-NHTSA-80-7 DOT-HS-805 538

LIGHT DUTY TRUCK WEIGHT REDUCTION EVALUATION

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OCTOBER 1980
FINAL REPORT

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U.S. DEPARTMENT OF TRANSPORTATION
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Washington DC 20590

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16. Abstract

The objective of this program is to identify the weight reduction potential of pickup trucks, vans, and utility vehicles less than or equal to 8500 lb. gross vehicle weight through design modification, redesign, and material substitution. The subobjectives inherent in this statement of the overall objective are: the documentation and characterization of the existing world light truck fleet; the identification of the currently most weight efficient light truck; the identification of the currently most weight efficient light truck; the identification of acceptable reductions in vehicle function; the evaluation of the potential for material substitution; the potential for redesign consistent with 1985 technology; and the documentation of the optimum weight efficient state of the art light duty truck (LDT).

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PREFACE

This final report is submitted by IIT Research Institute (IITRI) under contract to the U.S. Department of Transportation, Transportation Systems Center in support of the Automotive Fuel Economy program. The weight reduction evaluation herein presented for light duty trucks was conducted under Contract DOT-TSC-1467.

The program manager and principal investigator for this project was Mr. Owen J. Viergutz, P.E. Major contributing effort was supplied by Messrs. M. Nusbaum, W. Fillman, C. Hales, and G. Waring. Other individuals who deserve recognition include D. Hanify, G. Ebey, K. Norikane, L. Barbarek, C. Schramm and Ms. D. Hooper. Additionally the authors wish to acknowledge the assistance provided by Mr. W. Tanner, Consultant for the automotive industry.

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Special appreciation is expressed to Dr. Hsi-Sheng Hsia and H. Gould of the Transportation Systems Center for their cooperation and support which helped to maintain the intensive program schedule.

Finally we would like to acknowledge the contributions of individuals in the industry to support our technology assessment. Specifically we would like to thank:

<u>Ford Motor Company</u>

L. V. Farago
M. A. Wheeler
F. N. Parrill
S. G. Lyons
B. H. Simpson
F. J. Baccari

<u>Chrysler Motors</u>

R. O. Sorenson
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C. Lanchec

Vauxhall-Bedford

J. Wedge

Daimler-Benz A. G.

G. Wolters
A. Stenglein

Volkswagen Werk

R. Schmidt

Considerable ffort was devoted to the thoughtful response to our investigations. The comments acquired provided a meaningful insight into the industry's concern for weight efficiency.

The shifting national energy consumption pattern and the increasing emphasis placed upon improving automotive efficiency is of utmost concern to the industry and research communities alike. The automotive industry is actively engaged in a major realignment of its automotive and light duty truck lines to improve efficiency. In order to achieve these Government mandated fuel economy standards the industry must continue to aggressively pursue every available technological avenue.

This report attempts to identify the potential for improving the weight efficiency of the light duty truck fleet while maintaining the utility and marketability of the vehicles. Of principal concern to this determination was the characterization of market acceptance of improved efficiency vehicles and the derivation of functional requirements for specific vehicle missions.

In the development of design and material substitution options available to the 1985 vehicle manufacturers it was important that the perspective technology be critically selected. The industry as a whole has a wide variety of technological options available. However, any single manufacturer is limited to available in-house technology. As the in-place plant is replaced new technology may be incorporated, but the introduction of this technology is contingent upon normal production equipment life cycles.

It is apparent that new technology will need to be introduced in an accelerated manner if the mandated fuel economies are to be achieved. The economic tradeoff between on the road efficiency improvements and the cost of obtaining these economies is a critical issue. This report identifies technologically feasible weight efficiency improvements and first order cost impacts. It remains unanswered if the level of weight reduction achievable warrants the expenditure required.

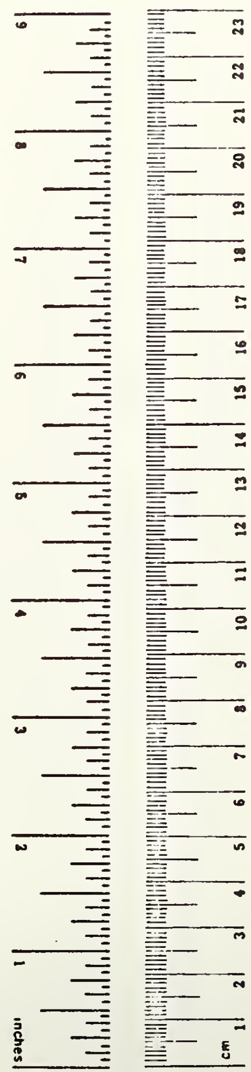
This report is being submitted in an effort to identify potential weight reduction options and levels of improvement. We feel confident that the results presented herein represent a thorough assessment of the industry's ability to manufacture and the consumer's willingness to accept improved weight efficient light duty trucks.

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

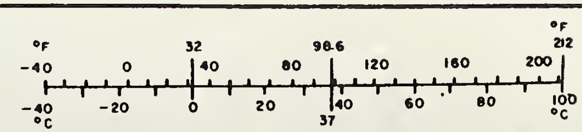
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2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

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



Approximate Conversions from Metric Measures

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



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1. INTRODUCTION

The domestic automotive industry is vigorously pursuing the goal of improved fuel economy throughout the automotive and light duty truck (LDT) fleet. The governmental pressures placed upon the industry to develop more fuel efficient and weight efficient vehicles is directing engineering development at all levels of industry. The objective of the industry is to develop a vehicle fleet which can achieve the mandated fuel economy goals as presented by Congress without adversely affecting their marketability or desirability. To achieve this objective, the industry is increasingly becoming aware of the need to provide a high order of weight efficiency in its LDT fleet.

The necessity for an LDT vehicle in personal use is well established in the U.S. market. The established market for this class of vehicle sets a precedent nowhere apparent outside of the United States. Therefore, the domestic industry is confronted with the unique problem of developing a fuel efficient LDT vehicle acceptable to the primary personal use application of such a vehicle.

Extensive capital investment as well as research and development funds are being applied throughout the industry in order to develop these improved efficiency vehicles. The industry as a whole, is committed and soundly behind the improved fuel economy needs of the U.S. automotive fleet. The ability of the industry to provide the necessary technology and manufacturing resources to produce this improved efficiency fleet is not fully confirmed. However, the requirement for the 1980 fleet to achieve a 16 mph fuel economy and the 1981 fleet to achieve 18 mph fuel economy, as mandated, is the overriding consideration within the industry.

IIT Research Institute (IITRI) has engaged in this program to evaluate the ability of the automotive industry to develop improved weight efficient LDT. The intent is to identify specifically the weight reduction potential for pickup trucks, vans, and utility vehicles less than or equal to 8500 lb gross vehicle weight through design modifications, redesign, and material substitution. Inherent in the investigation of this weight reduction potential is the documentation and characterization of the existing LDT fleet, and particularly the identification of world-wide technology which could be brought to bear on improving domestic LDT efficiency. Additionally the identification of the optimum current weight efficient LDT; the identification of acceptable reductions in downsizing a vehicle function; the evaluation for the potential for material substitution; the potential for redesign consistent with 1985 technology; and the documentation of the optimum weight efficient, state of the art LDT.

This program approaches the identification of weight reduction potential from the perspective of the entire automotive industry. This perspective provides for identification of potential weight reductions which are achievable across-the-board for the entire industry as a whole. What it does not do is identify specific technologies which a single LDT manufacturer may have available in place today or by 1985 to begin production of improved LDT. Therefore, the weight reductions identified while technologically achievable within the industry could not, in all probability, be implemented in their total context by a single manufacturer without extensive capital investment in improved manufacturing techniques. Each of the domestic manufacturers has a portion of the required technology in place today or will have by 1985. Further, IITRI feels that the capital investment necessary for implementing all of the weight reduction techniques by each manufacturing company producing domestic LDT will eventually be achieved. Therefore it was believed appropriate to characterize the weight reduction potential in terms of industry-wide capability without singling out a specific manufacturer as having a manufacturing or technology lead in weight efficient LDT. Each of the manufacturers could achieve an equivalent position in the production of weight efficient LDT depending upon the willingness to expend the necessary capital resources to establish existing, competing technologies.

From the standpoint of the marketplace, the LDT fleet that will be desired by 1985 had to be identified along with detailed vehicle specifications. The identification of market acceptance for proposed vehicle configurations is very difficult. IITRI has presented the approach to identifying market acceptance in terms of the existing fleet penetration and projections of these penetrations to the 1985 time frame. However, this market acceptance is developed in an iterative manner which is continually being refined as the industry shifts the buyers perception of vehicle desirability. The actual utility required for a given LDT application varies widely from one use to another. In very general terms, IITRI has found that the utility required from an LDT is considerably less than the utility provided in vehicles of today. The maximum cargo carrying capability of vehicles is seldom required and therefore is a very small segment of vehicle usage. It was found necessary to identify a set of vehicle specifications in the context of a given level of usage or market acceptability. This correlation allowed for the projection of vehicle sizing as a function of percent of the market satisfied.

Proceeding from the market defined specifications for the 1985 LDT fleet, IITRI evaluated the redesign and material substitution permitted by 1985 technology that could increase the weight efficiency of these selected vehicles. The design and materials improvements were considered independent and separate for the initial analysis. Specific reductions achievable through redesign and through selected material substitutions were identified. These independent analyses were then integrated to evaluate the combined potential for redesign and material substitution. Obviously the extent to which materials may be utilized in these vehicles is highly dependent upon the extent of redesign and conversely the ability to redesign certain functional components of the vehicle is highly dependent upon the materials selected.

To validate the weight reduction potential and specifically establish the feasibility of improving the weight efficiency for the LDT fleet, a detailed design layout of a proposed weight efficient pickup truck was prepared. This integrated conceptual design (ICD) was developed by the Fiat Research Center and indicates the ability of industry to optimize an LDT in terms of weight efficiency.

2. MISSION ANALYSIS

The mission analysis provides a definition of the function required to achieve a specified level of usage within a given LDT market segment. The mission analysis is presented by means of four major sections:

- Mission Profiles
- Selection of Current Weight Efficient Vehicles
- LDT Market Requirements
- LDT Specifications

Mission profiles were prepared for six LDT uses. These profiles were defined by performing a detailed analysis of the U.S. domestic LDT fleet. The six missions considered three vehicle types: pickup trucks, vans, and utility vehicles. The mission profiles are presented in Section 2.1. Weight efficient vehicles are those which optimize the primary mission measures of effectiveness (MOE). These vehicles are identified in Section 2.2.

The market study was performed to define the marketplace priority for the various MOE identified in each mission. Current sales in LDT categories (pickup, van, and utility) were used to establish the priority. The market survey was used to establish levels of performance which should be provided for each mission LDT to assure buyer acceptance. This acceptance level was used to establish the specifications for the various missions. The user survey is described in Section 2.3 and the specifications are presented in Section 2.4.

2.1 MISSION PROFILE

The objectives of the mission analysis are to identify the physical and performance attributes of the 1977 world fleet of LDT; to identify the design criteria for the structural components and powertrains for identified LDT missions; and classify and document the LDT in the world fleet with respect to specific measures of weight efficiency.

This initial task proved to be the most challenging with the most unknowns, and the least number of current available data sources. The thrust of this task was to identify and classify the world LDT fleet. The goal was to develop a baseline of information which would define:

- the range of physical and performance characteristics available in American domestic and European pickups, vans, and utility vehicles
- the primary uses of each of the three types of LDT
- the range of physical and performance attributes for each type of LDT in each of its identified uses
- the "consumer identifiable" attributes such as high-performance engine, automatic transmission, four-wheel drive, custom interior, etc., which are most often purchased by LDT owners in each LDT type by use segment of the market.

Before embarking on a research effort to reduce the weight of LDT through material substitution and redesign, the project team wanted to become more knowledgeable of the current fleet requirements. In addition, the team would attempt to answer the question: does the current fleet of LDT really meet the needs of American consumers, or are they only provided models which offer production and profit efficiencies to the manufacturers? This question could not be answered and it may be that consumer needs and manufacturer needs are jointly served. Certainly the LDT must be produced at a marketable price.

The user survey described in Subsection 2.3 was conducted to determine what features the consumer wants. In this case the frequency of purchase of variously configured LDT was determined which characterized the market acceptance of available options. However, there is no answer to the questions: what features would be desired and what would be the frequency of use for such non-existing configurations?

There seems to be little doubt that the consumer wants individualized vehicles and that the manufacturers are quite sensitive to these desires. Automobile options are quite numerous and these choices are now generally available to the LDT buyer.

A middle management official in one assembly plant stated that there was no such thing as a standard LDT and that every vehicle was "custom ordered". Thus it seems quite likely that the buyer's options are not complete--even in a practical sense. The manufacturers are not willing, and it is understandable, to divulge their explicit marketing determinations. Therefore this type of data could not be developed during the program.

An important facet of this task was establishing the functional requirements for each of the missions (LDT type by LDT use market segment). In effect the intent was to identify the minimum load and passenger capacities acceptable to the consumer, and specify on the basis of available information, the minimum performance characteristics of vehicles within a mission to satisfy a majority of the mission consumers.

To the writer's knowledge, IITRI has made the sole attempt to characterize the world fleet, and identify its missions in terms of physical and performance attributes. While funding and time constraints precluded or warranted an in-depth analysis, a serious effort was made to draw objective data from the available sources. The significance of these results should be clearly understood. The entire range of tasks which followed were directed in focus by the mission specifications developed herein. The IITRI approach was a demarkation from the "that's the way its always been made" attitude. The preceding quote was heard more than once as IITRI discussed the LDT fleet with U.S. manufacturers, and may reflect the inherent conservatism of the major truck manufacturers which is rationalized by the high monetary risk involved in the production and introduction of new and innovative designs.

While only a surface-scraping attempt, the project team efforts provided insights which allowed the undertaking of material substitution and redesign tasks with a better perspective of what limits could not be exceeded and still result in sellable vehicles.

The list of attributes for which data were collected is presented in Table 1. Incorporated in this table are examples of data and identification of the primary choice of a data source for each attribute.

The four types of attributes: physical; user-perceived; societal; and manufacturer-related; were consciously developed to provide a significant and meaningful characterization of each vehicle within the LDT world fleet. They represent performance specifications, in an engineering sense; consumer identifiable attributes that are apparent to the end user of the vehicle; attributes impacting on the environment; and manufacturer related cost considerations.

To facilitate data assimilation, the LDT world fleet was segmented by body type into five classes and these classes are pictured in Figure 1. The body type classifications in Figure 1 were chosen on the basis of U.S. Bureau of Census Truck Inventory and Use Survey classifications, and LDT manufacturers classifications. Characteristic use categories were also developed to include all identifiable uses of domestic LDT. Figure 2 presents a listing of the LDT uses, coupled with statistics from the U.S. Bureau of Census 1972 Truck Inventory and Use Survey.

Note that the first five categories include approximately 89 percent of all LDT $\leq$ 10,000 lb gross vehicle weight (GVW), and represent 94 percent of all truck miles driven by this weight group. To bound the program scope and enable concentration on the largest use sectors, only the following top five use sectors were evaluated:

- Personal
- Agriculture
- Services (hotel, automobile, repair, laundry, plumbing repair)
- Construction
- Wholesale/Retail

TABLE 1. -ATTRIBUTES CONSIDERED

Attribute	Data Source	Example
LDT Manufacturer	Product Literature	Chevrolet
Model Name	Product Literature	Sportvan
Certified for United States Sale		Yes
I. PHYSICAL		
1.1 General Indicators		
1.1.1 Type of Body	Product Literature	Panel
1.1.2 Number of Seats	Product Literature	4 to 12
1.2 Engine		
1.2.1 Engine Model	Product Literature	350 cu in. V-8 LM-1
1.2.2 Fuel	Product Literature	Unleaded, regular gasoline
1.2.3 Configuration	Product Literature	V
1.2.4 Installed Position	Product Literature	Front/Longitudinal
1.2.5 Number of Cylinders	Product Literature	8
1.2.6 Displacement	Product Literature	5733 cc
1.2.7 Horsepower Rating	Product Literature	165 hp SAE/3800 rpm
1.2.8 Compression Ratio	Product Literature	8.5:1
1.2.9 Torque Rating at Given rpm	Product Literature	265 lb-ft/2400 rpm
1.2.10 Fuel Feed	Product Literature	Mech. Diaph. Pump
1.2.11 Fuel Tank Capacity	Product Literature	24 gal. total
1.2.12 Carburetor/Injection Pump	Product Literature	IV Rochester Downdraft
1.2.13 Oil Capacity	Product Literature	6 qt
1.2.14 Cooling System-Type/Capacity	Product Literature	Water Cooled/4 qt
1.2.15 Electrical System Voltage	Product Literature	12 volts
1.2.16 Catalytic Converter	Product Literature	No
1.2.17 Air Pump	Product Literature	No
1.3 Transmission		
1.3.1 Clutch/Fluid Coupling	Product Literature	Torque-Converter
1.3.2 Gearbox	Product Literature	Automatic
1.3.3 Gear Ratio 1st	Product Literature	5.70-2.48:1
1.3.3.1 Gear Ratio 2nd	Product Literature	3.40-1.48:1
1.3.3.2 Gear Ratio 3rd	Product Literature	2.30-1.00:1
1.3.3.3 Gear Ratio 4th	Product Literature	....
1.3.3.4 Gear Ratio 5th	Product Literature	....
1.3.3.5 Gear Ratio Reverse	Product Literature	2.83-2.10:1

TABLE 1. -ATTRIBUTES CONSIDERED (CONTINUED)

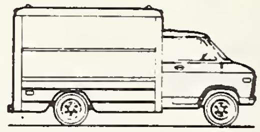
Attribute	Data Source	Example
1.4 Traction		
1.4.1 Drive Position	Product Literature	Rear
1.4.2 Final Drive Ratio	Product Literature	4.11:1
1.5 Chassis Details		
1.5.1 Type	Product Literature	Monocoque
1.5.2 Suspension: Front	Product Literature	Independent Wheel with Parallel Links
1.5.3 Suspension: Rear	Product Literature	Rigid Axle
1.5.4 Springs: Front	Product Literature	Coil Springs
1.5.5 Springs: Rear	Product Literature	Semielliptic Leaf Springs
1.5.6 Shock Absorbers: Front	Product Literature	Telescopic
1.5.7 Shock Absorbers: Rear	Product Literature	Telescopic
1.5.8 Tires: Front (Number Size)	Product Literature	2/8.75-16.5
1.5.9 Tires: Rear (Number Size)	Product Literature	2/8.75-16.5
1.5.10 Steering (Type/ Assisted or Not)	Product Literature	Recirculating Ball/ Hydraulic Assist
1.5.11 Service Brake (Service Type)	Product Literature	Hydraulic and Vacuum Assisted
1.5.12 Parking Brake Type	Product Literature	Mechanically Operated Handbrake on Rear Wheel
1.6 Dimensions		mm
1.6.1 Wheelbase	Product Literature	3175
1.6.2 Overall Length	Product Literature	5102
1.6.3 Overall Width	Product Literature	2050
1.6.4 Overall Height	Product Literature	2032
1.6.5 Front Overhang	Product Literature	747
1.6.6 Rear Overhang	Product Literature	1182
1.6.7 Front Track	Product Literature	1712
1.6.8 Rear Track	Product Literature	1730
1.6.9 Ground Clearance	Product Literature	251
1.6.10 Loadspace Length	Product Literature	3213
1.6.11 Loadspace Width	Product Literature	1785
1.6.12 Loadspace Height	Product Literature	1366
1.6.13 Turning Circle (Diameter)	Product Literature	14 meters
1.6.14 Gross Vehicle Weight	Product Literature	3357 kg
1.6.15 Curb Weight	Product Literature	2090 kg
1.6.16 Payload (Carrying Capacity)	Product Literature	1100 kg
1.6.17 Gross Trailer Weight	Product Literature	1633 kg

TABLE 1. -ATTRIBUTES CONSIDERED (CONTINUED)

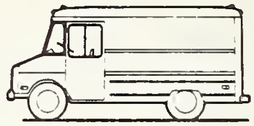
Attribute	Data Source	Example
1.6.18 Passenger Volume	Product Literature	
1.7 Equipment		
1.7.1 Window Washer	Product Literature	Yes
1.7.2 Review Mirrors	Product Literature	Two - Single Post
1.7.3 Defrosters	Product Literature	Front Window-Air Rear Window-Electric
1.7.4 Inside Luggage Space	Product Literature	0.48 cu m
1.7.5 Spare Wheel and Tire	Product Literature	One Spare/8.75-16.5
1.7.6 Heater Type	Product Literature	Hot Water
1.7.7 Air Conditioner	Product Literature	Freon Piston Type
1.7.8 Radio	Product Literature	Yes
1.7.9 Special Insulation Package	Product Literature	Yes
II. USER PERCEIVED		
2.1 Acceleration		
2.1.1 Time: xx km/h mph	Manufacturer	4.0 seconds/30 km/h
2.1.2 Time: xx km/h mph	Manufacturer	6.4 seconds/50 km/h
2.2 Passing Ability (IITRI Only)		
2.2.1 Time: xx-xx mph	U.S. Consumer Protection Agency	3.0 seconds/30-50 km/h
2.2.2 Time: xx-xx mph	U.S. Consumer Protection Agency	4.0 seconds/50-80 km/h
2.3 Braking		
2.3.1 Stopping Distance at xxx mph/ km/h	Manufacturer	79 feet/ 30-0 km/h
2.3.2 Stopping Distance at xxx mph/ km/h	Manufacturer	241 feet/ 100-0 km/h
2.4 Fuel and Consumption		
2.4.1 Mile/Gallon	EPA	21
2.4.2 Range in Miles	IITRI	420
III. SOCIETAL		
3.1 Meets U.S. Pollution Standards?	Manufacturer	Yes
3.2 Meets FVMSS	Manufacturer	Yes
IV. MANUFACTURER RELATED		
4.1 Cost and Profitability		
4.1.1 Base Price	Manufacturer	$6587.01

Pickup

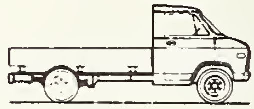
Panel



Multistop



Platform Stake and Rack



Van

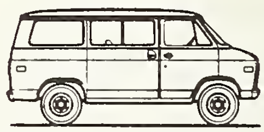


FIGURE 1. LDT WORLD FLEET CLASSES

Uses	Trucks Use Category (%)	Truck Miles Use Category (%)
Personal	53.4	50
Agriculture	20.1	17
Wholesale/Retail	6.1	9
Construction	6.9	9
Services	7.7	9
For Hire	0.6	1
Utilities	2.5	2
Manufacturing	1.3	2
Forestry/Lumbering	0.5	1
Mining	0.2	0.3
Other	1.2	1

FIGURE 2. TOTAL LIGHT TRUCK USES

Implicit in the mission evaluation was the inclusion of the sixth category, for-hire. This stems from the characteristics of the for-hire use category. This group includes trucking services known as drayage, daily rental or short-term-lease without driver, local cartage, household goods movers, common or contract motor carriers, commercial motor carriers leased with drivers, and owner-operators under lease or contract. For-hire vehicles are used principally in the preceding five use categories, and are symbolized by the vehicle types and the physical and performance requirements of LDT used in those avocations. In targeting on the top five use categories, on the basis of annual mileage, and including the for hire category, concentration is on the six uses which comprise over 94 percent of the total U.S. LDT fleet, $\leq$ 10,000 lb GVW.

