7.2
FRONT BRAKE DISC	IRON	44.5	AL	22.3
FRONT BRAKE PEDAL & SUPPORT	STEEL	3.7	HSS	3.0
REAR BRAKE DRUM	IRON	29.5	AL	14.8
REAR BRAKE BACKING PLATE	STEEL	6.4	HSS	5.1
MASTER CYLINDER	IRON	7.1	AL	3.6
ENGINE BLOCK	IRON	158.7*	IRON	158.7
CYLINDER HEAD	IRON	83.2*	AL	41.6
INTAKE MANIFOLD	IRON	39.7*	AL	19.9

*ESTIMATED WEIGHT

TABLE A-9 (CONT'D)

PART NAME	CURRENT		ALTERNATIVE	
	MATERIAL	WT. (LBS)	MATERIAL	WT. (LBS)
EXHAUST MANIFOLD	IRON	31.0	STAINLESS STEEL	11.6
WATER PUMP	IRON	12.2	AL	6.1
CONNECTING ROD	STEEL	11.6*	STEEL	11.6
VALVE COVER	STEEL	4.4	HSS	3.7
AIR CLEANER	STEEL	5.5	HSS	4.6
OIL PAN	STEEL	6.5	HSS	5.4
ENGINE MOUNT	STEEL	9.6	HSS	7.7
ENGINE #1 CROSSMEMBER	STEEL	18.6	HSS	14.9
ENGINE #2 CROSSMEMBER	STEEL	2.9	HSS	2.3
RADIATOR	COPPER	15.0	AL	7.5
HEATER CORE	COPPER	3.3	AL	1.7
FUEL TANK	TERNE	26.7	HDPE	17.4
TRANSMISSION FLUID PAN	STEEL	2.5	HSS	2.1
WHEEL	STEEL	107.0	AL	53.5
MISC. BRACKET & SUPPORT	STEEL	20.0*	HSS	16.0

*ESTIMATED WEIGHT

TABLE A-10 1977 CHEVROLET IMPALA 4-DOOR SEDAN EQUIPPED WITH 305 CID ENGINE FRP DOMINANT CASE

PART NAME	CURRENT		ALTERNATIVE	
	MATERIAL	WT. (LBS)	MATERIAL	WT. (LBS)
FRONT FENDER OUTER PANEL	STEEL	31.0	FRP	24.2
FRONT FENDER INNER PANEL	STEEL	24.0	FRP	18.7
FRONT WHEEL HOUSING	STEEL	23.0	FRP	17.9
HOOD OUTER PANEL	STEEL	32.5	FRP	25.4
HOOD INNER PANEL	STEEL	20.0	FRP	15.6
HOOD HINGE	STEEL	12.0	HSS	9.6
RADIATOR SUPPORT	STEEL	26.5	HSS	21.2
FRONT DOOR OUTER PANEL	STEEL	24.0	FRP	18.7
FRONT DOOR INNER PANEL	STEEL	39.0	FRP	30.4
FRONT DOOR GUARD BEAM	STEEL	17.0	HSS	13.6
FRONT DOOR HINGE & LATCH PLATE	STEEL	23.4	HSS	18.7
REAR DOOR OUTER PANEL	STEEL	9.0	FRP	7.0
REAR DOOR INNER PANEL	STEEL	36.0	FRP	28.1
REAR DOOR GUARD BEAM	STEEL	11.0	HSS	8.8
DECK LID OUTER PANEL	STEEL	28.5	FRP	22.2
DECK LID INNER PANEL	STEEL	13.5	FRP	10.5
DECK LID HINGE	STEEL	6.0	HSS	4.8
QUARTER PANEL & WHEEL WELL	STEEL	72.0	FRP	56.2
TAIL LIGHT PANEL	STEEL	11.5	FRP	9.0
FIREWALL	STEEL	51.5	FRP	40.2
ROOF OUTER PANEL	STEEL	35.0	FRP	27.3
ROOF INNER PANEL	STEEL	25.5	FRP	19.9
FRAME	STEEL	261.0	HSS	208.8
SILL	STEEL	55.0	HSS	44.0
A POST	STEEL	45.0	HSS	36.0
B POST	STEEL	25.0	HSS	20.0
C POST	STEEL	18.0	HSS	14.4

*ESTIMATED WEIGHT

TABLE A-10 (CONT'D)

PART NAME	CURRENT		ALTERNATIVE	
	MATERIAL	WT.(LBS)	MATERIAL	WT.(LBS)
FLOOR PANEL	STEEL	106.0	FRP	82.7
REAR SHELF	STEEL	17.0	FRP	13.3
LOWER INSTRUMENT PANEL	STEEL	5.5	FRP	4.3
BATTERY TRAY	STEEL	2.4	FRP	1.9
WINDOW CHANNEL, RAIL & FRAME	STEEL	10.4	HSS	8.3
WINDOW CONTROL MECHANISM	STEEL	13.5	HSS	10.8
FRONT SEAT TRACK	STEEL	8.5	HSS	6.8
FRONT SEAT FRAME	STEEL	34.5	HSS	27.6
FRONT SEAT BACK	STEEL	10.5	FRP	8.2
REAR SEAT FRAME	STEEL	9.5	HSS	7.6
REAR SEAT BACK	STEEL	11.0	FRP	8.6
FRONT BUMPER & ENERGY ABSORBER	VARIOUS	73.5	FOAM	27.0
REAR BUMPER & ENERGY ABSORBER	VARIOUS	70.9	FOAM	27.0
FRONT COIL SPRING	STEEL	25.0	HRP	10.0
FRONT CONTROL ARM	STEEL	35.6	HSS	28.5
SWAY BAR & TIE ROD	STEEL	22.0	HSS	17.6
REAR LEAF SPRING	STEEL	15.0	HRP	6.0
REAR CONTROL ARM	STEEL	13.0	HSS	10.4
DRIVE SHAFT	STEEL	18.1	HRP	7.2
FRONT BRAKE DISC	IRON	44.5	AL	22.3
FRONT BRAKE PEDAL & SUPPORT	STEEL	3.7	HSS	3.0
REAR BRAKE DRUM	IRON	29.5	AL	14.8
REAR BRAKE BACKING PLATE	STEEL	6.4	HSS	5.1
MASTER CYLINDER	IRON	7.1	AL	3.6
ENGINE BLOCK	IRON	158.7*	IRON	158.7
CYLINDER HEAD	IRON	83.2*	AL	41.6
INTAKE MANIFOLD	IRON	39.7*	AL	19.9

*ESTIMATED WEIGHT

TABLE A-10 (CONT'D)

PART NAME	CURRENT		ALTERNATIVE	
	MATERIAL	WT. (LBS)	MATERIAL	WT. (LBS)
EXHAUST MANIFOLD	IRON	31.0	STAINLESS STEEL	11.6
WATER PUMP	IRON	12.2	AL	6.1
CONNECTING ROD	STEEL	11.6*	STEEL	11.6
VALVE COVER	STEEL	4.4	FRP	3.4
AIR CLEANER	STEEL	5.5	FRP	4.3
OIL PAN	STEEL	6.5	FRP	5.1
ENGINE MOUNT	STEEL	9.6	HSS	7.7
ENGINE #1 CROSSMEMBER	STEEL	18.6	HSS	14.9
ENGINE #2 CROSSMEMBER	STEEL	2.9	HSS	2.3
RADIATOR	COPPER	15.0	AL	7.5
HEATER CORE	COPPER	3.3	AL	1.7
FUEL TANK	TERNE	26.7	HDPE	17.4
TRANSMISSION FLUID PAN	STEEL	2.5	FRP	2.0
WHEEL	STEEL	107.0	HRP	42.8
MISC. BRACKET & SUPPORT	STEEL	20.0*	HSS	16.0

*ESTIMATED WEIGHT

TABLE A-11 1977 CHEVROLET IMPALA 4-DOOR SEDAN
EQUIPPED WITH 305 CID ENGINE
ALUMINUM DOMINANT CASE

PART NAME	CURRENT		ALTERNATIVE	
	MATERIAL	WT.(LBS)	MATERIAL	WT.(LBS)
FRONT FENDER OUTER PANEL	STEEL	31.0	AL	18.0
FRONT FENDER INNER PANEL	STEEL	24.0	AL	13.9
FRONT WHEEL HOUSING	STEEL	23.0	AL	13.3
HOOD OUTER PANEL	STEEL	32.5	AL	18.9
HOOD INNER PANEL	STEEL	20.0	AL	11.6
HOOD HINGE	STEEL	12.0	HSS	9.6
RADIATOR SUPPORT	STEEL	26.5	HSS	21.2
FRONT DOOR OUTER PANEL	STEEL	24.0	AL	13.9
FRONT DOOR INNER PANEL	STEEL	39.0	AL	22.6
FRONT DOOR GUARD BEAM	STEEL	17.0	HSS	13.6
FRONT DOOR HINGE & LATCH PLATE	STEEL	23.4	HSS	18.7
REAR DOOR OUTER PANEL	STEEL	9.0	AL	5.2
REAR DOOR INNER PANEL	STEEL	36.0	AL	20.9
REAR DOOR GUARD BEAM	STEEL	11.0	HSS	8.8
DECK LID OUTER PANEL	STEEL	28.5	AL	16.5
DECK LID INNER PANEL	STEEL	13.5	AL	7.8
DECK LID HINGE	STEEL	6.0	HSS	4.8
QUARTER PANEL & WHEEL WELL	STEEL	72.0	Al	41.8
TAIL LIGHT PANEL	STEEL	11.5	AL	6.7
FIREWALL	STEEL	51.5	AL	29.9
ROOF OUTER PANEL	STEEL	35.0	AL	20.3
ROOF INNER PANEL	STEEL	25.5	AL	14.8
FRAME	STEEL	261.0	HSS	208.8
SILL	STEEL	55.0	HSS	44.0
A POST	STEEL	45.0	HSS	36.0
B POST	STEEL	25.0	HSS	20.0
C POST	STEEL	18.0	HSS	14.4

*ESTIMATED WEIGHT

TABLE A-11 (CONT'D)

PART NAME	CURRENT		ALTERNATIVE	
	MATERIAL	WT. (LBS)	MATERIAL	WT. (LBS)
FLOOR PANEL	STEEL	106.0	AL	61.5
REAR SHELF	STEEL	17.0	AL	9.9
LOWER INSTRUMENT PANEL	STEEL	5.5	AL	3.2
BATTERY TRAY	STEEL	2.4	AL	1.4
WINDOW CHANNEL, RAIL & FRAME	STEEL	10.4	HSS	8.3
WINDOW CONTROL MECHANISM	STEEL	13.5	HSS	10.8
FRONT SEAT TRACK	STEEL	8.5	HSS	6.8
FRONT SEAT FRAME	STEEL	34.5	HSS	27.6
FRONT SEAT BACK	STEEL	10.5	AL	6.1
REAR SEAT FRAME	STEEL	9.5	HSS	7.6
REAR SEAT BACK	STEEL	11.0	AL	6.4
FRONT BUMPER & ENERGY ABSORBER	VARIOUS	73.5	FOAM	27.0
REAR BUMPER & ENERGY ABSORBER	VARIOUS	70.9	FOAM	27.0
FRONT COIL SPRING	STEEL	25.0	HRP	10.0
FRONT CONTROL ARM	STEEL	35.6	HSS	28.5
SWAY BAR & TIE ROD	STEEL	22.0	HSS	17.6
REAR LEAF SPRING	STEEL	15.0	HRP	6.0
REAR CONTROL ARM	STEEL	13.0	HSS	10.4
DRIVE SHAFT	STEEL	18.1	HRP	7.2
FRONT BRAKE DISC	IRON	44.5	AL	22.3
FRONT BRAKE PEDAL & SUPPORT	STEEL	3.7	HSS	3.0
REAR BRAKE DRUM	IRON	29.5	AL	14.8
REAR BRAKE BACKING PLATE	STEEL	6.4	HSS	5.1
MASTER CYLINDER	IRON	7.1	AL	3.6
ENGINE BLOCK	IRON	158.7*	AL	79.4
CYLINDER HEAD	IRON	83.2*	AL	41.6
INTAKE MANIFOLD	IRON	39.7*	AL	19.9

*ESTIMATED WEIGHT

TABLE A-11 (CONT'D)

PART NAME	CURRENT		ALTERNATIVE	
	MATERIAL	WT. (LBS)	MATERIAL	WT. (LBS)
EXHAUST MANIFOLD	IRON	31.0	STAINLESS STEEL	11.6
WATER PUMP	IRON	12.2	AL	6.1
CONNECTING ROD	STEEL	11.6*	STEEL	11.6
VALVE COVER	STEEL	4.4	AL	2.6
AIR CLEANER	STEEL	5.5	AL	3.2
OIL PAN	STEEL	6.5	AL	3.8
ENGINE MOUNT	STEEL	9.6	HSS	7.7
ENGINE #1 CROSSMEMBER	STEEL	18.6	HSS	14.9
ENGINE #2 CROSSMEMBER	STEEL	2.9	HSS	2.3
RADIATOR	COPPER	15.0	AL	7.5
HEATER CORE	COPPER	3.3	AL	1.7
FUEL TANK	TERNE	26.7	HDPE	17.4
TRANSMISSION FLUID PAN	STEEL	2.5	AL	1.5
WHEEL	STEEL	107.0	AL	53.5
MISC. BRACKET & SUPPORT	STEEL	20.0*	HSS	16.0

