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NEAR TERM WEIGHT REDUCTION POTENTIAL IN A 1977 GENERAL MOTORS B BODY VEHICLE

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16. Abstract

This report presents an analysis of the potential for weight reduction through lightweight material and component substitutions in a 1977 General Motors Corporation B body vehicle. The changes were limited to those that appeared producible in the 1980 to 1985 time frame. The first portion of the analysis involved gathering weight data on selected components of a 1975 Chevrolet Impala 4-door sedan and a 1977 Chevrolet Impala 4-door sedan. The 1975 Impala data were used to illustrate the means used by General Motors to achieve a 650-pound weight reduction in the 1977 Impala. The second portion of the analysis involved the estimation of the potential weight reductions possible in the 1977 Impala through material and component substitutions. The vehicle's components were broken down into three different but interactive categories: the occupant compartment structure, the suspension/steering/braking system and the drive-train. Materials and component substitutions were conservatively carried out so as not to affect the appearance, safety, or acceleration performance of the vehicle. However, the costs of the changes were not explicitly considered, and they would be expected to contribute to some increase in the real price of the vehicle. The reduction in these three areas reduced the curb weight of the 1977 Chevrolet Impala 4-door sedan from 1682 kg (3708 lb) to 1429 kg (3150 lb). Thus, a total weight reduction of 250 kg (552 lb) or 15 percent resulted from this conservative analysis of the weight reduction potential in this vehicle for the 1980 to 1985 time frame.

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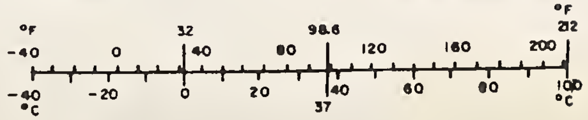
METRIC CONVERSION FACTORS

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

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



PREFACE

This report, prepared by Arthur D. Little, Inc., for the U.S. Department of Transportation, Transportation Systems Center, presents an analysis of the potential for weight reduction through further lightweight material and component substitutions in a 1977 General Motors Corporation B body vehicle. The changes suggested were limited to those that appeared producible in the 1980 to 1985 time frame. This report was sponsored by the U.S. Department of Transportation, National Highway Traffic Safety Administration, Office of Research and Development, Office of Passenger Vehicle Research, Technology Assessment Division.

The first portion of the analysis involved the gathering of weight data on selected components of a 1975 Chevrolet Impala 4-door sedan with a 350 C.I. V-8 engine and a 1977 Chevrolet Impala 4-door sedan with a 305 C.I. V-8 engine. The 1975 Impala data were used to illustrate the 650-pound weight reduction achieved in the 1977 Impala.

The second portion of the analysis involved the estimation of the potential weight reductions possible in the 1977 Impala through material and component substitutions. The vehicle's components were broken down into three different but interactive categories: the occupant compartment structure, the suspension/steering/braking system and the drivetrain. The weight of the occupant compartment structure was reduced by using 6009-T4, 6010-T4 and 5182-0 aluminum in selected body panels and components, and by reducing window thicknesses slightly. These changes produced a 73.7 kg (162.4 lb) reduction in the occupant compartment structure weight. The weight of the drivetrain was reduced by substituting a new lightweight, 4 cylinder turbocharged engine for the current engine, and by using HDPE plastic and 5182-0 aluminum in components such as the fuel tank, air cleaner housing and transmission pan. Drivetrain weight was reduced by 135.1 kg (297.8 lb) as a result of these changes. The suspension/steering/braking system weight was reduced through the substitution of torsion bar front suspension and leaf spring rear suspension from a 1975 Plymouth Valiant 4-door sedan with a 318 C.I. V-8 engine. In addition, the weights of the leaf springs and driveshaft, wheels, master cylinder and differential cover were reduced through the use of graphite fiber-reinforced plastic, high strength low alloy steel, mild sheet steel and 5182-0 aluminum, respectively. These changes produced a 44.6 kg (98.3 lb) weight reduction in the suspension/steering/braking system.

The reductions in these three areas reduced the curb weight of the 1977 Chevrolet Impala 4-door sedan from 1682 kg (3708 lb) to 1429 kg (3150 lb). Thus, a total weight reduction of 250 kg (552 lb) or 15 percent resulted from this conservative analysis of the weight reduction potential in this vehicle for the 1980 to 1985 time frame.

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1. INTRODUCTION

1.1 MOTIVATIONS FOR AUTOMOBILE WEIGHT REDUCTION

There are a number of important reasons for both the U.S. automobile manufacturers and public to want to reduce the weight of the automobile fleet:

1. New car fuel economy regulations motivated by the desire to reduce U.S. dependence on foreign aid and conserve petroleum resources;
2. New car emission regulations motivated by the desire to protect our health and environment by limiting concentrations of harmful pollutants; and
3. The potential social and economic benefits from decreases in the amount of raw materials and energy needed to produce a vehicle.

The new car fuel economy regulations can be met by:

1. Further improving drivetrain efficiency;
2. Reducing engine displacement and sacrificing performance;
3. Downsizing the vehicle;
4. Reducing aerodynamic drag and rolling resistance;
5. Switching to an inherently more efficient type of engine;

and a wide variety of combinations of these and other methods. There can be no doubt, however, that vehicle weight plays an integral role in determining the fuel economy of a vehicle.[1,2]

New car emission regulations may be met through further use of add-on emission control devices, the use of more efficient or smaller engines burning less fuel per mile more completely, the adoption of an inherently cleaner burning engine, or some combination of these and other methods. No matter which method is chosen, it will be easier to meet the regulations with a light vehicle than with a heavy one.

Design improvements and changes that result in a decrease in the amount of raw materials and energy needed to produce a vehicle benefit both manufacturers and the public. Manufacturers realize slightly lower or more stable manufacturing costs and the public realizes the social and economic benefits of conserving valuable raw materials and energy.

The existence of Federal safety regulations does not appear to be a barrier to the reduction of automobile weight. Historically, it has been true that occupants of smaller cars sustain more serious injuries than occupants of larger cars involved in crashes.[3,4,5] This result is unchanged even when data for collisions between different size cars are eliminated from consideration. The key parameter in this result seems to be available crush distance and not vehicle weight.[6] Small cars have inherently less crush distance to hold down the level of deceleration experienced by the vehicle's occupants and maintain occupant compartment integrity. Therefore, the weight of all cars may be substantially reduced by properly using lightweight materials without adversely affecting current safety performance if the crush distance is adequate.

In summary, there is not a shortage of motivations for the automobile manufacturers to reduce vehicle weight, or for the public to expect them to do so.

1.2 PRIMARY METHODS OF AUTOMOBILE WEIGHT REDUCTION

There are at least four primary methods of reducing automobile weight:

1. Vehicle downsizing;
2. Component optimization using conventional materials;
3. Lightweight material substitution with conventional component design; and
4. Component optimization with lightweight materials.

When lightweight materials are substituted throughout a vehicle, a secondary weight savings is possible in addition to the primary savings. This results from the reduced structural loads to be handled by the suspension, steering and braking system and chassis, and from the ability to substitute a lighter, less powerful drivetrain while maintaining a constant level of performance.

Vehicle downsizing usually refers to the reduction of the exterior dimensions of a vehicle without substantially changing the passenger and luggage room. For example, Table 1.1 describes the changes that occurred in the interior and exterior dimensions of the Chevrolet Impala (B body) 4-door sedan from 1976 to 1977. It can be seen that nearly all of the exterior dimensions were substantially reduced while only a few of the interior dimensions were reduced. Two currently popular measures of vehicle interior room, the Interior Volume Index and the Roominess Index, indicate decreases of only 1.5 percent and 1.2 percent respectively.

Component optimization using standard materials involves redesigning each component to meet its functional requirements with a minimum amount of the materials traditionally used for the part.

Lightweight material substitution with conventional component design represents the first phase of weight reduction with new lightweight materials. This direct substitution does not, however, involve part redesign to compensate for the relative advantages and disadvantages of the new material's properties.

Finally, component optimization with lightweight materials involves redesigning the part with the new material's properties in mind. This approach should result in a more efficient use of the new material than direct substitution.

The 1977 General Motors B body vehicles represent an important example of weight reduction using these four approaches. Table 1.2 outlines the areas in which weight reduction was achieved in the 1977 Chevrolet Impala 4-door sedan.

TABLE 1.1 COMPARISON OF 1976 AND 1977 CHEVROLET IMPALA 4-DOOR SEDAN DIMENSIONS

Vehicle Dimensions	1976		1977		Percent Change
Exterior Dimensions[1]					
Wheel Base cm (in)	308.6	(121.5)	294.6	(116.0)	-4.5
Front Tread cm (in)	163	(64.1)	157	(61.8)	-3.6
Rear Tread cm (in)	163	(64.0)	154	(60.8)	-5.0
Length cm (in)	565.7	(222.7)	538.7	(212.1)	-4.8
Width cm (in)	202	(79.5)	193	(76.0)	-4.4
Height cm (in)	139	(54.7)	142	(56.0)	+2.4
Interior Dimensions[2]					
Front Seat Height cm (in)	21	(8.2)	22	(8.8)	+7.3
Headroom					
Front cm (in)	97.8	(38.5)	99.1	(39.0)	+1.3
Rear cm (in)	96.0	(37.8)	97.0	(38.2)	+1.1
Legroom					
Front cm (in)	108	(42.6)	107	(42.2)	-0.9
Rear cm (in)	97.8	(38.5)	100	(39.5)	+2.6
Shoulder Room					
Front cm (in)	163	(64.0)	154	(60.8)	-5.0
Rear cm (in)	160	(63.1)	154	(60.8)	-3.6
Interior Volume Index[3]					
Passenger m^3 (ft^3)	3.23	(114)	3.06	(111)	-2.6
Trunk m^3 (ft^3)	0.535	(18.9)	0.572	(20.2)	+6.9
Total m^3 (ft^3)	3.77	(133)	3.72	(131)	-1.5
Roominess Index[2] cm (in)	743.5	(292.7)	734.8	(289.3)	-1.2

[1] Automotive Industries, Chilton Co., Radnor, PA, April 1, 1976 and April 1, 1977.

[2] Automotive Industries, Chilton Co., Radnor, PA, January 15, 1976 and October 1, 1976.

Roominess Index = front seat height + front and rear head-room + front and rear legroom + front and rear shoulder room

[3] B. McNutt, D. Perky, and R. Dulla, "Development of a System of Comparable Car Classes for Fuel Economy Labeling," SAE paper 760794, 1976.

Interior Volume Index = front seat volume + rear seat volume + luggage volume
Front Seat Volume = front head room x front shoulder room x front leg room
Rear Seat Volume = rear head room x rear shoulder room x rear leg room
Luggage Volume = useable luggage volume determined with standard luggage set

TABLE 1.2 BASIC WEIGHT COMPARISON OF THE 1976 AND 1977 CHEVROLET IMPALA 4-DOOR SEDANS (V-8 ENGINE)

	1977		1976		Change		Percent
BODY	Kg	(lb)	Kg	(lb)	Kg	(lb)	Reduction
Body as Purchased	501.9	(1107)	609	(1342)	-107.1	(-235)	17.5
Additional Body Parts	30.5	(67)	21	(46)	- 9.5	(- 21)	45.7
Body Mounts	4.3	(9)	5	(10)	- 0.7	(- 1)	10.0
TOTAL BODY	536.7	(1183)	634	(1398)	- 97.3	(-215)	15.4
CHASSIS							
Frame	118.3	(261)	148	(327)	- 29.7	(- 66)	20.2
Front Suspension	66.2	(146)	73	(161)	- 6.8	(- 15)	9.3
Rear Suspension	94.5	(208)	117	(259)	- 22.5	(- 51)	19.7
Brakes, Power Disc	70.3	(155)	85	(187)	- 14.7	(- 32)	17.1
Engine, 5.0 Litre, V8 305	272.6	(601)	-	-	- 9.4	(- 20)	3.2
Engine, 5.7 Litre, V8 350	-	-	282	(621)	-	-	-
Transmission, CBC	-	-	81	(179)	-	-	-
Transmission, THM 200	66.2	(146)	-	-	- 14.8	(- 33)	18.4
Fuel and Exhaust	52.9	(117)	56	(123)	- 3.1	(- 6)	4.9
Steering Power	41.5	(92)	44	(97)	- 2.5	(- 5)	5.2
Wheels & Tires (HR78 x 15; 15 x 6)	-	-	125	(276)	-	-	-
Wheels & Tires (FR78 x 15; 15 x 6)	109.2	(241)	-	-	- 15.8	(- 35)	12.7
Front End Sheet Metal	84.4	(186)	97	(214)	- 12.6	(- 28)	13.1
Chassis Electrical	29.4	(65)	35	(77)	- 5.6	(- 12)	15.6
Radiator and Grille	11.5	(25)	13	(28)	- 1.5	(- 3)	10.7
Front Bumpers	32.1	(71)	56	(124)	- 23.9	(- 53)	42.7
Rear Bumpers	32.5	(72)	52	(115)	- 19.5	(- 43)	37.4
Tools and Miscellaneous	13.5	(30)	13	(30)	+ 0.5	(-)	-
TOTAL CHASSIS	1095.1	(2415)	1278	(2818)	-182.9	(-403)	14.3
SHIPPING WEIGHT+	1631.8	(3598)	1912	(4216)	-280.2	(-618)	14.7
Gasoline (additional to fill to capacity)	50.0	(110)	63	(139)	- 13.0	(- 29)	20.9
CURB WEIGHT							
Front	918.2	(2025)	1053	(2321)	-134.8	(-296)	12.8
Rear	763.6	(1684)	923	(2034)	-159.4	(-350)	17.2
TOTAL	1681.8	(3708)	1975	(4355)	-293.2	(-647)	14.9

+Shipping weight includes coolant and 3 gallons of gasoline.

Source: Mr. Jim Williams, Chevrolet Public Relations, Detroit, Michigan.