The domestic fleet population distribution, as given in the 1972 U.S. Bureau of Census Truck Inventory and Use Survey, is presented in Table 2. The number of vehicles in each cell of the vehicle/use matrix is also shown in Table 2. There are two percentage figures in each cell. The upper figure represents the percentage usage for a given vehicle type and the lower figure represents the percentage of vehicles for a given usage. This presentation includes only the vehicle types specified and uses representing 94 percent of the fleet. The service use was folded into the remaining usages.

Base line criteria for weight reduction potential evaluation were obtained by means of a questionnaire. The questions posed to the manufacturers marketing LDT in the United States are presented in Table 3. The data obtained were related to each truck use sector and were useful in identifying and characterizing the design and marketing requirements for the U.S. fleet.

Data relating to specific models of American marketed and European marketed LDT were secured directly from the LDT manufacturers. Product literature was supplied by the manufacturers and these data were augmented by telephone conversations and visits with company personnel. Attribute data were collected by the IITRI/Fiat team for approximately 200 specific LDT models manufactured by 26 companies.

TABLE 2.—PRINCIPAL DOMESTIC FLEET PERCENTAGE DISTRIBUTION

U.S. Bureau of Census 1972 Truck Inventory and Use Survey

Uses \ Classes	Pickup (84%)	Van (6%)	Van and Pickup Four-Wheel Drive (10%)
Personal (62%)	(65%) / (87%)	(43%) / (4%)	(56%) / (9%)
Agriculture (22%)	(22%) / (84%)	(4%) / (1%)	(33%) / (15%)
Wholesale/Retail (7%)	(5%) / (61%)	(36%) / (34%)	(4%) / (5%)
Construction (9%)	(8%) / (80%)	(17%) / (12%)	(7%) / (8%)

Note: Percentages are based upon 81% of total U.S. fleet comprising the major use segments and body types.

TABLE 3.—LDT MANUFACTURERS SURVEY QUESTIONS

1. Which of the five classes of LDT do you sell most often for use in each of the five major use categories?

2. Which models of the classes chosen in question 1 for each use do you sell most often?

3. If more than one class was identified in question 1, which class is the most popular in each use category?

4. If more than one model was identified in question 2, which model is purchased most often?

5. What are the primary selling features of this model?

6. What options are most often added to the base package?

7. Is this model often purchased in place of a second car?

8. If the answer to question 7 is yes, what is the principal reason(s)?

    a. increased utility

    b. "macho image"

    c. four-wheel drive

    d. trailering

    e. off-the-road use

    f. other ______________________________

Note: Results included in Manufacturer Assessment Section 3.

Initially involved was the identification of the manufacturers of the LDT world fleet. The manufacturers contacted by IITRI and from whom attribute data were secured, included the manufacturers of all U.S. market LDT, and all non-U.S. market fleets which are subsidiaries of U.S. manufacturers. The list of manufacturers included:

- American Motors
- Chevrolet
- Chrysler
- Ford
- General Motors Corporation
- International Harvester
- Mazda of America
- Nissan Motors
- Subaru
- Toyota
- Bedford: Great Britian
- Dodge: Great Britian, Spain
- Ford: Great Britian
- Vauxhall: Great Britian

Fiat secured and provided attribute data for the remaining manufacturers of LDT in Europe including:

- Citroen: France
- EBRO: Spain
- Fiat: Italy
- Mercedes-Benz: Germany
- Renault: France
- Volkswagon: Germany
- Volvo: Sweden
- Scania: Sweden
- OM: Italy
- Peugeot: France
- Saviem: France
- British Layland: England

Specifically, the project team intent was to exclude all vehicles produced under license to a parent company, and which are for all practical purposes identical to those of the parent company. That is, the vehicles produced in South America and a major portion of those produced within Asia are European in design and produced under license to a parent company. It is our contention that all of the important design characteristics are developed within the parent company, and therefore this proliferation of vehicle types to be investigated was unnecessary.

The next phase of effort involved specifying representative LDT missions. By developing a mission profile, the necessary "first cut" would be made to segregate the world fleet and begin to identify representative LDT for further study. The matrix presented in Figure 3 was developed to illustrate the five identified LDT body types, and the five major uses of the domestic LDT.

The matrix was refined to the one presented in Figure 4 which reduced the number of representative body types to three: pickup, van, and utility, and the LDT uses to four: personal, agriculture, wholesale/retail, and construction.

The answers provided by the domestic LDT manufacturers to the questions posed to them by IITRI (Table 3) and the available data from the U.S. Bureau of Census 1972 Truck Inventory and Use Survey, were used to locate the highest concentration cells of the matrix. The cells of Figure 4 with vehicles embodied in them were identified for mission analysis.

A mission profile was developed for each identified matrix cell. The mission profile is comprised of a brief description of the environment in which the identified LDT type must operate, and a rationale statement of the adequacy of the LDT body type to meet the needs of the LDT use category.

Still concentrating on the domestic LDT fleet, the data on vehicles specified by LDT manufacturers and subjective characterization as located within the LDT matrix were assembled. A data base was then developed, composed of the range of physical and performance attributes of vehicles within a mission. The result of this activity was the selection of physical and performance attributes of each mission which represent the minimum LDT levels within each mission.

Basic to this evaluation was the assumption that since the models included within each selected cell were specified by the manufacturers, therefore implying consumer demand, the maximum performance limitations represented by actual data values for each attribute under study are currently the minimum performance levels acceptable within that mission. It also follows that the minimum values of the range of actual data for each physical attribute are also the minimum physical requirement for a vehicle within that mission.

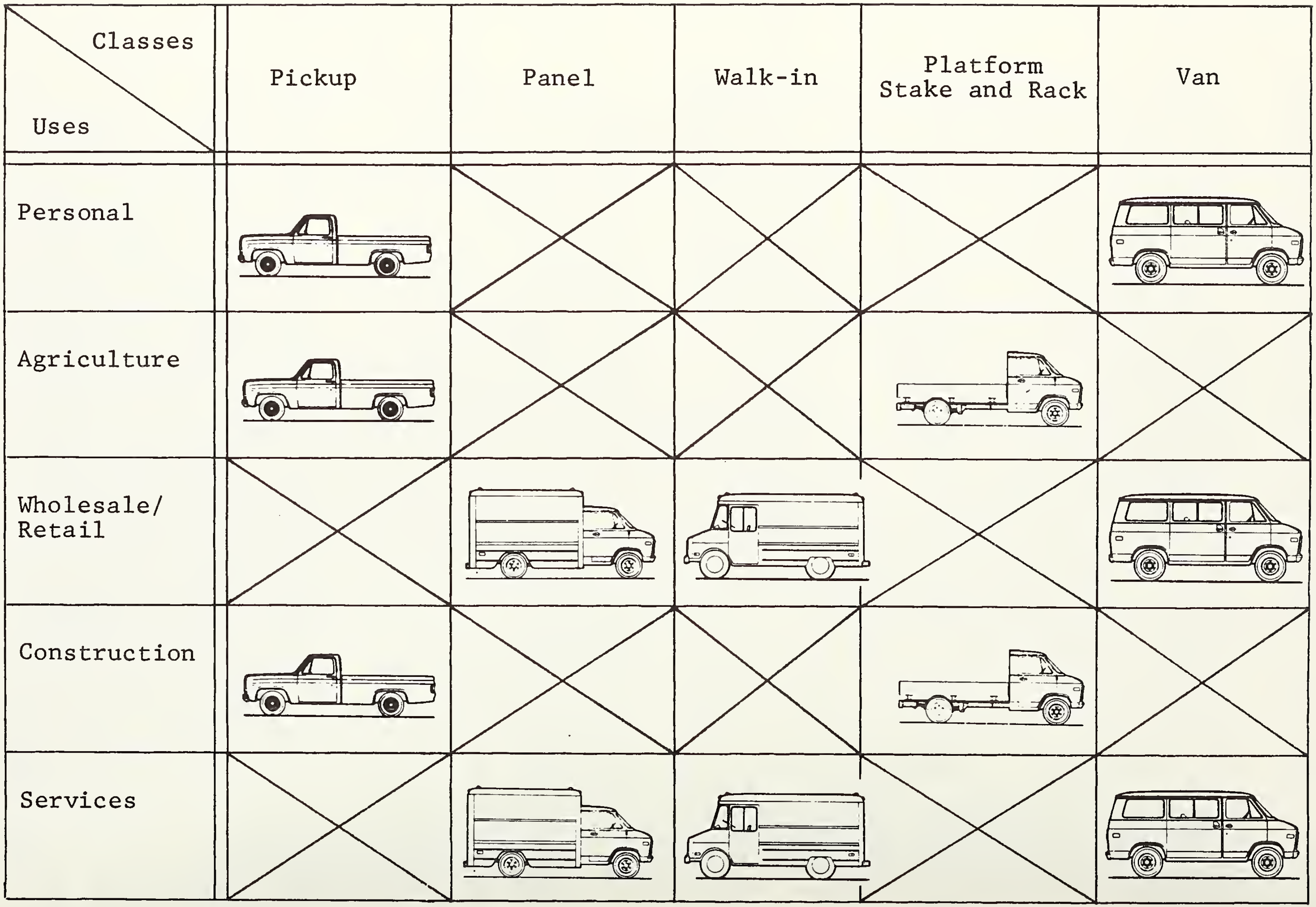


FIGURE 3. PROJECTION OF PRIORITY GROUPS FOR FURTHER STUDY

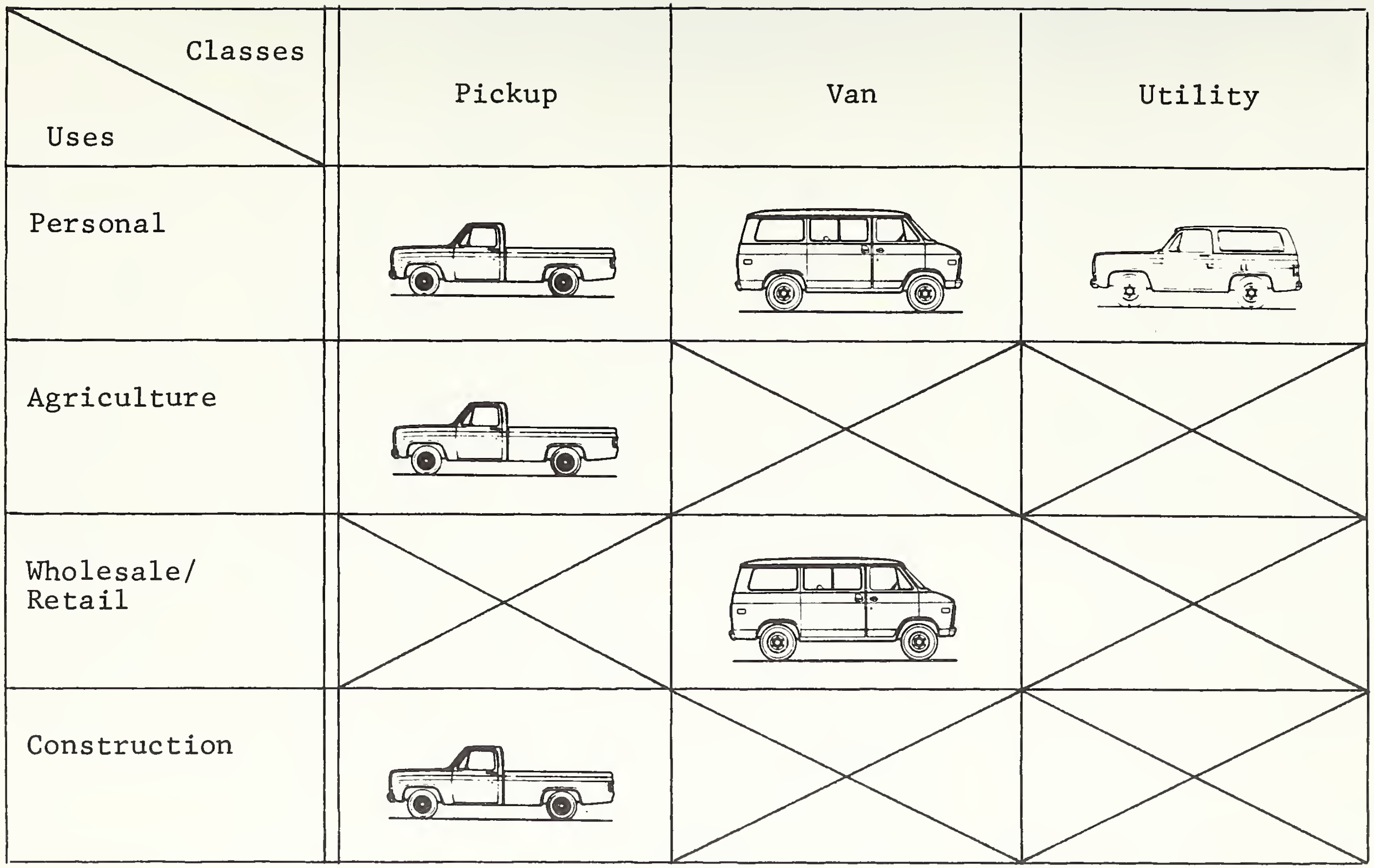


FIGURE 4. PRIORITY GROUPS FOR FURTHER STUDY

Each mission profile then, includes a presentation of the mission environment, a discussion of the relevant LDT characteristics which favor its use in the mission, and identification of selected attributes which vehicles must achieve to operate efficiently.

Once the mission profiles were completed, seven MOE were calculated for each vehicle of the world fleet. The range of values for each MOE for vehicles within each of the selected missions were documented. The seven MOE which were calculated for each vehicle of the world fleet are shown in Table 4.

TABLE 4.—VEHICLE CALCULATED MOE

- cargo weight versus curb weight
- cargo volume versus curb weight
- passenger capacity versus curb weight
- passenger capacity plus cargo volume versus curb weight
- horsepower versus gross vehicle weight
- gross vehicle weight versus maximum torque
- curb weight versus maximum torque

The mission profiles for the six identified primary missions are presented as Exhibits 1 through 6. The specific primary missions identified for LDT are shown in Table 5.

TABLE 5.—LDT PRIMARY MISSIONS

- pickup trucks: personal use
- pickup trucks: agricultural use
- pickup trucks: construction use
- vans: personal use
- vans: wholesale/retail trade
- utility vehicles: personal use

EXHIBIT 1

MISSION 1: PICKUP TRUCK PERSONAL USE

Light duty trucks (LDT) within the personal use mission must be able to accommodate a wide range of uses. They must be capable of primary operation at legal speed maximum, on paved highways at their top gross vehicle weight. Within this mission LDT often replace automobiles and are bought in place of a second car. A reason is that an LDT offers a wider range of load carrying and load pulling options than do passenger cars. In order to facilitate their substitution for passenger cars in this sector, LDT must also inherently provide for the aesthetic and functional characteristics which the American domestic market demands of their vehicles. LDT in the personal use mission must offer consumers, within reasonable limits: the same comfort that is available in a passenger car, a wide range of options to personalize the vehicle and customize the vehicle, and the colors and aesthetic value which make them pleasing to the eye.

Pickup trucks are the primary LDT used within the personal use mission. Pickup trucks provide more utility because their chassis, wheels, axles, suspension system, steering and brakes often are heavier and stronger than those on passenger cars. Thus a pickup truck can carry more, sustain more abuse and with reasonable care, stay serviceable over a longer period of time. Light pickup truck manufacturers have observed the trend to personal leisure use of pickup trucks and have developed a wide array of equipment and accessories to help owners enjoy their trucks and make them useful in more ways. Pickup cargo beds used for personal use vary in length from approximately 6 ft to approximately 8 ft. The cargo bed is usually steel and frequently is equipped with strips running the length of the box to assist in sliding cargo in and out. The pickup truck is well suited for the personal use mission for its multivaried uses and applications in that the open cargo bed allows it to be loaded from the top, from the rear and also from the side. The open cargo area also allows for a wide range of shapes to be loaded into the pickup truck. Pickup trucks are designed by current manufacturers to combine the needed gross vehicle weight of the pickup truck with an adequate suspension system which allows it to have a ride which is comparable to that of an automobile. Pickup trucks in the personal use mission are also frequently used in off-the-road excursions either for camping and/or leisure time activities and are suitable for campers which load onto the box of a pickup truck and also for trailers which are pulled behind pickup trucks.

Primary minimum functional specifications for a personal use pickup truck are:

- payload: 800 lb
- loadspace: 54 inches wide by 84 inches long
- passenger capacity: two (including driver)

The MOE required for optimum consumer acceptance are:

- cargo volume versus curb weight
- curb weight versus torque

EXHIBIT 2

MISSION 2: PICKUP TRUCK AGRICULTURAL USE

Light duty trucks (LDT) utilized in the agricultural mission must perform in on-highway and off-the-road applications. LDT in this sector are utilized for a wide range of load carrying, load trailering, and load pushing applications. While two-wheel drive is adequate for most over-the-road and incidental passenger trips, four-wheel drive is many times required for the off-the-road applications of load pulling, load trailering, and load pushing activities. LDT in this mission must offer to their users an open cargo area which allows for relatively easy loading and unloading of machinery, tools, parts, and agricultural products, which may necessitate loading from the rear, from the side, or from the top.

Pickup trucks are the primary vehicle used within the agricultural mission for passenger and light load moving. They are ideally suited for this application because they have an open cargo area behind an enclosed cab which allows the passengers to ride comfortably and in a secure environment, and have an open cargo area which meets the needs of the use environment. Pickup trucks provide storage/hauling area for objects of all sizes and shapes. Pickup trucks are typified by good all around visibility, relative low cost, ease of ingress and egress and available options to meet the most vigorous physical performance and comfort criteria. Pickup trucks are also well suited to this environment in that they are inherently designed to be capable of operation within a severe environment. Their structural soundness and integrity must, of necessity, be of the higher standard to withstand the bumps, the loads, and the abuse provided these vehicles by the American farmers.

Primary minimum functional specifications for an agricultural use pickup truck are:

- payload: 1500 lb
- loadspace: 60 inches wide by 84 inches long
- passenger capacity: two (including driver)
- four-wheel drive capability

The MOE required for optimum consumer acceptance are:

- cargo weight versus curb weight
- gross vehicle weight versus torque

EXHIBIT 3

MISSION 3: PICKUP TRUCKS CONSTRUCTION USE

The construction mission is very demanding on light duty trucks (LDT). LDT in this sector must be capable of operating in both on-the-road and off-the-road applications. It is necessary that these vehicles be capable of carrying a multitude of items within the medium weight range. Within the construction mission, pickup trucks are used not only for hauling workers between sites and between jobs within a site but also to haul tools, equipment, motors, ladders, and many other assorted items necessary to the construction trade. These items are of various sizes, shapes and weights; including such things as tools, pumps, motors, ladders; bulk cargo, such as dirt, sand, etc., bricks as well as other standard construction materials. These equipment requirements must be taken into the consideration of the design of LDT and employ a top loading cargo box and also one that is washable. In addition, a high payload capacity is an inherent functional requirement of an LDT within the construction mission. Since these vehicles must often operate on unpaved roads and in off-road situations, a durable suspension is another requirement of LDT in the construction sector.

Pickup trucks are the primary vehicle used in the construction mission for passenger and load carrying applications. They are ideally suited for this application because they are available with heavy suspensions, high ground clearances, they have open pickup boxes and come in standard cargo bed lengths of 8 ft. They also are available in mid and high range gross vehicle weights with appropriate wheels, tires, axles, springs, frame, etc. In addition, pickup trucks also allow the passenger to ride comfortably in a secure environment with many of the aesthetic and functional characteristics of passenger cars. Pickup trucks are well suited to the construction sector in that they are typified by good all around visibility, relative low cost, ease of ingress and egress and have available options to meet the most vigorous physical performance and comfort criteria.

Primary minimum functional specifications for a construction use pickup truck are:

- payload: 2000 lb
- loadspace: 60 inches wide by 98 inches long
- passenger capacity: two (including driver)

The MOE required for optimum consumer acceptance are:

- cargo weight versus curb weight
- gross vehicle weight versus torque

EXHIBIT 4

MISSION 4: VANS PERSONAL USE

Light duty trucks (LDT) within the personal use sector must be able to accommodate a wide range of uses. They must be capable of primary operation at legal speed maximum, on paved highways at their top gross vehicle weight. Within the personal use sector LDT often replace automobiles and are bought in place of a second car. The reason is that an LDT offers a wider range of load carrying and load pulling options than do passenger cars. To facilitate their substitution for passenger cars LDT in this sector must also inherently provide for the aesthetic and functional characteristics which the American domestic market demands of their vehicles. LDT in the personal use sector must offer consumers, within reasonable limits, the same comfort that is available in a passenger car, a wide range of options to personalize the vehicle and customize the vehicle and the colors and aesthetic value which make them pleasing to the eye.

Vans in the personal use sector have enjoyed a rapid rise in popularity. Vans are being substituted for station wagons as the traditional family carry all and incidental cargo hauler. A van body is large and basically rectangular with the engine and transmission mounted within or partially within the front driver-passenger compartment. Passenger vans (with windows) are being converted into sport vans, camping vans, and other specialized uses. The seats of these vehicles can be quickly removed without tools so that the vehicle can also double as a cargo van in the personal use mission. Vans are ideal in the personal use sector as leisure vans for day outings and light camping. Vans offer more interior space with relationship to outside dimensions than any other type of vehicle. Their enclosed body offers many advantages to the personal use owner. It enables large families to carry the whole family in one vehicle along with baggage and other necessities. In response to the desires of the American consumer the LDT manufacturers have responded by having passenger seats in the form of bench seats, individual captain's chairs or bucket seats. Frequently these seats can swivel around to face any direction. Vans offer relative ease of ingress and egress for multipassenger seats and cargo compartment areas. All vans have doors for the driver and the seat passenger, and side doors are usually located on the side of the van off of the passenger door. These doors may be sliding doors, swing out doors, or double swing out doors. In addition, most vans have double swing out doors that open across the entire width of the rear of the van. To further accommodate the personal use sector vans have also been engineered to handle on-the-road and in-traffic similar to a passenger car.

Primary minimum functional specifications for a personal use van are:

- payload: 1200 lb
- loadspace: 68 inches wide, 46 inches high, 55 inches long (behind seats)
- passenger capacity: five (including driver)

The MOE required for optimum consumer acceptance are:

- cargo plus passenger volume versus curb weight
- gross vehicle weight versus torque

EXHIBIT 5

MISSION 5: VANS WHOLESALE-RETAIL TRADE

Light duty trucks (LDT) within the commercial use mission must meet a wide range of load hauling needs. For this mission, it is an inherent necessity that the LDT offer an enclosed cargo space which can be locked. This is due to the fact that within the wholesale-retail trade sector LDT are used for hauling and delivering wholesale and retail commodities. In many instances vehicles are loaded in the morning and may make 20 to 50 stops in a single day at different locations unloading merchandise. Therefore an enclosed compartment which can be locked is needed for security purposes. In addition, LDT within the commercial sector must be available in a range of gross vehicle weight ratings and volume ratings to accommodate the many sizes of products encountered in the wholesale-retail trade sector. These vehicles must also operate well both on the highway and in the city and be capable of maneuverability in tight situations around loading docks and parking areas. LDT in the commercial sector must offer to their operators ease of ingress and egress and ample doors to accommodate the loading and unloading of merchandise. In addition these vehicles must provide a level of comfort which is comparable to that of an automobile, since they are driven for long periods of time by their drivers. These vehicles must also offer the amenities more commonly seen on automobiles and the aesthetic value which is necessary to be sellable within the American consuming market.