*ESTIMATED WEIGHT

TABLE A-12 1977 CHEVROLET IMPALA 4-DOOR SEDAN
EQUIPPED WITH 305 CID ENGINE
HRP DOMINANT CASE

PART NAME	CURRENT		ALTERNATIVE	
	MATERIAL	WT. (LBS)	MATERIAL	WT. (LBS)
FRONT FENDER OUTER PANEL	STEEL	31.0	HRP	15.5
FRONT FENDER INNER PANEL	STEEL	24.0	HRP	12.0
FRONT WHEEL HOUSING	STEEL	23.0	HRP	11.5
HOOD OUTER PANEL	STEEL	32.5	HRP	16.3
HOOD INNER PANEL	STEEL	20.0	HRP	10.0
HOOD HINGE	STEEL	12.0	HRP	4.8
RADIATOR SUPPORT	STEEL	26.5	HRP	10.6
FRONT DOOR OUTER PANEL	STEEL	24.0	HRP	12.0
FRONT DOOR INNER PANEL	STEEL	39.0	HRP	19.5
FRONT DOOR GUARD BEAM	STEEL	17.0	HRP	6.8
FRONT DOOR HINGE & LATCH PLATE	STEEL	23.4	HRP	9.4
REAR DOOR OUTER PANEL	STEEL	9.0	HRP	4.5
REAR DOOR INNER PANEL	STEEL	36.0	HRP	18.0
REAR DOOR GUARD BEAM	STEEL	11.0	HRP	4.4
DECK LID OUTER PANEL	STEEL	28.5	HRP	14.3
DECK LID INNER PANEL	STEEL	13.5	HRP	6.8
DECK LID HINGE	STEEL	6.0	HRP	2.4
QUARTER PANEL & WHEEL WELL	STEEL	72.0	HRP	36.0
TAIL LIGHT PANEL	STEEL	11.5	HRP	5.8
FIREWALL	STEEL	51.5	HRP	25.8
ROOF OUTER PANEL	STEEL	35.0	HRP	17.5
ROOF INNER PANEL	STEEL	25.5	HRP	12.8
FRAME	STEEL	261.0	HRP	104.4
SILL	STEEL	55.0	HRP	22.0
A POST	STEEL	45.0	HRP	18.0
B POST	STEEL	25.0	HRP	10.0
C POST	STEEL	18.0	HRP	7.2

*ESTIMATED WEIGHT

TABLE A-12 (CONT'D)

PART NAME	CURRENT		ALTERNATIVE	
	MATERIAL	WT. (LBS)	MATERIAL	WT. (LBS)
FLOOR PANEL	STEEL	106.0	HRP	53.0
REAR SHELF	STEEL	17.0	HRP	8.5
LOWER INSTRUMENT PANEL	STEEL	5.5	HRP	2.8
BATTERY TRAY	STEEL	2.4	HRP	1.2
WINDOW CHANNEL, RAIL & FRAME	STEEL	10.4	HRP	4.2
WINDOW CONTROL MECHANISM	STEEL	13.5	HRP	5.4
FRONT SEAT TRACK	STEEL	8.5	HRP	3.4
FRONT SEAT FRAME	STEEL	34.5	HRP	13.8
FRONT SEAT BACK	STEEL	10.5	HRP	5.3
REAR SEAT FRAME	STEEL	9.5	HRP	3.8
REAR SEAT BACK	STEEL	11.0	HRP	5.5
FRONT BUMPER & ENERGY ABSORBER	VARIOUS	73.5	FOAM	27.0
REAR BUMPER & ENERGY ABSORBER	VARIOUS	70.9	FOAM	27.0
FRONT COIL SPRING	STEEL	25.0	HRP	10.0
FRONT CONTROL ARM	STEEL	35.6	HRP	14.2
SWAY BAR & TIE ROD	STEEL	22.0	HRP	8.8
REAR LEAF SPRING	STEEL	15.0	HRP	6.0
REAR CONTROL ARM	STEEL	13.0	HRP	5.2
DRIVE SHAFT	STEEL	18.1	HRP	7.2
FRONT BRAKE DISC	IRON	44.5	AL	22.3
FRONT BRAKE PEDAL & SUPPORT	STEEL	3.7	HRP	1.5
REAR BRAKE DRUM	IRON	29.5	AL	14.8
REAR BRAKE BACKING PLATE	STEEL	6.4	HRP	2.6
MASTER CYLINDER	IRON	7.1	AL	3.6
ENGINE BLOCK	IRON	158.7*	AL	79.4
CYLINDER HEAD	IRON	83.2*	AL	41.6
INTAKE MANIFOLD	IRON	39.7*	AL	19.9

*ESTIMATED WEIGHT

TABLE A-12 (CONT'D)

PART NAME	CURRENT		ALTERNATIVE	
	MATERIAL	WT. (LBS)	MATERIAL	WT. (LBS)
EXHAUST MANIFOLD	IRON	31.0	STAINLESS STEEL	11.6
WATER PUMP	IRON	12.2	AL	6.1
CONNECTING ROD	STEEL	11.6*	HRP	4.6
VALVE COVER	STEEL	4.4	HRP	2.2
AIR CLEANER	STEEL	5.5	HRP	2.8
OIL PAN	STEEL	6.5	HRP	3.3
ENGINE MOUNT	STEEL	9.6	HRP	3.8
ENGINE #1 CROSSMEMBER	STEEL	18.6	HRP	7.4
ENGINE #2 CROSSMEMBER	STEEL	2.9	HRP	1.2
RADIATOR	COPPER	15.0	ALUM	7.5
HEATER CORE	COPPER	3.3	ALUM	1.7
FUEL TANK	TERNE	26.7	HDPE	17.4
TRANSMISSION FLUID PAN	STEEL	2.5	HRP	1.3
WHEEL	STEEL	107.0	HRP	42.8
MISC. BRACKET & SUPPORT	STEEL	20.0*	HRP	8.0

*ESTIMATED WEIGHT

APPENDIX B

LIGHT TRUCK MATERIAL SUBSTITUTION

This appendix summarizes original material and weight of selected vehicular components and the weight of replacement components for the four baseline light trucks. For each baseline truck, four alternative material dominant cases are presented. Tables B-1 through B-4, B-5 through B-8, B-9 through B-12, and B-13 through B-16 tabulate component data for the baseline compact pickup truck, standard pickup truck, van, and utility vehicle respectively.

TABLE B-1 1978 CHEVROLET LUV PICKUP TRUCK HSS DOMINANT CASE

PART NAME	CURRENT		ALTERNATIVE	
	MATERIAL	WT. (LBS)	MATERIAL	WT. (LBS)
FRONT FENDER	STEEL	21.00	HSS	17.43
HOOD FRONT CLOSEOUT	STEEL	1.00	HSS	.83
AIR INTAKE GRILLE	STEEL	3.25	HSS	2.70
ENGINE COMP. SPLASH GUARD	STEEL	2.00	HSS	1.66
CARBON CANNISTER COVER	STEEL	3.00	HSS	2.49
BUMPER SPLASH GUARD	STEEL	3.50	HSS	2.91
HOOD INNER PANEL	STEEL	10.25	HSS	8.51
HOOD OUTER PANEL	STEEL	17.50	HSS	14.53
HOOD HINGE	STEEL	2.00	HSS	1.60
CAB	STEEL	234.00	HSS	194.22
CARGO BED	STEEL	195.00	HSS	161.85
TAILGATE	STEEL	31.50	HSS	26.15
TAILGATE LATCH & STRAP	STEEL	3.50	HSS	2.80
DOOR INNER PANEL	STEEL	29.00	HSS	24.07
DOOR OUTER PANEL	STEEL	21.00	HSS	17.43
DOOR HINGE	STEEL	5.50	HSS	4.40
SEAT FRAME	STEEL	16.00	HSS	12.80
SEAT TRACK	STEEL	4.75	HSS	3.80
FRAME	STEEL	221.50	HSS	177.20
FRONT SUSPENSION STRUT ARM	STEEL	5.50	HSS	4.44
SPINDLE	STEEL	20.00*	HSS	16.00
UPPER CONTROL ARM	STEEL	13.00*	HSS	10.40
LOWER CONTROL ARM	STEEL	10.00	HSS	8.00
TORSION BAR	STEEL	12.00	HSS	9.60
TORSION BAR MOUNT ARM	STEEL	9.00	HSS	7.20
STABILIZER BAR	STEEL	5.75	HSS	4.60
BRAKE DRUM	CI	28.00	AL	14.00
LEAF SPRING	STEEL	58.50	HRP	23.40

*ESTIMATED WEIGHT

TABLE B-1 (CONT'D)

PART NAME	CURRENT		ALTERNATIVE	
	MATERIAL	WT. (LBS)	MATERIAL	WT. (LBS)
REAR SHOCK MOUNT	STEEL	5.50	HSS	4.44
DRIVE SHAFT	STEEL	16.00	HRP	6.40
MASTER CYLINDER	CI	5.00*	AL	2.50
BRAKE ROTOR	CI	39.00	AL	19.5
DISC BRAKE CALIPER	STEEL	19.50	HSS	15.60
BRAKE PEDAL ASSEMBLY	STEEL	7.00	HSS	5.60
FUEL TANK	STEEL	16.75	HDPE	10.89
WHEEL	STEEL	100.00*	AL	50.00
RADIATOR	CU	9.00	AL	4.50
FRONT BUMPER	STEEL	10.50	AL	5.25
BUMPER MOUNT	STEEL	8.50	HSS	6.80
JACK & LUG WRENCH	STEEL	11.50	HSS	9.20
ENGINE BLOCK	CI	72.00**	CI	72.00
CONNECTING ROD	STEEL	5.00*	HSS	4.00
VALVE COVER	STEEL	2.00*	HSS	1.66
OIL PAN	STEEL	6.00*	HSS	4.98
AIR CLEANER	STEEL	3.50*	HSS	2.91
EXHAUST MANIFOLD	CI	8.00*	SS	3.04

*ESTIMATED WEIGHT

TABLE B-2 1978 CHEVROLET LUV PICKUP TRUCK FRP DOMINANT CASE

PART NAME	CURRENT		ALTERNATIVE	
	MATERIAL	WT. (LBS)	MATERIAL	WT. (LBS)
FRONT FENDER	STEEL	21.00	FRP	16.38
HOOD FRONT CLOSEOUT	STEEL	1.00	FRP	0.78
AIR INTAKE GRILLE	STEEL	3.25	FRP	2.54
ENGINE COMP. SPLASH GUARD	STEEL	2.00	FRP	1.56
CARBON CANNISTER COVER	STEEL	3.00	FRP	2.34
BUMPER SPLASH GUARD	STEEL	3.50	FRP	2.73
HOOD INNER PANEL	STEEL	10.25	FRP	8.00
HOOD OUTER PANEL	STEEL	17.50	FRP	13.65
HOOD HINGE	STEEL	2.00	HSS	1.60
CAB	STEEL	234.00	FRP	182.52
CARGO BED	STEEL	195.00	FRP	152.10
TAILGATE	STEEL	31.50	FRP	24.57
TAILGATE LATCH & STRAP	STEEL	3.50	HSS	2.80
DOOR INNER PANEL	STEEL	29.00	FRP	22.62
DOOR OUTER PANEL	STEEL	21.00	FRP	16.38
DOOR HINGE	STEEL	5.50	HSS	4.40
SEAT FRAME	STEEL	16.00	HSS	12.80
SEAT TRACK	STEEL	4.75	HSS	3.80
FRAME	STEEL	221.50	HSS	177.20
FRONT SUSPENSION STRUT ARM	STEEL	5.50	HSS	4.44
SPINDLE	STEEL	20.00*	HSS	16.00
UPPER CONTROL ARM	STEEL	13.00*	HSS	10.40
LOWER CONTROL ARM	STEEL	10.00	HSS	8.00
TORSION BAR	STEEL	12.00	HSS	9.60
TORSION BAR MOUNT ARM	STEEL	9.00	HSS	7.20
STABILIZER BAR	STEEL	5.75	HSS	4.60
BRAKE DRUM	CI	28.00	AL	14.00
LEAF SPRING	STEEL	58.50	HRP	23.40

*ESTIMATED WEIGHT

TABLE B-2 (CONT'D)

PART NAME	CURRENT		ALTERNATIVE	
	MATERIAL	WT.(LBS)	MATERIAL	WT.(LBS)
REAR SHOCK MOUNT	STEEL	5.50	HSS	4.44
DRIVE SHAFT	STEEL	16.00	HRP	6.40
MASTER CYLINDER	CI	5.00*	AL	2.50
BRAKE ROTOR	CI	39.00	AL	19.50
DISC BRAKE CALIPER	STEEL	19.50	HSS	15.60
BRAKE PEDAL ASSEMBLY	STEEL	7.00	HSS	5.60
FUEL TANK	STEEL	16.75	HDPE	10.89
WHEEL	STEEL	100.00*	AL	50.00
RADIATOR	CU	9.00	AL	4.50
FRONT BUMPER	STEEL	10.50	AL	5.25
BUMPER MOUNT	STEEL	8.50	HSS	6.80
JACK & LUG WRENCH	STEEL	11.50	HSS	9.20
ENGINE BLOCK	CI	72.00**	CI	72.00
CONNECTING ROD	STEEL	5.00*	HSS	4.00
VALVE COVER	STEEL	2.00*	FRP	1.56
OIL PAN	STEEL	6.00*	FRP	4.68
AIR CLEANER	STEEL	3.50*	FRP	2.73
EXHAUST MANIFOLD	CI	8.00*	SS	3.04

*ESTIMATED WEIGHT

TABLE B-3 1978 CHEVROLET LUV PICKUP TRUCK ALUMINUM DOMINANT CASE

PART NAME	CURRENT		ALTERNATIVE	
	MATERIAL	WT.(LBS)	MATERIAL	WT.(LBS)
FRONT FENDER	STEEL	21.00	AL	12.18
HOOD FRONT CLOSEOUT	STEEL	1.00	AL	0.58
AIR INTAKE GRILLE	STEEL	3.25	AL	1.89
ENGINE COMP. SPLASH GUARD	STEEL	2.00	AL	1.16
CARBON CANNISTER COVER	STEEL	3.00	AL	1.74
BUMPER SPLASH GUARD	STEEL	3.50	AL	2.03
HOOD INNER PANEL	STEEL	10.25	AL	5.95
HOOD OUTER PANEL	STEEL	17.50	AL	10.15
HOOD HINGE	STEEL	2.00	HSS	1.60
CAB	STEEL	234.00	AL	135.72
CARGO BED	STEEL	195.00	AL	113.10
TAILGATE	STEEL	31.50	AL	18.27
TAILGATE LATCH & STRAP	STEEL	3.50	HSS	2.80
DOOR INNER PANEL	STEEL	29.00	AL	16.82
DOOR OUTER PANEL	STEEL	21.00	AL	12.18
DOOR HINGE	STEEL	5.50	HSS	4.40
SEAT FRAME	STEEL	16.00	HSS	12.80
SEAT TRACK	STEEL	4.75	HSS	3.80
FRAME	STEEL	221.50	HSS	177.2
FRONT SUSPENSION STRUT ARM	STEEL	5.50	HSS	4.44
SPINDLE	STEEL	20.00*	HSS	16.00
UPPER CONTROL ARM	STEEL	13.00*	HSS	10.40
LOWER CONTROL ARM	STEEL	10.00	HSS	8.00
TORSION BAR	STEEL	12.00	HSS	9.60
TORSION BAR MOUNT ARM	STEEL	9.00	HSS	7.20
STABILIZER BAR	STEEL	5.75	HSS	4.60
BRAKE DRUM	CI	28.00	AL	14.00
LEAF SPRING	STEEL	58.50	HRP	23.40