1.3 PURPOSE

The purpose of this report is to present the results of analysis performed to estimate the potential for weight reduction through further material substitution and component substitution in a 1977 General Motors Corporation B body vehicle which could be produced in the 1980 to 1985 time frame.

1.4 PROCEDURE

The procedure followed to accomplish this analysis is outlined below:

1. Gather weight and other data on selected components of a 1975 and a 1977 Chevrolet 4-door sedan.
2. Determine the weight reduction potential of substituting lightweight materials for selected occupant compartment structure components.
3. Determine the weight reduction potential of substituting lighter weight <u>components</u> from other comparable vehicles for those currently in the drivetrain.
4. Determine the weight reduction possible by substituting lightweight <u>materials</u> in components of the new drivetrain.
5. Find the weight-saving potential of substituting lighter suspension/steering/braking system components from other vehicles for those currently used.
6. Find the weight reduction possible by substituting lightweight materials in the components of the new suspension/steering/braking system.
7. Estimate the total weight reduction potential through lightweight material and component substitution for the 1977 Chevrolet 4-door sedan for the 1980 to 1985 time frame.

2. DISCUSSION

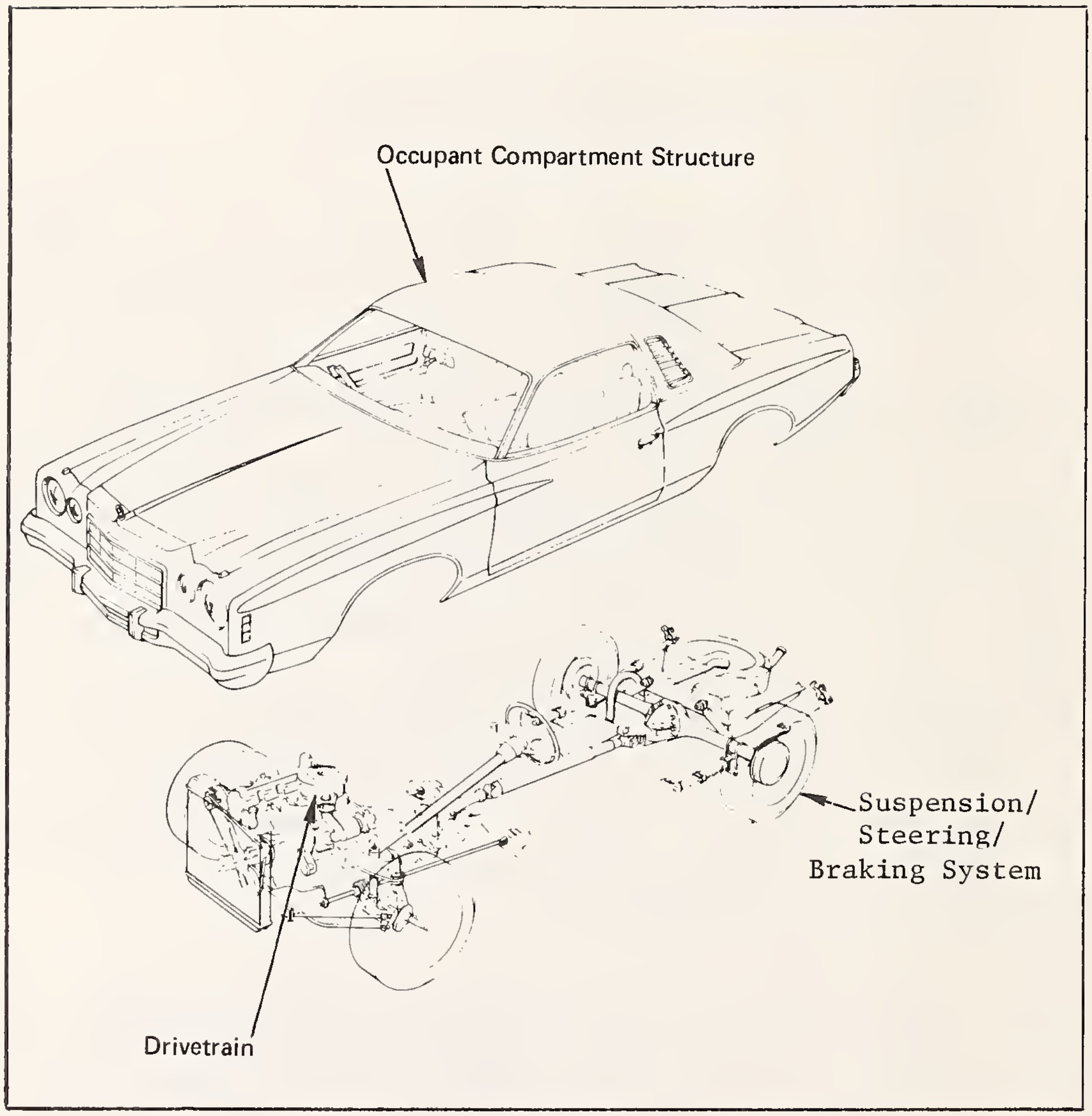
2.1 EXPERIMENTAL WEIGHT DATA

2.1.1 Elements of the Automobile Structure

The automobile may be separated into three categories that are essentially different, but highly interactive.[7] These three categories are shown in Figure 2.1 to be the occupant compartment structure, the steering/braking/suspension system and the drivetrain. The occupant compartment structure encloses the passengers and baggage, provides some measure of impact energy management in collisions, and provides protection from the outside environment. The weight of the occupant compartment structure is determined by those parts of the vehicle specified in defining its product character that are substantially independent of vehicle weight and power. The steering/braking/suspension system contains the driver control system and the suspension system. The weight of this system is made up by parts of the vehicle that are a strong function of gross vehicle weight. The drivetrain is composed of components whose weights are a direct function of engine power output and/or engine displacement.

This set of categories provides an organizational framework in which to fit experimentally obtained vehicle weight data. Table 2.1 outlines the vehicle components assigned to each category. These assignments are slightly different than those used in Reference 7 as a matter of convenience.

The majority of the experimental data reported in the following tables pertain to a 1977 Chevrolet Impala 4-door sedan equipped with a 305 cubic inch V-8 engine. Some additional comparison data pertaining to a 1975 Chevrolet Impala 4-door sedan equipped with a 350 cubic inch V-8 engine is also included. As a basis for comparison, the 1977 Impala has a shorter 0 to 60 mph acceleration time than the 1975 Impala.



Source: Arthur D. Little, Inc.

FIGURE 2.1 ELEMENTS OF THE AUTOMOBILE STRUCTURE

TABLE 2.1 COMPONENTS ASSIGNED TO EACH VEHICLE WEIGHT CATEGORY

- Occupant Compartment Structure Weight
  - Body and Frame
  - Heating, Ventilating and Air Conditioning System
  - Instruments and Electrical Distribution
  - Front-End Sheet Metal
  - Exhaust System
- Suspension/Steering/Braking System Weight
  - Suspension, Wheels, Tires, and Brakes
  - Steering System
  - Rear Axle
- Drivetrain Weight
  - Engine
  - Transmission and Clutch or Torque Converter
  - Cooling System
  - Fuel System and Fuel
  - Battery and Alternator

2.1.2 Weight Data

Table 2.2 lists selected occupant compartment structure weights for the 1977 Chevrolet Impala. The components concentrated on were chosen based on the belief that the first effective and economical applications of new lightweight materials will occur in "bolt on" applications. These applications will likely include hoods, decklids, fenders, doors and other front end sheet metal components.

Table 2.3 lists selected component weights from the drivetrain. Table 2.4 provides a comparison between the weight data available from a 1975 Chevrolet Impala and the 1977 Chevrolet Impala data.

Table 2.5 lists selected component weights for the suspension/steering/braking system of the 1977 Chevrolet Impala. Table 2.6 provides a comparison between the available 1975 Impala data and the 1977 Impala data.

Table 2.7 presents a summary of the weight data obtained from the 1977 Chevrolet Impala. It can be seen that the occupant compartment structure weight accounted for 55 percent of the base curb weight.* The suspension/steering/braking system accounted for 19 percent and the drivetrain made up the remaining 26 percent of the base curb weight.

2.2 ESTIMATION OF POTENTIAL WEIGHT REDUCTION

This Section presents an analysis of the near term weight reduction potential in the 1977 Chevrolet Impala 4-door sedan. Direct substitution of lightweight materials and the substitution of existing lighter weight components from comparable vehicles were the methods used. No changes in component design were considered and it should be emphasized that an optimum lightweight vehicle will probably be achieved only by making design and material changes in an iterative, creative process.

The reduction of automobile weight is an iterative process because of what are known as weight-weight interactions.[8,9,10]

TABLE 2.2 WEIGHTS OF SELECTED OCCUPANT COMPARTMENT STRUCTURE COMPONENTS FOR A 1977 CHEVROLET IMPALA 4-DOOR SEDAN (SHEET 1 OF 2)

	kg	(lb)*
Left Front Fender Assembly	12.9	(28.5)
Plastic Fender Extensions	0.45	(1.0)
Fender Support Structure	7.03	(15.5)
Rustproofing	-	-
Outer Skin with Paint	5.44	(12.0)
Left Front Wheel House Assembly	5.90	(13.0)
Rubber Splash Guard	0.2	(0.5)
Rustproofing	0.45	(1.0)
Fender Well with Paint	5.22	(11.5)
Hood Assembly with Hinges	29.9	(66.0)
Two Hood Hinges	5.44	(12.0)
Hood Support Structure with Latch Plate	9.07	(20.0)
Adhesive Bonding	0.68	(1.5)
Outer Skin with Paint	14.7	(32.5)
Radiator Support Frame without Fan Shroud and Hood Latch	12.0	(26.5)
Left Front Door Assembly with Mirror	32.0	(70.5)
Mirror	0.45	(1.0)
Glass with Bottom Rail	4.54	(10.0)
Door Support Structure with Window Frame	8.85	(19.5)
Guard Beam	3.9	(8.5)
Two Hinge Reinforcement Plates	0.23	(0.5)
Door Latch, Window Winding Mechanism and Assorted Trim	8.16	(18.0)
Rustproofing	0.45	(1.0)
Outer Skin with Paint	5.44	(12.0)
Left Rear Door Assembly	24.7	(54.5)
Glass - 2 Pieces with Bottom Rail on Large Piece	3.6	(8.0)
Door Support Structure with Window Frame	8.16	(18.0)
Guard Beam	2.5	(5.5)
Two Hinge Reinforcement Plates	0.23	(0.5)
Door Latch, Window Winding Mechanism and Assorted Trim	5.90	(13.0)
Rustproofing	0.2	(0.5)
Outer Skin with Paint	4.1	(9.0)
Deck Lid Assembly with Hinges (No Springs)	22.5	(49.5)
Deck Lid Support Structure without Latch	6.12	(13.5)
Two Hinges (No Springs)	2.7	(6.0)

* All weights are accurate to the nearest 0.2 kg (0.5 lb)

TABLE 2.2 WEIGHTS OF SELECTED OCCUPANT COMPARTMENT STRUCTURE COMPONENTS FOR A 1977 CHEVROLET IMPALA 4-DOOR SEDAN (SHEET 2 OF 2)

	kg	(lb)*
Adhesive and Latch	0.68	(1.5)
Outer Skin with Paint	12.9	(28.5)
Windshield - Laminated and Antenna	14.5	(32.0)
Backlight	9.75	(21.5)
Front Bumper Assembly with Energy Absorbers	33.3	(73.5)
Two Energy Absorbers	6.35	(14.0)
Six Piece Support Structure with Bolts	10.4	(23.0)
Bumper Face	16.6	(36.5)
Rear Bumper Assembly with Energy Absorbers	31.8	(70.0)
Two Energy Absorbers	6.35	(14.0)
Three Piece Support Structure with Bolts	10.4	(23.0)
Bumper Face	15.0	(33.0)
Two Lamp Headlight Assembly	2.5	(5.5)
Rectangular Headlight Bulb	0.45	(1.0)
Front License Plate Holder	0.68	(1.5)
Horn - One Unit	0.45	(1.0)
Bumper Jack	4.99	(11.0)
Battery Tray	0.91	(2.0)
Windshield Wiper Motor and Washer Pump	2.9	(6.5)
Front Seat Assembly	31.3	(69.0)
Rear Seat Bottom Cushion	7.26	(16.0)
Exhaust System without Mounting Brackets	29.7	(65.5)
Y-Pipe	3.2	(7.0)
Catalytic Converter	11.6	(25.5)
Intermediate Pipe and Muffler	11.3	(25.0)
Tailpipe	3.6	(8.0)
Total of Components Weighed	310.0	(683.5)

* All weights are accurate to the nearest 0.2 kg (0.5 lb)

Source: Arthur D. Little, Inc.