Vans are used in the wholesale-retail trade area because they offer more interior space in relationship to outside dimensions than any other type of vehicle. In addition, the basic concept of a van, which is to enclose as much space as possible, enables the vehicle to be loaded with merchandise and to be locked at intermediate stops ensuring safety of the materials inside. Vans used in the wholesale-retail trade sector generally have higher gross vehicle weight ratings than passenger vans. In addition to its weight and volume carrying characteristics, the doors of vans are a key selling feature for its use in the wholesale-retail trade area. Side doors are either sliding, swing out, or double swing out. In most models, sliding the door open reveals a step. This permits use in cramped quarters, for example, a van can be parked along side a loading dock where the level of the dock is higher than the lower edge of the door. This eliminates the opening of a swing out door. A swing out side door opens the same way a passenger door does but is wider. In addition, most vans have double swing out doors that open across almost the entire width of the van.

Primary minimum functional specifications for a van in the commercial mission are:

- payload: 2000 lb
- loadspace: 68 inches wide, 45 inches high, 114 inches long (behind seats)
- passenger capacity: one (including driver)

The MOE required for optimum consumer acceptance are:

- cargo volume versus curb weight
- curb weight versus torque

EXHIBIT 6

MISSION 6: UTILITY VEHICLES PERSONAL USE

Although the origins of the utility vehicle come strictly from the work related use sector and the military sector, utility vehicles are currently used almost solely for recreational purposes. To satisfy the needs of the personal use mission vehicles must be capable of operating in extreme off-road situations such as: negotiating rough terrain, up and down steep inclines, across shallow streams and over back woods trails. Four-wheel drive and high ground clearance are necessities of utility vehicles in the personal use sector. They must also be capable of maximum speed limit operation in on-highway operation as well as provide as near as possible a comfortable ride for their occupants. A utility vehicle in the personal use sector must have handling, maneuverability, and durability, which satisfy the most severe criteria. The utility vehicle in the personal use sector must also be capable of operating as a light cargo hauler.

Utility vehicles are designed for rugged service and equipped with four-wheel drive. The front wheels pull and the rear wheels push to deliver extra traction, stability and power. Four-wheel drive is available in utility vehicles in full or part time. Utility vehicles vary in size and are available in both two- and four-passenger versions. On most types of utility vehicles the driver sits high, as he does in a pickup truck or van. The ride is somewhat stiff and on smaller vehicles the short wheelbase causes a choppy ride on highways. Although utility vehicles are well equipped with heavy duty springs and shocks, the occupants of a utility vehicle cannot be fully insulated from the abrupt ups and downs, back and forth movements of off-road driving.

Like other types of light trucks, in the personal use sector, the utility vehicle is available with a long list of sporty and convenience features that seem to contradict the term utility. For example, exterior paint and interior trim packages, seats for up to six people, bucket seats, fog lamps, privacy glass and all of the various seating amenities and radio options.

Primary minimum functional specifications for a personal use utility vehicle are:

- payload: 800 lb
- loadspace: 80 cubic ft
- passenger capacity: two (including driver)
- four-wheel drive availability

The MOE required for optimum consumer acceptance are:

- horsepower versus gross vehicle weight
- curb weight versus torque

The selection of missions and the subsequent finalization of the mission profile resulted in a set of data for each which was in sufficiently significant detail to allow selection of the weight efficient domestic LDT, and also to identify the drive-train and structural components design criteria for these vehicles.

At this juncture, the European LDT were incorporated into the domestic vehicle mission cells which most nearly adhered to their physical and performance parameters. The primary emphasis, for evaluating a European LDT and fitting it into the mission matrix was placed on the European LDT physical attributes. This was necessitated by the almost complete lack of six- and eight-cylinder engines in foreign countries. While meeting the curb weight, payload capacity (dimension and weight), and gross vehicle weight limitations, their utilization of lower horsepower engines results in a completely distinct range of performance attributes both in a physical sense (size of engine drivetrain) and in its calculated MOE. The differing ranges of the MOE are illustrated in Figure 5.

Parallel to these efforts, activities were directed toward identification and characterization of applicable state of the art LDT manufacturing trends and to collect information on weight reducing material applications relevant to the 1980 to 1985 time frame. This activity was carried out through a review of available SAE and other technical publications. Additionally, telephone and/or personal contact was made with an extensive list of LDT component and material manufacturers as identified in Exhibit 7.

2.2 SELECTION OF WEIGHT EFFICIENT VEHICLES

The development of LDT data and mission profiles, by use, was a necessary preliminary step to the selection of weight efficient 1977 model year LDT for each mission. This selection was a fundamental step in the overall weight reduction prediction.

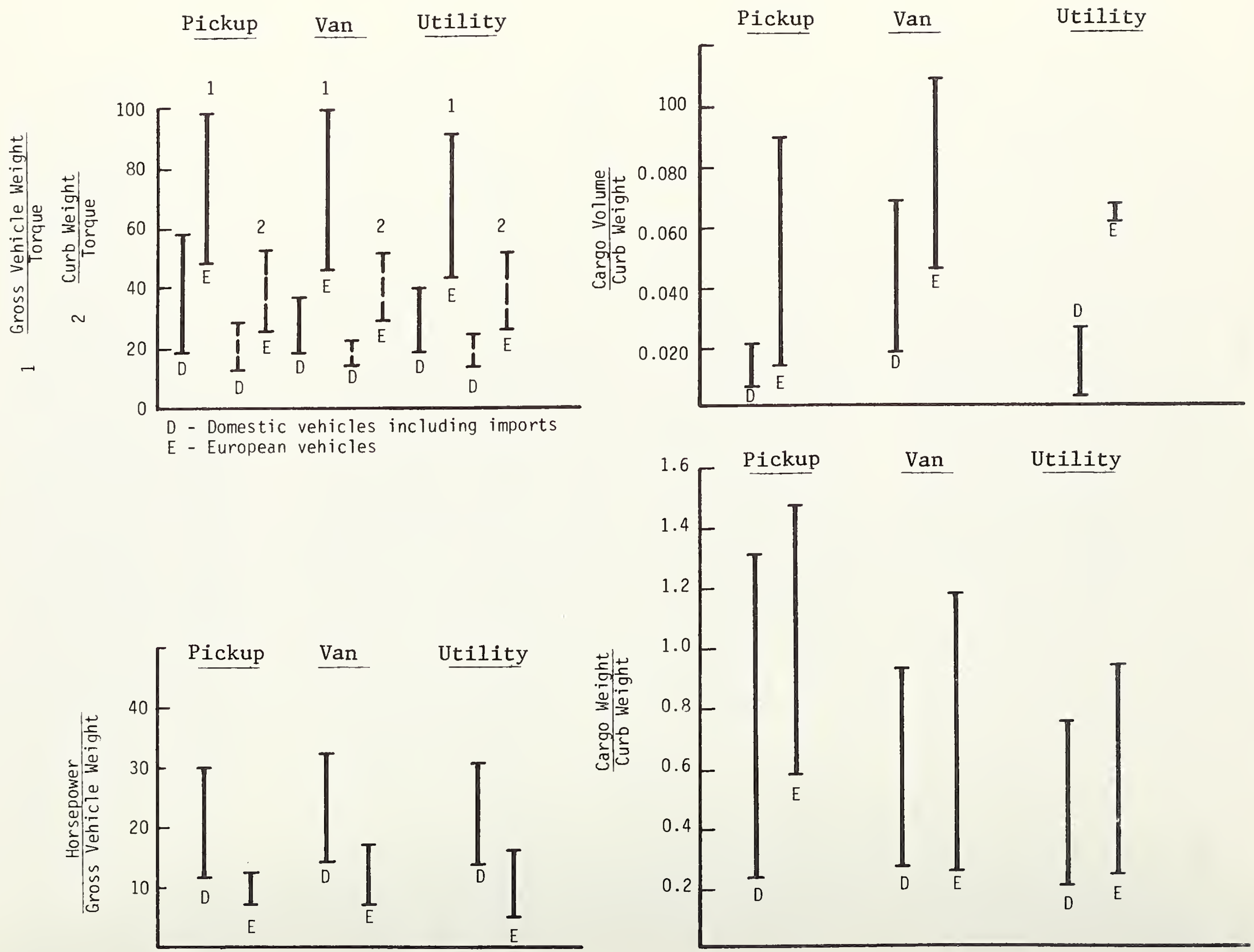


FIGURE 5. RELATIVE RANGES OF SELECTED MOE FOR AMERICAN AND EUROPEAN LDT

EXHIBIT 7: MANUFACTURERS CONTACTED FOR WEIGHT REDUCTION COMPONENTS AND MATERIALS

Company	Materials					Parts and Components					
	Ferrous Metals	Nonferrous Metals	Plastics	Elastomers	Glass	Brakes and Brake Parts	Engine and Engine Components	Structural Components and Trim	Drive Train Systems and Components	Running Gear	Comfort, Entertainment and Safety
Aluminum Co. of America		X									
American Cyanamid Co.				X							
Arco Polymers Inc.			X								
Celanese Plastics Co.			X				X				X
Dow Corning Corp.				X			X				
DuPont Co.			X	X			X			X	
GE Auto Polymers			X					X			
GE Silicone Products				X			X				
Inland Steel	X						X	X			
Lear Seigle Inc.					X	X		X	X	X	X
PPG Industries			X		X						
Reynolds Metals		X						X			
Rockwell International Auto.			X			X		X	X	X	
United States Steel	X										
Youngstown Sheet & Tube	X										
Amoco Chemicals Corp.			X								
Armco Steel Corp.	X		X								
Gulf Oil Chemicals			X								
Owens Corning Fiberglas Corp.			X								
Reynolds Aluminum Co.		X									
Shell Chemical Co.			X	X							
International Nickel Co.	X										
Union Carbide Corp.	X	X	X	X							
USM Corp-Bailey Div.			X	X							
Budd Co.						X		X	X		
Motor Wheel Corp.						X			X	X	
STockpole Carbon Co.							X			X	
TRW Inc.							X	X		X	X
Sheller-Globe								X		X	
Firestone Tire and Rubber				X				X	X		
Hercules Inc.			X								
Libbey Owens-Ford					X		X	X			X
National Steel	X	X									
Zinc Institute Inc.	X										
Merlin Technology		X									X
Velcro USA Inc.			X								
New England Instrument Co.								X			X
B. F. Goodrich				X							
Freeman Chemical Co.			X								
The Aluminum Association		X									

Selections were made from the American and European fleet for each mission/use. This selection of comparable American and European LDT established an initial design weight reduction potential. In addition, this activity had to be performed prior to conducting the detailed analysis of the additional weight-reducing options available from direct material substitution and additional redesign.

In undertaking identification of the most weight efficient vehicles, a key concept was that the vehicles chosen as the most weight efficient must be vehicles which meet the specifications of the U.S. domestic market. It would be counterproductive to select weight efficient vehicles only on the basis of their weight efficient characteristics without identifying and subjecting them to an evaluation of their capability of meeting the domestic market requirements. Toward accomplishing this goal, using the mission profiles of each mission developed for the U.S. domestic fleet, those American vehicles which are the most weight efficient for each mission as measured by the primary MOE were identified.

The selected American marketed LDT chosen as the most weight efficient and a listing of their basic attributes are presented in Table 6 along with their identified European counterparts.

The domestic and European LDT chosen were selected on the basis of meeting the mission profile criteria and evaluation of the MOE. With regard to the selected European LDT, the evaluation required a preliminary look at the level of reduced function expected within a mission due to the across-the-board lower performance levels inherent in European LDT. Without this preliminary step, it would have been impossible to choose a European LDT which met the performance requirements typified by the American fleet. The acceleration and gradeability of both the American and European LDT fleets was characterized by the vehicle weight versus torque ranges for the vehicles of each mission. It is readily apparent that due to the almost exclusive use of four-cylinder engines, the performance characteristics of the European LDT are substantially lower than their American counterparts.

TABLE 6. -SELECTED U.S. WEIGHT EFFICIENT LDT

Categories	I		II		III		IV		V		VI	
Mission	Personal Pickup	Personal Pickup	Agricultural Pickup	Agricultural Pickup	Construction Pickup	Construction Pickup	Personal Van	Personal Van	Commercial Van	Commercial Van	Personal Utility	Personal Utility
Model	Ford F100	Fiat 238	Chev K20	MB 307 DT	Dodge D200	MB 307 DT	Dodge B100	VW TL35	Dodge B200	Bedford CF280	Blazer K10	Fiat Compagiola
Engine type	302-V8	88-4 cyl	350-V8	147-4	400-V8	147-4	318-V8	121-4	318-V8	139-4	350-V8	122-4
Horsepower	136	52	165	64	170	64	150	71	150	81	165	81
Torque	254 lb-ft	77.4	260	101	300	101	255	108	255	124	255	111
Wheelbase	3378 mm	2400	3340	3050	3327	3050	2769	2500	2769	3200	2705	2300
Overall length	5359 mm	4590	5387	4840	5339	4840	4470	4840	4928	4770	4684	3775
Overall width	2007 mm	1800	2022	2000	2019	2000	2027	2080	2027	2235	2022	1580
Overall height	1800 mm	1970	1877	2115	1788	2115	2052	2200	1981	2121	1773	1943
Loadspace length	2494 mm	2760	2492	2809	2489	2809	1410	3060	2979	3035	1687	1260
Loadspace width	1778 mm	1650	1651	1900	1778	1900	1730	1815	1730	1924	1646	1500
Loadspace height	490 mm	770	490	655	485	655	1351	1460	1224	1539	953	1370
Gross vehicle weight	4700 lb	8048	8400	7716	8100	7716	4800	7716	6100	6240	6200	4806
Curb weight	3606 lb	2690	4693	3108	4146	3108	3770	3637	3615	3109	4306	3858
Payload capacity	1094 lb	2358	3707	4608	3954	4608	1030	4078	2485	3131	1894	947
Cargo volume	76.8 cu ft	122	71.2	124	75.8	124	116	286	239	337.4	93	99
GVW/maximum torque	19.8	65.2	32.3	76.4	27.0	76.4	18.82	71.4	23.92	51.77	24.31	42.3
CUW/maximum torque	14.72	34.8	18.05	30.8	13.82	30.8	14.78	33.7	14.18	25.07	16.88	34.8
CaW/CuW	0.3034	0.877	0.7899	1.482	0.9537	1.482	0.2732	1.127	0.687	1.007	0.6945	0.245
CaV/CuW	0.0213	0.0451	0.01517	0.0220	0.01828	0.0220	0.3077	0.0778	0.0661	0.102	0.0216	
Pass Cap/CuW	0.00083	0.00111	0.00063	0.00096	0.0007235	0.00096	0.001326	0.00085	0.00028	0.0064	0.00046	0.00078
CaV+Pass V/CuW	0.0379	0.0677	0.0279	0.0592	0.03275	0.0592	0.05729	0.0896	0.07165	0.1085	0.0309	
Hp/GVW	0.0289	0.0101	0.0196	0.0082	0.02099	0.0082	0.03125	0.0092	0.0245	0.0129	0.0266	0.0160

Conversely, the weight efficiency of the vehicles as shown by the cargo volume and cargo weight levels versus their curb weights indicate the European vehicles are more efficient.

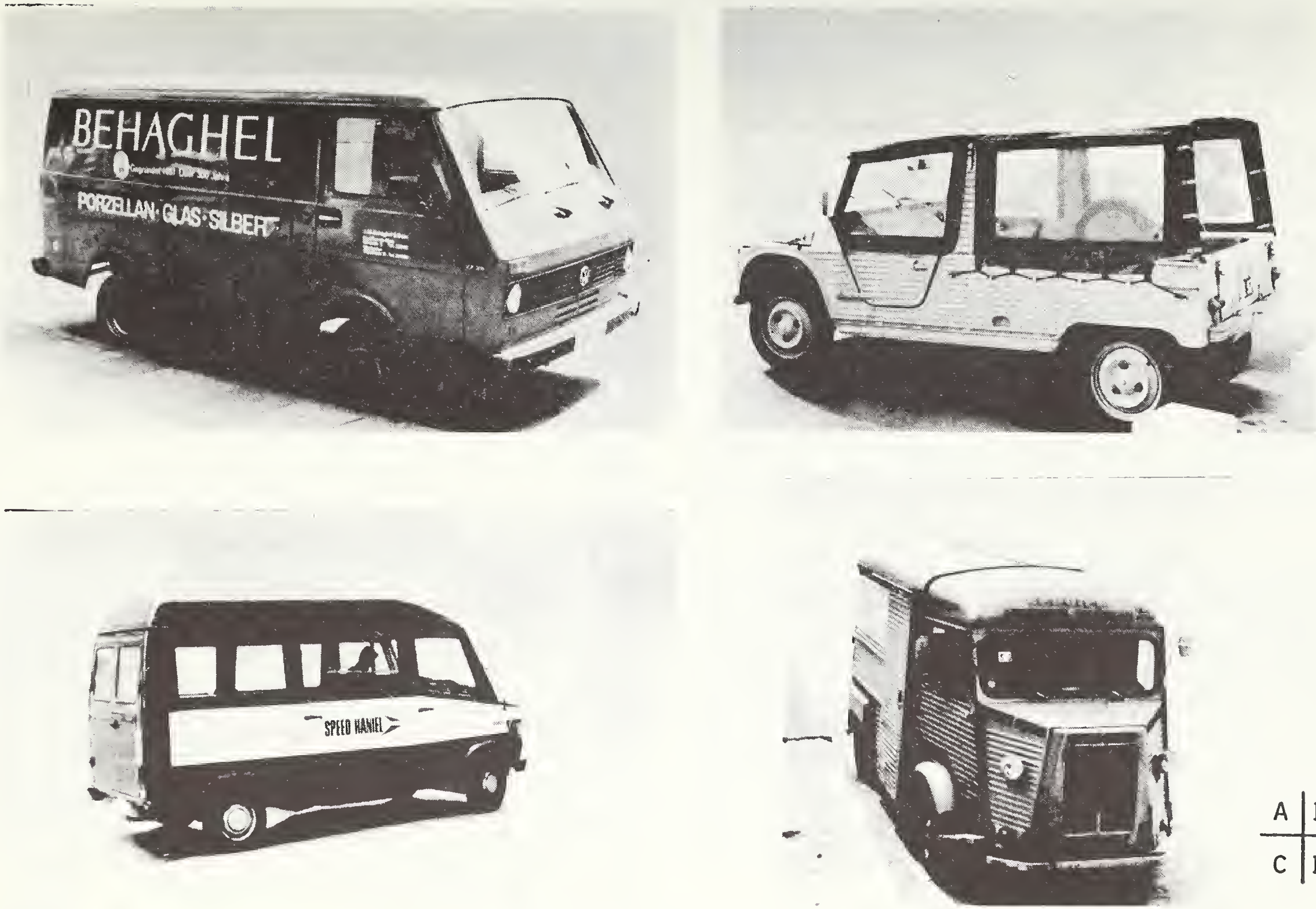
Photographs of typical European LDT are presented in Figures 6 through 8. Subsequent to selection of the weight efficient LDT for each mission, more detailed data were sought relating to each of the selected vehicles. For each of these vehicles the project team wanted to gather weight data for the characteristic vehicle components listed in Table 7 and related material and design considerations affecting the component.

TABLE 7.—WEIGHT ELEMENTS

Data Element	Weight Critical Element	Design Critical Element
I. Body Structure		
I.1 Main body assembly	I.1 Fender well	I.1 Elements connected to A-Pillar
I.2 Movable panels	I.2 Outer door panels	I.2 Inner door frames
I.3 Cargo box		
I.3.1 Cargo bed	I.3.1 Cargo floor	I.3.1 Cargo bed structure
II. Suspension		
II.1 Rear suspension	II.1 Springs	
III. Braking System	III. Drum	
IV. Engine Assembly	IV. Block	
IV.1 Cooling system	IV.1 Fan shroud	
V. Drivetrain		
V.1 Transmission	V.1 Case	
VI. Auxiliary Systems		
VI.1 Seat		VI.1 Seat frame

The IITRI/Fiat team also strove to reconstruct additional information related to the designed mission of each vehicle, and special considerations which affected its design.

This data collection effort was accomplished through personal visits by IITRI/Fiat team members to the manufacturers of each of the 12 selected vehicles.



A | B
C | D

FIGURE 6. EUROPEAN LDT

A | B
C | D

FIGURE 7. EUROPEAN LDT

A | B
C | D

FIGURE 8. EUROPEAN LDT

The documentation of reasons for weight efficiency included in the summaries range from the special efforts of some manufacturers to produce a weight efficient vehicle, to vehicles which happen to be weight efficient, but weight efficiency was not a prime consideration of vehicle design. It is evident that the European manufacturers have a much longer history of applied weight efficiency than American manufacturers.

2.3 LDT MARKET REQUIREMENTS

The U.S. market acceptance of the reduced weight LDT is a fundamental consideration in the preparation of vehicle specifications. It was the expectation of the program that the reduced weight vehicles will be smaller in size and have lower powered engines. The significant MOE defined previously in the program were to be used to establish the means for ensuring that the reduced weight LDT would have good market acceptance. The purpose of the users survey was to establish values for the MOE which were acceptable to the buying public. These values could then be used to determine the vehicle specifications (in conjunction with the mission definitions).

The market acceptance must be related to the parameters listed in Table 8. There is a problem in making this determination; there are a limited number of data sources available and they do not provide data for all of the desired parameters. The weight parameters are significant characteristics and it is necessary to establish any two of the three weights, with the third being calculated from the other two. The difficulty in identifying explicitly the actual curb weight or gross vehicle weight (GVW) undoubtedly arises from the variety of options which any given make and model LDT may include. R. L. Polk and Company do not provide the required data in any of their published or commerically available reports. The U.S. Bureau of Census 1972 Truck Inventory and Use Survey does not provide enough information to break out the data into the program missions. For example, our utility mission (number 6) includes Jeeps. The survey

TABLE 8.-PRELIMINARY MISSION CHARACTERISTICS

Parameters \ Mission Number / Truck Type	1 Pickup	3[c] Pickup	4 Panel	5 Panel	6 Utility
Cargo Weight, lb	1160	2100	1780	2300	800
Loadspace, in.:					
Width (minimum between wheel wells)	50	73.5	68	68	na
Length (not including front seating)	96[a]	96	55	114	na
No. Passengers (including driver)	2	2	5	1	2
Wheel Drive	2	2	2	2	4
Cargo Volume, cu ft	X[b]	-	-	X	80
Cargo Weight, lb	-	X	-	-	-
Cargo + Passenger Volume, cu ft	-	-	X	-	-
Horsepower/Gross Weight, hp/lb	-	-	-	-	X
Curb Weight/Torque, lb/ft-lb	X	-	X	X	X
Cargo Volume/Curb Weight, cu ft/lb	X	-	-	X	-
No. Passengers/Curb Weight, lb^{-1}	-	-	-	-	-
Cargo Weight/Curb Weight, lb/lb	-	X	-	-	-
Gross Weight/Torque, lb/ft-lb	-	X	-	-	-
Cargo + Passenger Volume/Curb Weight, cu ft/lb	-	-	X	-	-

na = not applicable; [a] = tailgate length in the horizontal position; [b] X = designated characteristics from mission profiles; [c] = mission 2 merged into mission 3 although the number of LDT with four-wheel drive is significant (366,637 out of a total pickup sales in 1977 of 1,474,637) the major difference is in curb weight due to the heavier drive. The added 500 lb cargo weight and 14 inches in cargo box length specified for mission 3 did not seem to provide a sufficient basis to retain mission 2 and an entity.

data aggregates Jeeps with pickup trucks instead of utility vehicles. However, the way the data have been presented precludes determining how many Jeeps are in the market; they constitute too small a fraction of pickup trucks to sustain a proper proportion of listings in the reported data.