*ESTIMATED WEIGHT

TABLE B-3 (CONT'D)

PART NAME	CURRENT		ALTERNATIVE	
	MATERIAL	WT. (LBS)	MATERIAL	WT. (LBS)
REAR SHOCK MOUNT	STEEL	5.50	HSS	4.44
DRIVE SHAFT	STEEL	16.00	HRP	6.40
MASTER CYLINDER	CI	5.00*	AL	2.50
BRAKE ROTOR	CI	39.00	AL	19.50
DISC BRAKE CALIPER	STEEL	19.50	HSS	3.61
BRAKE PEDAL ASSEMBLY	STEEL	7.00	HSS	5.60
FUEL TANK	STEEL	16.75	HDPE	10.89
WHEEL	STEEL	100.00*	AL	50.00
RADIATOR	CU	9.00	AL	4.50
FRONT BUMPER	STEEL	10.50	AL	5.25
BUMPER MOUNT	STEEL	8.50	AL	4.25
JACK & LUG WRENCH	STEEL	11.50	HSS	9.20
ENGINE BLOCK	CI	72.00*	AL	36.00
CONNECTING ROD	STEEL	5.00*	HSS	4.00
VALVE COVER	STEEL	2.00*	AL	1.16
OIL PAN	STEEL	6.00*	AL	3.48
AIR CLEANER	STEEL	3.50*	AL	2.03
EXHAUST MANIFOLD	CI	8.00*	SS	3.04

*ESTIMATED WEIGHT

TABLE B-4 1978 CHEVROLET LUV PICKUP
TRUCK HRP DOMINANT CASE

PART NAME	CURRENT		ALTERNATIVE	
	MATERIAL	WT.(LBS)	MATERIAL	WT.(LBS)
FRONT FENDER	STEEL	21.00	HRP	10.50
HOOD FRONT CLOSEOUT	STEEL	1.00	HRP	.50
AIR INTAKE GRILLE	STEEL	3.25	HRP	1.63
ENGINE COMP. SPLASH GUARD	STEEL	2.00	HRP	1.00
CARBON CANNISTER COVER	STEEL	3.00	HRP	1.50
BUMPER SPLASH GUARD	STEEL	3.50	HRP	1.75
HOOD INNER PANEL	STEEL	10.25	HRP	5.13
HOOD OUTER PANEL	STEEL	17.50	HRP	8.75
HOOD HINGE	STEEL	2.00	HRP	0.80
CAB	STEEL	234.00	HRP	117.00
CARGO BED	STEEL	195.00	HRP	97.50
TAILGATE	STEEL	31.50	HRP	15.75
TAILGATE LATCH & STRAP	STEEL	3.50	HRP	1.40
DOOR INNER PANEL	STEEL	29.00	HRP	14.50
DOOR OUTER PANEL	STEEL	21.00	HRP	10.50
DOOR HINGE	STEEL	5.50	HRP	2.20
SEAT FRAME	STEEL	16.00	HRP	6.40
SEAT TRACK	STEEL	4.75	HRP	1.90
FRAME	STEEL	221.50	HRP	88.6
FRONT SUSPENSION STRUT ARM	STEEL	5.50	HRP	2.20
SPINDLE	STEEL	20.00*	HRP	8.00
UPPER CONTROL ARM	STEEL	13.00*	HRP	5.20
LOWER CONTROL ARM	STEEL	10.00	HRP	4.00
TORSION BAR	STEEL	12.00	HRP	4.80
TORSION BAR MOUNT ARM	STEEL	9.00	HRP	3.60
STABILIZER BAR	STEEL	5.75	HRP	2.30
BRAKE DRUM	CI	28.00	AL	14.00
LEAF SPRING	STEEL	58.50	HRP	23.40

*ESTIMATED WEIGHT

TABLE B-4 (CONT'D)

PART NAME	CURRENT		ALTERNATIVE	
	MATERIAL	WT.(LBS)	MATERIAL	WT.(LBS)
REAR SHOCK MOUNT	STEEL	5.50	HRP	2.20
DRIVE SHAFT	STEEL	16.00	HRP	6.40
MASTER CYLINDER	CI	5.00*	AL	2.50
BRAKE ROTOR	CI	39.00	AL	19.50
DISC BRAKE CALIPER	STEEL	19.50	HRP	7.80
BRAKE PEDAL ASSEMBLY	STEEL	7.00	HRP	2.80
FUEL TANK	STEEL	16.75	HDPE	10.89
WHEEL	STEEL	100.00*	HRP	40.00
RADIATOR	CU	9.00	AL	4.50
FRONT BUMPER	STEEL	10.50	AL	5.25
BUMPER MOUNT	STEEL	8.50	HRP	3.40
JACK & LUG WRENCH	STEEL	11.50	HRP	4.60
ENGINE BLOCK	CI	72.00*	AL	36.00
CONNECTING ROD	STEEL	5.00*	HRP	2.00
VALVE COVER	STEEL	2.00*	HRP	1.00
OIL PAN	STEEL	6.00*	HRP	3.00
AIR CLEANER	STEEL	3.50*	HRP	1.75
EXHAUST MANIFOLD	CI	8.00*	SS	3.04

*ESTIMATED WEIGHT

TABLE B-5 FORD F-150 PICKUP TRUCK
HSS DOMINANT CASE

PART NAME	CURRENT		ALTERNATIVE	
	MATERIAL	WT.(LBS)	MATERIAL	WT.(LBS)
CAB FLOOR PAN	HRS	43.15	HSS	35.81
FLOOR PAN LONGITUDINAL	HRS	7.06	HSS	5.65
FLOOR PAN CROSSMEMBER	HRS	11.00	HSS	8.80
FLOOR PAN SIDEMEMBER	HRS	15.64	HSS	12.51
FLOOR PAN REINFORCEMENT	HRS	14.53	HSS	12.06
DASH PANEL	HRS	13.73	HSS	11.40
COWL TOP PANEL & EXTENSION	HRS	25.28	HSS	20.98
COWL VENT PANEL	CRS	4.32	HSS	3.59
STEERING COL. PEDAL SUP. BR.	AL	2.41	AL	2.41
STEER. COL. PEDAL SUP. BRACE	HRS	0.88	HSS	0.73
COWL SIDE PANEL-OUTER	HRS	3.44	HSS	2.86
COWL SIDE PANEL-INNER	HRS	6.90	HSS	5.73
FRONT PILLAR (A-POST)	CRS	15.42	HSS	12.34
FRONT PILLAR HINGE REINF.	HRS	6.64	HSS	15.50
FRONT PILLAR UPPER EXTENSION	HRS	2.86	HSS	2.29
LATCH PILLAR ASSY.(B-POST)	CRS	12.40	HSS	9.92
REAR CORNER PANEL	CRS	12.60	HSS	10.46
BACK PANEL-OUTER	HRS	10.50	HSS	8.72
BACK PANEL-INNER	HRS	5.82	HSS	4.83
ROOF PANEL-OUTER	CRS	19.50	HSS	16.19
ROOF PANEL-INNER	HRS	17.00	HSS	14.11
ROOF RAIL REINF.	HRS	2.40	HSS	1.92
SEAT BELT RETRACTOR HOUSING	HRS	2.64	HSS	2.11
DOOR PANEL-OUTER	CRS	20.00	HSS	16.60
DOOR PANEL-INNER	HSS	19.00	HSS	19.00
DOOR HINGE ASSY.	STEEL	7.38	HSS	5.90
SEAT FRAME	STEEL	18.10*	HSS	14.48
SEAT TRACK	STEEL	6.47	HSS	5.18

*ESTIMATED WEIGHT

TABLE B-5 (CONT'D)

PART NAME	CURRENT		ALTERNATIVE	
	MATERIAL	WT. (LBS)	MATERIAL	WT. (LBS)
SEAT BACK FRAME	STEEL	10.35	HSS	8.28
SEAT BACK HINGE	STEEL	1.91	HSS	1.53
DOOR WINDOW REGULATOR ASSY.	STEEL	6.20	HSS	4.96
VENT WINDOW FRAME ASSY.	STEEL	3.06	HSS	2.45
DOOR LATCH ASSY.	STEEL	2.32	HSS	1.86
ASH TRAY ASSY.	STEEL	0.99	HSS	0.82
HEADLAMP RETAIN. & ADJ. RING	STEEL	1.64	HSS	1.31
FRONT FENDER PANEL-OUTER	LCS	25.60	HSS	21.25
FRONT FENDER PANEL-INNER	LCS	25.40	HSS	21.08
BATTERY MOUNTING REINF.	GS	2.74	HSS	2.27
RADIATOR SUPPORT ASSY.	LCS	33.00	HSS	27.39
FENDER & APRON REINF.	GS	2.53	HSS	2.10
HOOD PANEL-OUTER	CRS	25.00	HSS	20.75
HOOD PANEL-INNER	HRS	26.00	HSS	21.58
HOOD HINGE ASSY.	STEEL	3.26	HSS	2.61
HOOD SUPPORT ASSY.	STEEL	3.86	HSS	3.09
HOOD LATCH ASSY. & BRACE	STEEL	3.68	HSS	2.94
RADIATOR GRILL SUPPORT	HRS	4.05	HSS	3.24
STONE DEFLECTOR	CRS	2.67	HSS	2.22
RADIATOR ASSY.	COPPER/ST.	17.40	AL	8.70
RADIATOR UPPER SUPPORT	STEEL	0.92	HSS	0.76
BOX FLOOR PAN	GS	70.00	HSS	58.10
CROSS SILL ASSY.	GS	51.10	HSS	40.88
BOX FRONT PANEL	CRS	19.50	HSS	16.19
BOX SIDE PANEL-OUTER	CRS	67.00	HSS	55.61
BOX SIDE PANEL-INNER	HRS	66.00	HSS	54.78
BOX FRONT CORNER PANEL ASSY.	HRS	2.86	HSS	2.37
BOX REAR CORNER PILLAR ASSY.	HRS	8.64	HSS	6.91

*ESTIMATED WEIGHT

TABLE B-5 (CONT'D)

PART NAME	CURRENT		ALTERNATIVE	
	MATERIAL	WT. (LBS)	MATERIAL	WT. (LBS)
REAR CORNER REINF. & GUSSET	HRS	2.18	HSS	1.81
TAILGATE LATCH PILLAR ASSY.	GS	3.14	HSS	2.51
TAILGATE PANEL	GS	39.00	HSS	32.37
TAILGATE END PLATE&LATCH LEV	GS	3.10	HSS	2.57
TAILGATE HINGE & REINF.	STEEL	0.84	HSS	0.67
WHEELHOUSE PANEL	GS	8.44	HSS	7.01
WHEELHOUSE REINF. STRUT	STEEL	1.52	HSS	1.22
HEAT DEFLECTOR	GS	5.63	HSS	4.67
FRAME ASSY.	HRS	319.00	HSS	255.20
FRONT CROSSMEMBER	HRS	10.00	HSS	8.00
CYLINDER BLOCK ASSY.	CI	118.50	CI	118.50
CYLINDER HEAD	CI	90.80	AL	45.40
OIL PAN	HRS	8.76	HSS	7.27
VALVE COVER	HRS	3.90	HSS	3.24
WATER PUMP HOUSING & HOB	CI	11.88	AL	5.94
WATER PUMP COVER	STEEL	1.08	HSS	0.09
FAN ASSY.	STEEL	3.42	HSS	2.84
EXHAUST MANIFOLD	CI	31.50	SS	11.97
AIR PUMP HOUSING & COVER	CI	4.03	AL	2.02
AIR PUMP PULLEY	STEEL	1.23	HSS	1.02
AIR LEANER BODY	AL	3.20	AL	3.20
PUSH ROD	STEEL	1.47	STEEL	1.47
ENGINE FRONT SUPPORT BRACKET	HRS	3.53	HSS	2.82
ENGINE REAR SUPPORT C'MEMBER	HRS	10.00	HSS	8.00
REAR SUPPORT C'MEMBER BRACKET	HRS	7.60	HSS	6.08
TRANSMISSION PAN	STEEL	3.35	HSS	2.78
DRIVE SHAFT	STEEL	20.70	HRP	8.28
TWIN I-BEAM	STEEL	43.10	HSS	34.48

*ESTIMATED WEIGHT

TABLE B-5 (CONT'D)