TABLE 2.3 DRIVETRAIN WEIGHTS FOR A 1977 CHEVROLET IMPALA 4-DOOR SEDAN

	kg	(lb)*
Basic 305 C.I. V-8 Engine with Fuel Pump, Oil Pump, Water Pump, Starter, Alternator, Distributor, Carburetor, Exhaust Manifolds, Oil Filter, Power Steering Pump, Air Cleaner, Fan, no Fan Belts, no Radiator Hoses, no Heater Hoses, no Engine Oil, and with all Small Hoses and Wires	270.8	(597.0)
Air Cleaner - No Hoses or Tubes Attached	2.9	(6.5)
Air Cleaner Top	0.91	(2.0)
Air Cleaner Bottom	1.6	(3.5)
Filter Element	0.45	(1.0)
Starter with Solenoid and Wire	8.85	(19.5)
Connecting Wire	0.45	(1.0)
Starter with Solenoid	8.39	(18.5)
Alternator with Mounting Brackets	5.44	(12.0)
Alternator	4.54	(10.0)
Three Mounting Brackets	0.91	(2.0)
Power Steering Pump with Mounting Brackets and without Fluid	6.12	(13.5)
Pump without Fluid	4.99	(11.0)
Mounting Brackets	1.1	(2.5)
Fan Blade with Pulley and Aluminum Spacer	2.0	(4.5)
Fan Blade	1.4	(3.0)
Pulley and Aluminum Spacer	0.68	(1.5)
Water Pump	6.35	(14.0)
Fuel Pump	0.45	(1.0)
Flywheel	2.5	(5.5)
Right Exhaust Manifold and Heat Shield	7.48	(16.5)
Distributor Cap and Spark Plug Wires	1.6	(3.5)
Rochester 2 Barrel Carburetor and Choke	3.4	(7.5)
Automatic Transmission with Torque Converter, Fluid, Dipstick and Fluid Cooling Lines	63.28	(139.5)
Torque Converter with Fluid	18.4	(40.5)
Transmission Fluid	1.4	(3.0)
Transmission with Dipstick and Fluid Cooling Lines	42.4	(93.5)
Transmission Fluid Pan	1.1	(2.5)
Brass Radiator with Cap	6.80	(15.0)
Engine Coolant - 17.0 liters at 1.0 kg/liter	17.0	(37.5)
Delco Freedom Battery - 12 volts, 3200 watts	14.5	(32.0)
Fuel Tank with Level Sender	12.9	(28.5)
Fuel - 75.7 liters (20 gals.) gas at 0.73 kg/liter	55.3	(122.0)
Engine Oil - 3.79 liters (4 qts) at 0.84 kg/liter	3.2	(7.0)
Total of Components Weighed	443.8	(978.5)

* All weights are accurate to the nearest 0.2 kg (0.5 lb.)

Source: Arthur D. Little, Inc.

TABLE 2.4 COMPARISON OF AVAILABLE 1975 AND 1977 CHEVROLET IMPALA 4-DOOR SEDAN DRIVETRAIN WEIGHTS

Part Description	1975 kg	1975 (lb)	1977 kg	1977 (lb)	Weight Change kg	Weight Change (lb)	%
Basic V-8 Engine with Fuel Pump, Oil Pump, Water Pump, Starter, Alternator, Power Steering Pump, Air Cleaner, Fan, Fan Belts, Distributor, No Radiator Hoses, No Heater Hoses, Engine Oil and Small Wires and Hoses	266 (5.7 litre)	(587)	274 (5.0 litre)	(604)	+ 7.7	(+17)	+ 3
Starter with Solenoid	9.1	(20)	8.4	(18.5)	- 0.7	(- 1.5)	- 8
Alternator	4.5	(10)	4.5	(10.0)	-		-
Automatic Transmission with Torque Converter and Fluid	77.1 (CBC)	(170)	63.3 (THM 200)	(139.5)	-13.8	(-30.5)	-18
Torque Converter with Fluid	15.9	(35)	18.4	(40.5)	+ 2.5	(+ 5.5)	+16
Fuel Tank with Level Sender	13.6	(30)	12.9	(28.5)	- 0.7	(- 1.5)	- 5
Fuel - 0.73 kg/liter	72.1 (98.4 litres)	(159)	55.3 (75.7 litres)	(122)	-16.8	(-37)	-23

Source: Arthur D. Little, Inc.

TABLE 2.5 SUSPENSION/STEERING/BRAKING SYSTEM WEIGHTS FOR A 1977 CHEVROLET IMPALA 4-DOOR SEDAN

	kg	(lb)*
Complete Front Suspension, Brakes and Steering	109.3	(241.0)
Two Shock Absorbers	1.8	(4.0)
Two Springs with Rubber Pads	11.3	(25.0)
Two Tie Rods	2.7	(6.0)
Two Lower Control Arms with Mounting Bolts	15.4	(34.0)
Two Upper Control Arms with Mounting Bolts	9.07	(20.0)
Two Rotors with Two Bearings Each	21.3	(47.0)
Two Deflectors	0.45	(1.0)
Two Spindles	13.6	(30.0)
Two Calipers	7.71	(17.0)
Two Sets of Two Pads	1.4	(3.0)
Sway Bar with Rubber Mounts, Clamps, Bolts and no Links	7.26	(16.0)
Draglink with Right Pitman Arm and Mounting Bracket	3.9	(8.5)
Steering Box with Pitman Arm	13.4	(29.5)
Driveshaft with Front and Rear Yokes and Two Universal Joints	9.07	(20.0)
Complete Rear End Assembly	102.7	(226.5)
Two Rear Brakes with Backing Plates, Shoes Springs, Wheel Cylinders, and Emergency Brake Cables	8.62	(19.0)
Two Rear Brake Drums	13.6	(30.0)
Two Upper Arms	2.7	(6.0)
Two Lower Arms	4.99	(11.0)
Two Shock Absorbers	3.2	(7.0)
Two Springs	6.80	(15.0)
Two Axle Half-Shafts	12.7	(28.0)
Differential Inspection Cover with Gasket	0.91	(2.0)
Differential Fluid	1.4	(3.0)
Rear End Casting with Gears and Bearings	47.85	(105.5)
Brake Master Cylinder without Fluid and with Power Booster	7.48	(16.5)
Brake Master Cylinder without Fluid	3.9	(8.5)
Power Booster	3.6	(8.0)
Road Wheel with B. F. Goodrich FR 78-15 Lifesaver Steel Belted Radial Tire	22.0	(48.5)
Road Wheel with Valve Stem (15x6)	9.75	(21.5)
Tire	12.2	(27.0)
Wheel Cover	0.45	(1.0)
Total of Components Weighed (Includes 4 Tires and 4 Wheel Covers)	318.4	(702.0)

* All weights are accurate to the nearest 0.2 kg (0.5lb.)

Source: Arthur D. Little, Inc.

TABLE 2.6 COMPARISON OF AVAILABLE 1975 CHEVROLET IMPALA 4-DOOR SEDAN STEERING/BRAKING/ SUSPENSION SYSTEM WEIGHTS (SHEET 1 OF 2)

Part Description	1975		1977		Weight Change		
	kg	(lb)	kg	(lb)	kg	(lb)	%
Front Suspension Including Two Shocks, Two Springs, Two Upper Control Arms, Two Lower Control Arms, Two Spindles, Two Rotors, Two Rotor Shields, and Two Calipers with Pads and Attaching Bolts	97.1	(214)	83.9	(185.0)	-13.2	(-29.0)	-14
Two Shock Absorbers	1.8	(4)	1.8	(4.0)	-		-
Two Springs with Pads	15.4	(34)	11.3	(25.0)	- 4.1	(- 9.0)	-26
Two Upper Control Arms, Two Lower Control Arms and Two Spindles	40.8	(90)	38.1	(84.0)	- 2.7	(- 6.0)	- 7
Two Rotors with Two Bearings Each	26.3	(58)	21.3	(47.0)	- 5.0	(11.0)	-19
Two Calipers with Two Pads Each	10.9	(24)	9.1	(20.0)	- 1.8	(- 4.0)	-17
Two Rotor Shields	0.5	(1)	0.5	(1.0)	-		-
Front Sway Bar with Rubber Mounts, Clamps, Bolts and No Links	6.1	(13.5)	7.3	(16.0)	+ 1.1	(+ 2.5)	+19
Draglink with Right Pitman Arm and Mounting Bracket, and Two Tie Rods	7.7	(17)	6.6	(14.5)	- 1.1	(- 2.5)	-15
Steering Box with Pitman Arm	13.2	(29)	13.4	(29.5)	+ 0.2	(+ 0.5)	+ 2

Source: Arthur D. Little, Inc.

TABLE 2.6 COMPARISON OF AVAILABLE 1975 CHEVROLET IMPALA 4-DOOR SEDAN STEERING/BRAKING/SUSPENSION SYSTEM WEIGHTS (SHEET 2 OF 2)

Part Description	1975		1977		Weight Change		
	kg	(lb)	kg	(lb)	kg	(lb)	%
Driveshaft with Front and Rear Yokes and Two Universal Joints	11.3	(25)	9.1	(20.0)	- 2.3	(- 5.0)	-20
Rear End Assembly Including Two Complete Brake Assemblies, Two Axle Shafts, Fluid and Connecting Hardware	113.4	(250)	86.2	(190.0)	-27.2	(-60.0)	-24
Two Rear Brakes with Backing Plates, Shoes, Springs, Wheel Cylinders, and Emergency Brake Cables	10.9	(24)	8.6	(19.0)	- 2.3	(- 5.0)	-21
Two Rear Brake Drums	15.4	(34)	13.6	(30.0)	- 1.8	(- 4.0)	-12
Two Axle Half-Shafts	16.3	(36)	12.7	(28.0)	- 3.6	(- 8.0)	-22
Rear End Casting with Gears, Bearings and Inspection Cover	68.0	(150)	48.8	(107.5)	-19.3	(-42.5)	-28
Differential Fluid	1.4	(3)	1.4	(3.0)	-		-
Road Wheel with Tire (1975 - HR 78-15 Radial, 1977 - FR 78-15 Radial)	23.1	(51)	22.0	(48.5)	- 1.1	(- 2.5)	- 5
Road Wheel with Valve Stem (15x6)	10.4	(23)	9.7	(21.5)	- 0.7	(- 1.5)	- 7
Tire	12.7	(28)	12.2	(27.0)	- 0.5	(- 1.0)	- 4

Source: Arthur D. Little, Inc.

TABLE 2.7 SUMMARY OF WEIGHT DATA FOR A 1977 CHEVROLET IMPALA 4-DOOR SEDAN

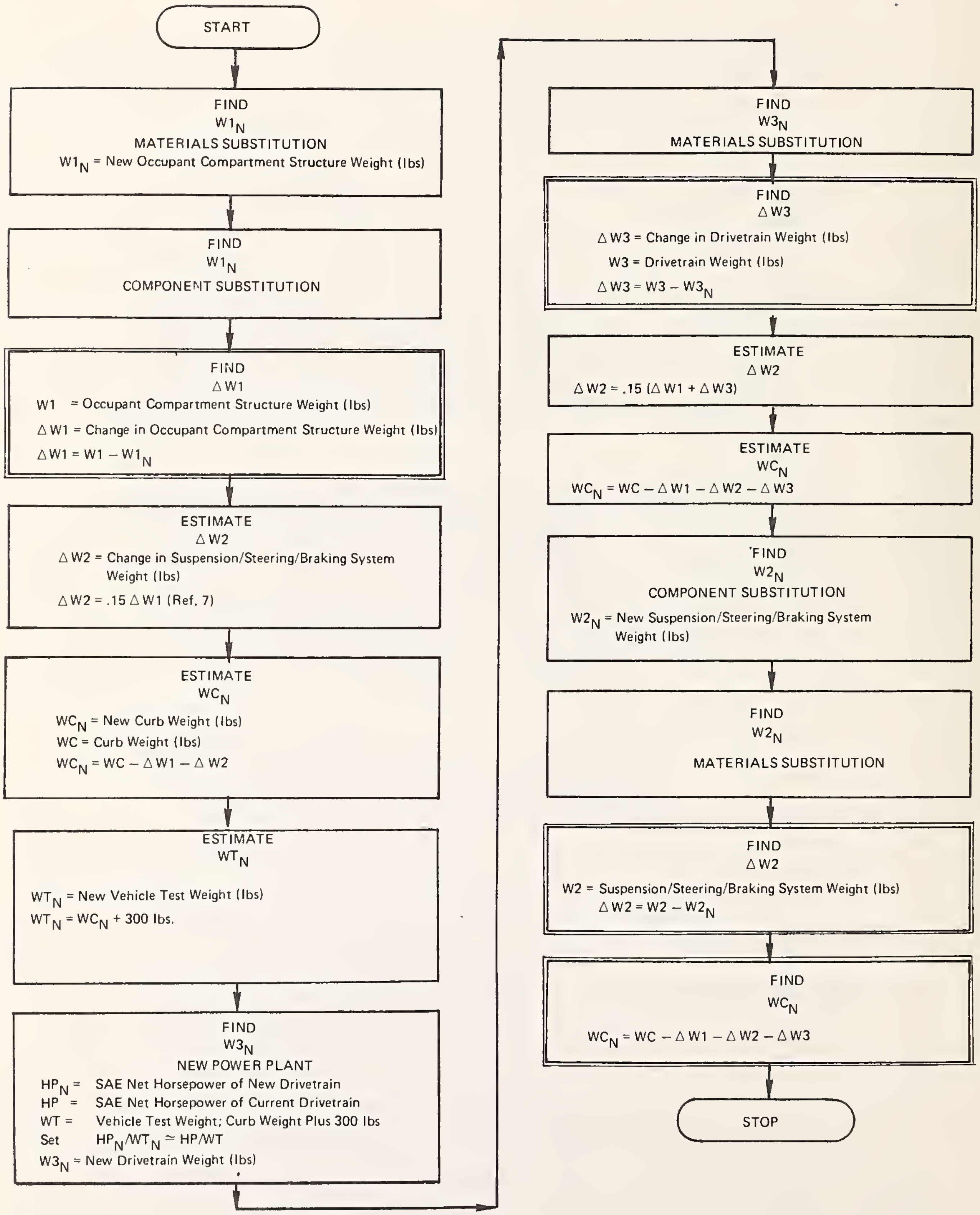
VEHICLE COMPONENT	Weight kg (lb)
Base Curb Weight (WC)	1681.9 (3708)*
Occupant Compartment Structure Weight (W1)	919.2 (2026.5)
Body and Frame	N/A
Heating, Ventilating and Air Conditioning Systems	N/A
Instruments and Electrical Distribution	N/A
Front End Sheet Metal	N/A
Exhaust System	29.7 (65.5)
Suspension/Steering/Braking System Weight (W2)	318.4 (702.0)
Suspension, Wheels, Tires and Brakes	226.6 (499.5)
Steering System Including Drag Links, Mounting Bracket, Pitman Arms, Steering Box and Tie Rods	19.9 (44.0)
Rear Axle Including Shafts, Casting, Fluid, Cover and Driveshaft	71.9 (158.5)
Drivetrain Weight (W3)	444.3 (979.5)
Engine with Oil Pump, Starter, Engine Oil, Distributor, Carburetor, Exhaust Manifolds, Oil Filter, Power Steering Pump, Air Cleaner, Fan, No Fan Belts, No Radiator Hoses, No Heater Hoses	261.7 (577.0)
Transmission and Torque Converter	63.3 (139.5)
Cooling System Including Radiator, Coolant and Water Pump	30.2 (66.5)
Fuel System Including Fuel Tank with Sender, Fuel Pump and Fuel	69.2 (152.5)
Battery and Alternator with Mounting Brackets	19.9 (44.0)

*Mr. J. Williams - Chevrolet Public Relations, Detroit, Michigan

Source: Arthur D. Little, Inc.