Sales volume projections for LDT by model, drivetrain and use were available. These data, in conjunction with manufacturer LDT data manuals, made it possible to estimate the various parameters required for establishing the market acceptance by these characteristics. The wheel base and GVW had to be assumed for a given inertia weight to establish a base curb weight. The drivetrain specifications were used to modify this base curb weight and obtain a final estimate for the curb weight. This, in turn, made it possible to calculate a cargo weight. Two other assumptions were made in preparing the data. The volume associated with a passenger was taken as 20 cu ft*. The cargo volume was calculated on the basis of the widest cargo box dimension.

The data for two-wheel drive pickup trucks, comprising missions 1 and 3, include 1,368,300 1977 model year LDT. Characteristics for 1,108,000 or 81.0 percent of these were extracted. In the case of panel LDT for missions 4 and 5, there were 550,200 data points. Characteristics for 83.2 percent or 458,000 panel trucks were prepared. The data for panel LDT included panel vans and wagon bodies on truck chassis "suburban". All of the available data for four-wheel drive personal use utility vehicles were utilized. This consisted of 212,400 LDT, 100 percent of the sales. Vehicles from five manufacturers were included in the data for mission 6.

Mission 2 (agriculture use pickup LDT) was dropped from the study. The vehicle for this mission was judged to be similar enough to that for mission 3 so that the two missions could be considered merged. The most significant difference between these two trucks is that mission 2 requires four-wheel drive and mission 3 does not.

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*EPA vehicle class size standards allocate approximately this volume for a passenger.

The data for all three truck types, pickup, van and utility, were treated in a similar manner. The parameters of interest were used with the cumulative percent of the market to establish vehicle characteristics. Both functional and MOE type parameters were treated in this manner.

The characteristics for the sample populations of the LDT fleet were established as described. Data for 54 two-wheel drive pickup truck model variations, 51 van types and 26 different personal use utility vehicles were collected. Figure 9 shows the data sheet used to record the pertinent characteristics. This form was adapted from the 1977 LDT Attribute Data Form. Figures 10, 11 and 12 show typical market acceptance curves for cargo weight (CaW), cargo volume (CaV), and GVW. It may be noted from Figure 10 that about 60 percent of the market would be achieved with a 2000 lb CaW capacity. Similarly, from Figure 11, 75 percent of the market was "satisfied" with a CaV capacity of about 76 cu ft. Figure 12 indicates that a GVW of about 5100 lb would satisfy about 60 percent of the LDT buyers' needs. Table 9 shows the results of two other data analyses performed on vehicle functions. A three-person bench seat and an automatic three-speed transmission are indicated most popular with the U.S. LDT buyers.

There are seven MOE which were considered in the users survey. These are listed on the bottom of Figure 9. Five of the market acceptance curves, cumulative percent of the market as a function of a given MOE are presented as Figures 13 through 17. These curves show, respectively, the cumulative percent of sales as a function of the following MOE: cargo volume versus curb weight (CaV/CuW), cargo weight versus curb weight (CaW/CuW), curb weight versus torque (CuW/T), horsepower versus gross vehicle weight (HP/GVW), and gross vehicle weight versus torque (GVW/T). Note that large values of CaV/CuW, CaW/CuW, and HP/GVW are desired while low values are desired for the other MOE.

1977 LDT MARKET ACCEPTANCE DATA

Identification Number

Sales Volume

Manufacturer

Model Name

Type of Body

Primary Functions:

- Number of Seats/People
- Displacement (cubic inches)
- Horsepower Rating (horsepower)
- Torque Rating/RPM (ft-lb/rpm)
- Transmission: Rear Axle Ratio (RAR)

  Type: Gearbox ____Manual, ____Automatic

  ____Number of Speeds
- Loadspace Length (inches)
- Loadspace Width (inches
- Loadspace Height (inches)
- Cargo Volume/Area (cu ft/sq ft)
- Gross Vehicle Weight (lb)
- Curb Weight (lb)
- Payload (carrying capacity), e.g., cargo weight (lb)

Measures of Effectiveness:

- Gross Vehicle Weight vs Maximum Torque (lb/ft-lb)
- Curb Weight vs Maximum Torque (lb/ft-lb)
- Cargo Weight vs Curb Weight (lb/lb)
- Cargo Volume vs Curb Weight (cu ft/lb)
- Number of Passengers vs Curb Weight (lb^{-1})
- [Cargo + Passenger] Volume vs Curb Weight (cu ft/lb)
- Horsepower vs Gross Vehicle Weight (hp/lb)