PART NAME	CURRENT		ALTERNATIVE	
	MATERIAL	WT.(LBS)	MATERIAL	WT.(LBS)
TWIN I-BEAM MTG BRACKET	STEEL	4.10	HSS	3.28
SPINDLE	CI	36.60	HSS	29.28
SPINDLE PIN	DI	3.43	HSS	2.74
RADIUS ARM ASSY.	HSS	18.64	HSS	18.64
FRONT SPRING	STEEL	22.63	HRP	9.05
FRONT SPRING SEAT	CI	3.31	HSS	2.65
SHOCK ABSORBER MTG. BRACKET	STEEL	1.40	HSS	1.12
POWER STEER. PUMP ADJ. BKT.	STEEL	0.93	HSS	0.74
GEARSHIFT TUBE & LEVEL ASSY.	STEEL	2.09	HSS	1.67
REAR SPRING	STEEL	109.00	HRP	43.60
REAR SPRING U-BOLT PLATE	STEEL	3.73	HSS	3.10
BRAKE ROTOR & HUB ASSY.	CI	53.46	AL	26.73
FRONT BRAKE SHIELD	STEEL	2.11	HSS	1.75
CALIPER HOUSING	CI	17.20	AL	8.60
BRAKE DRUM	CI	33.60	AL	16.80
REAR BRAKE SUPPORT PLATE	STEEL	10.62	HSS	8.81
PARKING BRAKE LEVEL & STRUT	STEEL	1.67	HSS	1.34
BRAKE PEDAL & SHAFT	STEEL	3.18	HSS	2.54
PARKING BRAKE PEDAL ASSY.	STEEL	4.20	HSS	3.36
MASTER CYLINDER HOUSING	CI	6.30	AL	3.15
WHEEL	STEEL	131.00	AL	65.50
SPARE WHEEL CARRIER ASSY.	HRS	11.43	HSS	9.14
CONVERTER SUPPORT BRACKET	STEEL	1.19	HSS	0.95
CONVERTER HEAT SHIELD	AS	2.58	HSS	2.14
FUEL TANK W/FILLER PIPE	TERNE	24.22	HDPE	15.74
FILLER PIPE DOOR	STEEL	1.10	HSS	0.91
FRONT BUMPER	HSS	32.80	AL	20.50
REAR BUMPER ASSY	HSS	41.30	AL	25.81

*ESTIMATED WEIGHT

TABLE B-5 (CONT'D)

PART NAME	CURRENT		ALTERNATIVE	
	MATERIAL	WT.(LBS)	MATERIAL	WT.(LBS)
REAR BUMPER SUPPORT ARM	HSS	8.72	HSS	8.72
CONNECTING ROD	STEEL	10.54	HSS	8.43

ABBREVIATIONS:

AL - ALUMINUM
AS - ALUMINIZED STEEL
CI - CAST IRON
CRS - COLD ROLLED STEEL
DI - DUCTILE IRON
FRP - FIBERGLASS REINFORCED PLASTICS
GS - GALVANIZED STEEL
HDPE - HIGH DENSITY POLYETHYLENE
HRP - HYBRID REINFORCED PLASTICS
HRS - HOT ROLLED STEEL
HSS - HIGH STRENGTH STEEL
LCS - LOW CARBON STEEL
SS - STAINLESS STEEL
STEEL - STEEL

*ESTIMATED WEIGHT

TABLE B-6 FORD F-150 PICKUP TRUCK
FRP DOMINANT CASE

PART NAME	CURRENT		ALTERNATIVE	
	MATERIAL	WT.(LBS)	MATERIAL	WT.(LBS)
CAB FLOOR PAN	HRS	43.15	FRP	33.66
FLOOR PAN LONGITUDINAL	HRS	7.06	HSS	5.65
FLOOR PAN CROSSMEMBER	HRS	11.00	HSS	8.80
FLOOR PAN SIDEMEMBER	HRS	15.64	HSS	12.50
FLOOR PAN REINFORCEMENT	HRS	14.53	FRP	11.33
DASH PANEL	HRS	13.73	FRP	10.71
COWL TOP PANEL & EXTENSION	HRS	25.28	FRP	19.72
COWL VENT PANEL	CRS	4.32	FRP	3.37
STEERING COL. PEDAL SUP. BR.	AL	2.41	AL	2.41
STEER. COL. PEDAL SUP. BRACE	HRS	0.88	HSS	0.73
COWL SIDE PANEL-OUTER	HRS	3.44	FRP	2.68
COWL SIDE PANEL-INNER	HRS	6.90	FRP	5.38
FRONT PILLAR (A-POST)	CRS	15.42	HSS	12.34
FRONT PILLAR HINGE REINF.	HRS	6.64	HSS	5.50
FRONT PILLAR UPPER EXTENSION	HRS	2.86	HSS	2.29
LATCH PILLAR ASSY.(B-POST)	CRS	12.40	HSS	9.92
REAR CORNER PANEL	CRS	12.60	FRP	9.83
BACK PANEL-OUTER	HRS	10.50	FRP	8.19
BACK PANEL-INNER	HRS	5.82	FRP	4.54
ROOF PANEL-OUTER	CRS	19.50	FRP	15.21
ROOF PANEL-INNER	HRS	17.00	FRP	13.26
ROOF RAIL REINF.	HRS	2.40	HSS	1.92
SEAT BELT RETRACTOR HOUSING	HRS	2.64	FRP	2.06
DOOR PANEL-OUTER	CRS	20.00	FRP	15.60
DOOR PANEL-INNER	HSS	19.00	FRP	17.86
DOOR HINGE ASSY.	STEEL	7.38	HSS	5.90
SEAT FRAME & SPRING	STEEL	18.10*	HSS	14.48
SEAT TRACK	STEEL	6.47	HSS	5.18

*ESTIMATED WEIGHT

TABLE B-6 (CONT'D)

PART NAME	CURRENT		ALTERNATIVE	
	MATERIAL	WT.(LBS)	MATERIAL	WT.(LBS)
SEAT BACK FRAME	STEEL	10.35	HSS	8.28
SEAT BACK HINGE	STEEL	1.91	HSS	1.53
DOOR WINDOW REGULATOR ASSY.	STEEL	6.20	HSS	4.96
VENT WINDOW FRAME ASSY.	STEEL	3.06	HSS	2.45
DOOR LATCH ASSY.	STEEL	2.32	HSS	1.86
ASH TRAY ASSY.	STEEL	0.99	HSS	0.82
HEADLAMP RETAIN. & ADJ. RING	STEEL	1.64	HSS	1.31
FRONT FENDER PANEL-OUTER	LCS	25.60	FRP	19.97
FRONT FENDER PANEL-INNER	LCS	25.40	FRP	19.81
BATTERY MOUNTING REINF.	GS	2.74	HSS	2.27
RADIATOR SUPPORT ASSY.	LCS	33.00	HSS	27.39
FENDER & APRON REINF.	GS	2.53	HSS	2.10
HOOD PANEL-OUTER	CRS	25.00	FRP	19.50
HOOD PANEL-INNER	HRS	26.00	FRP	20.28
HOOD HINGE ASSY.	STEEL	3.26	HSS	2.61
HOOD SUPPORT ASSY.	STEEL	3.86	HSS	3.09
HOOD LATCH ASSY. & BRACE	STEEL	3.68	HSS	2.94
RADIATOR GRILL SUPPORT	HRS	4.05	HSS	3.24
STONE DEFLECTOR	CRS	2.67	FRP	2.08
RADIATOR ASSY.	COPPER/ST	17.40	AL	8.70
RADIATOR UPPER SUPPORT	STEEL	0.92	HSS	0.76
BOX FLOOR PAN	GS	70.00	FRP	54.60
CROSS SILL ASSY.	GS	51.10	HSS	40.88
BOX FRONT PANEL	CRS	19.50	FRP	15.21
BOX SIDE PANEL-OUTER	CRS	67.00	FRP	52.26
BOX SIDE PANEL-INNER	HRS	66.00	FRP	51.48
BOX FRONT CORNER PANEL ASSY.	HRS	2.86	FRP	2.23
BOX REAR CORNER PILLAR ASSY.	HRS	8.64	HSS	6.91

*ESTIMATED WEIGHT

TABLE B-6 (CONT'D)

PART NAME	CURRENT		ALTERNATIVE	
	MATERIAL	WT.(LBS)	MATERIAL	WT.(LBS)
REAR CORNER REINF. & GUSSET	HRS	2.18	HSS	1.74
TAILGATE LATCH PILLAR ASSY.	GS	3.14	HSS	2.51
TAILGATE PANEL	GS	39.00	FRP	30.42
TAILGATE END PLATE&LATCH LEV	GS	3.10	HSS	2.57
TAILGATE HINGE & REINF.	STEEL	0.84	HSS	0.67
WHEELHOUSE PANEL	GS	8.44	FRP	6.58
WHEELHOUSE REINF. STRUT	STEEL	1.52	HSS	1.22
HEAT DEFLECTOR	GS	5.63	HSS	4.67
FRAME ASSY.	HRS	319.00	HSS	255.20
FRONT CROSSMEMBER	HRS	10.00	HSS	8.00
CYLINDER BLOCK ASSY.	CI	118.50	CI	118.50
CYLINDER HEAD	CI	90.80	AL	45.40
OIL PAN	HRS	8.76	FRP	6.83
VALVE COVER	HRS	3.90	FRP	3.04
WATER PUMP HOUSING & HOB	C.I.	11.88	AL	5.94
WATER PUMP COVER	STEEL	1.08	HSS	0.90
FAN ASSY.	STEEL	3.42	FRP	2.67
EXHAUST MANIFOLD	CI	31.50	SS	11.97
AIR PUMP HOUSING & COVER	CI	4.03	AL	2.02
AIR PUMP PULLEY	STEEL	1.23	HSS	1.02
AIR LEANER BODY	AL	3.20	AL	3.20
PUSH ROD	STEEL	1.47	STEEL	1.47
ENGINE FRONT SUPPORT BRACKET	HRS	3.53	HSS	2.82
ENGINE REAR SUPPORT C'MEMBER	HRS	10.00	HSS	8.00
REAR SUPPORT C'MEMBER BRACKET	HRS	7.60	HSS	6.08
TRANSMISSION PAN	STEEL	3.35	FRP	2.61
DRIVE SHAFT	STEEL	20.70	HRP	8.28
TWIN I-BEAM	STEEL	43.10	HSS	34.48

*ESTIMATED WEIGHT

TABLE B-6 (CONT'D)

PART NAME	CURRENT		ALTERNATIVE	
	MATERIAL	WT.(LBS)	MATERIAL	WT.(LBS)
TWIN I-BEAM MTG BRACKET	STEEL	4.10	HSS	3.28
SPINDLE	CI	36.60	HSS	29.28
SPINDLE PIN	DI	3.43	HSS	2.74
RADIUS ARM ASSY.	HSS	18.64	HSS	18.64
FRONT SPRING	STEEL	22.63	HRP	9.05
FRONT SPRING SEAT	CI	3.31	HSS	2.65
SHOCK ABSORBER MTG. BRACKET	STEEL	1.40	HSS	1.12
POWER STEER. PUMP ADJ. BKT.	STEEL	0.93	HSS	0.74
GEARSHIFT TUBE & LEVEL ASSY.	STEEL	2.09	HSS	1.67
REAR SPRING	STEEL	109.00	HRP	43.60
REAR SPRING U-BOLT PLATE	STEEL	3.73	HSS	3.10
BRAKE ROTOR & HUB ASSY.	CI	53.46	AL	26.73
FRONT BRAKE SHIELD	STEEL	2.11	HSS	1.75
CALIPER HOUSING	CI	17.20	AL	8.60
BRAKE DRUM	CI	33.60	AL	16.80
REAR BRAKE SUPPORT PLATE	STEEL	10.62	HSS	8.81
PARKING BRAKE LEVEL & STRUT	STEEL	1.67	HSS	1.34
BRAKE PEDAL & SHAFT	STEEL	3.18	HSS	2.54
PARKING BRAKE PEDAL ASSY.	STEEL	4.20	HSS	3.36
MASTER CYLINDER HOUSING	CI	6.30	AL	3.15
WHEEL	STEEL	131.00	HRP	52.40
SPARE WHEEL CARRIER ASSY.	HRS	11.43	HSS	9.14
CONVERTER SUPPORT BRACKET	STEEL	1.19	HSS	0.95
CONVERTER HEAT SHIELD	AS	2.58	HSS	2.14
FUEL TANK W/FILLER PIPE	TERNE	24.22	HDPE	15.74
FILLER PIPE DOOR	STEEL	1.10	FRP	0.86
FRONT BUMPER	HSS	32.80	AL	20.50
REAR BUMPER ASSY	HSS	41.30	AL	25.81

*ESTIMATED WEIGHT

TABLE B-6 (CONT'D)

PART NAME	CURRENT		ALTERNATIVE	
	MATERIAL	WT. (LBS)	MATERIAL	WT. (LBS)
REAR BUMPER SUPPORT ARM	HSS	8.72	HSS	8.72
CONNECTING ROD	STEEL	10.54	HSS	8.43

ABBREVIATIONS:

ALUM - ALUMINUM
AS - ALUMINIZED STEEL
CI - CAST IRON
CRS - COLD ROLLED STEEL
DI - DUCTILE IRON
FRP - FIBERGLASS REINFORCED PLASTICS
GS - GALVANIZED STEEL
HDPE - HIGH DENSITY POLYETHYLENE
HRP - HYBRID REINFORCED PLASTICS
HRS - HOT ROLLED STEEL
HSS - HIGH STRENGTH STEEL
LCS - LOW CARBON STEEL
SS - STAINLESS STEEL
STEEL - STEEL