All automobile components can be put into two groups: non-interacting and interacting weight-sensitive components. For the purpose of this analysis, the occupant compartment structure weight was considered to be non-interacting. That is, a reduction in weight caused by the substitution of aluminum hood and decklid panels, for example, would not structurally justify weight reductions in the seats, roof, doors or windows. On the other hand, this reduction in weight would result in lower engine power requirements which could result in lower engine weight. Reduction in occupant compartment structure weight and drivetrain weight would then be used to justify a lighter suspension/steering/braking system.

This type of qualitative, interactive weight model was quantified in a very simple form to allow hand calculation of the required quantities. Figure 2.2 shows the model in flow chart and equation form along with definitions of all of the variables used. First, the weight of the occupant compartment structure was reduced through lightweight material and component substitution. This weight reduction was then used to estimate the secondary weight savings possible in the suspension/steering/braking system.[7] These two weight reductions were used to estimate the new vehicle curb weight and test weight. This information enabled the choice of a lighter weight engine holding the horsepower to vehicle test weight ratio constant. Holding this ratio constant helped to ensure there would be no loss in vehicle performance as a result of this substitution. After substituting some lightweight material components in the new drivetrain, the actual change in drivetrain weight was calculated. The known weight reductions in the occupant compartment structure and the drivetrain were used to again estimate the secondary weight savings in the suspension/steering/braking system. The new curb weight was then calculated and this information used to choose new, lighter weight suspension/steering/braking system components from other vehicles with similar curb weights. It should be emphasized here that existing, lighter components from other vehicles were



Source: Arthur D. Little, Inc.

FIGURE 2.2 METHODOLOGY FOR ESTIMATION OF POTENTIAL WEIGHT REDUCTION used in this analysis in order to maintain credibility. There can be no question that the lighter weight components used in this analysis are practical, producible, marketable, acceptable to the public, and durable because they are currently or were very recently in production and are being used over the roads today. This was done in order to avoid some pitfalls such as questionable producibility or durability which would have been present had we proposed new, unique lightweight designs for these components.

Following substitution of some lightweight material components in the new suspension/steering/braking system, the actual change in suspension/steering/braking system weight was determined along with the final new curb weight. This procedure could have been extended to include further iterative changes in the drivetrain and the suspension/steering/braking system weights. However, it is believed that this abbreviated methodology provided an adequate estimate within the scope of this work of the weight reduction potential in this vehicle.

2.2.1 Material Substitution Methodology

The practicality of substituting lightweight materials for those currently being used depends on a number of business and technical factors:[11,14]

1. Business Factors
   a) material cost
   b) capital investment requirements
   c) raw material availability
   d) material industry production capacity
2. Technical Factors
   a) structural requirements
   b) ease of fabrication
   c) ease of joining and welding
   d) ease of finishing and repairing
   e) ease of handling
   f) ease of scrap disposal

g) durability
h) appearance
i) corrosion resistance
j) energy requirements for material production
k) environmental impact
l) potential for fuel economy improvement
m) potential for emissions reduction
n) effects on vehicle safety performance

Each of these factors should be carefully evaluated before a decision is made to make use of any new material.

Material substitution was employed in two of the three vehicle systems for analysis. For the body panels of the occupant compartment structure, weight reduction through direct material substitution was determined by "replacing" a production vehicle structure with an "equivalent" structure of the same dimensions, geometrical design characteristics and function, but possibly different gauge thickness.[14] (An "equivalent" structure is one which possesses the structural characteristics that have been established by the design criteria and operating environment pertinent to the production vehicle structure.) For the suspension/steering/braking system and drivetrain, weight reduction through material substitution was based upon information available about production components, components soon to be in production, or future components that have been studied by the auto or material manufacturers. The following discussion of vehicle design criteria and structural design requirements applies to many vehicle components. However, its purpose here is to provide some background on the methodology used to substitute light-weight materials in body panels.

There are essentially three vehicle design criteria that apply to all passenger car designs:[14]

1. static load design criteria;
2. dynamic laod design criteria; and
3. crashworthiness load design criteria

The first two criteria arise from functional and service requirements and the third criteria from federal motor vehicle safety standards. Static load design criteria are intended to ensure rigidity and/or strength of a specific component or of the entire vehicle structure. Loading conditions in this category include vehicle beaming, rear end beaming, vehicle torsion, vehicle hoisting and towing, and door, roof, center-pillar, dash panel and various deck-lid loadings. Dynamic load criteria are intended to ensure a certain level of vehicle or component strength, durability, and dynamic response. Dynamic loading conditions include the terrain, braking and turning loads generated at various vehicle speeds. Crashworthiness design criteria exist to ensure a certain minimum level of occupant protection in most types of accidents. These criteria derive from vehicle response requirements to the 30 mph front barrier impact, bumper impact, rollover, side-door penetration, roof-crash and fuel tank impact. It is important to note that the test conditions for all of these requirements are fixed and that a new design will be acceptable only if its structural responses are equal to or better than those of the production vehicle design. The objectives of each of the preceding design criteria can be related to four types of structural design requirements.[14]

1) stiffness requirements
2) strength requirements
3) vibration requirements
4) crash requirements

For the purpose of this analysis, a stiffness design requirement may be defined by the maximum allowable deflection of a structure under a specified load. The "structure" may be a component member or the total vehicle structure. A strength design requirement is defined by the maximum allowable stress under a specific loading condition. A vibration design requirement is defined by the desired frequency and mode response. A crash design requirement, a type of requirement unique to automobiles, attempts to define the relationship between a vehicle deformation mode and the allowable degree of occupant injury.

For a preliminary analysis, the following measures may be used to judge the degree to which the previously discussed structural requirements are met:

1) stiffness: resistance to oil canning
2) stiffness and strength: resistance to denting
3) stiffness: resistance to elastic buckling
4) strength: resistance to yielding
5) vibration: vibration response

To simplify the formulation of a "new" panel changed only by material substitution, it was assumed that the new panel would have the same boundary conditions as the original mild steel panel. That is, it was assumed that the new panel would be mounted in the same way as the old panel and thereby be subjected to the same stresses. The "equivalent" vehicle structure assumption allowed simplification of the functional relationships between the structural measures and the design variables by eliminating the many possible complicated geometry factors. Consequently, the design variables which had to be considered in direct material substitution were limited to the material thickness (t) and the material properties: Young's Modulus (E), Poisson's ratio (ν), density (ρ) and yield strength (σ_Y). The derivations of the equations describing the measures of structural suitability are shown in Reference 14 and the results are summarized in Table 2.8.

Panel stiffness, S, is defined as the concentrated load applied to the panel surface that is required to produce a unit deflection in the direction of the load. The requirement of a minimum level of stiffness is needed primarily to ensure adequate resistance to oil-canning.

Denting resistance, D, is one of the primary strength requirements for appearance-panel members since they are susceptible to denting during fabrication and in service. The yield strength in this equation is written as a function of the strain rate, $\dot{\varepsilon}$. Some materials, such as mild steel, exhibit different yield

TABLE 2.8 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	$\frac{Y_n}{Y_o} = \frac{\sigma_{yn}(\dot{\varepsilon})}{\sigma_{yo}(\dot{\varepsilon})}\frac{E_o}{E_n}\frac{\overline{S}_n}{\overline{S}_o}$	$\frac{\overline{S}_n}{\overline{S}_o} = \frac{E_n}{E_o}\frac{\sigma_{yo}(\dot{\varepsilon})}{\sigma_{yn}(\dot{\varepsilon})}$
Vibration Frequency, F	$\frac{F_n}{F_o} = \left(\frac{E_n}{E_o}\frac{t_n}{t_o}\frac{\rho_o}{\rho_n}\right)^{\frac{1}{2}}$	$\frac{t_n}{t_o} = \frac{E_o}{E_n}\frac{\rho_n}{\rho_o}$

Notes: t = material thickness
E = Young's modulus
ν = Poisson's ratio
ρ = density
Y = yield strength

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

Source: Chang, David C., Justusson, J. William, "Structural Requirements in Material Substitution for Car-Weight Reduction," Engineering Mechanics Department, General Motors Research Laboratories, GMR-2019, 1976.

strengths in low and high speed or static and dynamic denting situations. It is important to note that while denting resistance and stiffness are both dependent on panel thickness, denting resistance is inversely proportioned to the panel stiffness. Therefore, the stiffer the panel, the lower the denting resistance.

Buckling resistance, B, describes the resistance of panel members to buckling under compressive, bending, shearing, or combined loads.

Stress yield factor, Y, describes a panel's resistance to yielding under stress. The yield strength in this equation is also expressed as a function of the strain rate $\dot{\varepsilon}$. Some materials also exhibit different yield strengths under generalized static and dynamic loading conditions. In this case, the stress yield factor is directly proportional to the panel stiffness.

Vibration frequency, F, describes a panel's relative frequency response to vibration normal to a panel's surface (transverse vibration). This parameter is important because resonance and excessive sound levels in passenger cars can contribute to passenger discomfort.

The crash characteristics of panel members are dependent on total system behavior. Because of this, no simple analytical formulation of panel crash response is available for design evaluation. Typically, the impact response of panel members is evaluated after a vehicle design becomes firm and the total system response can be judged.

As a result of this problem, primary crash protection structures such as bumpers and door side guard beams were not considered in this study.

Based on the assumption that the geometry of the vehicle structure replaced during material substitution remains unchanged except for thickness, the percent weight saving can be evaluated with the expression below:

$$\text{Percent Weight Saving} = 100\left(1-\left(\frac{\rho_n}{\rho_o}\right)\left(\frac{t_n}{t_o}\right)\right)$$

The subscripts n and o refer to the new material and the old material, respectively.

2.2.2 Component Substitution Methodology

A widely known policy of U.S. automobile manufacturers is to develop a family of automobiles from a common set of major components. The manufacturer realizes a number of benefits as a result of this policy. Manufacturing costs are reduced, the investment needed to create a large number of models is minimized thereby spanning a braod spectrum of purchasers, and yearly styling changes are greatly simplified.

The price to be paid for these advantages is inefficiency in the design of all but the heaviest vehicle models in the family using these components. The extreme solution to this problem would be for each manufacturer to minimize the weight of each model by redesigning each component to provide just the structural characteristics that have been established by the design criteria and operating environment pertinent to that particular model.

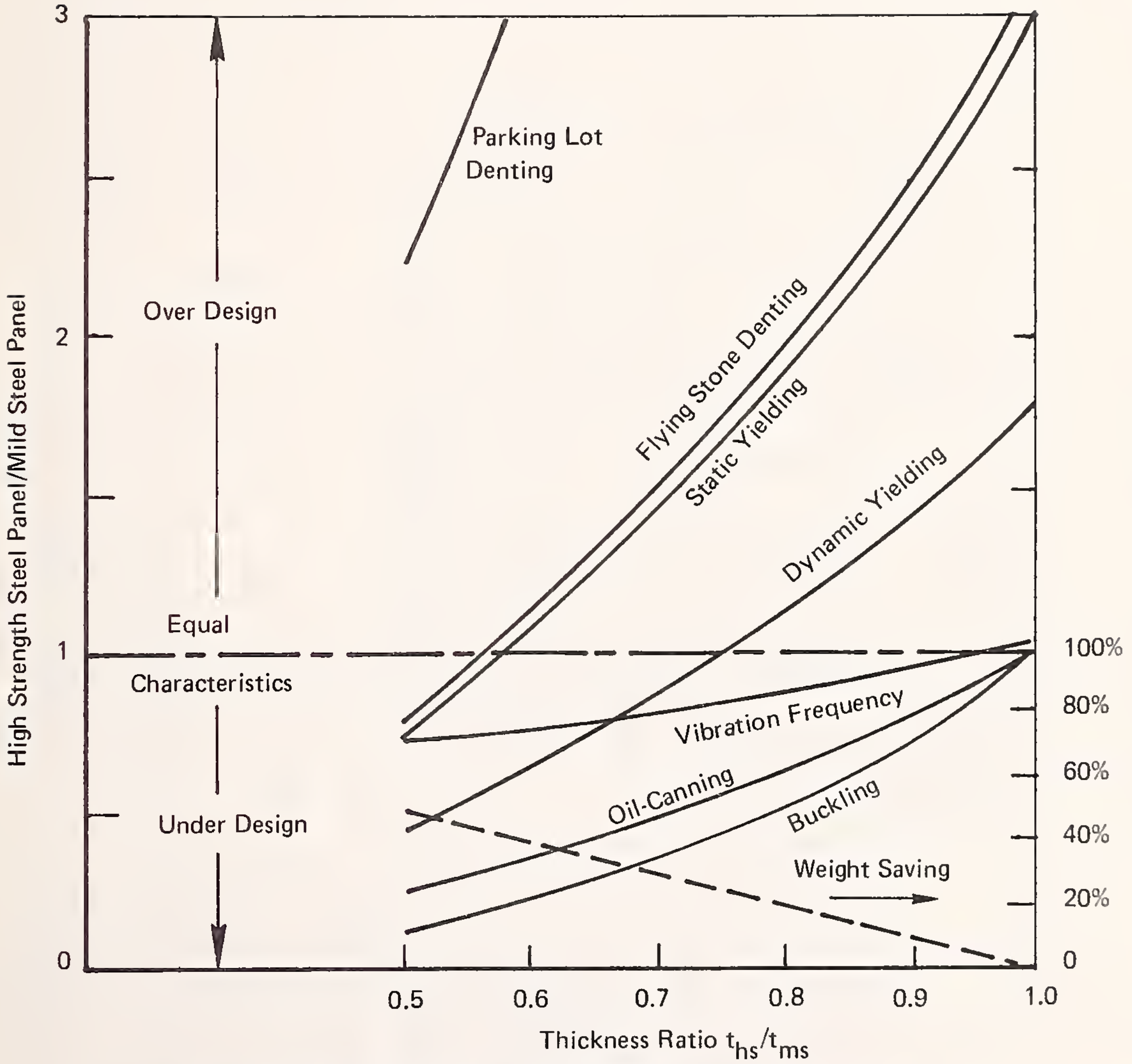
Another facet to the weight reduction problem is the fact that different manufacturers have come up with different component designs to do the same job. Naturally, some designs are inherently lighter than others. For example, Chrysler Corporation uses a torsion bar front suspension system that is roughly 15 percent lighter than the General Motors Corporation coil spring front suspension system on vehicles having approximately the same weight. These two designs probably evolved for a host of valid reasons, but there can be no argument that both systems work well enough to be acceptable to the buying public. Auto manufacturers might be encouraged to adopt and develop component design philosophies that have been proven to be inherently lighter in weight by their competitors. This approach was utilized in this analysis by substituting several lighter weight components made by other manufacturers for those used on the 1977 Chevrolet Impala.