FIGURE 9. 1977 LDT MARKET ACCEPTANCE DATA FORM

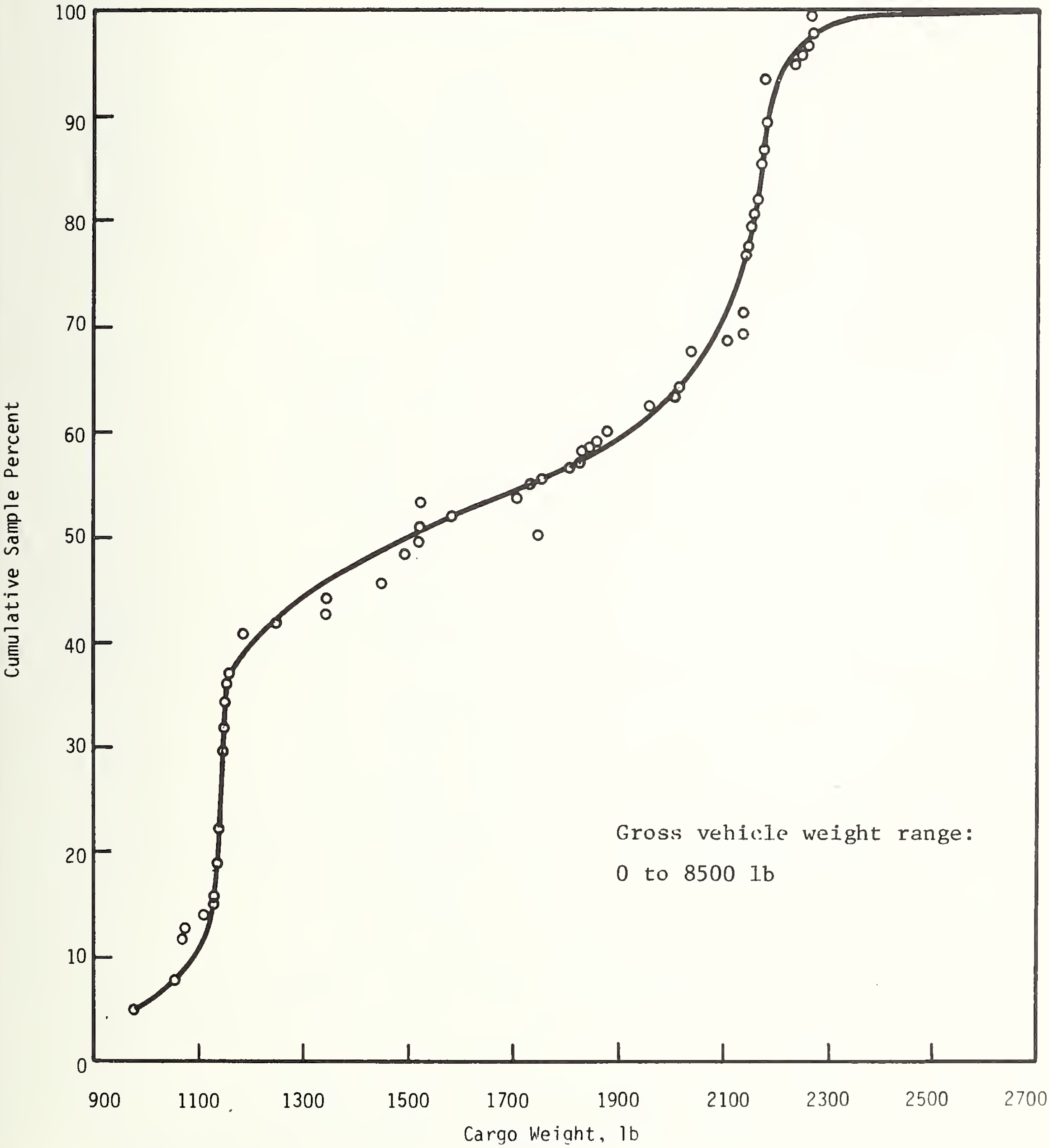

FIGURE 10. CUMULATIVE SAMPLE PERCENT VERSUS CARGO WEIGHT, TWO-WHEEL DRIVE PICKUP TRUCKS

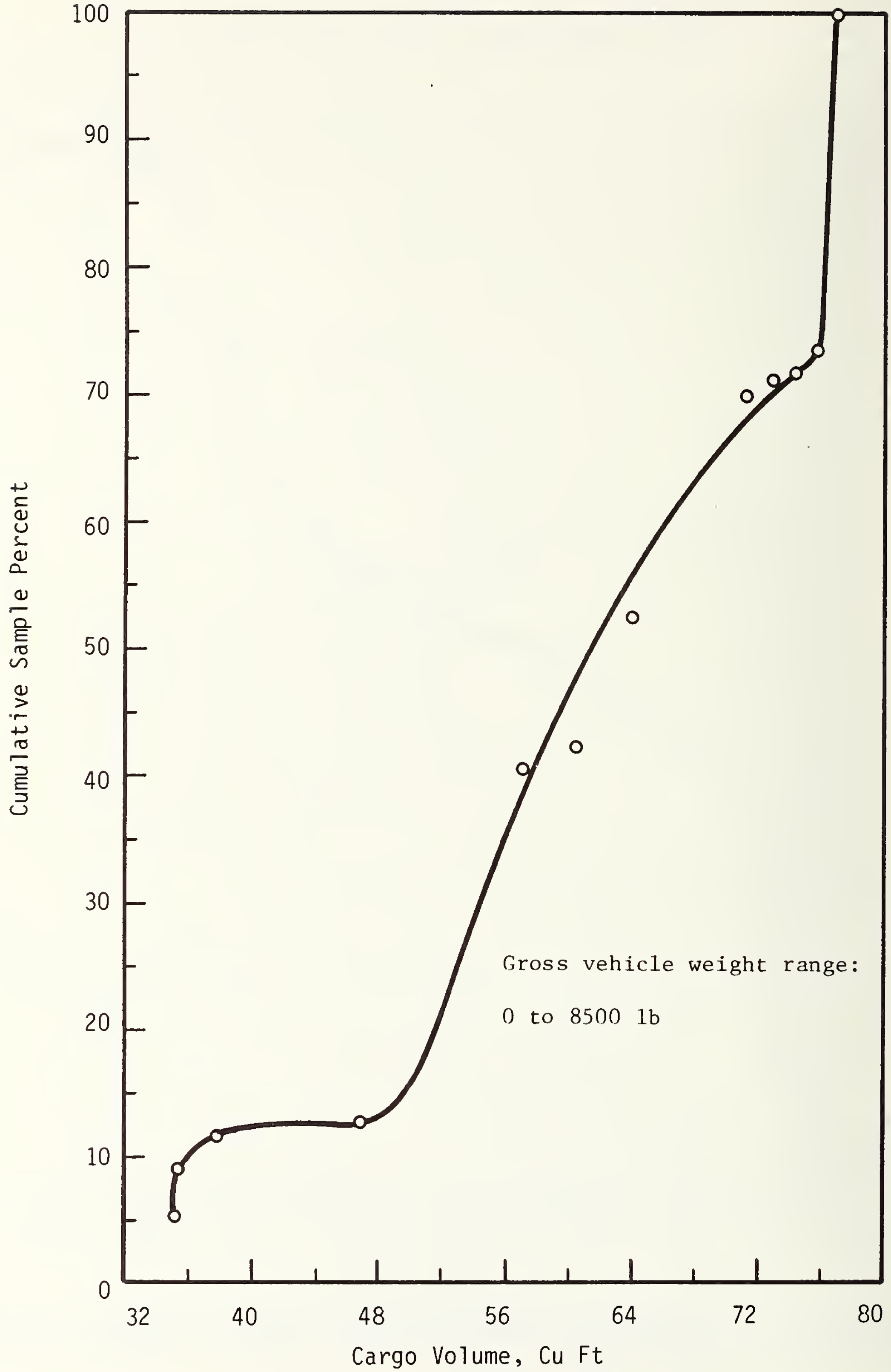

FIGURE 11. CUMULATIVE SAMPLE PERCENT VERSUS CARGO VOLUME, TWO-WHEEL DRIVE PICKUP TRUCKS

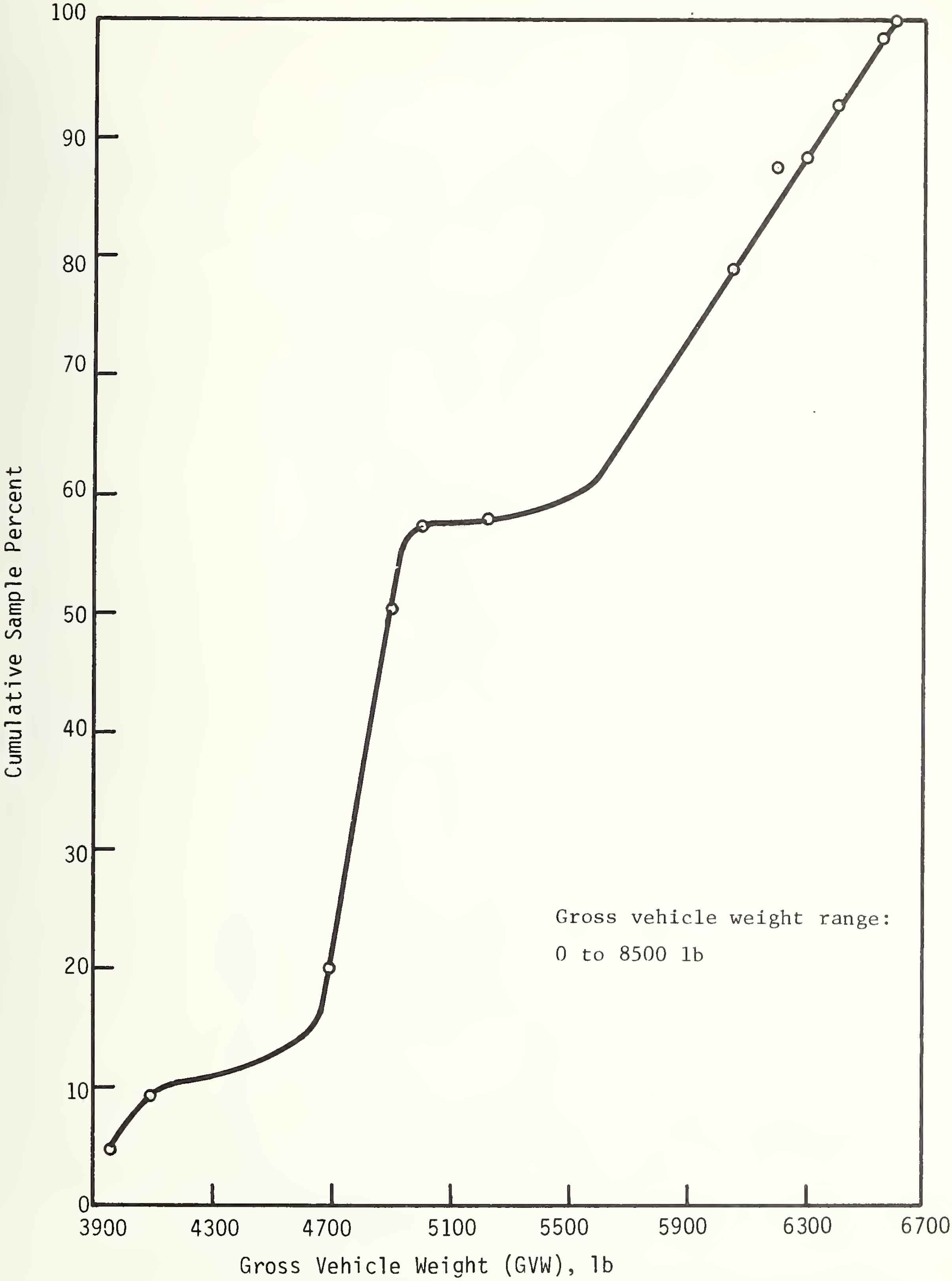

FIGURE 12. CUMULATIVE SAMPLE PERCENT VERSUS GROSS VEHICLE WEIGHT, TWO-WHEEL DRIVE PICKUP TRUCKS

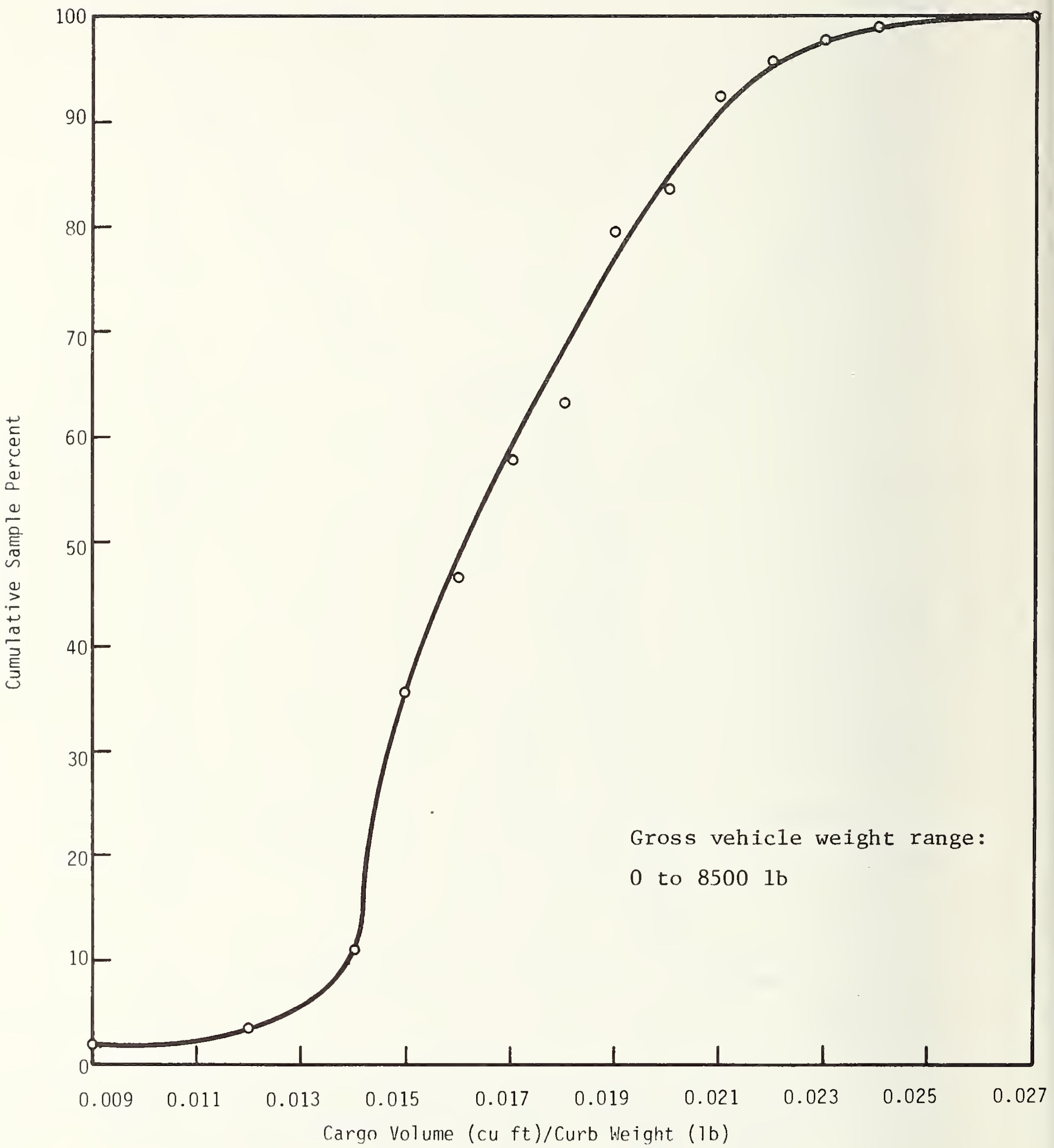

FIGURE 13. CUMULATIVE SAMPLE PERCENT VERSUS CARGO VOLUME/CURB WEIGHT, TWO-WHEEL DRIVE PICKUP TRUCKS

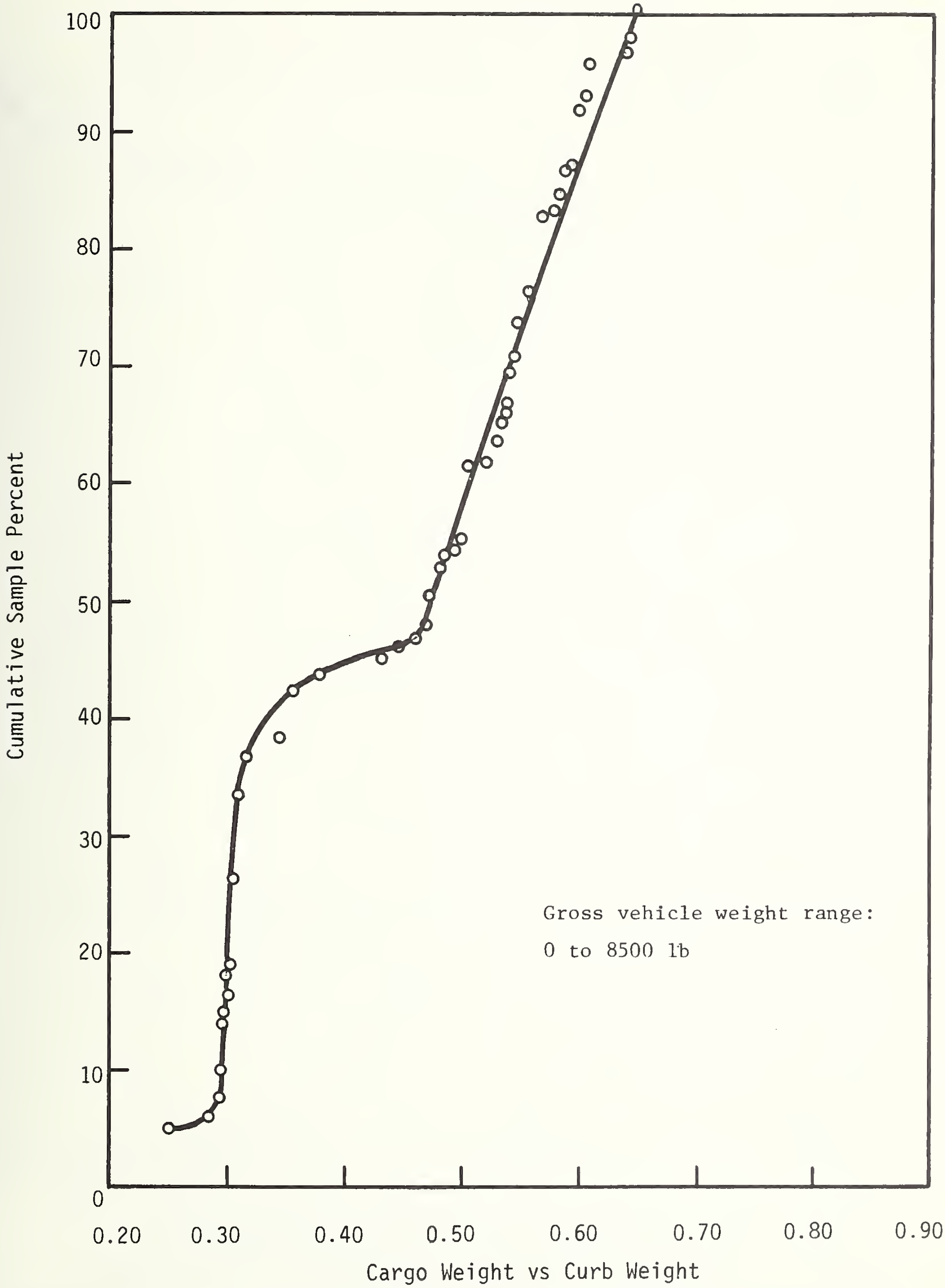

FIGURE 14. CUMULATIVE SAMPLE PERCENT VERSUS CARGO WEIGHT/CURB WEIGHT, TWO-WHEEL DRIVE PICKUP TRUCKS

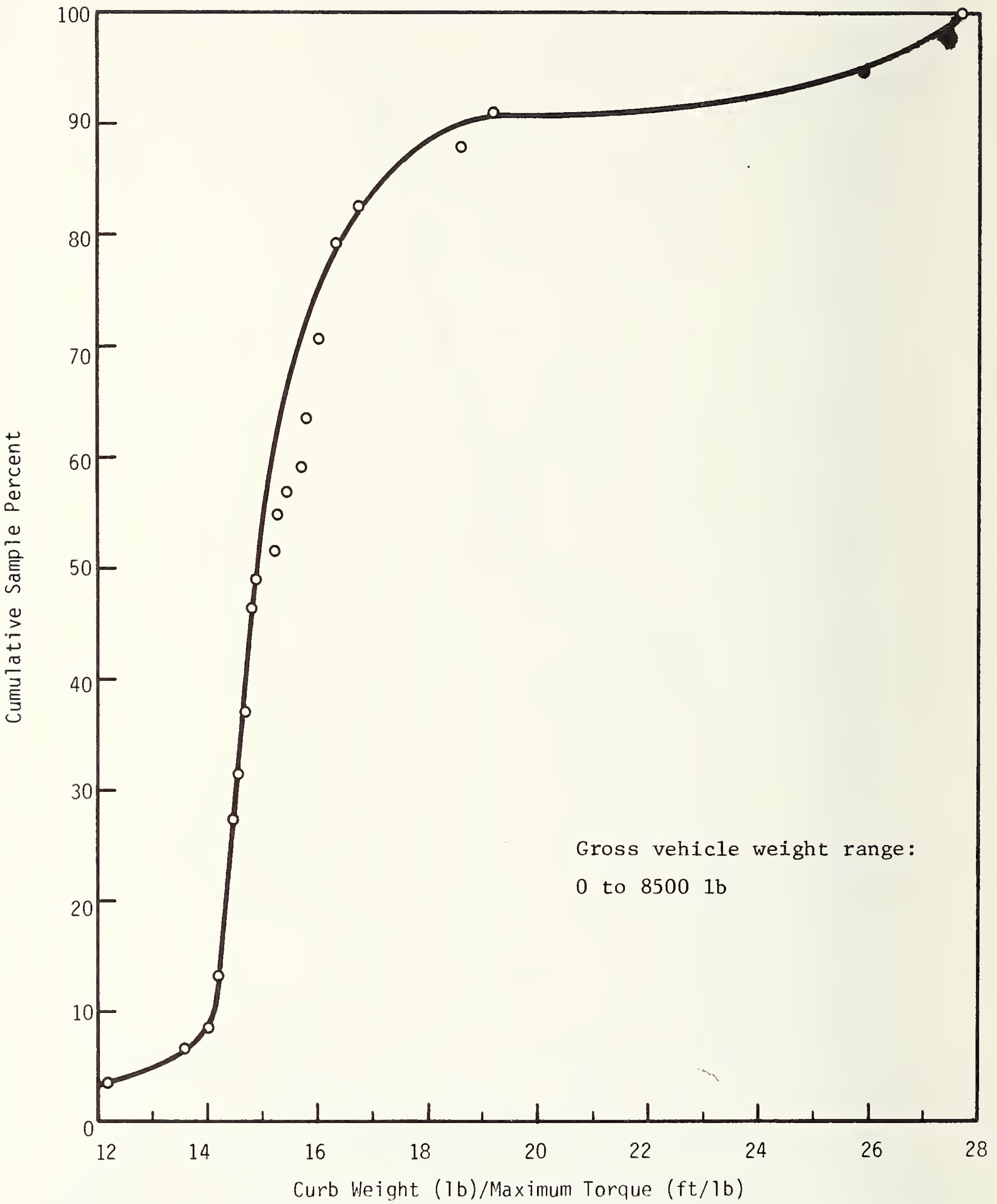

FIGURE 15. CUMULATIVE SAMPLE PERCENT VERSUS CURB WEIGHT/MAXIMUM TORQUE, TWO-WHEEL DRIVE PICKUP TRUCKS

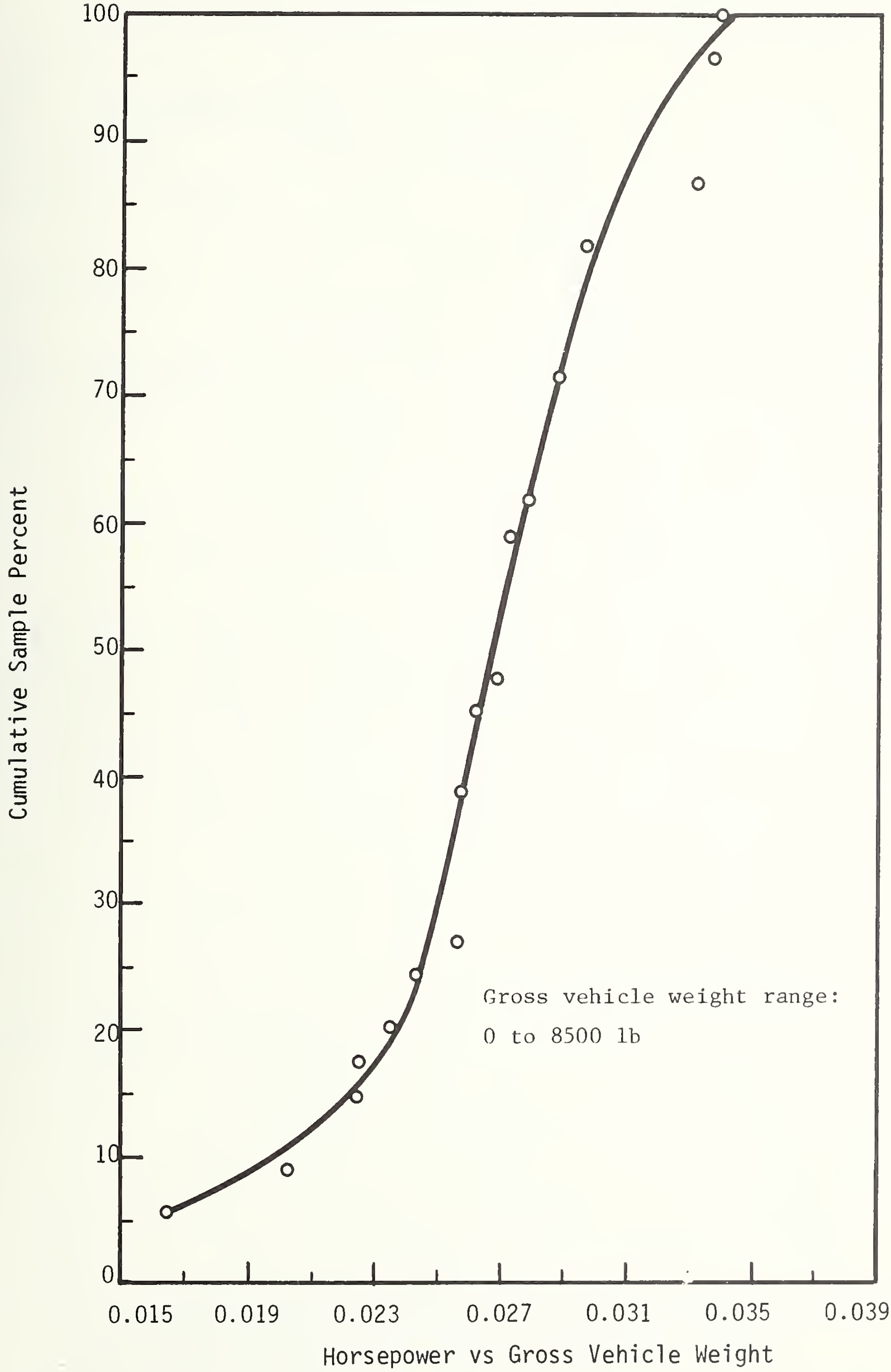

FIGURE 16. CUMULATIVE SAMPLE PERCENT VERSUS HORSEPOWER/GROSS VEHICLE WEIGHT, TWO-WHEEL DRIVE PICKUP TRUCKS

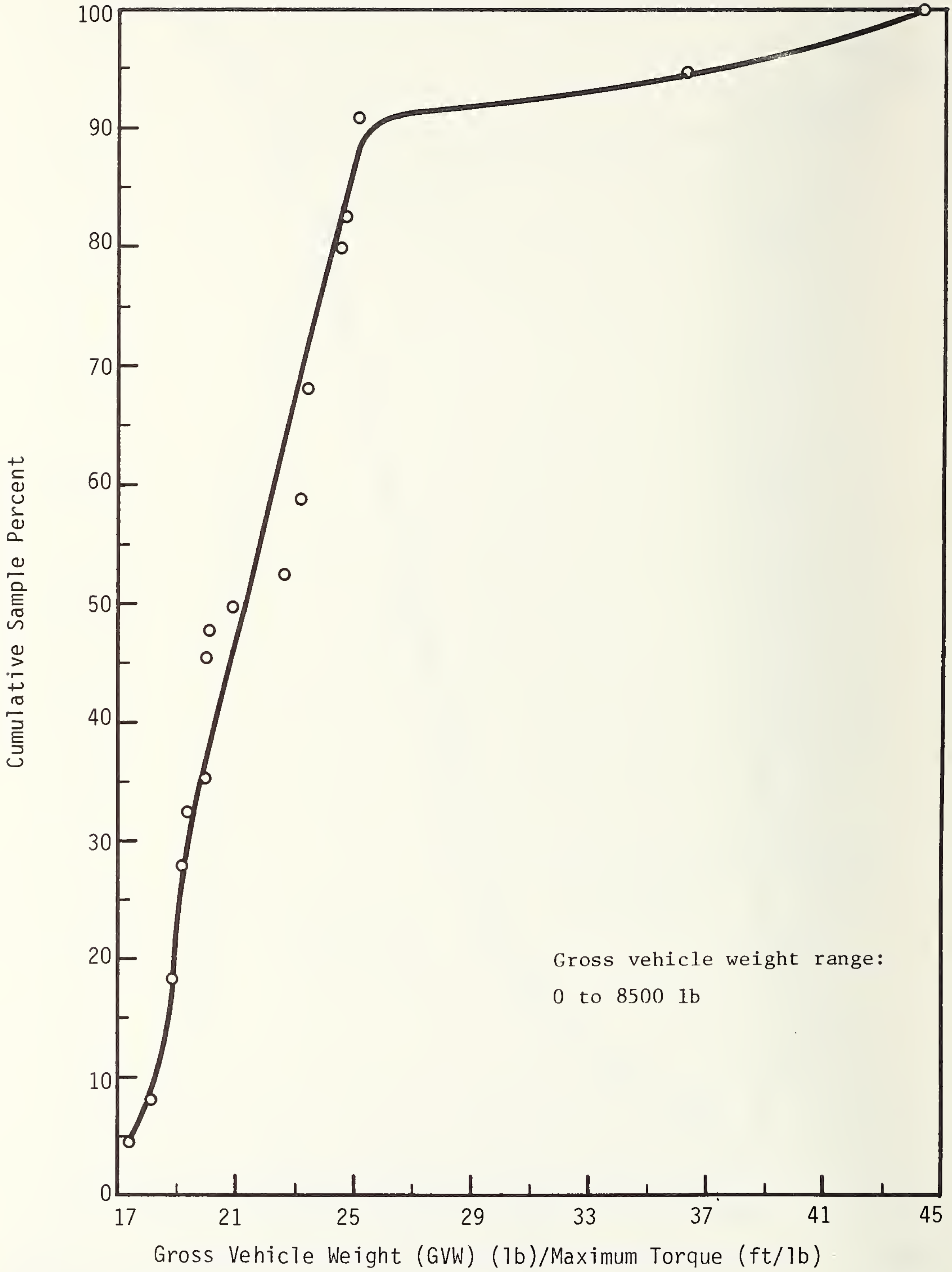

FIGURE 17. CUMULATIVE SAMPLE PERCENT VERSUS GROSS VEHICLE WEIGHT, TWO-WHEEL DRIVE PICKUP TRUCKS

TABLE 9.—1977 MODEL YEAR SEAT AND TRANSMISSION MARKET ANALYSIS

Seats:

Type	Bucket	Bench	
Number of People	2	3	Totals
Sales Volume	101,000	1,006,900	1,108,000
Percent of Sample	9.1	90.9	100.0

Transmissions:

Type	Automatic	Manual			
Number of Speeds	3	3	4	5	Totals
Sales Volume	762,400	197,400	136,000	12,000	1,108,000
Percent of Sample	68.8	17.8	12.3	1.1	100.0

For Missions: 1 and 3 -- Use a bench seat for three people and a three-speed automatic transmission

Data were gathered for all seven MOE for two-wheel drive pickup trucks; commercial and personal use panel trucks, and personal use utility vehicles. These parametric relationships constituted the data base for development of the vehicle specifications for each of the missions. The manner in which the data base was used is presented in subsection 2.4.

2.4 LDT SPECIFICATIONS

The acceptable level to which the LDT mission functions may be reduced are deduced from the MOE determined by the market acceptance data. The market acceptance of LDT with reduced function is expected to be a strong function of the MOE determined by those data. The particular parameters important in each mission were delineated in Table 8. Both the functional values and MOE designated are considered preliminary. It may also be noted from Table 8 that there are seven MOE and seven functional parameters. In addition to selecting values for the primary functions and MOE, additional assumptions must be made to develop the complete matrix of seven functions and seven MOE.

Reduced weight LDT were specified in relation to the mission profiles prepared. The individual profiles delinated LDT in terms of four (of seven) functions and six (of seven) MOE. To determine market acceptable specifications, for downsized LDT (reduced weight) vehicles, the market acceptance was based upon 1977 sales projections. The cumulative percent of the market corresponding to the various MOE was determined and used to develop the specifications.

An initial evaluation of the transmission type, manual and automatic, showed that 68 percent of the 1977 model year LDT were sold with automatic transmissions. Thus, all specifications called for this type as well as the following standard requirements:

- Truck center of gravity with a full uniform load to be ahead of rear axle.
- All U.S. safety and environmental standards applying to the 1977 model year appropriate for the truck specified are to be met.

The minimum values for the functions delinated by the mission profiles were assumed and the two major MOE set at 100 percent of the market values. Usually it was necessary to assume an MOE value in addition to the above data to identify a unique set of specifications. The assumed values were varied iteratively to maximize the total cumulative percent of the market which all of the MOE represented. It was always possible to develop the specification to represent 90 percent or more of the market.

The three functions defined for each mission were: payload (CaW), loadspace, and passenger capacity. Four-wheel drive was specified as an additional function for two missions. The MOE specified were ratios of various other functions:

cargo volume/cargo weight (CaV/CaW)
gross vehicle weight/maximum torque (GVW/T)
total volume/curb weight (TV/CuW)
horsepower/gross vehicle weight (HP/GVW)
curb weight/maximum torque (CuW/T)

and the seventh MOE, which was not specified by any mission, is passenger volume/curb weight (PV/CuW). The cumulative sales percent versus each MOE is considered to determine the market acceptance for the MOE.

Parametric manipulation of functions and MOE was made methodically and in a manner which led to the determination of the parameters providing the greatest market acceptance and significant weight reduction. This methodology was used to establish design specifications for weight efficient trucks (which will have the maximum market acceptance) for each mission. The maximum value of the mission specified MOE were assumed as were the minimum values of the functions specified by the mission.

The number of independent functions was reduced from seven to five. First it was recognized that the GVW is the sum of the CuW and CaW. Thus, only two of these weights need be determined. Secondly, a functional relation between engine horsepower and torque was developed (by the project team from existing data on 28 LDT) so that horsepower was eliminated from the list of independent functional parameters. The equation is:

$$HP = 0.2929(\text{torque})^{1.1300} \quad \text{(coefficient of determination=0.90)} \quad (1)$$

The values of the unspecified MOE are then varied parametrically, one at a time, and the acceptability of each set of resulting MOE determined. Table 8 shows the applicable functions and MOE for each mission. The market acceptance, obtained in this manner, may be plotted against a function such as CaW. This function, CaW, may be dependent on another function such as CuW. If so, as was the case for mission 1, the second function is used to obtain several independent relationships between market acceptance and the original function (e.g., CaW). After the appropriate parameter variations have been graphed, curves are established connecting the calculated points. The optimum values of each separate curve are connected to establish a locus of optimum functional values. The analysis made for mission 1 is presented and serves to provide a more complete description of the methodology.

Mission 1 Analysis—The key MOE for mission 1 and their values, with market acceptance are:

Key MOE	MOE Value	Market Acceptance
CaV/CuW	0.027	100%*
CuW/T	11.9	96%**

Mission 1 also specifies a minimum payload of 800 lb and a minimum of two passengers, including the driver. Then, since it is desired to establish the minimum weight vehicle with the maximum market acceptance, the 100 percent acceptance value for the ratio of CaW to CuW is assumed (0.63).#

The next step in the analysis is to assume a CaV which can be used with the CaV/CuW MOE to calculate the CuW. Next the CuW is used with the CaW/CuW MOE to obtain the CaW. Then the GVW is calculated from the sum of CuW and CaW. The CuW may then be used to calculate the engine torque from the CuW/T MOE and by use of equation (1), the horsepower may be calculated. If the number of passengers is assumed as two or three, all of the functions become defined. The MOE which were not assumed may be calculated. To calculate the MOE relating total volume (the sum of cargo and passenger volumes) to CuW, the relationship that each passenger occupies 20 cu ft is required. The market acceptance of each MOE may then be determined and summed to obtain an acceptability for the specific configuration of this mission 1 (or any other mission) LDT.

In this particular example the CaW was varied and plotted with the market acceptance as the dependent variable. Three values of CaV were used in conjunction with CaW to establish the locus of optimal CaW (as a function of implied CaV). The three volumes used were 35, 50 and 75 cu ft. These values are typical of the volumes common to most all pickup trucks with GVW of 8500 lb and less. Figure 18 shows the three curves, one for each volume and the locus they establish.

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* See Figure 13
** See Figure 15
\# See Figure 14

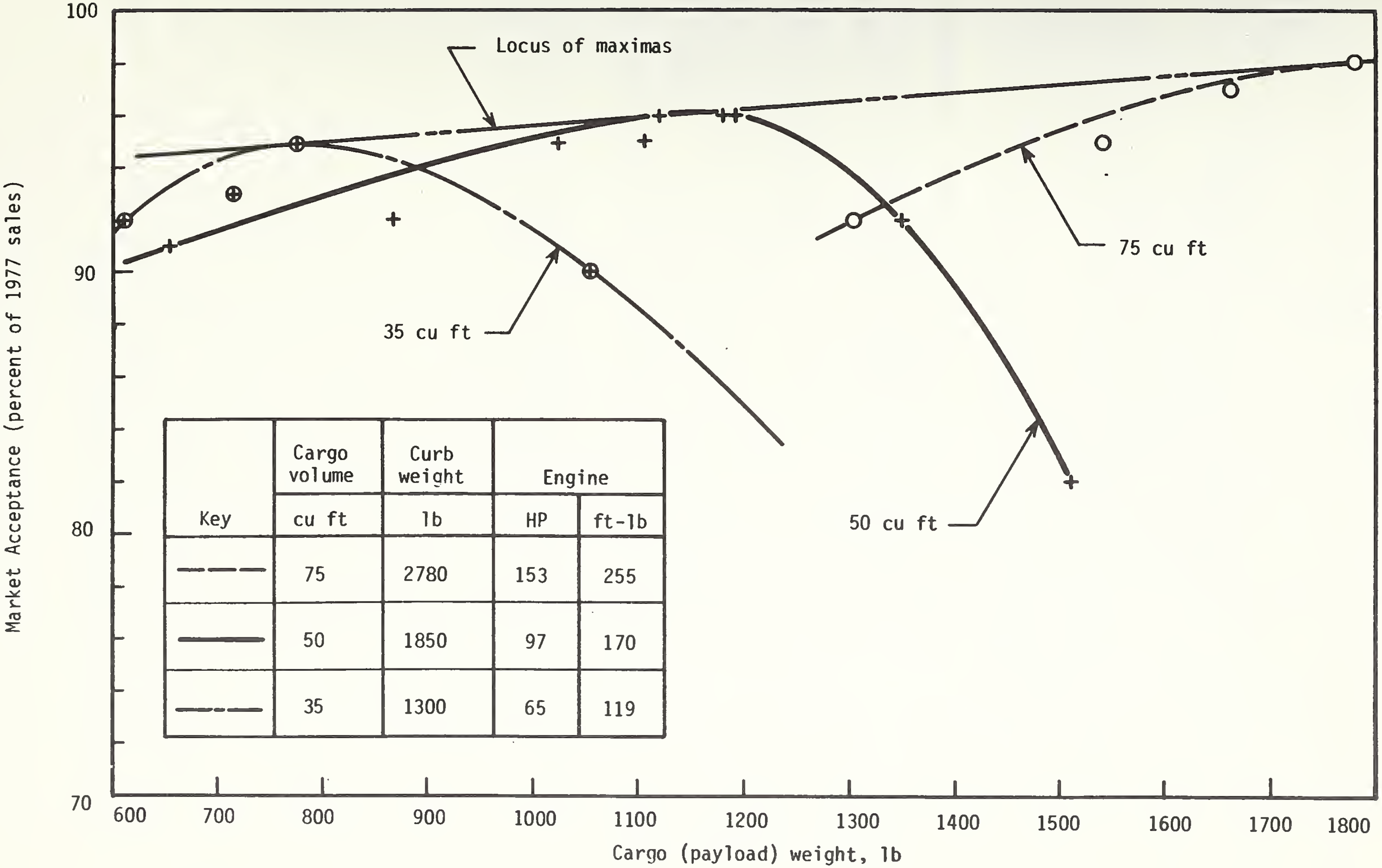


FIGURE 18. MARKET ACCEPTANCE VERSUS CARGO WEIGHT (FOR THREE CARGO VOLUMES)

The mission requirements dictate the minimum cargo box floor dimensions of 50 by 96 inches. Most 1977 U.S. built pickup trucks have cargo box depths between 19.3 and 19.5 inches. These dimensions combine to indicate that the minimum CaV should be 53 to 54 cu ft. Fifty cubic feet is representative of these values. The payload associated with this volume at maximum market acceptance is shown in Figure 18. From this figure it is seen that an 1100 lb payload, for 50 cu ft, corresponds to 95.5 percent of the market and that 1200 lb corresponds to 96.0 percent. Fortunately the market acceptance is not very sensitive to payload under these specific design conditions.