*ESTIMATED WEIGHT

TABLE B-7 1980 FORD F-150 PICKUP TRUCK
ALUMINUM DOMINANT CASE

PART NAME	CURRENT		ALTERNATIVE	
	MATERIAL	WT. (LBS)	MATERIAL	WT. (LBS)
CAB FLOOR PAN	HRS	43.15	AL	25.03
FLOOR PAN LONGITUDINAL	HRS	7.06	HSS	5.65
FLOOR PAN CROSSMEMBER	HRS	11.00	HSS	8.80
FLOOR PAN SIDEMEMBER	HRS	15.64	HSS	12.50
FLOOR PAN REINFORCEMENT	HRS	14.53	AL	8.43
DASH PANEL	HRS	13.73	AL	7.96
COWL TOP PANEL & EXTENSION	HRS	25.28	AL	14.66
COWL VENT PANEL	CRS	4.32	AL	2.51
STEERING COL. PEDAL SUP. BR.	AL	2.41	AL	2.41
STEER. COL. PEDAL SUP. BRACE	HRS	0.88	HSS	0.73
COWL SIDE PANEL-OUTER	HRS	3.44	AL	2.00
COWL SIDE PANEL-INNER	HRS	6.90	AL	4.00
FRONT PILLAR (A-POST)	CRS	15.42	HSS	12.34
FRONT PILLAR HINGE REINF.	HRS	6.64	HSS	5.50
FRONT PILLAR UPPER EXTENSION	HRS	2.86	HSS	2.29
LATCH PILLAR ASSY.(B-POST)	CRS	12.40	HSS	9.92
REAR CORNER PANEL	CRS	12.60	AL	7.31
BACK PANEL-OUTER	HRS	10.50	AL	6.09
BACK PANEL-INNER	HRS	5.82	AL	3.38
ROOF PANEL-OUTER	CRS	19.50	AL	11.31
ROOF PANEL-INNER	HRS	17.00	AL	9.86
ROOF RAIL REINF.	HRS	2.40	AL	1.39
SEAT BELT RETRACTOR HOUSING	HRS	2.64	AL	1.53
DOOR PANEL-OUTER	CRS	20.00	AL	11.60
DOOR PANEL-INNER	HSS	19.00	AL	13.28
DOOR HINGE ASSY.	STEEL	7.38	HSS	5.90
SEAT FRAME	STEEL	18.10*	HSS	14.48
SEAT TRACK	STEEL	6.47	HSS	5.18

*ESTIMATED WEIGHT

TABLE B-7 (CONT'D)

PART NAME	CURRENT		ALTERNATIVE	
	MATERIAL	WT. (LBS)	MATERIAL	WT. (LBS)
SEAT BACK FRAME	STEEL	10.35	HSS	8.28
SEAT BACK HINGE	STEEL	1.91	HSS	1.53
DOOR WINDOW REGULATOR ASSY.	STEEL	6.20	HSS	4.96
VENT WINDOW FRAME ASSY.	STEEL	3.06	AL	1.77
DOOR LATCH ASSY.	STEEL	2.32	HSS	1.86
ASH TRAY ASSY.	STEEL	0.99	AL	0.57
HEADLAMP RETAIN. & ADJ. RING	STEEL	1.64	HSS	1.31
FRONT FENDER PANEL-OUTER	LCS	25.60	AL	14.85
FRONT FENDER PANEL-INNER	LCS	25.40	AL	14.73
BATTERY MOUNTING REINF.	GS	2.74	HSS	2.27
RADIATOR SUPPORT ASSY.	LCS	33.00	HSS	27.39
FENDER & APRON REINF.	GS	2.53	HSS	2.10
HOOD PANEL-OUTER	CRS	25.00	AL	14.50
HOOD PANEL-INNER	HRS	26.00	AL	15.08
HOOD HINGE ASSY.	STEEL	3.26	HSS	2.61
HOOD SUPPORT ASSY.	STEEL	3.86	HSS	3.09
HOOD LATCH ASSY. & BRACE	STEEL	3.68	HSS	2.94
RADIATOR GRILL SUPPORT	HRS	4.05	HSS	3.24
STONE DEFLECTOR	CRS	2.67	AL	1.55
RADIATOR ASSY.	COPPER/STEEL	17.40	AL	8.70
RADIATOR UPPER SUPPORT	STEEL	0.92	HSS	0.76
BOX FLOOR PAN	GS	70.00	AL	40.60
CROSS SILL ASSY.	GS	51.10	HSS	40.88
BOX FRONT PANEL	CRS	19.50	AL	11.31
BOX SIDE PANEL-OUTER	CRS	67.00	AL	38.86
BOX SIDE PANEL-INNER	HRS	66.00	AL	38.28
BOX FRONT CORNER PANEL ASSY.	HRS	2.86	AL	1.66
BOX REAR CORNER PILLAR ASSY.	HRS	8.64	HSS	6.91

*ESTIMATED WEIGHT

TABLE B-7 (CONT'D)

PART NAME	CURRENT		ALTERNATIVE	
	MATERIAL	WT. (LBS)	MATERIAL	WT. (LBS)
REAR CORNER REINF. & GUSSET	HRS	2.18	HSS	1.74
TAILGATE LATCH PILLAR ASSY.	GS	3.14	HSS	2.51
TAILGATE PANEL	GS	39.00	AL	30.42
TAILGATE END PLATE&LATCH LEV	GS	3.10	HSS	2.57
TAILGATE HINGE & REINF.	STEEL	0.84	HSS	0.67
WHEELHOUSE PANEL	GS	8.44	AL	4.90
WHEELHOUSE REINF. STRUT	STEEL	1.52	HSS	1.22
HEAT DEFLECTOR	GS	5.63	AL	3.27
FRAME ASSY.	HRS	319.00	HSS	255.20
FRONT CROSSMEMBER	HRS	10.00	HSS	8.00
CYLINDER BLOCK ASSY.	CI	118.50	AL	59.25
CYLINDER HEAD	CI	90.80	AL	45.40
OIL PAN	HRS	8.76	AL	5.08
VALVE COVER	HRS	3.90	AL	2.26
WATER PUMP HOUSING & HOB	CI	11.88	AL	5.94
WATER PUMP COVER	STEEL	1.08	AL	0.63
FAN ASSY.	STEEL	3.42	AL	1.98
EXHAUST MANIFOLD	CI	31.50	SS	11.97
AIR PUMP HOUSING & COVER	CI	4.03	AL	2.02
AIR PUMP PULLEY	STEEL	1.23	HSS	1.02
AIR LEANER BODY	AL	3.20	AL	3.20
PUSH ROD	STEEL	1.47	STEEL	1.47
ENGINE FRONT SUPPORT BRACKET	HRS	3.53	HSS	2.82
ENGINE REAR SUPPORT C'MEMBER	HRS	10.00	HSS	8.00
REAR SUPPORT C'MEMBER BRACKET	HRS	7.60	HSS	6.08
TRANSMISSION PAN	STEEL	3.35	AL	1.94
DRIVE SHAFT	STEEL	20.70	HRP	8.28
TWIN I-BEAM	STEEL	43.10	HSS	34.48

*ESTIMATED WEIGHT

TABLE B-7 (CONT'D)

PART NAME	CURRENT		ALTERNATIVE	
	MATERIAL	WT.(LBS)	MATERIAL	WT.(LBS)
TWIN I-BEAM MTG BRACKET	STEEL	4.10	HSS	3.28
SPINDLE	CI	36.60	HSS	29.28
SPINDLE PIN	DI	3.43	HSS	2.74
RADIUS ARM ASSY.	HSS	18.64	HSS	18.64
FRONT SPRING	STEEL	22.63	HRP	9.05
FRONT SPRING SEAT	CI	3.31	HSS	2.65
SHOCK ABSORBER MTG. BRACKET	STEEL	1.40	HSS	1.12
POWER STEER. PUMP ADJ. BKT.	STEEL	0.93	HSS	0.74
GEARSHIFT TUBE & LEVEL ASSY.	STEEL	2.09	HSS	1.67
REAR SPRING	STEEL	109.00	HRP	43.60
REAR SPRING U-BOLT PLATE	STEEL	3.73	HSS	3.10
BRAKE ROTOR & HUB ASSY.	CI	53.46	AL	26.73
FRONT BRAKE SHIELD	STEEL	2.11	AL	1.22
CALIPER HOUSING	CI	17.20	AL	8.60
BRAKE DRUM	CI	33.60	AL	16.80
REAR BRAKE SUPPORT PLATE	STEEL	10.62	HSS	8.81
PARKING BRAKE LEVEL & STRUT	STEEL	1.67	HSS	1.34
BRAKE PEDAL & SHAFT	STEEL	3.18	HSS	2.54
PARKING BRAKE PEDAL ASSY.	STEEL	4.20	HSS	3.36
MASTER CYLINDER HOUSING	CI	6.30	AL	3.15
WHEEL	STEEL	131.00	AL	65.50
SPARE WHEEL CARRIER ASSY.	HRS	11.43	HSS	9.14
CONVERTER SUPPORT BRACKET	STEEL	1.19	HSS	0.95
CONVERTER HEAT SHIELD	AS	2.58	AL	1.50
FUEL TANK W/FILLER PIPE	TERNE	24.22	HDPE	15.74
FILLER PIPE DOOR	STEEL	1.10	AL	0.64
FRONT BUMPER	HSS	32.80	AL	20.50
REAR BUMPER ASSY	HSS	41.30	AL	25.81

*ESTIMATED WEIGHT

TABLE B-7 (CONT'D)

PART NAME	CURRENT		ALTERNATIVE	
	MATERIAL	WT. (LBS)	MATERIAL	WT. (LBS)
REAR BUMPER SUPPORT ARM	HSS	8.72	HSS	8.72
CONNECTING ROD	STEEL	10.54	HSS	8.43

ABBREVIATIONS:

ALUM - ALUMINUM
AS - ALUMINIZED STEEL
CI - CAST IRON
CRS - COLD ROLLED STEEL
DI - DUCTILE IRON
FRP - FIBERGLASS REINFORCED PLASTICS
GS - GALVANIZED STEEL
HDPE - HIGH DENSITY POLYETHYLENE
HRP - HYBRID REINFORCED PLASTICS
HRS - HOT ROLLED STEEL
HSS - HIGH STRENGTH STEEL
LCS - LOW CARBON STEEL
SS - STAINLESS STEEL
STEEL - STEEL

*ESTIMATED WEIGHT

TABLE B-8 FORD F-150 PICKUP TRUCK
HRP DOMINANT CASE

PART NAME	CURRENT		ALTERNATIVE	
	MATERIAL	WT.(LBS)	MATERIAL	WT.(LBS)
CAB FLOOR PAN	HRS	43.15	HRP	21.58
FLOOR PAN LONGITUDINAL	HRS	7.06	HRP	2.82
FLOOR PAN CROSSMEMBER	HRS	11.00	HRP	4.40
FLOOR PAN SIDEMEMBER	HRS	15.64	HRP	6.26
FLOOR PAN REINFORCEMENT	HRS	14.73	HRP	7.27
DASH PANEL	HRS	13.73	HRP	6.87
COWL TOP PANEL & EXTENSION	HRS	25.28	HRP	12.64
COWL VENT PANEL	CRS	4.32	HRP	2.16
STEERING COL. PEDAL SUP. BR.	AL	2.41	HRP	1.93
STEER. COL. PEDAL SUP. BRACE	HRS	0.88	HRP	0.44
COWL SIDE PANEL-OUTER	HRS	3.44	HRP	1.72
COWL SIDE PANEL-INNER	HRS	6.90	HRP	3.45
FRONT PILLAR (A-POST)	CRS	15.42	HRP	6.17
FRONT PILLAR HINGE REINF.	HRS	6.64	HRP	2.66
FRONT PILLAR UPPER EXTENSION	HRS	2.86	HRP	1.14
LATCH PILLAR ASSY.(B-POST)	CRS	12.40	HRP	4.96
REAR CORNER PANEL	CRS	12.60	HRP	6.30
BACK PANEL-OUTER	HRS	10.50	HRP	5.25
BACK PANEL-INNER	HRS	5.82	HRP	2.91
ROOF PANEL-OUTER	CRS	19.50	HRP	9.75
ROOF PANEL-INNER	HRS	17.00	HRP	8.50
ROOF RAIL REINF.	HRS	2.40	HRP	0.96
SEAT BELT RETRACTOR HOUSING	HRS	2.64	HRP	1.06
DOOR PANEL-OUTER	CRS	20.00	HRP	10.00
DOOR PANEL-INNER	HSS	19.00	HRP	11.45
DOOR HINGE ASSY.	STEEL	7.38	HRP	2.95
SEAT FRAME	STEEL	18.10*	HRP	7.24
SEAT TRACK	STEEL	6.47	HRP	2.59

*ESTIMATED WEIGHT

TABLE B-8 (CONT'D)

PART NAME	CURRENT		ALTERNATIVE	
	MATERIAL	WT. (LBS)	MATERIAL	WT. (LBS)
SEAT BACK FRAME	STEEL	10.35	HRP	4.14
SEAT BACK HINGE	STEEL	1.91	HRP	0.76
DOOR WINDOW REGULATOR ASSY.	STEEL	6.20	HRP	2.48
VENT WINDOW FRAME ASSY.	STEEL	3.06	HRP	1.22
DOOR LATCH ASSY.	STEEL	2.32	HRP	0.93
ASH TRAY ASSY.	STEEL	0.99	AL	0.57
HEADLAMP RETAIN. & ADJ. RING	STEEL	1.64	HRP	0.66
FRONT FENDER PANEL-OUTER	LCS	25.60	HRP	12.80
FRONT FENDER PANEL-INNER	LCS	25.40	HRP	12.70
BATTERY MOUNTING REINF.	GS	2.74	HRP	1.37
RADIATOR SUPPORT ASSY.	LCS	33.00	HRP	16.50
FENDER & APRON REINF.	GS	2.53	HRP	1.27
HOOD PANEL-OUTER	CRS	25.00	HRP	12.50
HOOD PANEL-INNER	HRS	26.00	HRP	13.00
HOOD HINGE ASSY.	STEEL	3.26	HRP	1.28
HOOD SUPPORT ASSY.	STEEL	3.86	HRP	1.54
HOOD LATCH ASSY. & BRACE	STEEL	3.68	HRP	1.47
RADIATOR GRILL SUPPORT	HRS	4.05	HRP	1.62
STONE DEFLECTOR	CRS	2.67	HRP	1.34
RADIATOR ASSY.	COPPER/STEEL	17.40	AL	8.70
RADIATOR UPPER SUPPORT	STEEL	0.92	HRP	0.46
BOX FLOOR PAN	GS	70.00	HRP	35.00
CROSS SILL ASSY.	GS	51.10	HRP	25.55
BOX FRONT PANEL	CRS	19.50	HRP	9.75
BOX SIDE PANEL-OUTER	CRS	67.00	HRP	33.50
BOX SIDE PANEL-INNER	HRS	66.00	HRP	33.00
BOX FRONT CORNER PANEL ASSY.	HRS	2.86	HRP	1.43
BOX REAR CORNER PILLAR ASSY.	HRS	8.64	HRP	3.46