2.2.3 Reduction of Occupant Compartment Structure Weight

Table 2.9 shows the materials and their associated properties chosen for the evaluation of weight reduction potential through materials substitution in the occupant compartment structure. The materials currently in use in all of the components considered in this analysis are SAE 1006-1008 steels. The properties shown are considered representative of this group of metals. A representative ultra-high strength steel was included for comparison, and 6009-T4, 6010-T4 and 5182-0 were the aluminum alloys chosen for this analysis.

The leading material contenders for occupant compartment structure weight reduction are high strength steels, reinforced plastics, and aluminum alloys. The development of high strength steels for application in this area has received a good deal of attention.[15-20] Chang and Justusson[14] concluded from their method of analysis that stiffness seemed to be the most restrictive structural requirement of the total vehicle and of its components. Meeting the requirement of equal stiffness automatically ensured that the remaining structural requirements were met. This assumption was also made during this analysis and led to the conclusion that replacing mild steel with high strength steel does not result in any direct weight reduction. The basis for this conclusion is illustrated in Figure 2.3 which shows the results of calculations using the formulas from Table 2.8 and the material properties from Table 2.9. If stiffness was found not to be the limiting structural requirement of the part redesigned for the new material, weight savings could be achieved with high strength steel.

The development of reinforced plastics for automotive use has also been given a good deal of attention.[21-25] While plastics do offer a number of advantages over the metals being considered, several important problems such as cost, finish and uniformity of fiber content of mass produced parts remain to be overcome.[21,23,25] The most important reason for not using reinforced plastics in this analysis is the fact that an exact weight comparison with



Source: Chang, David C., and Justussen, J. William, "Structural Requirements in Material Substitution for Car-Weight Reduction," General Motors Research Laboratories, GMR–2019, 1976.

FIGURE 2.3 COMPARISON OF STRUCTURAL CHARACTERISTICS OF HIGH STRENGTH STEEL AND MILD STEEL PANELS

TABLE 2.9 MATERIAL PROPERTIES ASSUMED

Material	Young's Modulus E $10^9 N/m^2$	Poisson's Ratio ν	Yield Strength σ_y $10^6 N/m^2$	Density ρ $10^3 kg/m^3$
Mild Steel - SAE 1006-1008(4)	200	0.27	207 (5)	7.83
High - Strength Steel (4)	200	0.27	621	7.83
Aluminum - 6009-T4 (1)	69.0	0.33	262 (2)	2.71
Aluminum - 6010-T4 (1)	69.0	0.33	296 (2)	2.70
Aluminum - 5182-0 (1)	71.0	0.33	186 (3)	2.65

1. "Data on Aluminum Alloy Properties and Characteristics for Automotive Applications," The Aluminum Association, Report T9, January 1977.
2. 5% Stretch Plus 1 Hour Bake at 177 C
3. 10% Stretch Plus 1 Hour Bake at 177 C
4. Arthur D. Little, Inc.
5. Dynamic yield strength assumed to be 380 X 10^6 N/m^2

DiCello, J.A. and George, R.A., "Design Criteria for the Dent Resistance of Auto Body Panels", Chrysler Corp., SAE paper 740081, 1974.

steel cannot be made because of the high degree of part redesign necessary for proper use.[25]

For these reasons, aluminum was chosen as the material for substitution in this analysis. This choice in no way implies that it is believed aluminum is the most likely or the only material that will be used for body panels in the 1980-1985 time period. However, a review of some of the literature available on the use of aluminum in body panels[26-41] indicates that aluminum offers a significant potential for near-term weight reduction.

The two newly developed aluminum alloys chosen for inner and outer body panels, 6009-T4 and 6010-T4, offer several advantages over other aluminum body sheet alloys.[41] They offer excellent formability, higher strengths after a paint-bake cycle, improved corrosion resistance, improved spot weldability, improved surface appearance and elimination of scrap segregation problems. The alloy 5182-0 was also considered for use in hood and decklid hinges,[42] and for front wheelhouses where an unusual amount of deformation during forming is required. This alloy posseses most of the characteristics of 6009-T4 except that it is more ductile and prone to the formation of Luder's lines, a type of stretch mark.

These alloys compare very favorably with mild steel for body panels in most all respects. Referring to page 19, several general statements may be made about the suitability of these alloys for body panels based on conversations with Mr. W. C. Weltman of ALCOA Laboratories:[42,45]

1) A material cost penalty is involved in their use. Plain body sheet steel currently costs about 16¢/lb versus 70¢/lb for aluminum sheet.

2) There should be almost no additional capital investment requirements for manufacturing as a result of making use of these materials. The processes used to produce components from aluminum are essentially identical and only small changes in the tooling are required.

3) There appear to be no near term problems with the availability of the raw material bauxite. A 1973 estimate showed the proven bauxite reserves appear to be adequate until 2043 assuming an 8 percent annual growth in consumption.[45]

4) There should be adequate material industry processing capacity. However, there is currently and there will continue to be a shortage of material industry heat capacity. It has been estimated by ALCOA that the industry could handle an increase in aluminum usage of 200 pounds per vehicle between now and 1981.

5) As this report has shown, the structural properties of aluminum panels can be made equal or superior to the properties of mild steel panels.

6) There should be no major fabrication problems associated with aluminum panels. The number of parts produced per hour could remain essentially the same.

7) There will be some joining and welding problems which will result in slightly higher production costs for aluminum components.

8) It is expected that aluminum panels will have the same finishing and repairing requirements as mild steel panels. No major changes in the painting process are expected to be required.

9) There should be no significant problems with compensating for the slightly more delicate handling requirements of aluminum components.

10) Scrap disposal will not be substantially hindered by aluminum components, especially if compatible alloys such as 6009 and 6010 are used together.

11) No component durability problems are expected. Fatigue resistance is expected to be adequate.

12) Appearance is expected to be comparable with that of mild steel panels.

13) Corrosion resistance is superior to that of mild steel panels.

14) The amount of energy required to produce aluminum from its raw materials is higher than that required to produce steel. However, this difference is more than made up by the fuel saved during the lifetime of the vehicle due to fuel economy improvement and the small amount of energy required to recycle aluminum compared to mild steel.

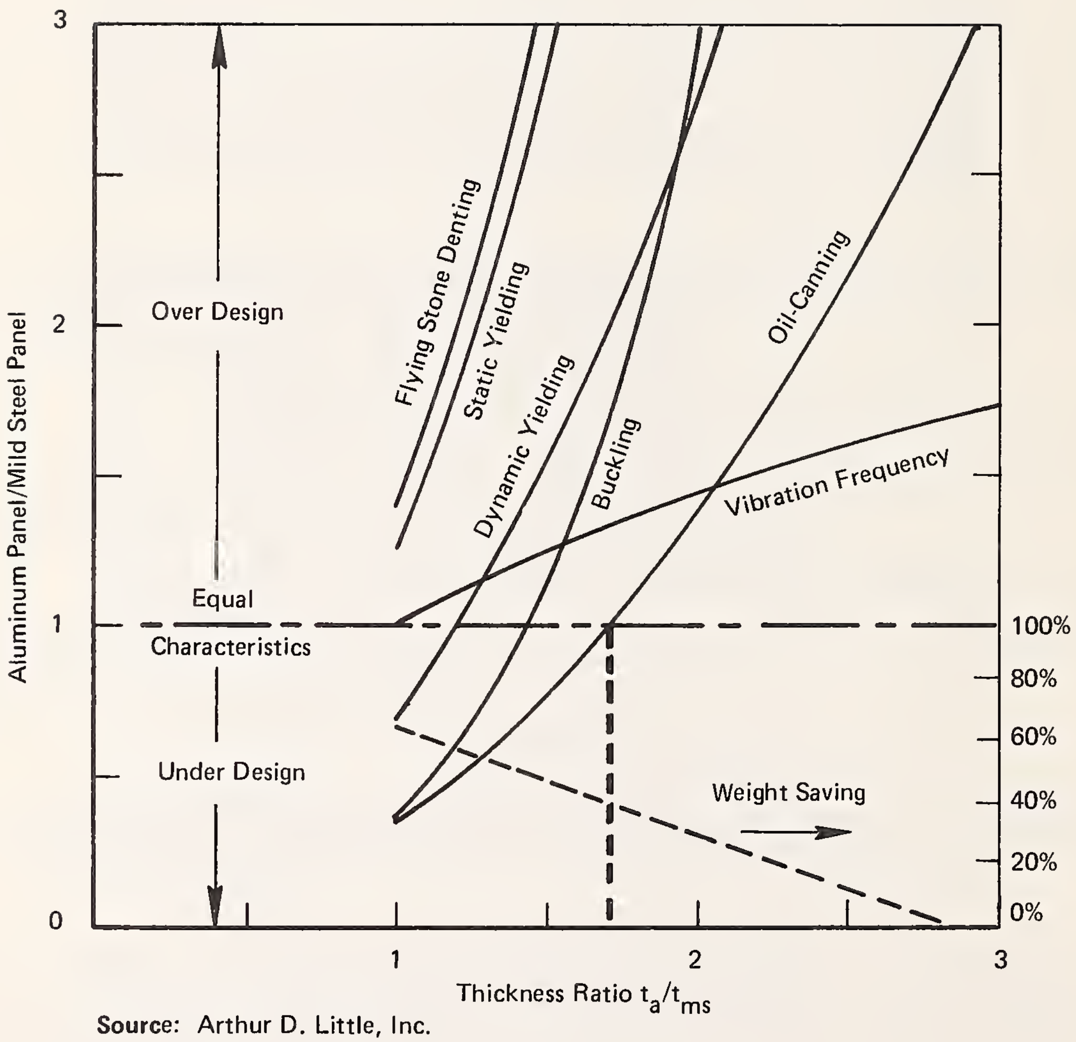
15) The environmental impact of greatly increased aluminum usage is currently unknown. The benefits of this type of transition should be balanced against the social and economic environmental costs involved.

16) The use of aluminum body panels appears to offer a significant potential for fuel economy improvement through primary and secondary weight savings.

17) The use of aluminum body panels aids in the reduction of emissions by improving fuel economy and possibly allowing engine downsizing.

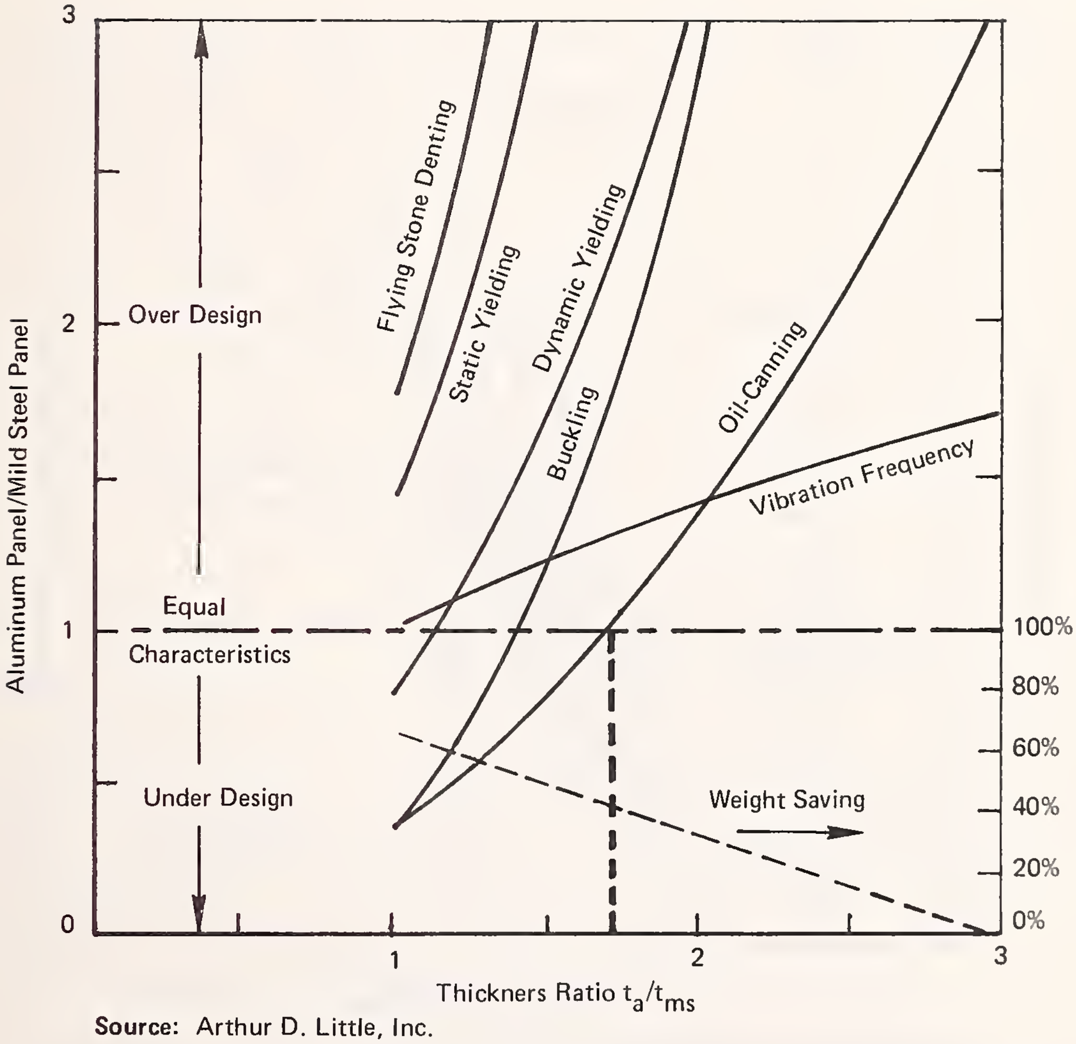
18) It is anticipated that well designed aluminum body components will have no adverse effects on vehicle safety performance.