The market acceptance curves for each CaV have maximas because although the percent of the market rises with increased payload, the GVW also goes up. Then for a given engine capability the performance MOE deteriorate in terms of market acceptance. Note that the engine specified in Figure 18 corresponds to the optimized MOE and CuW relationships. Some judgment must be used to determine the maximum size engine which will be used to limit the CaV which in turn sets the maximum optimum CaW. Exhibit 8 shows the specification which was prepared in this manner for mission 1.

This same methodology was applied to missions 3, 4, 5 and 6 to prepare the other specifications for the downsized LDT. Respectively, Exhibits 9 through 12 present the remainder of the mission specifications. In all cases, the specifications provide at least 90 percent market acceptance. Table 10 summarizes the specifications prepared for each mission as well as the functions and MOE for each of the selected weight efficient American and European LDT. There was no European utility vehicle for mission 6. In all cases the specified LDT have lower CuW than the comparable U.S. vehicles. This is also true for the European trucks except in the case of mission 3. It is emphasized that the values specified for the LDT: weights, load space, and engines are derived and not engineering design values.

EXHIBIT 8

MISSION 1: TRUCK SPECIFICATION

FUNCTIONS

Cargo weight = 1160 lb
Cargo box dimensions:
  width - minimum clear space at any location = 50 inches*
  length - minimum, including distance obtained from tailgate positioned horizontally = 96 inches
  nominal minimum depth = 18 inches
Number of passengers = three (including driver)
Transmission type = three-speed automatic
Truck center of gravity with a full uniform load to be ahead of rear axle
All U.S. safety and environmental standards applying to the 1977 model year appropriate for the truck specified are to be met

MEASURES OF EFFECTIVENESS (MOE)

Curb weight/torque = 11.9 lb/(ft-lb)
Horsepower/gross vehicle weight = 0.0289 hp/lb
Cargo volume/curb weight = 0.027 cu ft/lb

NOMINAL DESIGN GOALS

Cargo volume = 50 cu ft
Curb weight = 1850 lb
Gross vehicle weight = 3010 lb
Engine:
  torque = 155 ft-lb
  horsepower = 87 hp** (SAE)
Minimum shoulder space = 64 inches

---

* 50 inches based on 48 + 2 inches to accommodate a 4 ft x 8 ft sheet of plywood in the cargo box and normally between wheel wells

** horsepower calculated by $hp = 0.2929(torque)^{1.1300}$

EXHIBIT 9

MISSION 3: TRUCK SPECIFICATION

FUNCTIONS

Cargo weight = 2100 lb
Cargo space dimensions:
  width - minimum clear space at any location = 50 inches*
  - nominal = 73.5 inches
  length - minimum, excluding distance obtained from tailgate positioned horizontally = 96 inches
  nominal minimum depth = 19.5 inches
Number of passengers = three (including driver)
Transmission type = three-speed automatic
Truck center of gravity with a full uniform load to be ahead of rear axle
All U.S. safety and environmental standards applying to the 1977 model year appropriate for the truck specified are to be met

MEASURES OF EFFECTIVENESS (MOE)

Gross weight/torque = 19.2 lb/(ft-lb)
Cargo weight/curb weight = 0.644 lb/lb

NOMINAL DESIGN GOALS

Cargo volume = 75 cu ft#
Curb weight = 3260 lb
Gross vehicle weight = 5360 lb
Engine:
  torque = 279 ft-lb
  horsepower = 170 hp** (SAE)
  minimum shoulder space = 64 inches

---

* 50 inches based on 48 + 2 inches to accommodate a 4 ft by 8 ft sheet of plywood in the cargo box and normally between wheel wells

** horsepower calculated by $hp = 0.2929(torque)^{1.1300}$

cargo box volume loss due to wheel wells approximately 5.3 cu ft

EXHIBIT 10

MISSION 4: TRUCK SPECIFICATION

FUNCTIONS

Cargo weight = 1780 lb
Cargo space dimensions:
  width - minimum clear space at any location = 50 inches*
        - nominal = 68 inches
  length - minimum, behind seats = 55 inches
  nominal height = 50 inches
Number of passengers = five (including driver)
Transmission type = three-speed automatic
Truck center of gravity with a full uniform load to be ahead of rear axle
All U.S. safety and environment standards applying to the 1977 model year appropriate for the truck specified are to be met

MEASURES OF EFFECTIVENESS (MOE)

Curb weight/torque = 12.8 lb/(ft-lb)
(Passenger volume + cargo volume)/curb weight = 0.0694 cu ft/lb

NOMINAL DESIGN GOALS

Cargo volume = 108 cu ft
Curb weight = 3000 lb
Gross vehicle weight = 4780 lb
Engine:
  torque = 234 ft-lb
  horsepower = 139 hp** (SAE)
  minimum shoulder space = 64 inches

---

* 50 inches based on 48 + 2 inches to accommodate a 4 ft by 8 ft sheet of plywood in the cargo box and normally between wheel wells

** horsepower calculated by $hp = 0.2929(\text{torque})^{1.1300}$

EXHIBIT 11

MISSION 5: TRUCK SPECIFICATION

FUNCTIONS

Cargo weight = 2300 lb
Cargo volume = 215 cu ft
Cargo space dimensions:
- width - minimum clear space at any location = 50 inches*
  - nominal = 68 inches
- length - minimum = 114 inches
- nominal height = 48 inches

Number of passengers = one (including driver)
Transmission type = three-speed automatic
Truck center of gravity with a full uniform load to be ahead of rear axle
All U.S. safety and environmental standards applying to the 1977 model year appropriate for the truck specified are to be met

MEASURES OF EFFECTIVENESS (MOE)

Curb weight/torque = 12.5 lb/(ft-lb)
Cargo volume/curb weight = 0.0716 cu ft/lb

NOMINAL DESIGN GOALS

Curb weight = 3000 lb
Gross vehicle weight = 5300 lb
Engine:
- torque = 240 ft-lb
- horsepower = 143 hp** (SAE)
- minimum shoulder space = 64 inches

---

* 50 inches based on 48 + 2 inches to accommodate a 4 ft by 8 ft sheet of plywood in the cargo box and normally between wheel wells

** horsepower calculated by $hp = 0.2929(torque)^{1.1300}$

EXHIBIT 12

MISSION 6: TRUCK SPECIFICATION

FUNCTIONS

Cargo weight = 800 lb
Number of passengers = two (including driver)
Transmission type = three-speed automatic
Truck center of gravity with a full uniform load to be ahead of rear axle
All U.S. safety and environmental standards applying to the 1977 model year appropriate for the truck specified are to be met

MEASURES OF EFFECTIVENESS (MOE)

Curb weight/torque = 12.0 lb/(ft-lb)
Horsepower/gross vehicle weight = 0.0296 hp/lb

NOMINAL DESIGN GOALS

Cargo volume = 80 cu ft
Curb weight = 1480 lb
Gross vehicle weight = 2280 lb
Engine:
- torque = 123 ft-lb
- horsepower = 67 hp* (SAE)
- minimum shoulder space = 64 inches

---

* horsepower calculated by $hp = 0.2929(\text{torque})^{1.1300}$

TABLE 10. -SUMMARY OF WEIGHT EFFICIENT AMERICAN, EUROPEAN, AND SPECIFIED LTD CHARACTERISTICS

Item / Mission	1 Personal Use Pickup			3 Construction Use Pickup			4 Personal Use Van			5 Wholesale/Retail Van			6 Utility		
LDT Designation	US[b] WE	EUR[c] WE	SPEC[d]	US WE	EUR WE	SPEC	US WE	EUR WE	SPEC	US WE	EUR WE	SPEC	US WE	EUR WE	SPEC
Manufacturer	Ford	Fiat	NA[e]	Dodge	Daimler Benz	NA	Dodge	VW	NA	Dodge	Bedford	NA	GM	NS[g]	NA
Model	F100	238	DS[f]	D200	307DT	DS	B100	LT20	DS	B200	CF280	DS	K10	NS	DS
WEIGHT:															
Curb, CuW	3606	2690	1850	4146	3108	3260	3770	3637	3000	3615	3110	3000	3406	NS	2253
Cargo, CaW	1094	2359	1160	3954	4608	2100	1030	2536	1780	2485	3130	2300	1894	NS	1200
Gross, GVW	4700	5048	3010	8100	7716	5360	4800	6173	4780	6100	6240	5300	6200	NS	3453
LOADSPACE:															
Volume, CaV (cu ft)	76.8	122	50	75.8	124	75	116	286	108	239	317	215	93	NS	80
Length, (in.)	98	108	96	98	110	96	56	120	55	117	119.5	114	66	NS	NS
Width, (in.)	70	65	64	70	75	74	68	71	68	68	75.8	68	64	NS	NS
Height, (in.)	19	30	18	19	26	19	53	58	50	48	60.6	48	37	NS	NS
ENGINE:															
CID (cu in.)	302	88	NA	400	97	NA	318	121	NA	318	139	NS	350	NS	NA
Horsepower, hp	136	52	87	170	64	170	150	76	139	150	80.5	143	165	NS	114
Torque, T (ft-lb)	245	77.4	155	300	101	279	255	108	234	255	124	240	255	NS	196
NO. PASSENGERS, NP	3	3	3	3	3	3	5	2	5	1	3	1	2	3	2
MEASURES OF EFFECTIVENESS (MOE):															
GVW/T	19.2	65.2	19.4	27.0	76.4	19.2	18.8	57.2	20.4	23.9	50.3	22.1	24.3	NS	17.6
CuW/T	14.7	34.8	11.9	13.8	30.8	11.7	14.8	32.7	12.8	14.2	25.1	12.5	16.9	NS	11.5
CaW/CuW	0.303	0.877	0.627	0.954	1.482	0.644	0.273	0.673	0.594	0.687	1.006	0.766	0.694	NS	0.533
CaV/CuW	0.0213	0.0451	0.0270	0.0183	0.0220	0.0230	0.0308	0.0786	0.0360	0.0661	0.1019	0.0720	0.0216	NS	NA
NP/CuW	0.00083	0.00111	0.00160	0.00072	0.00096	0.00090	0.00133	0.0005	0.00170	0.00028	0.00032	0.00030	0.00046	NS	0.00089
TV/CuW[a]	0.0379	0.0677	0.0590	0.0328	0.0592	0.0410	0.0573	0.0896	0.0690	0.0716	0.1084	0.0780	0.0309	NS	NA
HP/GVW	0.0289	0.0101	0.0290	0.0209	0.0082	0.0320	0.0313	0.0123	0.0290	0.0245	0.0129	0.0270	0.0266	NS	0.0330

[a] TV = Total Volume (cu ft) = (20)(NP) + (CaV); [b] US = United States Fleet; WE = Weight Efficient; [c] EUR = European Fleet; [d] SPEC = Specified LDT; [e] NA = Not Applicable; [f] DS = Downsized; [g] NS = Not Specified

3. INDUSTRY ASSESSMENT OF WEIGHT EFFICIENCY TECHNOLOGY

In response to the mandated fuel economy levels that must be achieved by the automobile and LDT fleet, each of the major domestic manufacturers is aggressively pursuing improved weight efficient vehicles. The manufacturers have indicated that their new vehicle fleet will in fact achieve these federally mandated standards. Therefore, research, development, and design activities for improving vehicle efficiency are currently on-going in each of the companies. In order to assess the technology issues confronting weight efficiency, IITRI and Fiat visited each of the major manufacturers engaged in LDT production.

In the following sections an assessment of the industry's position on improved weight efficiency is presented. The United States position is one of having to achieve mandated fuel efficiency and thereby weight efficiency levels. The European position is one of having to achieve improved weight efficiency on a cost conscious basis as well as from an improved fuel efficiency standpoint.

3.1 DOMESTIC INDUSTRY ASSESSMENT

Meetings were held with the Ford Motor Company, Chrysler Corporation, and General Motors Corporation to discuss the existing and projected technology trends in improved weight efficient LDT. The foremost issue that was raised by each of the manufacturers when presented with the problem of how to improve weight efficiency, was how much is the consumer willing to pay for weight reduction. Each of the manufacturers expects a high level of expenditure for new tooling and introduction of advanced lightweight materials into its vehicle fleet. These major investments must be passed on to the consumer, therefore, it is strictly a market decision as to what level of weight reduction is technologically achievable.

Although each of the manufacturers are engaged in independent weight reduction studies for each of their vehicle lines, overall trends were quite consistent from one manufacturer to another. The initial attempt at improved weight efficiency consists of significant downsizing or "shrinking" the skin of the current vehicles as much as possible to surround the existing cargo and passenger compartments. Additional weight reduction is being achieved through the use of thinner gauge steels and less convoluted or reduced surface area design. These techniques will result in approximately a 7 to 10 percent weight reduction from existing LDT weights.

The current industry philosophy concerning design of the LDT is to develop a vehicle design to the "worst case" or most strenuous mission requirement for the entire LDT vehicle line. This means that the vehicle chassis and frame as well as most of the running gear, are designed for the maximum GVW configuration occurring within that line of vehicles. This approach will yield a less than optimum weight efficiency for any vehicle other than the maximum GVW design. Additionally, the consideration of designing and developing new running gear and suspension components specifically for LDT vehicles is one of high cost impact. Considerable component commonality is designed into the LDT fleet from the manufacturer automotive line. Therefore if the automotive fleet has a high level of weight efficiency, the manufacturer's LDT fleet may also.

In general, all of the manufacturers are aggressively pursuing weight reduction programs. All of these programs must, by necessity, be conducted within the technology constraints presented to a single manufacturer. Certain techniques that may seem desirable for one manufacturer may, in no way, be achievable by another. Therefore it was necessary to be quite conservative in identifying material applications that could be applied across the entire industrywide vehicle fleet to improve weight efficiency.

Of each of the manufacturers, Chrysler Corporation tended to be more concerned in previous vehicle designs with weight efficiency, not necessarily because of fuel economy considerations, but most significantly from cost considerations. It was evident that the monocoque design of Chrysler vans was introduced as a cost cutting technique to allow them to compete more effectively with the other manufacturers. The precedent is established for reduced cost vehicles through reduced weight or improved weight efficiency vehicles.

Each of the manufacturers was quite conservative about the ability to downsize the cargo and passenger capacities of the vehicles below current fleet levels. Each of the manufacturers has established market experience with these classes of vehicles. Therefore they are quite hesitant to undertake a downsizing program which may adversely impact their marketability. Specifically, the vehicle downsizing is primarily in terms of exterior sheet metal. Indications are that the next generation downsized cargo and passenger capacity vehicles are in the final stages of design and development within each of the manufacturing companies. Initially it would seem that these vehicles are designed to augment the current model lines before eventually replacing a major market share. The existing vehicle dimensions have evolved over an extensive period of time and no single manufacturer is likely to develop a new line of vehicles which cannot take advantage of various after-market add-ons such as slide-in camper bodies. The industry is as concerned with the requirements of the specialty vehicle manufacturers who utilize LDT chassis for special purpose vehicles as with the direct consumer market.

3.2 EUROPEAN INDUSTRY ASSESSMENT

Structures—European companies normally design a complete class of vehicles as a way of minimizing costs. The two different possibilities in designing a class of vehicles are with a body and frame design, or with a monocoque structure. The choice depends primarily on industry tradition. Mechanical component solutions follow the manufacturer car solutions for light trucks, and for heavy trucks a more independent traditional solution.

New design trends are taking into account aerodynamic and weight problems. Current technologies for LDT production utilize car technology where possible for large production and new materials like plastics for nonstructural components to reduce costs and weight.

In Europe manufacturers normally design a class of LDT to minimize both weight and production costs. This method of designing was initiated a few years ago when industries began large-scale production in LDT adopting automotive procedures. When Daimler-Benz and Fiat design a new special LDT, they now consider all the other vehicles that will be derived from the base vehicle. The result of this design technique is a complete line that has been optimized to reduce the production costs.

The two primary methods of designing an LDT are the traditional solution coming from the large truck with chassis, cargo box, and cab, and the alternative solution coming from the car production system with monocoque structure. Most companies are now using the latter European or automotive design solution. Monocoque structures are less adaptive and for this reason industries must design a complete class of vehicle rather than individually. In order to reduce production costs the trend is to design components common to many parts of the vehicle. For instance, right side panel equal to the left one; right and left doors; roof panel and structural channels used for both van and pickup versions.

European industry designs LDT starting from car production experience. The mechanical components of LDTs such as engines, transmissions, drivetrains, steering and brake systems, and suspensions, are normally derived from car production lines. The subsystems adopted are usually designed using automotive components because of their low costs. Now LDT manufacturers are designing their vehicles considering aerodynamic problems. The new Fiat Daily is an LDT vehicle that has been designed to reduce vehicle weight taking into account the aerodynamic problems. In fact, a more aerodynamically efficient vehicle needs less power to achieve the same performance level, and less power means lighter engines and drivetrain, lighter suspensions, and lighter vehicles.

Moreover, industry is now taking into account the vehicle weight to reduce fuel consumption. Production goals are low production costs and weight reduction is achieved when the vehicle is so designed. The technologies now used in LDT production are very close to the automotive production technologies because of the increasing levels of LDT production. The production lines are now similar to those of cars using spot welding machines. Plastic materials are more frequently used in nonstructural components, inner parts of doors, and movable panels. The use of plastic material provides for low production costs.

Materials Used in Production to Reduce Weight—Aluminum is used in mechanical components and the vehicle body. Normally aluminum is used to reduce engine weight when necessary, i.e., inlet manifold, block, oil pan, and radiator. Aluminum is also used for the side wall of pickups. If it is to be used for the frame or wheels, the cost will be higher. The application of aluminum in structural elements creates the problem of joining or bonding adjacent panels; here also aluminum is more costly than steel.

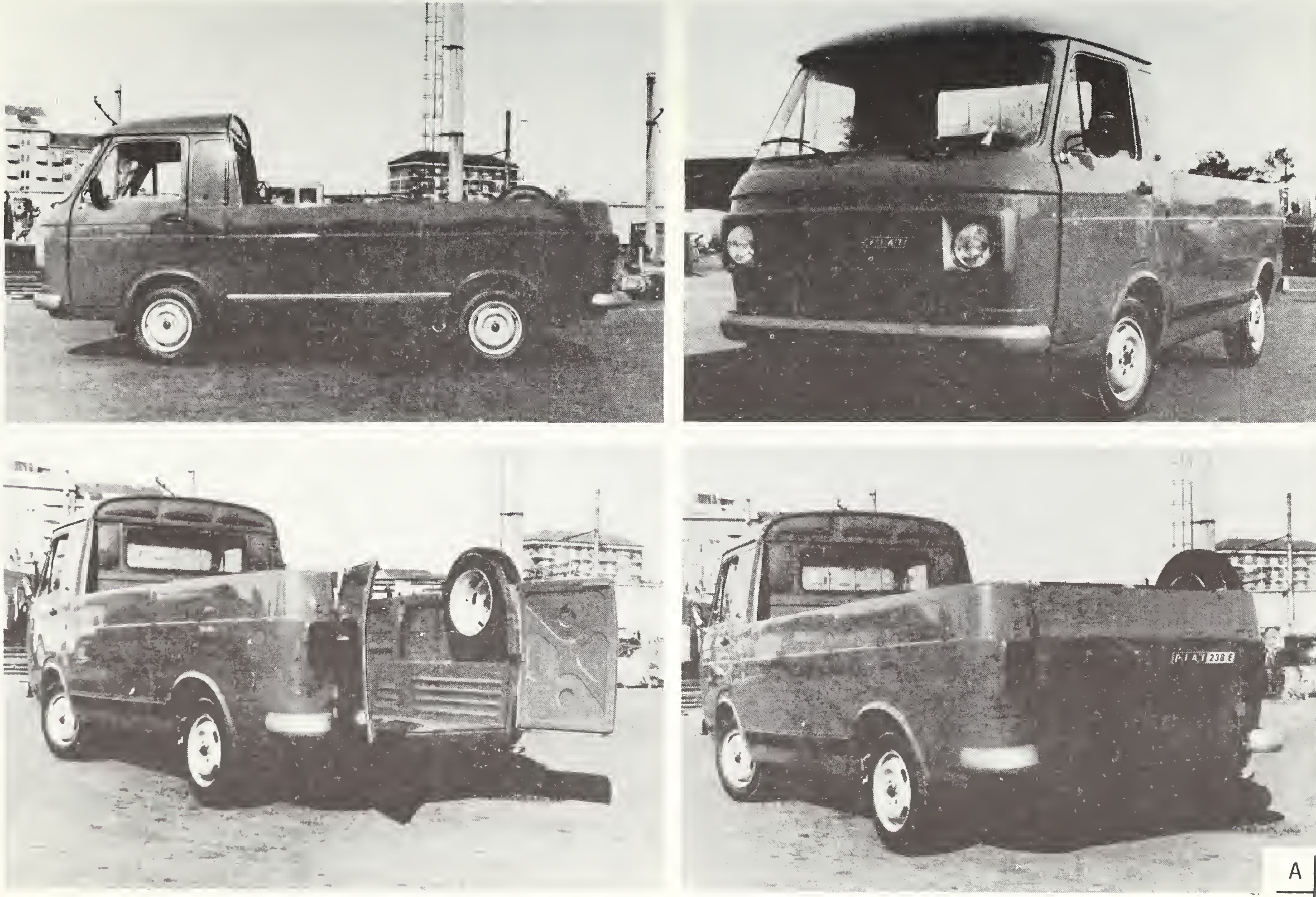
Plastic materials are not commonly used in structural elements, but only in components like instrument panels, inside parts and components of the vehicle bumpers, movable panels and cabs for large trucks. Only the bumpers may be considered close to a structural element and now they are designed in a composite (plastic and steel). Some solutions have been tried for the movable panels like hood or doors that do not have structural functions. In large trucks some plastic cabs (composite short fiber) have been tried in production. Research is being done at Fiat to study the composite application; some solutions have been studied and some prototypes built of a leaf spring and of a transmission shaft. Composite applications in series production need newer production technologies.

High strength low alloy (HSLA) steel is not normally used to save weight but to alleviate technical problems that cannot be solved with common steel (design or strength problems). The difficulties in using thin common steel sheet make the HSLA solution more commonly used in production.

Production Problems—The most important problem is the cost of raw materials coupled with prime costs. Manufacturing problems are linked to the material and the technologies used. For instance, spot welding machines cannot normally be used in assembling aluminum components. Painting problems also arise when using aluminum. European industry is now using the same production methods for LDT as those used in producing cars.