*ESTIMATED WEIGHT

TABLE B-8 (CONT'D)

PART NAME	CURRENT		ALTERNATIVE	
	MATERIAL	WT. (LBS)	MATERIAL	WT. (LBS)
REAR CORNER REINF. & GUSSET	HRS	2.18	HRP	1.09
TAILGATE LATCH PILLAR ASSY.	GS	3.14	HRP	1.26
TAILGATE PANEL	GS	39.00	HRP	19.50
TAILGATE END PLATE&LATCH LEV	GS	3.10	HRP	1.55
TAILGATE HINGE & REINF.	STEEL	0.84	HRP	0.34
WHEELHOUSE PANEL	GS	8.44	HRP	4.22
WHEELHOUSE REINF. STRUT	STEEL	1.52	HRP	0.61
HEAT DEFLECTOR	GS	5.63	AL	3.27
FRAME ASSY.	HRS	319.00	HRP	127.60
FRONT CROSSMEMBER	HRS	10.00	HRP	4.00
CYLINDER BLOCK ASSY.	CI	118.50	AL	59.25
CYLINDER HEAD	CI	90.80	AL	45.40
OIL PAN	HRS	8.76	HRP	4.38
VALVE COVER	HRS	3.90	HRP	1.95
WATER PUMP HOUSING & HOB	CI	11.88	AL	5.94
WATER PUMP COVER	STEEL	1.08	AL	0.63
FAN ASSY.	STEEL	3.42	HRP	1.71
EXHAUST MANIFOLD	CI	31.50	SS	11.97
AIR PUMP HOUSING & COVER	CI	4.03	AL	2.02
AIR PUMP PULLEY	STEEL	1.23	HRP	0.49
AIR CLEANER BODY	AL	3.20	HRP	1.60
PUSH ROD	STEEL	1.47	HRP	0.59
ENGINE FRONT SUPPORT BRACKET	HRS	3.53	HRP	1.41
ENGINE REAR SUPPORT C'MEMBER	HRS	10.00	HRP	4.00
REAR SUPPORT C'MEMBER BRACKET	HRS	7.60	HRP	3.04
TRANSMISSION PAN	STEEL	3.35	HRP	1.68
DRIVE SHAFT	STEEL	20.70	HRP	8.28
TWIN I-BEAM	STEEL	43.10	HRP	17.24

*ESTIMATED WEIGHT

TABLE B-8 (CONT'D)

PART NAME	CURRENT		ALTERNATIVE	
	MATERIAL	WT.(LBS)	MATERIAL	WT.(LBS)
TWIN I-BEAM MTG BRACKET	STEEL	4.10	HRP	1.64
SPINDLE	CI	36.60	HRP	14.64
SPINDLE PIN	DI	3.43	HRP	1.37
RADIUS ARM ASSY.	HSS	18.64	HRP	9.32
FRONT SPRING	STEEL	22.63	HRP	9.05
FRONT SPRING SEAT	CI	3.31	HRP	1.66
SHOCK ABSORBER MTG. BRACKET	STEEL	1.40	HRP	0.56
POWER STEER. PUMP ADJ. BKT.	STEEL	0.93	HRP	0.37
GEARSHIFT TUBE & LEVEL ASSY.	STEEL	2.09	HRP	0.84
REAR SPRING	STEEL	109.00	HRP	43.60
REAR SPRING U-BOLT PLATE	STEEL	3.73	HRP	1.87
BRAKE ROTOR & HUB ASSY.	CI	53.46	AL	26.73
FRONT BRAKE SHIELD	STEEL	2.11	HRP	1.06
CALIPER HOUSING	CI	17.20	HRP	6.88
BRAKE DRUM	CI	33.60	AL	16.80
REAR BRAKE SUPPORT PLATE	STEEL	10.62	HRP	5.31
PARKING BRAKE LEVEL & STRUT	STEEL	1.67	HRP	0.67
BRAKE PEDAL & SHAFT	STEEL	3.18	HRP	1.27
PARKING BRAKE PEDAL ASSY.	STEEL	4.20	HRP	1.68
MASTER CYLINDER HOUSING	CI	6.30	HRP	2.52
WHEEL	STEEL	131.00	HRP	52.40
SPARE WHEEL CARRIER ASSY.	HRS	11.43	HRP	4.57
CONVERTER SUPPORT BRACKET	STEEL	1.19	HSS	0.95
CONVERTER HEAT SHIELD	AS	2.58	AL	1.50
FUEL TANK W/FILLER PIPE	TERNE	24.22	HDPE	15.74
FILLER PIPE DOOR	STEEL	1.10	HRP	0.55
FRONT BUMPER	HSS	32.80	HRP	16.40
REAR BUMPER ASSY	HSS	41.30	HRP	20.65

*ESTIMATED WEIGHT

TABLE B-8 (CONT'D)

PART NAME	CURRENT		ALTERNATIVE	
	MATERIAL	WT. (LBS)	MATERIAL	WT. (LBS)
REAR BUMPER SUPPORT ARM	HSS	8.72	HRP	4.36
CONNECTING ROD	STEEL	10.54	HRP	4.22

ABBREVIATIONS:

ALUM - ALUMINUM
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GS - GALVANIZED STEEL
HDPE - HIGH DENSITY POLYETHYLENE
HRP - HYBRID REINFORCED PLASTICS
HRS - HOT ROLLED STEEL
HSS - HIGH STRENGTH STEEL
LCS - LOW CARBON STEEL
SS - STAINLESS STEEL
STEEL - STEEL

*ESTIMATED WEIGHT

TABLE B-9 1978 DODGE B-100 VAN EQUIPPED WITH 225 CID ENGINE HSS DOMINANT CASE

PART NAME	CURRENT		ALTERNATIVE	
	MATERIAL	WT.(LBS)	MATERIAL	WT.(LBS)
ROOF	STEEL	125.0	HSS	103.8
DASH PANEL	STEEL	33.0	HSS	27.4
FLOOR	STEEL	155.0	HSS	128.7
SIDE PANEL LEFT	STEEL	70.0	HSS	58.1
SIDE PANEL RIGHT	STEEL	35.0	HSS	29.1
FRONT QUARTER OUTER	STEEL	15.0	HSS	12.5
FRONT QUARTER INNER	STEEL	7.0	HSS	5.8
UNDERBODY STRUCTURE	STEEL	250.0	HSS	200.0
FRONT DOOR OUTER	STEEL	39.0	HSS	32.4
FRONT DOOR INNER	STEEL	39.0	HSS	32.4
SIDE DOOR OUTER	STEEL	28.5	HSS	23.7
SIDE DOOR INNER	STEEL	28.5	HSS	23.7
REAR DOOR OUTER	STEEL	25.0	HSS	20.8
REAR DOOR INNER	STEEL	25.0	HSS	20.8
COWL VENT PANEL	STEEL	4.0	HSS	3.3
DOOR WINDOW REGULATOR	STEEL	8.0	HSS	6.4
HOOD	STEEL	17.5	HSS	14.5
FRONT STRUCTURE	STEEL	7.5	HSS	6.0
SIDE SILL	STEEL	28.0	HSS	22.4
REAR SILL	STEEL	14.0	HSS	11.2
ROOF BOW	STEEL	26.0	HSS	20.8
SIDE CHANNEL	STEEL	18.0	HSS	14.4
UNDERBODY RAIL	STEEL	112.0	HSS	89.6
WHEELHOUSE	STEEL	48.0	HSS	39.8
FRONT SUSPENSION CROSS-MEMBER	STEEL	36.0	HSS	28.8
ENGINE SUPPORT CROSSMEMBER	STEEL	5.5	HSS	4.4
SEAT PLATFORM	STEEL	15.3	HSS	12.2

*ESTIMATED WEIGHT

TABLE B-9 (CONT'D)

PART NAME	CURRENT		ALTERNATIVE	
	MATERIAL	WT. (LBS)	MATERIAL	WT. (LBS)
SEAT FRAME	STEEL	4.5	HSS	3.6
FRONT BUMPER	STEEL	28.8	FOAM	14.4
REAR BUMPER	STEEL	22.8	FOAM	11.4
BUMPER MOUNTING & BRACKET	STEEL	11.5	HSS	9.2
RADIATOR SUPPORT BRACKET	STEEL	7.5	HSS	6.0
FRONT SPRING	STEEL	23.0	HRP	9.2
UPPER CONTROL ARM	STEEL	18.0	HSS	14.4
LOWER CONTROL ARM	STEEL	14.5	HSS	11.6
REAR SPRING	STEEL	57.6	HRP	23.0
REAR SPRING SHACKLE	STEEL	9.0	HSS	7.2
AXLE U-BOLT PLATE	STEEL	5.0	HSS	4.0
DRIVE SHAFT	STEEL	12.5	HRP	5.0
MASTER CYLINDER	IRON	10.2	AL	5.1
FRONT BRAKE DISC	IRON	36.5	AL	18.2
REAR BRAKE DRUM	IRON	22.0	AL	11.0
BRAKE PEDAL	STEEL	6.0	HSS	4.8
PARKING BRAKE PEDAL & BRACKET	STEEL	4.0	HSS	3.2
WHEEL	STEEL	107.5	AL	53.8
FUEL TANK	TERNE	22.2	HDPE	14.4
CYLINDER HEAD	IRON	74.0	AL	37.0
ENGINE BLOCK	IRON	145.0	IRON	145.0
INTAKE MANIFOLD	IRON	35.6	AL	17.8
EXHAUST MANIFOLD	IRON	24.9	STAINLESS STEEL	9.4
AIR CLEANER HOUSING	STEEL	6.0	HSS	5.0
VALVE COVER	STEEL	6.5	HSS	5.4
OIL PAN	STEEL	7.5	HSS	6.2
WATER PUMP	STEEL	7.5	AL	3.8
CONNECTING ROD	STEEL	10.0	STEEL	10.0

*ESTIMATED WEIGHT

TABLE B-9 (CONT'D)

PART NAME	CURRENT		ALTERNATIVE	
	MATERIAL	WT.(LBS)	MATERIAL	WT.(LBS)
WINDSHIELD	GLASS	43.5	GLASS	34.8
DOOR WINDOW	GLASS	14.0	GLASS	9.3
RADIATOR	COPPER	14.0	AL	7.0
HEATER CORE	COPPER	5.0	AL	2.5
STEERING GEAR HOUSING	IRON	13.5	AL	6.8

*ESTIMATED WEIGHT

TABLE B-10 1978 DODGE B-100 VAN EQUIPPED
WITH 225 CID ENGINE
FRP DOMINANT CASE

PART NAME	CURRENT		ALTERNATIVE	
	MATERIAL	WT. (LBS)	MATERIAL	WT. (LBS)
ROOF	STEEL	125.0	FRP	97.5
DASH PANEL	STEEL	33.0	FRP	25.7
FLOOR	STEEL	155.0	FRP	120.9
SIDE PANEL LEFT	STEEL	70.0	FRP	54.6
SIDE PANEL RIGHT	STEEL	35.0	FRP	27.3
FRONT QUARTER OUTER	STEEL	15.0	FRP	11.7
FRONT QUARTER INNER	STEEL	7.0	FRP	5.5
UNDERBODY STRUCTURE	STEEL	250.0	HSS	200.0
FRONT DOOR OUTER	STEEL	39.0	FRP	30.4
FRONT DOOR INNER	STEEL	39.0	FRP	30.4
SIDE DOOR OUTER	STEEL	28.5	FRP	22.2
SIDE DOOR INNER	STEEL	28.5	FRP	22.2
REAR DOOR OUTER	STEEL	25.0	FRP	19.5
REAR DOOR INNER	STEEL	25.0	FRP	19.5
COWL VENT PANEL	STEEL	4.0	FRP	3.1
DOOR WINDOW REGULATOR	STEEL	8.0	HSS	6.4
HOOD	STEEL	17.5	FRP	13.7
FRONT STRUCTURE	STEEL	7.5	HSS	6.0
SIDE SILL	STEEL	28.0	HSS	22.4
REAR SILL	STEEL	14.0	HSS	11.2
ROOF BOW	STEEL	26.0	HSS	20.8
SIDE CHANNEL	STEEL	18.0	HSS	14.4
UNDERBODY RAIL	STEEL	112.0	HSS	89.6
WHEELHOUSE	STEEL	48.0	FRP	37.4
FRONT SUSPENSION CROSS-MEMBER	STEEL	36.0	HSS	28.8
ENGINE SUPPORT CROSSMEMBER	STEEL	5.5	HSS	4.4
SEAT PLATFORM	STEEL	15.3	HSS	12.2

*ESTIMATED WEIGHT

TABLE B-10 (CONT'D)

PART NAME	CURRENT		ALTERNATIVE	
	MATERIAL	WT.(LBS)	MATERIAL	WT.(LBS)
SEAT FRAME	STEEL	4.5	HSS	3.6
FRONT BUMPER	STEEL	28.8	FOAM	14.4
REAR BUMPER	STEEL	22.8	FOAM	11.4
BUMPER MOUNTING & BRACKET	STEEL	11.5	HSS	9.2
RADIATOR SUPPORT BRACKET	STEEL	7.5	HSS	6.0
FRONT SPRING	STEEL	23.0	HRP	9.2
UPPER CONTROL ARM	STEEL	18.0	HSS	14.4
LOWER CONTROL ARM	STEEL	14.5	HSS	11.6
REAR SPRING	STEEL	57.6	HRP	23.0
REAR SPRING SHACKLE	STEEL	9.0	HSS	7.2
AXLE U-BOLT PLATE	STEEL	5.0	HSS	4.0
DRIVE SHAFT	STEEL	12.5	HRP	5.0
MASTER CYLINDER	IRON	10.2	AL	5.1
FRONT BRAKE DISC	IRON	36.5	AL	18.2
REAR BRAKE DRUM	IRON	22.0	AL	11.0
BRAKE PEDAL	STEEL	6.0	HSS	4.8
PARKING BRAKE PEDAL & BRACKET	STEEL	4.0	HSS	3.2
WHEEL	STEEL	107.5	HRP	43.0
FUEL TANK	TERNE	22.2	HDPE	14.4
CYLINDER HEAD	IRON	74.0	AL	37.0
ENGINE BLOCK	IRON	145.0	IRON	145.0
INTAKE MANIFOLD	IRON	35.6	AL	17.8
EXHAUST MANIFOLD	IRON	24.9	STAINLESS STEEL	9.4
AIR CLEANER HOUSING	STEEL	6.0	FRP	4.7
VALVE COVER	STEEL	6.5	FRP	5.1
OIL PAN	STEEL	7.5	FRP	5.9
WATER PUMP	STEEL	7.5	AL	3.8
CONNECTING ROD	STEEL	10.0	STEEL	10.0