Figures 2.4, 2.5, and 2.6 show comparisons of the structural characteristics of 6009-T4, 6010-T4 and 5182-0 aluminum panels with mild steel panels. In each case it is assumed that the new panel must have the same oil-canning resistance as the current steel panel as is indicated by the heavy dashed line. This assumption guarantees that the structural performance of the new panels is better than or equal to that of the old since the oil-canning resistance requirement is the most stringent of those parameters considered. This conservative approach indicates a possible 41



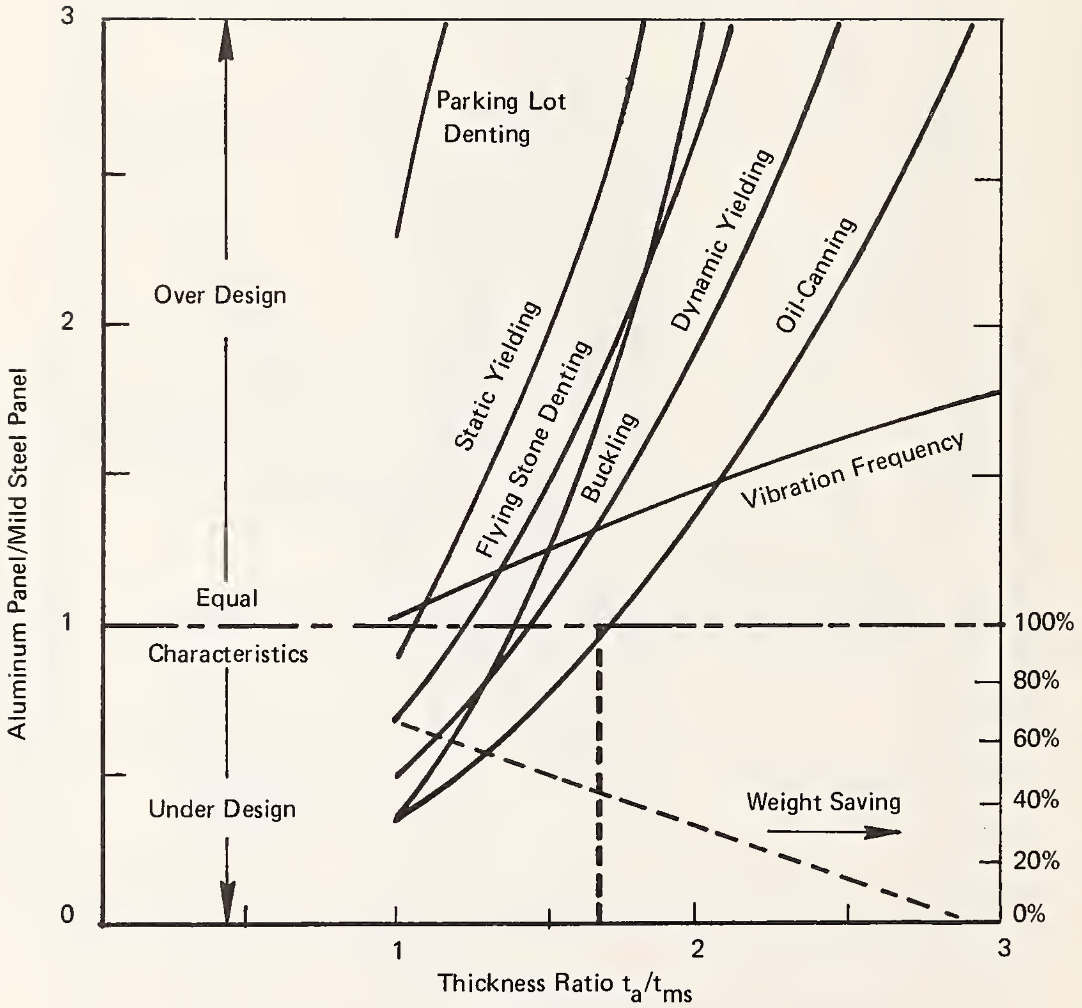
Source: Arthur D. Little, Inc.

FIGURE 2.4 COMPARISON OF STRUCTURAL CHARACTERISTICS OF 6009-T4 ALUMINUM AND MILD STEEL PANELS



Source: Arthur D. Little, Inc.

FIGURE 2.5 COMPARISON OF STRUCTURAL CHARACTERISTICS OF 6010-T4 ALUMINUM AND MILD STEEL PANELS



Source: Arthur D. Little, Inc.

FIGURE 2.6 COMPARISON OF STRUCTURAL CHARACTERISTICS OF 5182-0 ALUMINUM AND MILD STEEL PANELS percent component weight saving with 6009-T4 and 6010-T4 panels and a possible 43 percent weight saving with 5182-0 panels. A 66 percent potential weight saving is indicated for a gage for gage replacement of mild steel hood and decklid hinges with 5182-0 hinges (42).

Table 2.10 summarizes the weight reductions achieved with the material substitutions just described. It shows a total reduction of 59.6 kg (131.4 lb) is possible through the use of aluminum alloys without any sacrifice in structural performance.

Table 2.11 describes the weight saving potential found through the reduction of windshield, backlight and side window thicknesses. The proposed thicknesses were based on information presented in Reference 43. It should be recognized that many factors such as window curvature, area, whether the window rolls up and down, whether it is supported by a frame, and others all contribute to the choice of thickness. Therefore, estimates of potential thickness reductions were kept conservative.

Windshield thickness was reduced by .020 inch to .210 inch and the backlight thickness by an equal amount to .200 inch. The minimum side window thickness mentioned in Reference 43 was .125 inch. Therefore, the rear side windows were reduced by .030 to .130 inch and the front side windows by an equal amount to .160 inch. These reductions in thickness produced a total savings of 5.0 kg (11.0 pound).

A temporary spare tire was substituted for the conventional tire in the 1977 Impala. Firestone is currently producing a weight and space saving tire that will be used in all General Motors' 1978 intermediate cars. It was estimated that this type of tire and rim, if it were built to replace the FR78-15 tire on the 1977 Impala, would weigh 12.9 kg (28.5 lb).[44] Since the current tire and wheel weigh 22.0 kg (48.5 lb), this substitution resulted in a saving of 9.1 kg (20 lb).

Through component redesign and material substitution, additional weight reductions are possible in the body, frame, heating,

TABLE 2.10 WEIGHT REDUCTION POTENTIAL THROUGH MATERIAL SUBSTITUTION IN THE OCCUPANT COMPARTMENT STRUCTURE

Part Description	Current Material	Weight kg(lb)	Substituted Material	Weight kg(lb)	Thickness Ratio t_n/t_o	Weight Reduction kg(lb)	Weight Reduction %
Hood							
Inner Support	Mild Steel	9.1 (20.0)	6009-T4	5.4 (11.8)	1.70	3.7(8.2)	41
Outer Panel	Mild Steel	14.7 (32.5)	6010-T4	8.7 (19.1)	1.70	6.1(13.4)	41
Two Hinges	Mild Steel	5.4 (12.0)	5182-0	1.9 (4.1)	1.00	3.6(7.9)	66
Decklid							
Inner Support	Mild Steel	6.1 (13.5)	6009-T4	3.6 (8.0)	1.70	2.5(5.5)	41
Outer Panel	Mild Steel	12.9 (28.5)	6010-T4	7.6 (16.7)	1.70	5.4(11.8)	41
Two Hinges	Mild Steel	2.7 (6.0)	5182-0	0.9 (2.0)	1.00	1.8(4.0)	66
Two Front Fenders							
Two Inner Supports	Mild Steel	14.1 (31.0)	6009-T4	8.3 (18.3)	1.70	5.8(12.7)	41
Two Outer Panels	Mild Steel	10.9 (24.0)	6010-T4	6.4 (14.1)	1.70	4.5(9.9)	41
Two Front Wheel Houses	Mild Steel	10.4 (23.0)	5182-0	5.9 (13.1)	1.68	4.5(9.9)	43
Two Front Doors							
Two Inner Supports	Mild Steel	17.7 (39.0)	6009-T4	10.4 (23.0)	1.70	7.3(16.0)	41
Two Outer Panels	Mild Steel	10.9 (24.0)	6010-T4	6.4 (14.1)	1.70	4.5(9.9)	41
Two Rear Doors							
Two Inner Supports	Mild Steel	16.3 (36.0)	6009-T4	9.6 (21.2)	1.70	6.7(14.8)	41
Two Outer Panels	Mild Steel	8.2 (18.0)	6010-T4	4.8 (10.6)	1.70	3.4(7.4)	41
TOTAL		139.5(307.5)		79.9(176.1)		59.6(131.4)	43

TABLE 2.11 WEIGHT REDUCTION POTENTIAL IN THE OCCUPANT COMPARTMENT STRUCTURE THROUGH GLASS THICKNESS REDUCTION

Part Description	Current Thickness cm(in)	Current Weight kg(lb)	Proposed Thickness* cm(in)	Proposed Weight kg(lb)	Weight Reduction	
					kg(lb)	%
Windshield	.58 (.23)	14.5 (32.0)	.53 (.21)	13.2 (29.2)	1.3 (2.8)	9
Backlight	.56 (.22)	9.8 (21.5)	.51 (.20)	8.9 (19.5)	0.9 (2.0)	9
Side Windows						
Two Front	.48 (.19)	9.1 (20.0)	.41 (.16)	7.6 (16.8)	1.5 (3.2)	16
Two Large and Two Small Rear	.41 (.16)	7.3 (16.0)	.33 (.13)	5.9 (13.0)	1.4 (3.0)	19
Total		40.6 (89.5)		35.6 (78.5)	5.0 (11.0)	12

* Arthur D. Little, Inc. Estimates Based On:

Wrigley, AL, "Glass Pays Down Sizing Price", <u>Ward's Auto World</u>, October 1976, p. 69.

ventilating and air conditioning systems, the instrument and electrical distribution systems and the exhaust system. However, the components examined in this report represent the major, primary areas in which weight savings can be achieved. Some components such as air conditioning represent options which do not contribute to the bare weight of the car. The remaining components were not considered to be areas where primary, near term (1980-1985) efforts at weight reduction would be made. Hence, those areas were not considered in this program.

The weight of the occupant compartment structure, after making the changes described above, was reduced from 919.2 kg (2026.5 lb .) to 845.6 kg (1864 lb .). The potential weight reduction $\Delta W1$, was found to be 73.7 kg (162.4 lb .) or approximately 8 percent as shown in Table 2.12.

2.2.4 Reduction of Drivetrain Weight

Table 2.13 describes the weights of the potential new drivetrain components considered in this analysis. The calculations performed to determine the new drivetrain power requirements followed the flow chart in Figure 2.2 and the actual calculations are shown in the Appendix.

The reduction in occupant compartment structure weight allowed a secondary weight reduction in the suspension/steering/braking system weight. The estimated secondary weight savings from the equation in Figure 2.2, $\Delta W2 = .15\Delta W1$, was 11.0 kg (24.4 lb .). The new curb weight, WC_N, resulting from these two reductions was 1597 kg (3521 lb) and the new test weight, WT_N, was 1733 kg (3821 lb .). The power to weight ratio for the 4-door Impala with the 305 cubic inch V-8 engine, the current sales leader,[46] was .059 kws/kg (.036 hp/lb). This indicated that a vehicle having the new test weight would have the same power to weight ratio if the new engine had 102 kws (138 hp). The engine chosen for substitution was the 2-liter, 4 cylinder, all aluminum, fuel injected and turbocharged engine to be used in a limited

TABLE 2.12 SUMMARY OF WEIGHT REDUCTION POTENTIAL IN THE OCCUPANT COMPARTMENT STRUCTURE

	kg	(lb)
Initial Occupant Compartment Structure Weight	919.2	(2026.5)
Material Substitution Weight Reduction	59.6	(131.4)
Glass Thickness Reduction Weight Savings	5.0	(11.0)
Temporary Spare Tire Weight Savings	9.1	(20.0)
Total Potential Weight Reduction, ΔW1	73.7	(162.4)
New Occupant Compartment Structure Weight	845.6	(1864)

Source: Arthur D. Little, Inc.