3.3 EUROPEAN LDT DESIGN REVIEW

To characterize the design philosophy embodied in European designed vehicles, we present in the following figures, two selected European weight efficient LDT. The first vehicle is a Fiat 238 pickup truck and the second vehicle is a Mercedes-Benz 207D panel van. Figure 19 provides general views of the Fiat 238 pickup truck design. This specific vehicle has a design that originated approximately 12 years ago. The vehicle is front engine front-wheel drive, powered by an in-line water cooled four-cylinder engine. The engine is mounted underneath the driver's seat. The cargo area is a very long open area with high boxed sides. Figure 20 indicates interior structure details of the cargo box design. It should be noted that this vehicle is a semimonocoque construction with a supplemental frame incorporated into the cargo bed. Therefore the sheet metal sides on the cargo box are stressed members for the vehicle. It was evident in this photograph that the box has only an exterior sheet metal skin with interior stringers to provide structural support. Due to the interior length of the cargo box, the rear doors swing out horizontally. Figure 21 indicates the chassis detail underneath the pickup truck. In Figure 21a it is evident the supplemental frame structure provided under the cargo box to provide localized



A | B
C | D

FIGURE 19. FIAT 238 PICKUP LDT

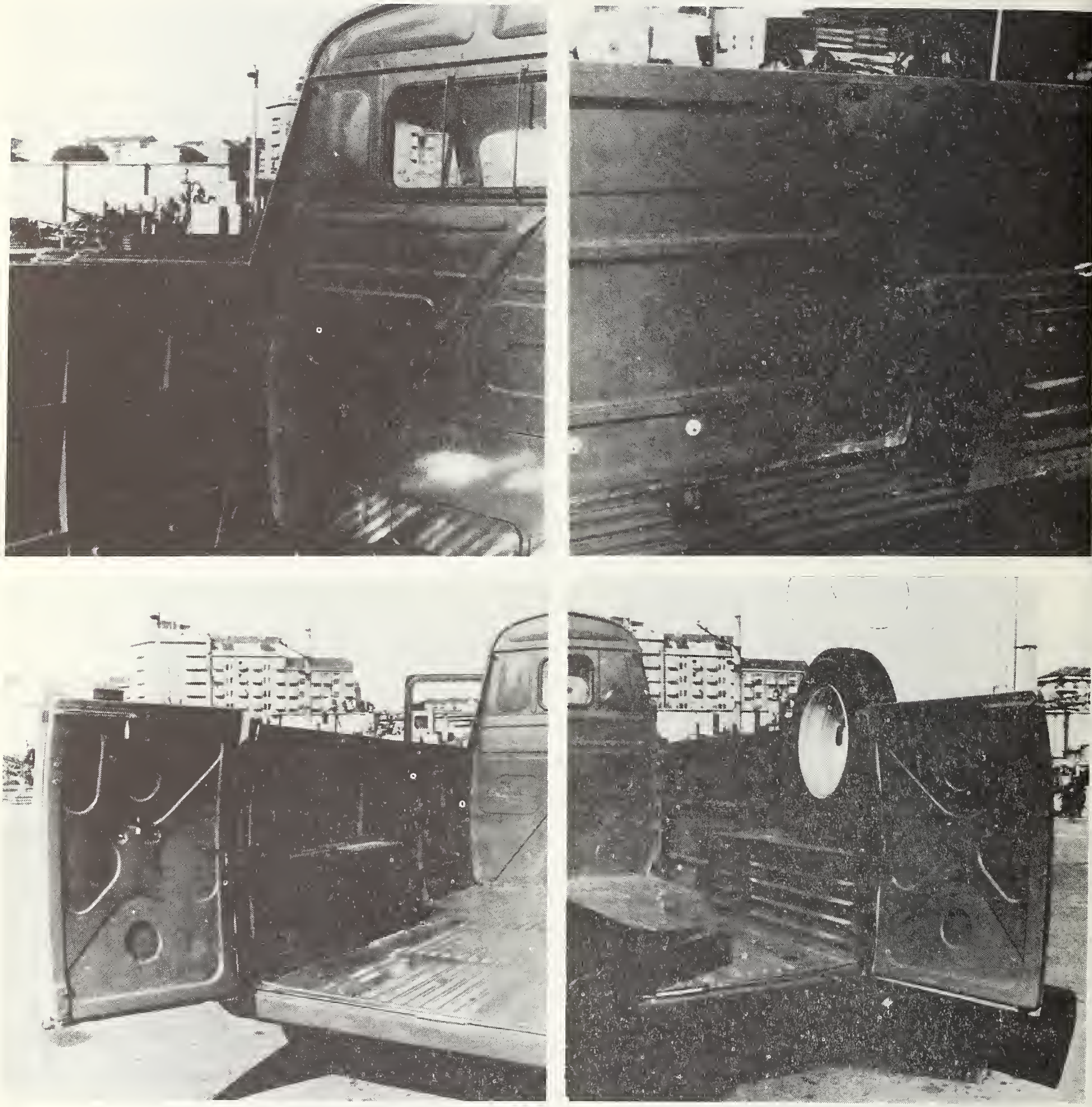


FIGURE 20. FIAT 238 DESIGN DETAIL

A | B
C | D

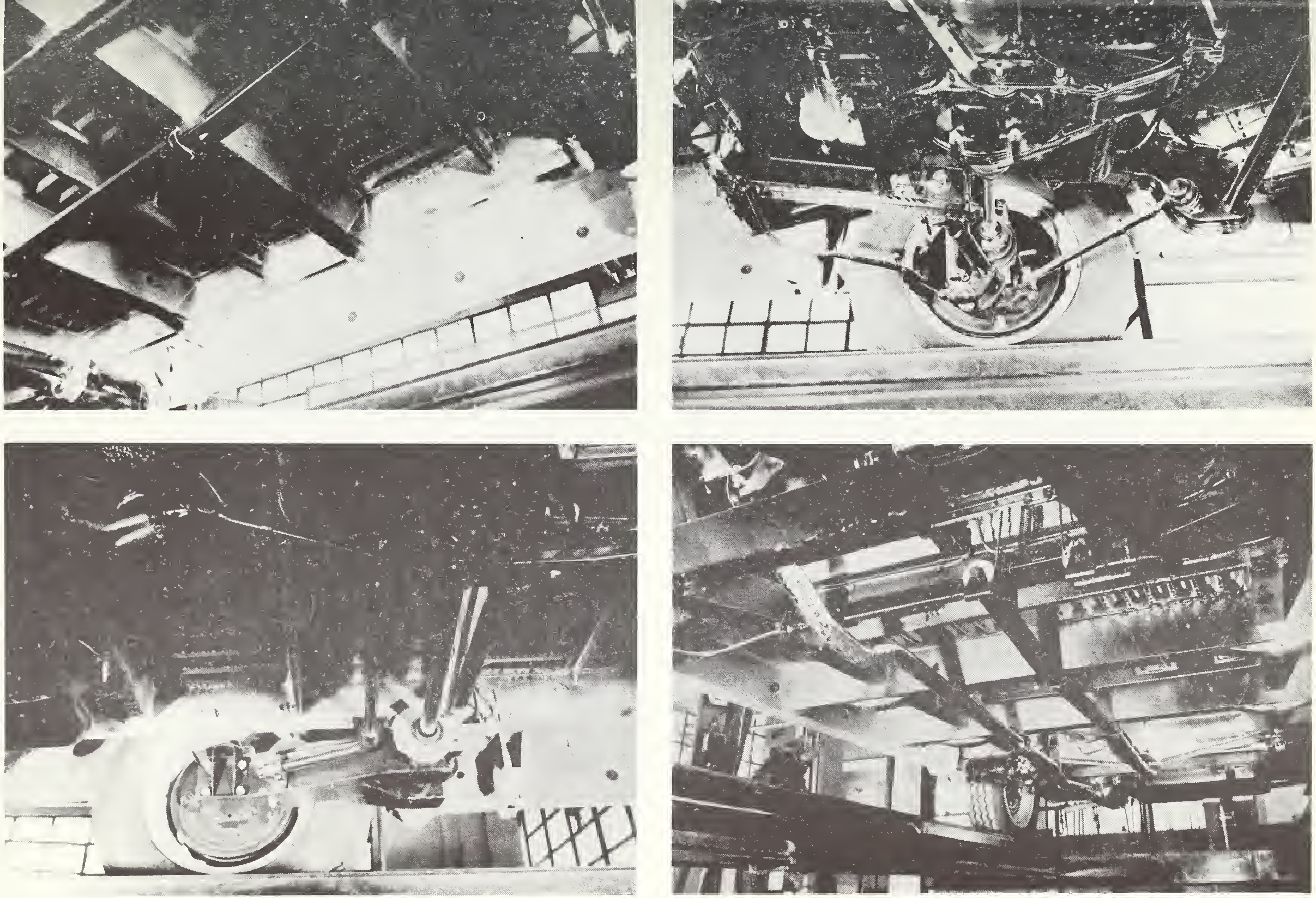


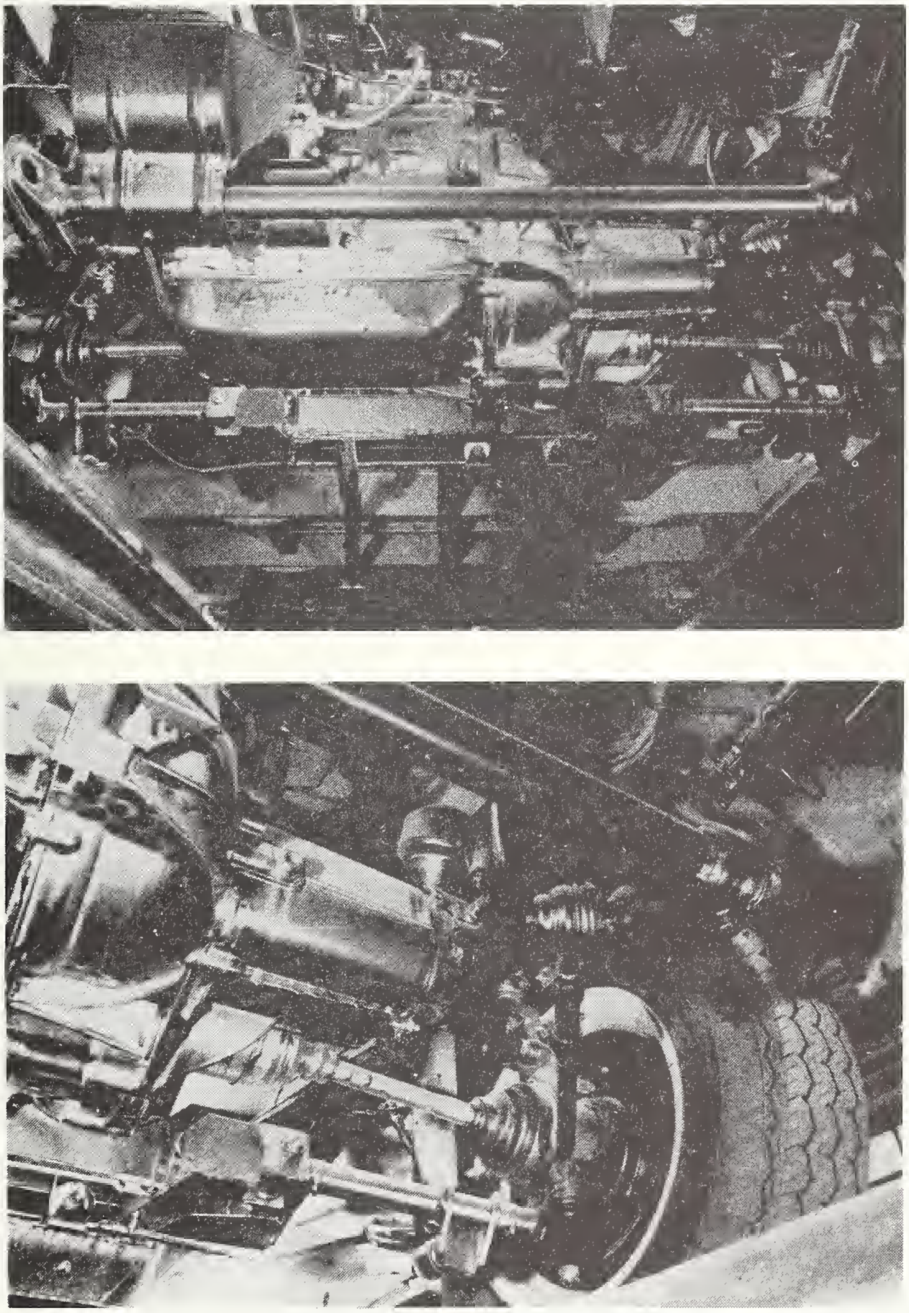
FIGURE 21. FIAT 238 CHASSIS DETAIL

A | B
C | D

stiffening for the monocoque structure. Figure 21b provides a general view of the front wheel drive suspension layout. The design detail for the trailing arm, torsion bar rear suspension is shown in Figure 21c. Figure 22 gives detailed design on the drivetrain and suspension layout for this configuration. The engine is mounted in a subframe carrier and then bolted into the vehicle along with all of the front suspension takeoff points. Therefore the entire front substructure provides an integrated structure.

The following figures show design details for a typical European panel van. The general vehicle layout for the Mercedes-Benz 207D is shown in Figure 23. Details of the side door and interior panels are indicated in Figure 24. In Figure 25 the front end design detail is shown. All of the front end sheet metal is bolted on and is quickly replaceable to increase the collision repair of this vehicle. Control layout and the forward passenger position are integrated into the forward cab structure. The Mercedes-Benz interior panel detail shown in Figure 26 indicates the single exterior skin with internal stringer bracing for structural integrity. The chassis details for the Mercedes-Benz 207D are presented in Figure 27. The vehicle drivetrain layout is front engine rear wheel drive, typical of U.S. LDT. However, specific note should be made of the front suspension details indicated in Figure 27d. This detail indicates the unique design of a two-element leaf spring used in the vehicle. Specific design features to be highlighted are:

- All exterior side panels are symmetric in each version from side to side. Therefore they are completely interchangeable.
- The roof section is composed of a stressed roof section with the number of sections determining the length for each version of the vehicle.
- The cross section of the roof has a unique shape to allow a uniform height in all parts of the interior cargo area.