*ESTIMATED WEIGHT

TABLE B-10 (CONT'D)

PART NAME	CURRENT		ALTERNATIVE	
	MATERIAL	WT. (LBS)	MATERIAL	WT. (LBS)
WINDSHIELD	GLASS	43.5	GLASS	34.8
DOOR WINDOW	GLASS	14.0	GLASS	9.3
RADIATOR	COPPER	14.0	AL	7.0
HEATER CORE	COPPER	5.0	AL	2.5
STEERING GEAR HOUSING	IRON	13.5	AL	6.8

*ESTIMATED WEIGHT

TABLE B-11 1978 DODGE B-100 VAN EQUIPPED WITH 225 CID ENGINE ALUMINUM DOMINANT CASE

PART NAME	CURRENT		ALTERNATIVE	
	MATERIAL	WT. (LBS)	MATERIAL	WT. (LBS)
ROOF	STEEL	125.0	AL	72.5
DASH PANEL	STEEL	33.0	AL	19.1
FLOOR	STEEL	155.0	AL	89.9
SIDE PANEL LEFT	STEEL	70.0	AL	40.6
SIDE PANEL RIGHT	STEEL	35.0	AL	20.3
FRONT QUARTER OUTER	STEEL	15.0	AL	8.7
FRONT QUARTER INNER	STEEL	7.0	AL	4.1
UNDERBODY STRUCTURE	STEEL	250.0	HSS	200.0
FRONT DOOR OUTER	STEEL	39.0	AL	22.6
FRONT DOOR INNER	STEEL	39.0	AL	22.6
SIDE DOOR OUTER	STEEL	28.5	AL	16.5
SIDE DOOR INNER	STEEL	28.5	AL	16.5
REAR DOOR OUTER	STEEL	25.0	AL	14.5
REAR DOOR INNER	STEEL	25.0	AL	14.5
COWL VENT PANEL	STEEL	4.0	AL	2.3
DOOR WINDOW REGULATOR	STEEL	8.0	HSS	6.4
HOOD	STEEL	17.5	AL	10.2
FRONT STRUCTURE	STEEL	7.5	HSS	6.0
SIDE SILL	STEEL	28.0	HSS	22.4
REAR SILL	STEEL	14.0	HSS	11.2
ROOF BOW	STEEL	26.0	HSS	20.8
SIDE CHANNEL	STEEL	18.0	HSS	14.4
UNDERBODY RAIL	STEEL	112.0	HSS	89.6
WHEELHOUSE	STEEL	48.0	AL	27.8
FRONT SUSPENSION CROSS-MEMBER	STEEL	36.0	HSS	28.8
ENGINE SUPPORT CROSSMEMBER	STEEL	5.5	HSS	4.4
SEAT PLATFORM	STEEL	15.3	HSS	12.2

*ESTIMATED WEIGHT

TABLE B-11 (CONT'D)

PART NAME	CURRENT		ALTERNATIVE	
	MATERIAL	WT. (LBS)	MATERIAL	WT. (LBS)
SEAT FRAME	STEEL	4.5	HSS	3.6
FRONT BUMPER	STEEL	28.8	FOAM	14.4
REAR BUMPER	STEEL	22.8	FOAM	11.4
BUMPER MOUNTING & BRACKET	STEEL	11.5	HSS	9.2
RADIATOR SUPPORT BRACKET	STEEL	7.5	HSS	6.0
FRONT SPRING	STEEL	23.0	HRP	9.2
UPPER CONTROL ARM	STEEL	18.0	HSS	14.4
LOWER CONTROL ARM	STEEL	14.5	HSS	11.6
REAR SPRING	STEEL	57.6	HRP	23.0
REAR SPRING SHACKLE	STEEL	9.0	HSS	7.2
AXLE U-BOLT PLATE	STEEL	5.0	HSS	4.0
DRIVE SHAFT	STEEL	12.5	HRP	5.0
MASTER CYLINDER	IRON	10.2	AL	5.1
FRONT BRAKE DISC	IRON	36.5	AL	18.2
REAR BRAKE DRUM	IRON	22.0	AL	11.0
BRAKE PEDAL	STEEL	6.0	HSS	4.8
PARKING BRAKE PEDAL & BRACKET	STEEL	4.0	HSS	3.2
WHEEL	STEEL	107.5	AL	53.8
FUEL TANK	TERNE	22.2	HDPE	14.4
CYLINDER HEAD	IRON	74.0	AL	37.0
ENGINE BLOCK	IRON	145.0	AL	70.5
INTAKE MANIFOLD	IRON	35.6	AL	17.8
EXHAUST MANIFOLD	IRON	24.9	STAINLESS STEEL	9.4
AIR CLEANER HOUSING	STEEL	6.0	AL	3.5
VALVE COVER	STEEL	6.5	AL	3.8
OIL PAN	STEEL	7.5	AL	4.4
WATER PUMP	STEEL	7.5	AL	3.8
CONNECTING ROD	STEEL	10.0	STEEL	10.0

*ESTIMATED WEIGHT

TABLE B-11 (CONT'D)

PART NAME	CURRENT		ALTERNATIVE	
	MATERIAL	WT.(LBS)	MATERIAL	WT.(LBS)
WINDSHIELD	GLASS	43.5	GLASS	34.8
DOOR WINDOW	GLASS	14.0	GLASS	9.3
RADIATOR	COPPER	14.0	AL	7.0
HEATER CORE	COPPER	5.0	AL	2.5
STEERING GEAR HOUSING	IRON	13.5	AL	6.8

*ESTIMATED WEIGHT

TABLE B-12 1978 DODGE B-100 VAN EQUIPPED WITH 225 CID ENGINE HRP DOMINANT CASE

PART NAME	CURRENT		ALTERNATIVE	
	MATERIAL	WT. (LBS)	MATERIAL	WT. (LBS)
ROOF	STEEL	125.0	HRP	62.5
DASH PANEL	STEEL	33.0	HRP	16.5
FLOOR	STEEL	155.0	HRP	77.5
SIDE PANEL LEFT	STEEL	70.0	HRP	35.0
SIDE PANEL RIGHT	STEEL	35.0	HRP	17.5
FRONT QUARTER OUTER	STEEL	15.0	HRP	7.5
FRONT QUARTER INNER	STEEL	7.0	HRP	3.5
UNDERBODY STRUCTURE	STEEL	250.0	HRP	100.0
FRONT DOOR OUTER	STEEL	39.0	HRP	19.5
FRONT DOOR INNER	STEEL	39.0	HRP	19.5
SIDE DOOR OUTER	STEEL	28.5	HRP	14.3
SIDE DOOR INNER	STEEL	28.5	HRP	14.3
REAR DOOR OUTER	STEEL	25.0	HRP	12.5
REAR DOOR INNER	STEEL	25.0	HRP	12.5
COWL VENT PANEL	STEEL	4.0	HRP	2.0
DOOR WINDOW REGULATOR	STEEL	8.0	HRP	3.2
HOOD	STEEL	17.5	HRP	8.8
FRONT STRUCTURE	STEEL	7.5	HRP	3.0
SIDE SILL	STEEL	28.0	HRP	11.3
REAR SILL	STEEL	14.0	HRP	5.6
ROOF BOW	STEEL	26.0	HRP	10.4
SIDE CHANNEL	STEEL	18.0	HRP	7.2
UNDERBODY RAIL	STEEL	112.0	HRP	44.8
WHEELHOUSE	STEEL	48.0	HRP	24.0
FRONT SUSPENSION CROSS-MEMBER	STEEL	36.0	HRP	14.4
ENGINE SUPPORT CROSSMEMBER	STEEL	5.5	HRP	2.2
SEAT PLATFORM	STEEL	15.3	HRP	6.6

*ESTIMATED WEIGHT

TABLE B-12 (CONT'D)

PART NAME	CURRENT		ALTERNATIVE	
	MATERIAL	WT.(LBS)	MATERIAL	WT.(LBS)
SEAT FRAME	STEEL	4.5	HRP	1.8
FRONT BUMPER	STEEL	28.8	FOAM	14.4
REAR BUMPER	STEEL	22.8	FOAM	11.4
BUMPER MOUNTING & BRACKET	STEEL	11.5	HRP	4.6
RADIATOR SUPPORT BRACKET	STEEL	7.5	HRP	3.0
FRONT SPRING	STEEL	23.0	HRP	9.2
UPPER CONTROL ARM	STEEL	18.0	HRP	7.2
LOWER CONTROL ARM	STEEL	14.5	HRP	5.8
REAR SPRING	STEEL	57.6	HRP	23.0
REAR SPRING SHACKLE	STEEL	9.0	HRP	3.6
AXLE U-BOLT PLATE	STEEL	5.0	HRP	2.0
DRIVE SHAFT	STEEL	12.5	HRP	5.0
MASTER CYLINDER	IRON	10.2	AL	5.1
FRONT BRAKE DISC	IRON	36.5	AL	18.2
REAR BRAKE DRUM	IRON	22.0	AL	11.0
BRAKE PEDAL	STEEL	6.0	HRP	2.4
PARKING BRAKE PEDAL & BRACKET	STEEL	4.0	HRP	1.6
WHEEL	STEEL	107.5	HRP	43.0
FUEL TANK	TERNE	22.2	HDPE	14.4
CYLINDER HEAD	IRON	74.0	AL	37.0
ENGINE BLOCK	IRON	145.0	AL	70.5
INTAKE MANIFOLD	IRON	35.6	AL	17.8
EXHAUST MANIFOLD	IRON	24.9	STAINLESS STEEL	9.4
AIR CLEANER HOUSING	STEEL	6.0	HRP	3.0
VALVE COVER	STEEL	6.5	HRP	3.3
OIL PAN	STEEL	7.5	HRP	3.8
WATER PUMP	STEEL	7.5	AL	3.8
CONNECTING ROD	STEEL	10.0	HRP	4.0

*ESTIMATED WEIGHT

TABLE B-12 (CONT'D)

PART NAME	CURRENT		ALTERNATIVE	
	MATERIAL	WT. (LBS)	MATERIAL	WT. (LBS)
WINDSHIELD	GLASS	43.5	GLASS	34.8
DOOR WINDOW	GLASS	14.0	GLASS	9.3
RADIATOR	COPPER	14.0	AL	7.0
HEATER CORE	COPPER	5.0	AL	2.5
STEERING GEAR HOUSING	IRON	13.5	AL	6.8

*ESTIMATED WEIGHT

TABLE B-13 1978 DODGE RAMCHARGER EQUIPPED WITH 225 CID ENGINE HSS DOMINANT CASE

PART NAME	CURRENT		ALTERNATIVE	
	MATERIAL	WT.(LBS)	MATERIAL	WT.(LBS)
TOP	STEEL	175.0	HSS	145.3
DASH	STEEL	32.0	HSS	26.6
FLOOR	STEEL	97.0	HSS	80.5
TAILGATE	STEEL	44.0	HSS	36.5
HOOD OUTER PANEL	STEEL	34.7	HSS	28.8
HOOD INNER PANEL	STEEL	20.3	HSS	16.8
HOOD HINGE BRACKET	STEEL	10.0	HSS	8.0
FRONT FENDER OUTER	STEEL	35.1	HSS	29.1
FRONT FENDER INNER	STEEL	16.9	HSS	14.0
FRONT WHEELHOUSE	STEEL	21.0	HSS	17.4
RADIATOR SUPPORT	STEEL	40.0	HSS	32.0
GRILLE LOWER PANEL	STEEL	4.0	HSS	3.3
COWL SIDE	STEEL	22.0	HSS	18.3
COWL VENT PANEL	STEEL	4.0	HSS	3.3
DOOR OUTER PANEL	STEEL	40.0	HSS	33.2
DOOR INNER PANEL	STEEL	40.0	HSS	33.2
SIDE PANEL OUTER	STEEL	46.8	HSS	38.8
SIDE PANEL INNER	STEEL	32.7	HSS	27.1
REAR WHEELHOUSE	STEEL	24.0	HSS	19.9
FRAME	STEEL	300.0	HSS	240.0
ENGINE SUPPORT CROSSMEMBER	STEEL	20.5	HSS	16.4
ENGINE MOUNTING BRACKET	STEEL	8.5	HSS	6.8
SEAT FRAME	STEEL	12.0	HSS	9.6
FRONT BUMPER	STEEL	29.0	FOAM	14.5
REAR BUMPER	STEEL	23.0	FOAM	11.5
BUMPER MOUNTING BRACKET	STEEL	9.0	HSS	7.2
FRONT SPRING	STEEL	75.0	HRP	30.0
REAR SPRING	STEEL	80.0	HRP	32.0

*ESTIMATED WEIGHT

TABLE B-13 (CONT'D)