TABLE 2.13 DETERMINATION OF NEW DRIVETRAIN WEIGHT THROUGH COMPONENT SUBSTITUTION

	kg(lb)
1977 Saab EMS 2 Liter 4 Cylinder Basic Engine including Clutch, Exhaust Manifolds, Oil Filter, Throttle Valve Housing, Starter (1)	139.7 (308)
Estimated Weight of 1978 Saab EMS Turbocharger and Attaching Parts (2)	9.1 (20)
1977 Chevrolet Impala Power Steering Pump and Mounting Brackets	6.1 (13.5)
1977 Chevrolet Impala Air Cleaner Housing and Element	2.9 (6.5)
1977 Chevrolet Impala Automatic Transmission without Torque Converter	44.9 (99.0)
1977 Chevrolet Impala Cooling System Including Radiator, Coolant and Water Pump	30.2 (66.5)
Downsized 1977 Chevrolet Impala Fuel Tank (Reduced from 76.5 liters (20.2 Gals) to 68.1 Liters (18 Gals))	11.1 (24.5)
1977 Chevrolet Impala Fuel Level Sender and Fuel Pump	0.9 (2.0)
68.1 Liters (18 Gals) of Gasoline	49.8 (109.8)
1977 Chevrolet Impala Battery and Alternator with Mounting Brackets	20.0 (44.0)
Total	314.7 (693.8)

(1) Mr. Glenn Staub, Saab-Scania of America, Orange, Connecticut.

(2) Mr. Chuck Danielson, Airesearch Industrial Division of Garrett Corporation, Los Angeles, California.

Source: Arthur D. Little, Inc.

number of 1978 Saab EMS'. This engine produces an SAE net maximum power of 101 kws (135hp) at 5,000 rpm and 217 Nm (160 lb ft) of torque at 3500 rpm.[47] It was chosen because of its high power to weight ratio and the fact that General Motors is currently thinking about the possibility of moving toward inline 4-cylinder and V-6 engines to meet fuel economy regulations in the 1980 to 1985 time frame.[48] Weights of the current Impala power steering unit, air cleaner, automatic transmission, cooling system, battery and alternator were added to the weight of the Saab engine and turbocharger. Since the weight obtained for the Saab engine included a weight of a clutch, the weight of the automatic transmission did not include the torque converter. The 1977 Impala fuel tank was reduced from 76.5 liters (20.2 gals) to 68.1 liters (18 gals) to compensate for an expected increase in fuel economy while keeping the vehicle range roughly constant. The total new weight of the drivetrain after component substitution was found to be 314.7 kg (693.8 lb). The weight of the original 1977 drivetrain was 444.3 kg (974.5 lb).

Table 2.14 describes the weight reduction potential of using lightweight materials in several of the components in the new drivetrain. The weight of the down-sized fuel tank was reduced by 35 percent by using high density polyethylene (HDPE) plastic. This type of fuel tank is currently used on the 1977 Ford Bronco[49] and is reportedly being planned for further use in the near future by Ford, Chrysler and General Motors.[22] The air cleaner housing and transmission pan were changed from mild steel to 5182-0 aluminum. This alloy was chosen over 6009-T4 for its superior formability, and the same 43 percent weight reduction was conservatively assumed in these two cases as it was for the body panel applications previously described. Some additional weight savings may be possible in the current lightweight automatic transmission, cooling system, fuel system, battery and alternator, but it is believed they will be similar in magnitude to the savings found for the air cleaner and transmission pan. The potential weight reduction due to materials substitution in the drivetrain was found to be 5.5 kg (12.1 lb).

TABLE 2.14 WEIGHT REDUCTION POTENTIAL IN THE DRIVETRAIN THROUGH MATERIALS SUBSTITUTION

Part Description	Current Material	Current Weight kg(lb)	Proposed Material	Proposed Weight	Weight Reduction kg(lb)	Weight Reduction %
Fuel Tank (68.1 Liter (18 Gal.))	Terneplate[1]	11.1 (24.5)	HDPE	7.2 (15.9)	3.9 (8.6)	35[2]
Air Cleaner Housing	Mild Steel	2.5 (5.5)	5182-0	1.4 (3.1)	1.1 (2.4)	43
Transmission Pan	Mild Steel	1.1 (2.5)	5182-0	0.6 (1.4)	0.5 (1.1)	43
Total		14.7 (32.5)		9.3 (20.4)	5.5 (12.1)	37

[1]Terneplate is steel coated with terne, a hot dip coating generally containing 10-15% tin, that is used for gasoline tanks becuase of its corrosion resistance.

[2]"Super Tanks through Marlex Resins: A Look At The 'Un-Metal' Passenger Car Tank," Phillips Chemical Company (Company Literature).

Source: Arthur D. Little, Inc.

The weight of the new drivetrain, $W3_N$, after the component and materials substitutions described was 309.2 kg (681.7 lb). The difference between old and new drivetrain weights, $\Delta W3$, was found to be 135.1 kg (297.8 lb) or approximately 30 percent. Using the equation in Figure 2.2, $\Delta W2 = .15 (\Delta W1 + \Delta W3)$, the estimated secondary weight savings in the suspension/steering/ braking system as a result of all changes was then 31.3 kg (69.0 lb). The new estimated curb weight WC_N, was then 1442 kg (3179 lb).

2.2.5 Reduction of Suspension/Steering/Braking System Weight

In order to facilitate the choice of lighter weight suspension components from other current vehicles, it was necessary to determine the weight distribution of the estimated new curb weight, WC_N. Table 2.15 illustrates the computation of the desired minimum and maximum front and rear wheel weights. It was assumed that the actual weight reduction in the occupant compartment structure, $\Delta W1$, and the estimated weight reduction in the suspension/steering/ braking system, $\Delta W2$, were evenly distributed. It was also assumed that 85 percent of the drivetrain weight reduction, $\Delta W3$, would come off the front wheels and 15 percent off the rear wheels. These last figures were estimated from the distribution of the marginal weight increases from optional larger engines in reference 50. The new curb weight, WC_N was found to be distributed with 741 kg (1633 lb) or 51 percent on the front and 701 kg (1546 lb) or 49 percent on the rear wheels. The maximum new curb weight was estimated by adding the weight of all available options plus the Caprice option package to WC_N. The available options were distributed according to reference 50 and the Caprice package was evenly distributed between the front and rear wheels. The maximum weight of the Impala 4-door sedan after performing the previously discussed weight reductions and adding all available options was found to be 1554 kg (3426 lb). The weight was distributed with 813 kg (1793 lb) or 52 percent on the front and 741 kg (1633 lb) or 48 percent on the rear wheels.

TABLE 2.15 ESTIMATION OF NEW MINIMUM AND MAXIMUM LAODS ON THE FRONT AND REAR WHEELS OF THE CHEVROLET IMPALA

Condition	Front Wheels kg (lb)	Front Wheels %	Rear Wheels kg (lb)	Rear Wheels %	Total kg (lb)
1977 Impala	908 (2002)	54*	774 (1706)	46*	1682 (3708)
-ΔW1	871 (1921)	54	737 (1625)	46	1608 (3546)
-ΔW3	757 (1668)	51	717 (1580)	49	1473 (3248)
(Min)-ΔW2	741 (1633)	51	701 (1546)	49	1442 (3179)
+All Options	802 (1769)	52	730 (1609)	48	1532 (3378)
(Max)+Caprice	813 (1793)	52	741 (1633)	48	1554 (3426)

*Current Weight Distribution for 1977 Chevrolet Impala 4-Door Sedan with 305 C.I. V-8 Engine

"1977 MVMA Specifications Form: Passenger Car - Chevrolet," Chevrolet Engineering Center, Chevrolet Motor Division, General Motors Corp., Warren, Michigan, 1976.

Source: Arthur D. Little, Inc.

Available weight data was then examined and it was found that the 1976 Plymouth Valiant 4-door sedan had a similar curb weight distribution and possessed some suspension components that weighed less than those used on the 1977 Impala. It was found that the total curb weight of the Valiant ranged from 1458 kg (3215 lb) to 1685 kg (3714 lb) with all available options. The front end weight was found to vary from 816 kg (1800 lb) to 955 kg (2105 lb) and the rear end weight from 642 kg (1415 lb) to 730 kg (1609 lb) with all available options.[51]

Table 2.16 shows experimentally obtained weight data for selected front suspension components on a 1975 Plymouth Valiant 4-door sedan equipped with a 318 C.I. V-8 engine. It was assumed that few changes were made in the curb weight of this vehicle from 1975 to 1976. Table 2.16 shows how some of these components were substituted for those used in the 1977 Impala to reduce the weight of the Impala front suspension. The substitutions described resulted in a decrease in front suspension weight of 18 kg (40 lb).

While it is understood that the Valiant system would not be <u>directly</u> transferable to the Impala, it is believed that the weight saving indicated would not be significantly affected by minor component design changes and adaptation of the Impala's frame to accept the torsion bar.

It was estimated that the leaf springs in the rear suspension of the 1975 Plymouth Valiant weigh 27 kg (60 lb). These springs were substituted for the two upper and two lower trailing arms and the two springs in the 1977 Impala rear suspension weighing 15 kg (32 lb). It was assumed that the mounting hardware for both systems weighed approximately the same. This component substitution resulted in an increase in the suspension weight of 12.7 kg (28 lb), but provided the opportunity for material substitution in the leaf springs. The resulting net reduction in the suspension/steering/braking system weight from all component substitutions was 5.4 kg (12 lb).

TABLE 2.16 WEIGHTS OF SELECTED FRONT SUSPENSION COMPONENTS FOR A 1975 PLYMOUTH VALIANT 4-DOOR SEDAN WITH A 318 CID V-8 ENGINE

	kg	(lb)
Left Front Suspension	35.6	(78.5)
Upper Control Arm with Ball Joint and Bushings	2.3	(5.0)
Lower Control Arm with Bushings	4.76	(10.5)
Lower Arm with Ball Joint	1.8	(4.0)
Lower Arm Locating Strut	0.91	(2.0)
Spindle	3.6	(8.0)
Tie Rod with Both Ends and No Nuts	0.91	(2.0)
Shock Absorber	1.1	(2.5)
Disc Brake Caliper	4.3	(9.5)
Disc Brake Rotor with Two Bearings	10.9	(24.0)
Two Brake Pads	0.68	(1.5)
Rotor Shield	0.2	(0.5)
Caliper Adapter	1.4	(3.0)
Torsion Bar	2.7	(6.0)
Road Wheel with D78-14 B.F. Goodrich Silvertown Belted Tire	17.5	(38.5)
Wheel Cover	0.2	(0.5)

*All weights are accurate to the nearest 0.2 kg (0.5 lb)

Source: Arthur D. Little, Inc.

TABLE 2.17 DETERMINATION OF NEW FRONT SUSPENSION WEIGHT THROUGH COMPONENT SUBSTITUTION

	kg (lb)
Valiant Upper Control Arm with Ball Joint and Bushings	2.3 (5.0)
Valiant Lower Control Arm with Bushings	4.76 (10.5)
Valiant Lower Arm with Ball Joint	1.8 (4.0)
Valiant Lower Arm Locating Strut	0.91 (2.0)
Valiant Spindle	3.6 (8.0)
Valiant Tie Rod with Both Ends and No Nuts	0.91 (2.0)
Impala Shock Absorber	0.91 (2.0)
Impala Disc Brake Caliper	3.9 (8.5)
Two Impala Disc Brake Pads	0.68 (1.5)
Impala Rotor with Two Bearings	10.7 (23.5)
Valiant Rotor Shield	0.2 (0.5)
Valiant Torsion Bar	2.7 (6.0)
Left Front Suspension Weight	33.3 (73.5)
Total Front Suspension Weight	66.7 (147.0)
1977 Impala Front Suspension Weight	84.8 (187.0)
Potential Weight Reduction	18.1 (40.0)

Source: Arthur D. Little, Inc.

Table 2.18 describes the material substitution considered for selected components in the suspension/steering/braking system. Graphite fiber-reinforced epoxy may provide substantial weight savings in leaf springs and driveshafts in the 1980 to 1985 time frame according to Ford.[52,53] Currently, the primary drawback to this type of lightweight composite is cost, but the material appears to be physically capable of performing as well as or better than steel in these two applications. Insufficient experience with this material in automotive applications prevents a detailed discussion of its advantages and disadvantages at this point. The weight saving potential of using this material in the leaf springs and driveshaft was estimated to be 28.3 kg (62.3 lb). The use of a fabricated sheet steel master cylinder was estimated to save 2.7 kg (5.9 lb).[54] General Motors is currently working to apply GM 980 X, a high strength low alloy steel, to wheels.[20] This alloy appears to provide enough strength and fatigue resistance to allow an approximate 20 percent decrease in wheel weight.[55] Information regarding this material's advantages and disadvantages is also very limited. The use of this material in four Impala wheels resulted in a savings of 7.80 kg (17.2 lb). Finally, the mild steel differential cover was replaced with a 5182-0 aluminum version. A conservative 43 percent weight reduction was again assumed resulting in a savings of 0.4 kg (0.9 lb). The total weight savings achieved through materials substitution in the suspension/steering/braking system was 39.1 kg (86.3 lb).

In summary, a savings of 5.4 kg (12 lb) resulted from component substitution, and a savings of 39.1 kg (86.3 lb) resulted from material substitution in the suspension/steering/braking system. The total reduction found in the suspension/steering/braking system weight was 44.6 kg (98.3 lb).

TABLE 2.18 WEIGHT REDUCTION POTENTIAL THROUGH MATERIAL SUBSTITUTION IN THE SUSPENSION/ STEERING/BRAKING SYSTEM

Part Description	Current Material	Current Weight kg(lb)	Proposed Material	Proposed Weight kg(lb)	Weight Reduction kg(lb)	Weight Reduction %
Two Leaf Springs	Spring Steel	27 (60)	Graphite Composite	4.4 (9.6)	22.9(50.4)	84 (1)
Driveshaft	Steel	8.16(18.0)	Graphite Composite	2.8 (6.1)	5.40(11.9)	66 (1)
Master Cylinder	Cast Iron	3.9 (8.5)	Mild Steel	1.2 (2.6)	2.7 (5.9)	70 (2)
Four Road Wheels	Mild Steel	39.0 (86.0)	GM 980X	31.2 (68.8)	7.80(17.2)	20 (3)
Differential Cover	Mild Steel	0.91 (2.0)	5182-0	0.52 (1.1)	0.4 (0.9)	43
Total		79.15(174.5)		40.0 (88.2)	39.1 (86.3)	49

(1) "Ford, GM Vie in Disclosing Future Plans." Automotive Design and Development, September 1976, pp 12-13.