PART NAME	CURRENT		ALTERNATIVE	
	MATERIAL	WT. (LBS)	MATERIAL	WT. (LBS)
REAR SPRING SHACKLE	STEEL	3.0	HSS	2.4
AXLE U-BOLT PLATE	STEEL	10.0	HSS	8.0
STEERING GEAR HOUSING	IRON	15.5	AL	7.8
MASTER CYLINDER	IRON	10.2	AL	5.1
BRAKE & CLUTCH PEDAL	STEEL	6.0	HSS	4.8
PARKING BRAKE PEDAL & BRACKET	STEEL	4.0	HSS	3.2
DRIVE SHAFT	STEEL	24.0	HRP	9.6
WHEEL	STEEL	107.5	AL	53.8
FUEL TANK	TERNE	24.0	HDPE	15.5
RADIATOR	COPPER	14.0	AL	7.0
HEATER CORE	COPPER	5.0	AL	2.5
WINDSHIELD	GLASS	31.0	GLASS	24.8
REAR WINDOW	GLASS	18.0	GLASS	12.0
DOOR GLASS	GLASS	16.0	GLASS	10.7
SIDE WINDOW	GLASS	35.0	GLASS	23.3
BRAKE DISC	IRON	55.5	AL	27.8
BRAKE DRUM	IRON	26.0	AL	13.0
BATTERY TRAY	STEEL	3.0	HSS	2.5
CYLINDER HEAD	IRON	74.0	AL	37.0
ENGINE BLOCK	IRON	145.0	IRON	145.0
INTAKE MANIFOLD	IRON	35.6	AL	17.8
EXHAUST MANIFOLD	IRON	24.9	STAINLESS STEEL	9.4
AIR CLEANER HOUSING	STEEL	6.0	HSS	5.0
VALVE COVER	STEEL	6.5	HSS	5.4
OIL PAN	STEEL	7.5	HSS	6.2
WATER PUMP	IRON	7.5	AL	3.7
CONNECTING ROD	STEEL	10.0	STEEL	10.0

*ESTIMATED WEIGHT

TABLE B-14 DODGE RAMCHARGER EQUIPPED WITH 225 CID ENGINE FRP DOMINANT CASE

PART NAME	CURRENT		ALTERNATIVE	
	MATERIAL	WT. (LBS)	MATERIAL	WT. (LBS)
TOP	STEEL	175.0	FRP	136.5
DASH	STEEL	32.0	FRP	25.0
FLOOR	STEEL	97.0	FRP	75.7
TAILGATE	STEEL	44.0	FRP	34.3
HOOD OUTER PANEL	STEEL	34.7	FRP	27.1
HOOD INNER PANEL	STEEL	20.3	FRP	15.8
HOOD HINGE BRACKET	STEEL	10.0	HSS	8.0
FRONT FENDER OUTER	STEEL	35.1	FRP	27.4
FRONT FENDER INNER	STEEL	16.9	FRP	13.2
FRONT WHEELHOUSE	STEEL	21.0	FRP	16.4
RADIATOR SUPPORT	STEEL	40.0	HSS	32.0
GRILLE LOWER PANEL	STEEL	4.0	FRP	3.1
COWL SIDE	STEEL	22.0	FRP	17.2
COWL VENT PANEL	STEEL	4.0	FRP	3.1
DOOR OUTER PANEL	STEEL	40.0	FRP	31.2
DOOR INNER PANEL	STEEL	40.0	FRP	31.2
SIDE PANEL OUTER	STEEL	46.8	FRP	36.5
SIDE PANEL INNER	STEEL	32.7	FRP	25.5
REAR WHEELHOUSE	STEEL	24.0	FRP	18.7
FRAME	STEEL	300.0	FRP	234.0
ENGINE SUPPORT CROSSMEMBER	STEEL	20.5	HSS	16.4
ENGINE MOUNTING BRACKET	STEEL	8.5	HSS	6.8
SEAT FRAME	STEEL	12.0	HSS	9.6
FRONT BUMPER	STEEL	29.0	FOAM	14.5
REAR BUMPER	STEEL	23.0	FOAM	11.5
BUMPER MOUNTING BRACKET	STEEL	9.0	HSS	7.2
FRONT SPRING	STEEL	75.0	HRP	30.0
REAR SPRING	STEEL	80.0	HRP	32.0

*ESTIMATED WEIGHT

TABLE B-14 (CONT'D)

PART NAME	CURRENT		ALTERNATIVE	
	MATERIAL	WT. (LBS)	MATERIAL	WT. (LBS)
REAR SPRING SHACKLE	STEEL	3.0	HSS	2.4
AXLE U-BOLT PLATE	STEEL	10.0	HSS	8.0
STEERING GEAR HOUSING	IRON	15.5	AL	7.8
MASTER CYLINDER	IRON	10.2	AL	5.1
BRAKE & CLUTCH PEDAL	STEEL	6.0	HSS	4.8
PARKING BRAKE PEDAL & BRACKET	STEEL	4.0	HSS	3.2
DRIVE SHAFT	STEEL	24.0	HRP	9.6
WHEEL	STEEL	107.5	AL	53.8
FUEL TANK	TERNE	24.0	HDPE	15.5
RADIATOR	COPPER	14.0	AL	7.0
HEATER CORE	COPPER	5.0	AL	2.5
WINDSHIELD	GLASS	31.0	GLASS	24.8
REAR WINDOW	GLASS	18.0	GLASS	12.0
DOOR GLASS	GLASS	16.0	GLASS	10.7
SIDE WINDOW	GLASS	35.0	GLASS	23.3
BRAKE DISC	IRON	55.5	AL	27.8
BRAKE DRUM	IRON	26.0	AL	13.0
BATTERY TRAY	STEEL	3.0	AL	2.5
CYLINDER HEAD	IRON	74.0	AL	37.0
ENGINE BLOCK	IRON	145.0	IRON	145.0
INTAKE MANIFOLD	IRON	35.6	AL	17.8
EXHAUST MANIFOLD	IRON	24.9	STAINLESS STEEL	9.4
AIR CLEANER HOUSING	STEEL	6.0	FRP	4.7
VALVE COVER	STEEL	6.5	FRP	5.1
OIL PAN	STEEL	7.5	FRP	5.9
WATER PUMP	IRON	7.5	AL	3.7
CONNECTING ROD	STEEL	10.0	STEEL	10.0

*ESTIMATED WEIGHT

TABLE B-15 1978 DODGE RAMCHARGER EQUIPPED WITH 225 CID ENGINE ALUMINUM DOMINANT CASE

PART NAME	CURRENT		ALTERNATIVE	
	MATERIAL	WT.(LBS)	MATERIAL	WT.(LBS)
TOP	STEEL	175.0	AL	101.5
DASH	STEEL	32.0	AL	18.6
FLOOR	STEEL	97.0	AL	56.3
TAILGATE	STEEL	44.0	AL	25.5
HOOD OUTER PANEL	STEEL	34.7	AL	20.1
HOOD INNER PANEL	STEEL	20.3	AL	11.8
HOOD HINGE BRACKET	STEEL	10.0	HSS	8.0
FRONT FENDER OUTER	STEEL	35.1	AL	20.4
FRONT FENDER INNER	STEEL	16.9	AL	9.8
FRONT WHEELHOUSE	STEEL	21.0	AL	12.2
RADIATOR SUPPORT	STEEL	40.0	HSS	32.0
GRILLE LOWER PANEL	STEEL	4.0	AL	2.3
COWL SIDE	STEEL	22.0	AL	12.8
COWL VENT PANEL	STEEL	4.0	AL	2.3
DOOR OUTER PANEL	STEEL	40.0	AL	23.2
DOOR INNER PANEL	STEEL	40.0	AL	23.2
SIDE PANEL OUTER	STEEL	46.8	AL	27.1
SIDE PANEL INNER	STEEL	32.7	AL	19.0
REAR WHEELHOUSE	STEEL	24.0	AL	13.9
FRAME	STEEL	300.0	AL	174.0
ENGINE SUPPORT CROSSMEMBER	STEEL	20.5	HSS	16.4
ENGINE MOUNTING BRACKET	STEEL	8.5	HSS	6.8
SEAT FRAME	STEEL	12.0	HSS	9.6
FRONT BUMPER	STEEL	29.0	FOAM	14.5
REAR BUMPER	STEEL	23.0	FOAM	11.5
BUMPER MOUNTING BRACKET	STEEL	9.0	HSS	7.2
FRONT SPRING	STEEL	75.0	HRP	30.0
REAR SPRING	STEEL	80.0	HRP	32.0

*ESTIMATED WEIGHT

TABLE B-15 (CONT'D)

PART NAME	CURRENT		ALTERNATIVE	
	MATERIAL	WT. (LBS)	MATERIAL	WT. (LBS)
REAR SPRING SHACKLE	STEEL	3.0	HSS	2.4
AXLE U-BOLT PLATE	STEEL	10.0	HSS	8.0
STEERING GEAR HOUSING	IRON	15.5	AL	7.8
MASTER CYLINDER	IRON	10.2	AL	5.1
BRAKE & CLUTCH PEDAL	STEEL	6.0	HSS	4.8
PARKING BRAKE PEDAL & BRACKET	STEEL	4.0	HSS	3.2
DRIVE SHAFT	STEEL	24.0	HRP	9.6
WHEEL	STEEL	107.5	AL	53.8
FUEL TANK	TERNE	24.0	HDPE	15.5
RADIATOR	COPPER	14.0	AL	7.0
HEATER CORE	COPPER	5.0	AL	2.5
WINDSHIELD	GLASS	31.0	GLASS	24.8
REAR WINDOW	GLASS	18.0	GLASS	12.0
DOOR GLASS	GLASS	16.0	GLASS	10.7
SIDE WINDOW	GLASS	35.0	GLASS	23.3
BRAKE DISC	IRON	55.5	AL	27.8
BRAKE DRUM	IRON	26.0	AL	13.0
BATTERY TRAY	STEEL	3.0	AL	2.5
CYLINDER HEAD	IRON	74.0	AL	37.0
ENGINE BLOCK	IRON	145.0	AL	72.5
INTAKE MANIFOLD	IRON	35.6	AL	17.8
EXHAUST MANIFOLD	IRON	24.9	STAINLESS STEEL	9.4
AIR CLEANER HOUSING	STEEL	6.0	AL	3.5
VALVE COVER	STEEL	6.5	AL	3.8
OIL PAN	STEEL	7.5	AL	4.4
WATER PUMP	IRON	7.5	AL	3.7
CONNECTING ROD	STEEL	10.0	STEEL	10.0

*ESTIMATED WEIGHT

TABLE B-16 1978 DODGE RAMCHARGER EQUIPPED
WITH 225 CID ENGINE
HRP DOMINANT CASE

PART NAME	CURRENT		ALTERNATIVE	
	MATERIAL	WT. (LBS)	MATERIAL	WT. (LBS)
TOP	STEEL	175.0	HRP	87.5
DASH	STEEL	32.0	HRP	16.0
FLOOR	STEEL	97.0	HRP	48.5
TAILGATE	STEEL	44.0	HRP	22.0
HOOD OUTER PANEL	STEEL	34.7	HRP	17.4
HOOD INNER PANEL	STEEL	20.3	HRP	10.2
HOOD HINGE BRACKET	STEEL	10.0	HRP	4.0
FRONT FENDER OUTER	STEEL	35.1	HRP	17.6
FRONT FENDER INNER	STEEL	16.9	HRP	8.5
FRONT WHEELHOUSE	STEEL	21.0	HRP	10.5
RADIATOR SUPPORT	STEEL	40.0	HRP	16.0
GRILLE LOWER PANEL	STEEL	4.0	HRP	2.0
COWL SIDE	STEEL	22.0	HRP	11.0
COWL VENT PANEL	STEEL	4.0	HRP	2.0
DOOR OUTER PANEL	STEEL	40.0	HRP	20.0
DOOR INNER PANEL	STEEL	40.0	HRP	20.0
SIDE PANEL OUTER	STEEL	46.8	HRP	23.4
SIDE PANEL INNER	STEEL	32.7	HRP	16.4
REAR WHEELHOUSE	STEEL	24.0	HRP	12.0
FRAME	STEEL	300.0	HRP	120.0
ENGINE SUPPORT CROSSMEMBER	STEEL	20.5	HRP	8.2
ENGINE MOUNTING BRACKET	STEEL	8.5	HRP	3.4
SEAT FRAME	STEEL	12.0	HRP	4.8
FRONT BUMPER	STEEL	29.0	FOAM	14.5
REAR BUMPER	STEEL	23.0	FOAM	11.5
BUMPER MOUNTING BRACKET	STEEL	9.0	HRP	3.6
FRONT SPRING	STEEL	75.0	HRP	30.0
REAR SPRING	STEEL	80.0	HRP	32.0

*ESTIMATED WEIGHT

TABLE B-16 (CONT'D)

PART NAME	CURRENT		ALTERNATIVE	
	MATERIAL	WT.(LBS)	MATERIAL	WT.(LBS)
REAR SPRING SHACKLE	STEEL	3.0	HRP	1.2
AXLE U-BOLT PLATE	STEEL	10.0	HRP	4.0
STEERING GEAR HOUSING	IRON	15.5	AL	7.8
MASTER CYLINDER	IRON	10.2	AL	5.1
BRAKE & CLUTCH PEDAL	STEEL	6.0	HRP	2.4
PARKING BRAKE PEDAL & BRACKET	STEEL	4.0	HRP	1.6
DRIVE SHAFT	STEEL	24.0	HRP	9.6
WHEEL	STEEL	107.5	HRP	43.0
FUEL TANK	TERNE	24.0	HDPE	15.5
RADIATOR	COPPER	14.0	AL	7.0
HEATER CORE	COPPER	5.0	AL	2.5
WINDSHIELD	GLASS	31.0	GLASS	24.8
REAR WINDOW	GLASS	18.0	GLASS	12.0
DOOR GLASS	GLASS	16.0	GLASS	10.7
SIDE WINDOW	GLASS	35.0	GLASS	23.3
BRAKE DISC	IRON	55.5	AL	27.8
BRAKE DRUM	IRON	26.0	AL	13.0
BATTERY TRAY	STEEL	3.0	HRP	1.5
CYLINDER HEAD	IRON	74.0	AL	37.0
ENGINE BLOCK	IRON	145.0	AL	72.5
INTAKE MANIFOLD	IRON	35.6	AL	17.8
EXHAUST MANIFOLD	IRON	24.9	STAINLESS STEEL	9.4
AIR CLEANER HOUSING	STEEL	6.0	HRP	3.0
VALVE COVER	STEEL	6.5	HRP	3.3
OIL PAN	STEEL	7.5	HRP	3.8
WATER PUMP	IRON	7.5	AL	3.8
CONNECTING ROD	STEEL	10.0	HRP	4.0

*ESTIMATED WEIGHT

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