Wrigley, Al, "SAE Materials Menu Mixes Reality and Dreams," Ward's Auto World, March 1977, pp 48-53.

(2) United States Steel (Advertisement), Pittsburgh, Pennsylvania.

(3) Personal conversation with Mr. Joseph Hunter, Metallurgy Department, General Motors Research Laboratories, Warren, Michigan.

Source: Arthur D. Little, Inc.

3. CONCLUSIONS

A 73.7 kg (162.4 lb) weight reduction in the occupant compartment structure was found possible. Three aluminum alloys, 6009-T4, 6010-T4 and 5182-0, were used in selected body panels, and window thicknesses were reduced a small amount. It was found that the weight of the drivetrain could be reduced by 132.1 kg (297.8 lb) through component and materials substitutions. A new, lightweight, high power output engine was substituted for the current engine, and the weights of the fuel tank, air cleaner housing and transmission pan were reduced through the use of HDPE plastic and 5182-0 aluminum. A 44.6 kg (98.3 lb) weight reduction in the suspension/steering/braking system weight was found possible through component and materials substitutions. Torsion bar front suspension and leaf spring rear suspension were used in place of the standard coil spring system. The weights of the leaf springs, driveshaft, wheels, master cylinder, and differential cover were reduced through materials substitution.

These savings reduced the curb weight of the 1977 Chevrolet Impala 4-door sedan from 1682 kg (3708 lb) to 1429 kg (3150 lb). Thus, a savings of 250 kg (552 lb) or 15 percent resulted from this conservative analysis of the potential weight reduction in this vehicle for the 1980 to 1985 time frame.

APPENDIX A
LIST OF REFERENCES

1. Huebner, G. J., and Gasser, Donald J., "Energy and the Automobile - General Factors Affecting Vehicle Fuel Consumption," Chrysler Corp., SAE paper 730518, 1973.

2. Austin, Thomas C., and Hellman, Karl H., "Passenger Car Fuel Economy - Trends and Influencing Factors," Environmental Protection Agency, SAE paper 730790, 1973.

3. Campbell, B. J., "Driver Injury in Automobile Accidents Involving Certain Car Models," Highway Safety Research Center, University of North Carolina, July 1970.

4. Campbell, B. J. and Reinfurt, D. W., "Relationship Between Driver Crash Injury and Passenger Car Weight," Highway Safety Research Center, University of North Carolina, November 1973.

5. Campbell, B. J., "Safety, Small Cars and the Gasoline Shortage," Highway Safety Highlights, Vol. 7, No. 10, Highway Safety Research Center, University of North Carolina, January 1974.

6. Cochran, C. N., and Weltman, W. C., "Aluminum Car Parts, the No Trade-off Safety Option," Aluminum Company of America, Fifth International Congress on Automotive Safety, July 1977.

7. The Report by the Federal Task Force on Motor Vehicle Goals Beyond 1980. Volume 2, Task Force Report, draft, U.S. Department of Transportation, September 1976, pgs. 5B-1 to 5B-16.

8. Artinian, L. And Terry, S. L., "The Total Cost of Weight," Chrysler Corporation, SAE paper 325D, 1961.

9. Adams, D. G., DiCello, J. A., Hoppe, C., Kasper, A. S. Keisoglou, A. N., and McVinnie, W. W., "High Strength Materials and Vehicle Weight Reduction Analysis," Engineering Office, Chrysler Corporation,SAE paper 750221, 1975.

10. Adams, D. G. Dinda, S., George, R. A., Karry, R. W. Kasper, A. S., Pogorel, J., Swenson, W. E., and Weeks, W. L., "Charger XL: a Lightweight Materials Development Vehicle," Materials Engineering, Chrysler Corporation, SAE paper 760203, 1976.

11. Gray, Edward K. and McLeefe, Roy W., "The New Trade-offs in Engineering Materials Selection," Plastics Department, E. I. duPont de Nemours and Co., SAE paper 760263, 1976.

12. Bartell, B. E., "Automotive Sheet Metal Component Conversion from Steel to Aluminum," Chevrolet Motor Division, General Motors Corporation, SAE paper 760057, 1976.

13. Eissinger, R. C., Jewell, N. H., and Livermore, J. L. "Development and Evaluation of Aluminum Body Sheet Metal Panels," Ford Motor Company, SAE paper 770303, 1977.

14. Chang, David C., and Justusson, J. William, "Structural Requirements in Material Substitution for Car-Weight Reduction," Engineering Mechanics Department, General Motors Research Laboratories, GMR-2019, 1976.

15. Dinda, S., Karry, R. W., and Kasper, A.S., "High-Strength Steel for Cost Effective Weight Reduction," Materials Engineering, Chrysler Corporation, SAE paper 760207, 1976.

16. Dinda, S., and Kasper, A.S., "A Family of High-Strength Steels for Today's Automotive Requirements," Materials Engineering, Chrysler Corporation, SAE paper 770209, 1977.

17. Krupitzer, R. P., Miner, R. E., Vander Arend, P. J., Reis, F., Slane, J. A., Abraham, J. K., and Matos, S. J., "Progress in HSLA Steels in Automotive Applications," Research Center, Republic Steel Corporation, SAE paper 770162, 1977.

18. Bucher, J. H., and Hamburg, E. G., "High Strength Formable Sheet Steel," Jones and Laughlin Steel Corporation, SAE paper 770164, 1977.

19. Lake, P. B., and Grenawalt, J.J., "Partially Annealed High Strength Cold Rolled Steels," Youngstown Sheet and Tube Company, SAE paper 770163, 1977.

20. Rashid, M. S., "GM 980X - Potential Applications and Review," Metallurgy Dept., General Motors Research Laboratories, SAE paper 770211, 1977.

21. "Development Key to Plastics' Future," Ward's Automotive Reports, Vol. 52, No. 34, August 22, 1977.

22. Tuttle, Howard, "Auto Makers Holding to Plastics Timetable," Automotive Design and Development, May 1977, pgs. 13-16.

23. Simanaitis, Dennis J., "High-Performance Composites: An Automotive Revolution?", Automotive Engineering, May 1977, pgs. 40-47

24. "The Future for Exterior Plastic Body Parts," Automotive Engineering, March 1976, p. 34.

25. Trueman, Eldon D., "Weight Saving Approaches Through the Use of Fiber Glass-Reinforced Plastic, "Transportation Materials Division, Owens-Corning Fiberglas Corporation, SAE paper 750155, 1975.

26. George, R. A., Swenson, W. E., and Adams, D. G., "Aluminum in Automobiles: Why and How It's Used," Materials Engineering, Chrysler Corporation, SAE paper 760164, 1976.

27. Abernathy, John L., "Manufacturing Processes for Aluminum - Steel Hoods," Oldsmobile Division, General Motors Corporation, SAE paper 760056, 1976.

28. Bortell, B. E., "Automotive Sheet Metal Component Conversion from Steel to Aluminum," Chevrolet Motor Division, General Motors Corporation, SAE paper 760057, 1976.

29. Dilay, W., Rogala, E. A., and Zulinski, E. J., "Resistance Welding Aluminum for Automotive Production," Ford Motor Company, SAE paper 770305, 1977.

30. Motwani, M. B., "Application of Aluminum in Body Weight Reduction," Ford Motor Company, SAE paper 770306, 1977.

31. Finelli, Thomas M., and Kelly, Bruce G., "Design and Manufacturing Considerations for Aluminum Hood Assemblies," Oldsmobile Division, General Motors Corporation, SAE paper 770336, 1977.

32. Eissinger, R. C., Jewell, N. H., and Livermore, J. L. "Development and Evaluation of Aluminum Body Sheet Metal Panels," Ford Motor Company, SAE paper 770303, 1977.

33. Glagola, Michael A., "Bimetallic Aluminum/Steel Auto Body Panels," Reynolds Metals Company, SAE paper 770304, 1977.

34. "Tentative Guide to Automotive Resistance Spot Welding of Aluminum," The Aluminum Association, Report T10, Washington, D.C., 1973.

35. "Mig Spot Welding of Aluminum," The Aluminum Association, Report T11, Washington, D.C., 1975.

36. "Comparison of Olsen Cup Values on Aluminum Alloys," The Aluminum Association, Report T13, Washington, D.C., 1975.

37. "Adhesive Bonding of Aluminum Automotive Body Sheet Alloys," The Aluminum Association, Report T14, Washington, D.C., 1975.

38. "Repair of Aluminum Automotive Sheet by TIG and MIG Welding," The Aluminum Association, Report T15, Washington, D.C., 1975.

39. "In Plant Handling and Repair of Aluminum Auto Body Sheet," The Aluminum Association, ReportT16, Washington, D.C., 1976.

40. "Data on Aluminum Alloy Properties and Characteristics for Automotive Applications," The Aluminum Association, Report T9, Washington, D.C. 1977.

41. Evancho, J.W., and Kaufman, J.G., "New 6XXX - Series Alloys for Auto Body Sheet," Aluminum Company of America, SAE paper 770307, 1977.

42. Personal conversation with Mr. W. C. Weltman, Senior Application Engineer, ALCOA Laboratories, Pittsburgh, Pennsylvania.

43. Wrigley, A., "Glass Pays Downsizing Price," Wards Auto World, October 1976, p. 69.

44. Personal conversation with Mr. William W. Lyle, Passenger Tire Engineering, Firestone Tire and Rubber Company, Akron, Ohio.

45. "Aluminum and the Automobile," Aluminum Company of America, 1973.

46. "Dramatic Change in Engine Mix: Chevy Makes Downsizing Look Easy at G.M.," Ward's Automotive Reports, August 1, 1977, p. 243.

47. "Turbo Saab Promises Speed, Economy," Ward's Engine Update, May 27, 1977, p. 4.

48. "GM May End V-8 Production by 1984," Ward's Engine Update, May 13, 1977, p. 1.

49. "Materials Play Limited (But Vital) Role in '77's Weight Savings," Automotive Design and Development, September 1976, pgs. 11-14.

50. "1977 MVMA Specifications Form: Passenger Car - Chevrolet," Chevrolet Engineering Center, Chevrolet Motor Division, General Motors Corp., Warren, Michigan, 1976.

51. "1976 MVMA Specifications Form: Passenger Car - Plymouth Valiant," Chrysler Corporation, Detroit, Michigan, 1976.

52. "Ford, GM Vie in Disclosing Future Plans," Automotive Design and Development, September 1976, pgs. 12-13.

53. Wrigley, Al, "SAE Materials Menu Mixers Reality and Dreams," Ward's Auto World, March 1977, pgs. 48-53.

54. United States Steel (advertisement), Pittsburgh, Pennsylvania.

55. Personal conversation with Mr. Joseph Hunter, Metallurgy Department, General Motors Research Laboratories, Warren, Michigan.

APPENDIX B
SAMPLE CALCULATION FOLLOWING FLOW CHART IN FIGURE 2.2

HP = 108 kws (145 hp)

WC = 1682 kgs (3708 lbs)

WT = WC + 136.1 kgs (300 lbs) = 1818 kgs (4008 lbs)

W1 = 919.2 kgs (2026.5 lbs)

W2 = 318.4 kgs (702.0 lbs)

W3 = 444.3 kgs (979.5 lbs)

$W1_N$ (materials substitution) = 859.6 kgs (1895 lbs)

$W1_N$ (component substitution) = 845.6 kgs (1864 lbs)

$\Delta W1 = W1 - W1_N$ = 73.7 kgs (162.4 lbs)

$\Delta W2 = .15\ \Delta W1^*$ = 11.0 kgs (24.4 lbs)

$WC_N = WC - \Delta W1 - \Delta W2$ = 1597 kgs (3521 lbs)

$WT_N = WC_N$ + 300 lbs = 1733 kgs (3821 lbs)

$HP_N/WT_N \simeq HP/WT$ = .059 kws/kg (.036 hp/lb)

Find engine with $HP_N \simeq (WT_N\ HP)/WT \simeq$ 102 kws (138 hp)

HP_N = 101 kws (135 hp) (Saab 2 liter engine)

$W3_N$ (component substitution) = 314.7 kgs (693.8 lbs)

$W3_N$ (materials substitution) = 309.2 kgs (681.7 lbs)

$\Delta W3 = W3 - W3_N$ = 135.1 kgs (297.8 lbs)

$\Delta W2 = .15\ (\Delta W1 + \Delta W3)$ = 31.3 kgs (69.0 lbs)

$WC_N = WC - \Delta W1 - \Delta W2 - \Delta W3$ = 1442 kgs (3179 lbs)

$W2_N$ (component substitution) = 313.0 kgs (690.0 lbs)

$W2_N$ (materials substitution) = 273.8 kgs (603.7 lbs)

$\Delta W2 = W2 - W2_N$ = 44.6 kgs (98.3 lbs)

$WC_N = WC - \Delta W1 - \Delta W2 - \Delta W3$ = 1429 kgs (3150 lbs)

$\Delta WC = WC - WC_N$ = 250 kgs (552 lbs)

$\Delta W1$ must be in pounds

APPENDIX C
REPORT OF INVENTIONS

After a diligent review of work performed under this contract, no new innovation, discovery, improvement, or invention was made. However, analysis was performed on the potential for weight reduction through lightweight material and component substitutions in a 1977 General Motors Corporation B body vehicle. The analysis indicated that a conservative weight reduction of 250 kg (552 lb) or 15 percent is possible for this vehicle in the 1980 to 1985 time frame.

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