A
—
B

FIGURE 22. FIAT 238 DRIVETRAIN DETAIL

FIGURE 23. MERCEDES-BENZ 207D VAN

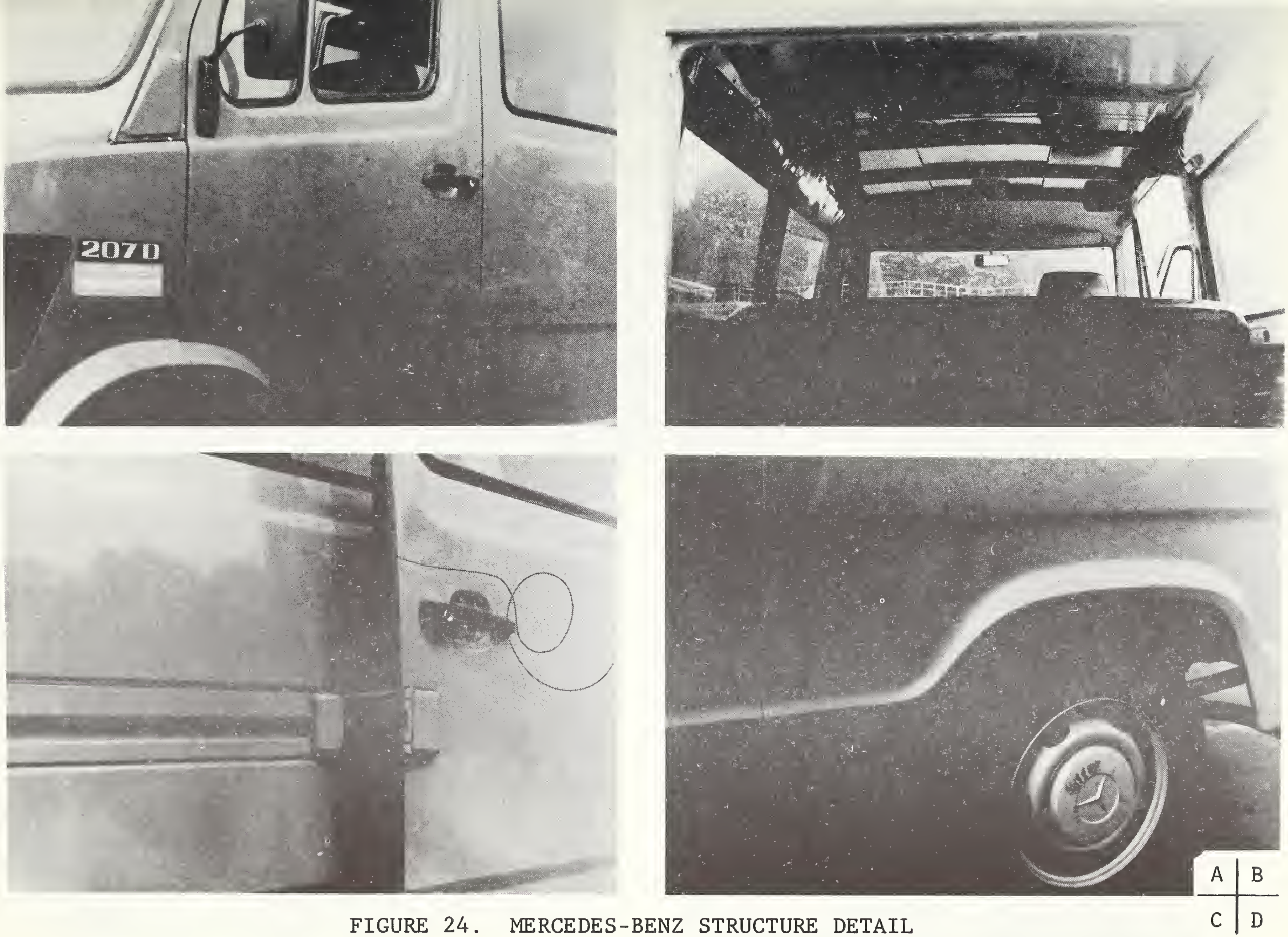


FIGURE 24. MERCEDES-BENZ STRUCTURE DETAIL

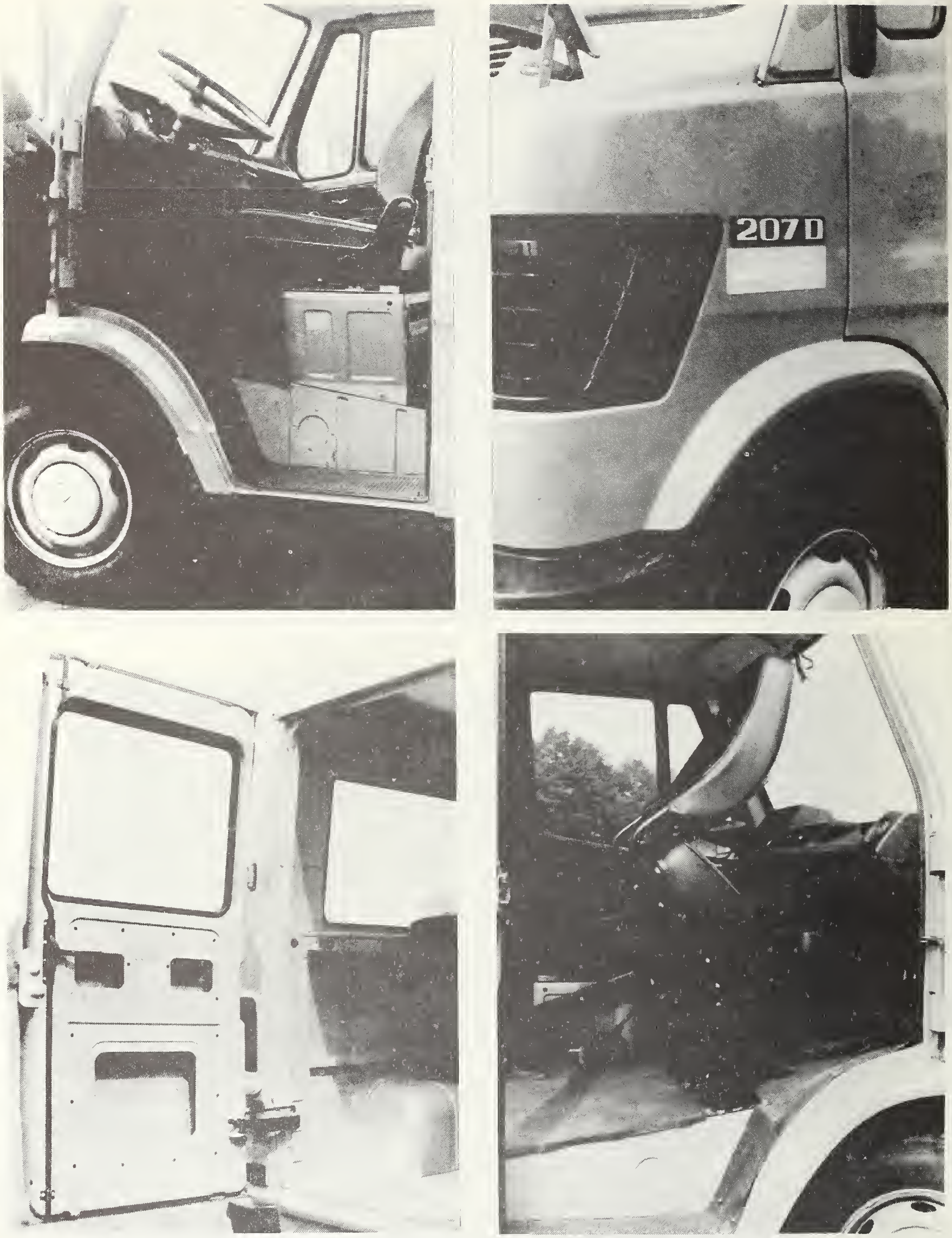


FIGURE 25. MERCEDES-BENZ DESIGN DETAIL

A | B
C | D

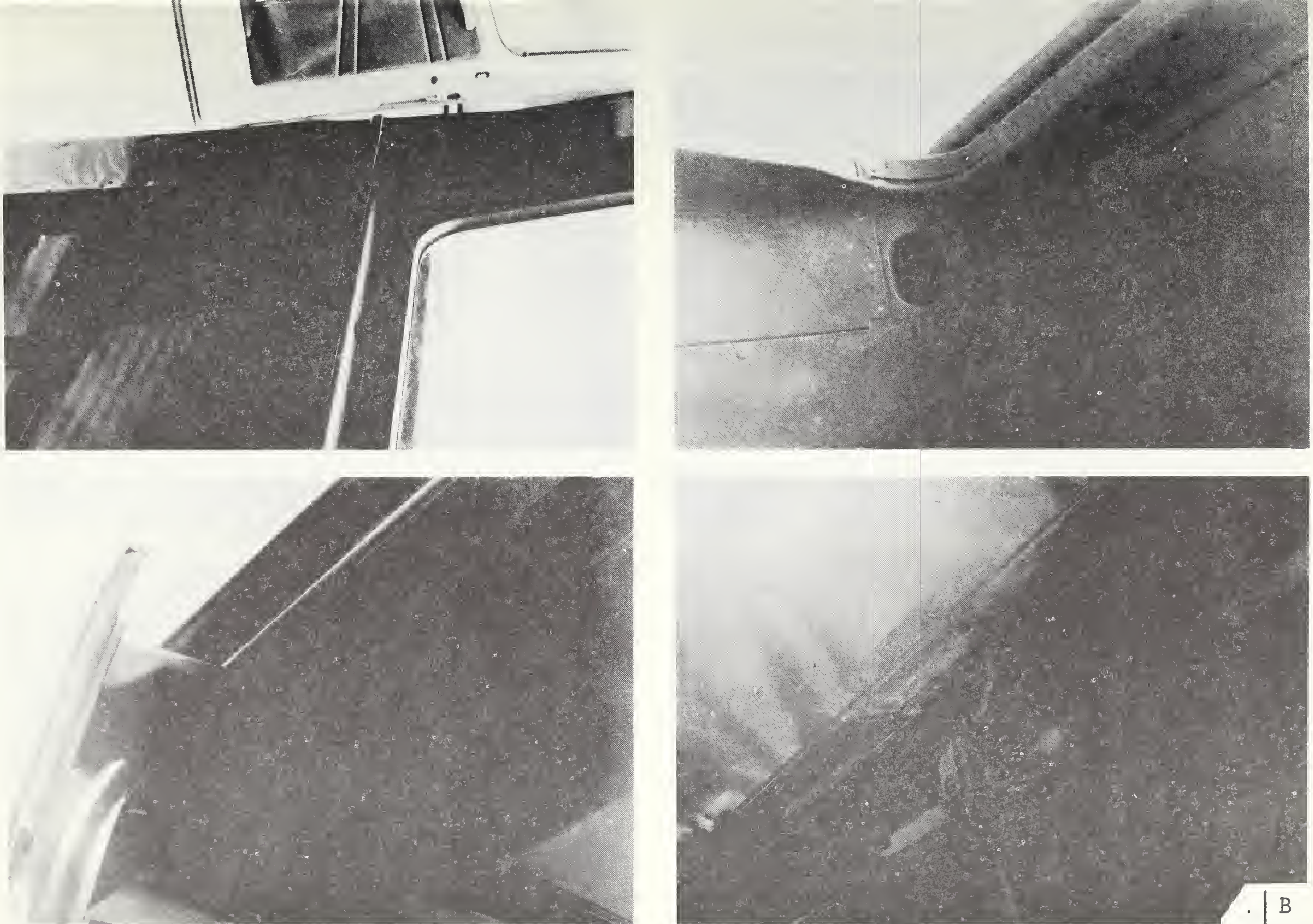
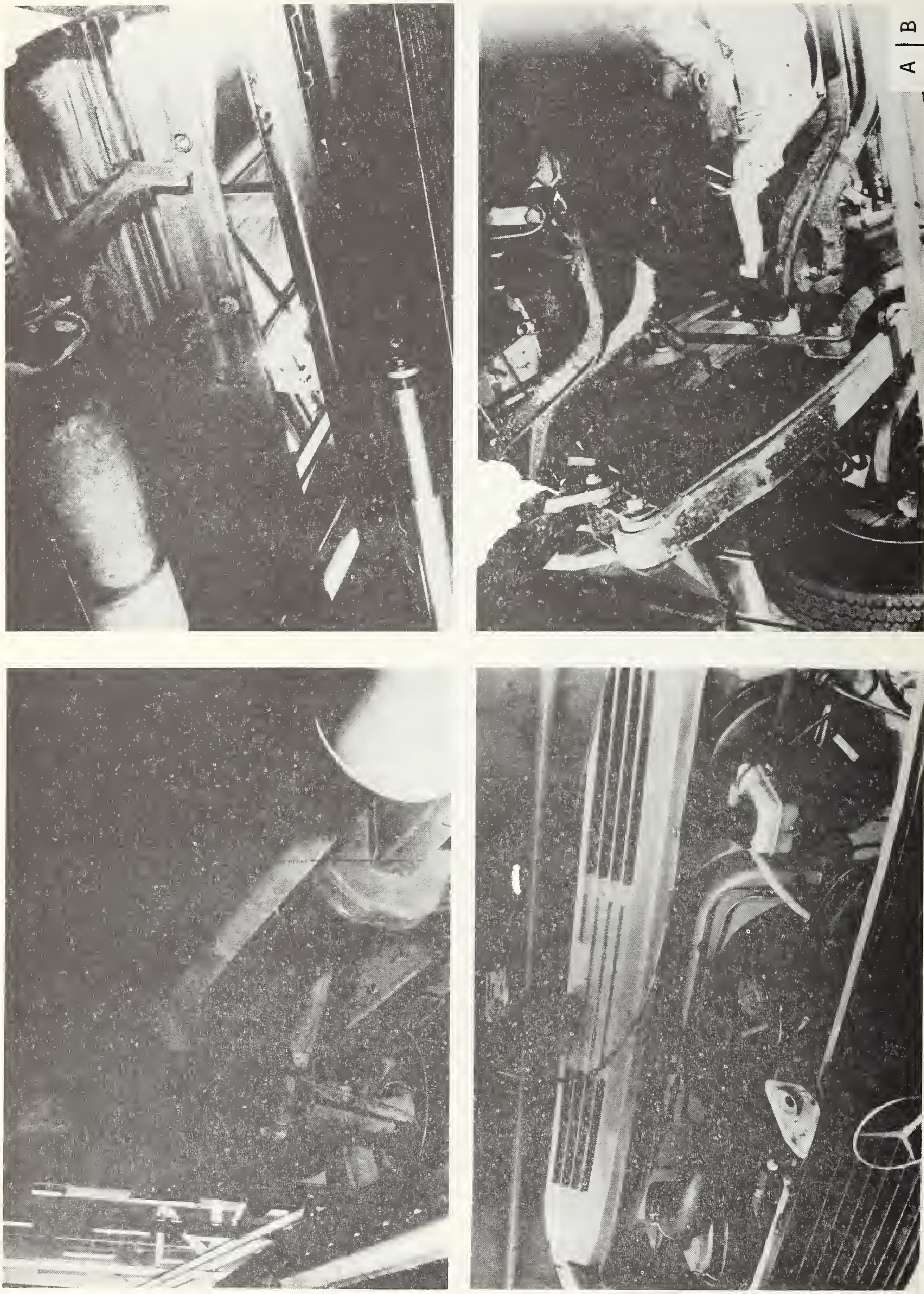


FIGURE 26. MERCEDES-BENZ PANEL DETAIL



A | B
C | D

FIGURE 27. MERCEDES-BENZ CHASSIS DETAIL

- The interior width between the rear wheels is greater than other vehicles in this weight class due to the use of a special size 14 inch single tire instead of traditional dual tires.
- The body support for the van is composed of an inverted channel structure (hat section) closed by the floor. The front suspension leaf spring is of a special design with two noncontacting leaves with double wound-eyes to increase vehicle reliability.

Initial barrier crash tests performed with the Daimler-Benz vehicle at 30 mph indicated that the vehicle structure is capable of achieving current U.S. safety standards.

4. DESIGN WEIGHT REDUCTION

The reduction of LDT weight through design proceeded on a multistep path. The initial step was to select a weight efficient American vehicle and its European counterpart. Although European LDT do not provide sufficiently large engines to satisfy the U.S. market, the other vehicle systems provided an initial significant design weight reduction. Section 4.1 presents the subsequent steps taken in this design weight optimization. European vehicle design is presented in Section 4.2. A description of European LDT and a comparison to American LDT are also provided. The final presentation, Section 4.3, provides specific design weight reductions. The specific designs dealt with are the Ford F100 and the Fiat 238 pickup trucks. The design effort required substitution of a larger engine and appropriate related systems to provide the projected market acceptance for engine related MOE. The payload of the Fiat 238 is larger than required by the specification for mission 1, the personal use pickup truck. Thus the cargo box was downsized.

4.1 DESIGN OPTIMIZATION

The underlying design weight reduction philosophy was that the totality of production technology is available to all manufacturers. While it is apparent, that today, no one manufacturer may utilize this total technology, it can be expected that this utilization will be achieved as time and capital become available and each manufacturer implements the new design elements. As indicated, for all missions except that of the utility vehicle, American and European LDT were identified which are suitable for each mission. There is no comparable European LDT for the personal use utility vehicle. In general, the European LDT had smaller engines and more payload capacity than their U.S. counterparts. However, this first step in the design weight reduction was significant.

The potential of U.S. manufacturers to design weight efficient vehicles was assessed from the range of production vehicles currently manufactured. This potential is predicted by means of equation (2).

$$\text{cargo weight} = 8.2875(10^{-13})\ (\text{curb weight})^{4.3475},\ \text{lb} \qquad (2)$$

for: nine data points with the coefficient of determination of $r^2 = 0.9168$

A similar relationship was determined for the European pickup trucks. These weights could be achieved with current design practices, production methods and materials. Equation (3) presents this relationship:

$$\text{cargo weight} = 0.0305\ (\text{curb weight})^{1.4363} \qquad (3)$$

for: 18 data points and with a coefficient of determination of $r^2 = 0.8985$

These relationships indicated that U.S. designs have lower ratios of cargo weight and curb weight up to a curb weight of 4260 lb. At this weight, both designs (American and European) will have the same cargo weight, 4980 lb. At larger curb weights, U.S. designs would be expected to be more weight efficient (see Figure 28). According to these predictions, a mission 1 pickup truck with a cargo weight of 1160 lb would have a curb weight of 3047 lb with a U.S. design and a curb weight of 1545 lb for a European design. Thus, it is believed that a significant weight reduction can be achieved through application of European design philosophy at low cargo weights. The potential demonstrated by equations (2) and (3), coupled with material substitution and advanced design assures achieving the program goals of weight reduction.

The next step in the design optimization was to reduce the cargo space and substitute a more powerful engine. Depending upon the mission, the steering, the propulsion shaft, driving axles, and cooling system had to be reconfigured to be compatible with the larger engine. In almost all cases, due to buyer preference, the manual transmission had to be replaced with an automatic transmission to meet the specifications established to maintain market acceptance.

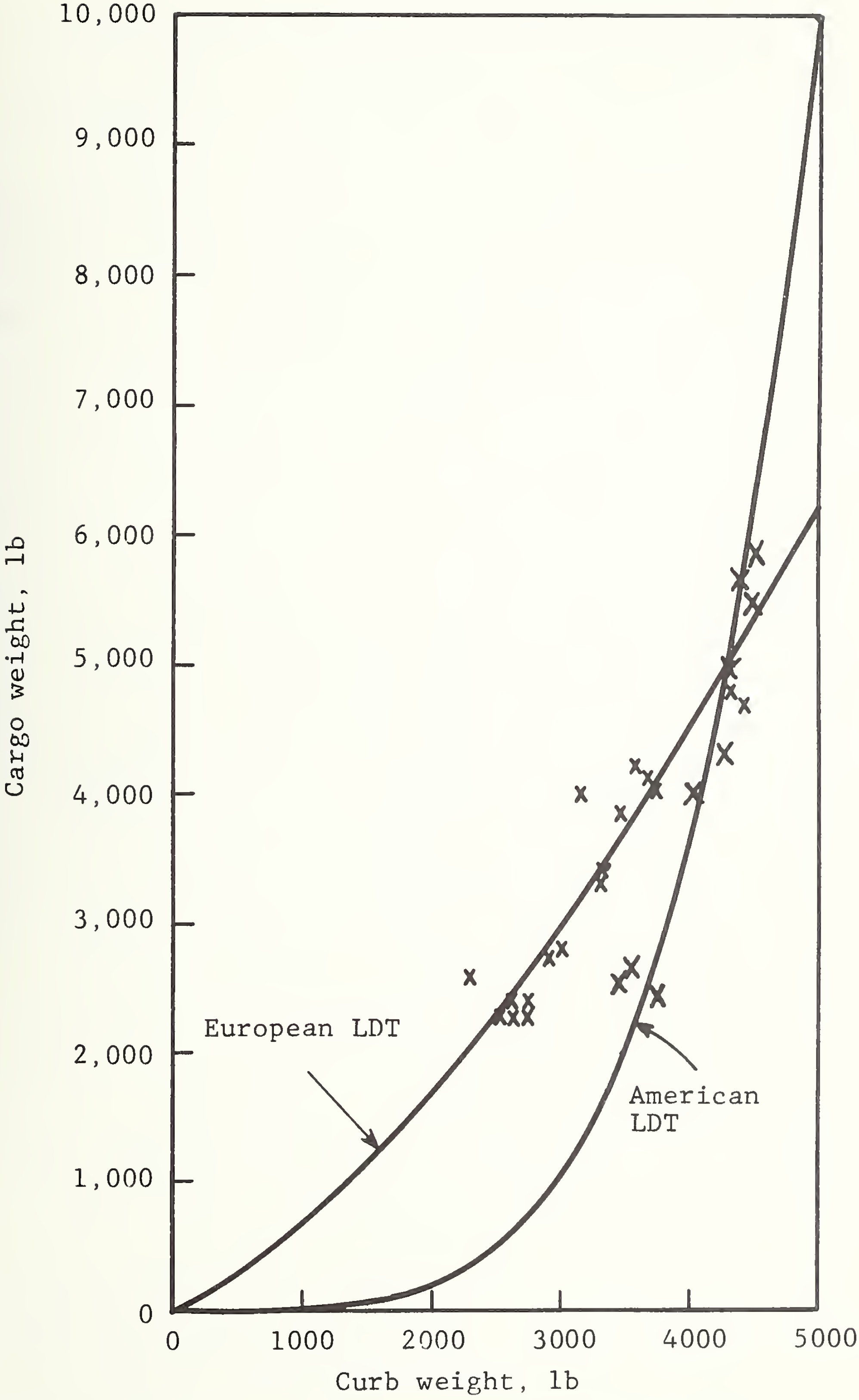


FIGURE 28. CARGO WEIGHT VERSUS CURB WEIGHT FOR EUROPEAN AND AMERICAN LDT PICKUP TRUCKS (LEAST MEAN SQUARE FIT TO DATA)

The most weight efficient designs result from an approach which develops an individual LDT design for each vehicle use. However this design philosophy results in the most expensive solution for weight reduction. Production volume leads to reduced costs so that a design philosophy which utilized commonality of system, subsystem and component designs can achieve reduced costs due to the development of a large base production rate. This modular approach in design does not provide the minimum weight solution, but is most often followed by the manufacturers to remain competitive in the marketplace. The methodology utilized was to have all of the vehicles specified for the various missions stem from a base design that could be considered part of a modular vehicle line. In this analysis the pickup truck, the Fiat 238, was considered the base vehicle and appropriate adjustments were made to take into account important design differences associated with features such as front and rear wheel drive. By considering that the various LDT were of a common design family, it was possible to implement the design weight reduction methodology realistically. This concept is particularly important in the next weight reduction procedure.

After replacing the engine and transmission and downsizing the cargo box, the design for each vehicle system was examined. The LDT was divided into 11 systems for this purpose. These systems and the associated subsystems are listed in Tables 11 and 12. System, subsystem and components weights were identified where possible for all the select weight efficient LDT. This was quite difficult to accomplish as detailed teardown data were not available from most manufacturers. Teardown weight data were obtained for a 1973 F100 Ford truck* and were developed by Fiat for the Fiat 238. These data are presented in Tables 11 and 12.

Based upon the U.S. fleet, weights for identifiable optional equipment items are given. These weights represent add-on weights to the curb weight of the vehicle specified.

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* Justje, R. E. and Martin, R. L. Light Truck Materials Evaluation, Armco, September 1975.

TABLE 11. -FUNCTIONAL WEIGHT GROUPINGS FOR DETERMINING WEIGHT REDUCTION

Mission 1; Basic Weight 1973 Ford F100 Ranger, 103 in. wheel base[a]
Engine: Configuration L-4[b]; CID 302; HP 136; Torque 245 ft/lb
Load space, in.: Length ____; Width ____; Height ____; Volume ____ cu ft
Weights, lb: Curb 3776 (dry, no driver); Gross 5000; Date: 9/29/78

Three-speed manual transmission, power steering, steel belted radial tires

1. STRUCTURE		1436 lb
1.1 Nonstructural panels	466	
1.2 Frame	385	
1.3 Movable panels	261	
1.4 Structural panels	324	
2. ENGINE		721 lb
2.1 Engine assembly	591	
2.2 Starting system	22	
2.3 Exhaust system	38	
2.4 Cooling system	20	
2.5 Emission control system	0	
2.6 Fuel system	50	
3. DRIVETRAIN		336 lb
3.1 Transmission/clutch	138	
3.2 Propulsion shaft	29	
3.3 Differential/axle	169	
4. SUSPENSION		569 lb
4.1 Front suspension	159	
4.2 Rear suspension	110	
4.3 Wheels/tires (5)	300	
5. BRAKE SYSTEM		168 lb
5.1 Front brakes	97	
5.2 Rear brakes	66	
5.3 Parking brakes	5	
6. STEERING SYSTEM		78 lb
6.1 Steering gear	39	
6.2 Power assist	39	
7. ELECTRICAL SYSTEM		62 lb
7.1 Battery	40	
7.2 Alternator	16	
7.3 Misc electrical	6	
8. BUMPER SYSTEM		31 lb
8.1 Front bumper	31	
8.2 Rear bumper	0	
9. INSTRUMENTS & CONTROLS		40 lb
9.1 Instrument panel	1	
9.2 Controls	36	
9.3 Instruments	3	
10. MISC FUNCTIONAL ITEMS		335 lb
10.1 Glass	62	
10.2 Seats	88	
10.3 Heating/ventilation	21	
10.4 Wiper/washer	10	
10.5 Exterior lighting	13	
10.6 Insulation	21	
10.7 Miscellaneous (cloth, plastic and steel)	120	
11. OPTIONAL SYSTEMS		0 lb
11.1 AC system	0	
11.2 Aux packages	0	
11.3 Miscellaneous	0	

[a] Serial F10GLR97249, Model F103, Body B4, Transmission C, and 17J rear axle. Ref. "Light Truck Materials Evaluation", Armco, R. E. Justje and R. L. Martin, September 1975.

[b] L-4 = in line four cylinder

TABLE 12. -FUNCTIONAL WEIGHT GROUPINGS FOR DETERMINING WEIGHT REDUCTION

Mission 1 ; Basic Weight: Fiat 238 Pickup Truck (European Weight Efficient)
Engine: Configuration L-4[a]; CID 88; HP 52; Torque 77.4 ft/lb
Load space, in.: Length 108.7; Width 65; Height 30.3; Volume 124 cu ft
Weights, lb: Curb 2513; Cargo 2205; Gross 4718 (dry weight, no driver)

1. STRUCTURE		903 lb
1.1 Nonstructural panels	275	
1.2 Frame	240	
1.3 Movable panels	108	
1.4 Structural panels	280	
2. ENGINE		322 lb
2.1 Engine assembly	250	
2.2 Starting system	10	
2.3 Exhaust system	27	
2.4 Cooling system	17	
2.5 Emission control system	0	
2.6 Fuel system	18	
3. DRIVETRAIN		104 lb
3.1 Transmission/diff	90	
3.2 Propulsion shaft	0	
3.3 Both front axles	14	
4. SUSPENSION		467 lb
4.1 Front suspension	162	
4.2 Rear suspension	80	
4.3 Wheels/tires (5)	225	
5. BRAKE SYSTEM		168 lb
5.1 Front brakes	80	
5.2 Rear brakes	79	
5.3 Parking brakes	9	
6. STEERING SYSTEM		44 lb
6.1 Steering gear	44	
6.2 Power assist	0	

7. ELECTRICAL SYSTEM		68 lb
7.1 Battery	41	
7.2 Alternator	18	
7.3 Misc electrical	9	
8. BUMPER SYSTEM		14 lb
8.1 Front bumper	11	
8.2 Rear bumper	3	
9. INSTRUMENTS & CONTROLS		7 lb
9.1 Instrument panel	7	
9.2 Controls	0	
9.3 Instruments	0	
10. MISC FUNCTIONAL ITEMS		416 lb
10.1 Glass	60	
10.2 Seats	53	
10.3 Heating/ventilation	13	
10.4 Wiper/washer	7	
10.5 Exterior lighting	11	
10.6 Insulation	15	
10.7 Miscellaneous (cloth, plastic and steel)	257	
11. OPTIONAL SYSTEMS		0 lb
11.1 AC system	0	
11.2 Aux packages	0	
11.3 Miscellaneous	0	

[a] L-4 = in line four cylinder

IDENTIFIABLE OPTIONAL EQUIPMENT WEIGHT

	Pickup	Van	Utility
H.D. battery	16	16	14
Auxiliary fuel tank	148	148	72
Power brakes	-	8	-
Power steering	50	38	37
Skid plate	-	-	10
Step bumper	80	30	-
Insulated carpet	-	50	-
Sliding side door	-	58	-
Insulation package	-	58	-
Air conditioning	90	100	-
Optional seats	150	263	-
Auxiliary air conditioning	-	151	-
H.D. Cooling	20	31	-
Emission control (Calif)	-	12	-
Radio AM/FM and tape	10	15	-
Speed control	5	5	-
Box cover	240	-	-
Stabilizer bar	35	24	-
Trailer towing package	85	7	-

After establishing subsystem weights, typical components in subsystems were identified which were candidates for weight reduction by means of redesign. The percent weight reduction achieved for the typical part was determined and a judgement made as to whether or not this percent weight reduction would apply to the entire subsystem. If it did not, the percentage was adjusted up or down, and applied to the subsystem. The total weight reduction for each system was determined from the difference in the original system weight and the weight of the redesigned system. The percent weight reduction was calculated based upon the initial system weight.

Two types of design weight reduction were considered. First, a system, subsystem or component could be "redesigned" by substitution. The use of a more powerful engine or the replacement of a manual transmission with an automatic transmission are of this type. The second type is more nearly a true redesign. For example, thinner glazing or reduced cargo space dimensions are of this type.

4.2 EUROPEAN VEHICLE DESIGNS

European Weight Efficient Van and Pickup—During this study, Fiat developed certain MOE for evaluating the world fleet of LDT. The result of this was the selection of weight efficient vehicles among the European fleet. This study was based only on 1977 production vehicles. The selected vehicles were the Mercedes 307D, the Renault Saviem SB2 and VW LT35D vans, and the Fiat 238. The Renault SB2 is more similar to a U.S. multistop than the van versions of Mercedes 307D, VW LT35D, and Fiat 238, and therefore the SB2 was replaced with a smaller Bedford van. The Renault SB2 was designed specifically as a van with no other versions and therefore preserved some unique design considerations. The Fiat 238 van, was originally designed as a van from which Fiat derived other versions. The Mercedes and VW vans were designed as a complete line of vehicles rather than a single model. Descriptions are included in subsequent paragraphs, for the selected European vehicles complete with their versions.

Renault-Saviem SB2—First note that this vehicle is more like a multistop than a van due to its high cargo space. This vehicle was designed as a single vehicle and not as part of a line of vehicles typified by many versions which initially explains its weight efficiency. When a line of vehicles is being designed, the structural and cargo needs of the whole class must be included in the overall design criteria, rather than those which only a single vehicle must meet. Renault SB2 is a monocoque design with no chassis, the longitudinal member is composed of two C-channel members and by three box-beam transverse members on which the engine and transmission rest. The front torsion bar operates on the upper arm of a four-bar linkage suspension. The rear suspension is leaf spring. The body structure is quite rigid because it is part of the vehicle structure. The acoustic insulation is quite extensive in this vehicle. The cargo area is very wide because the vehicle was designed to use single rather than dual wheels on the rear axle. The vehicle is produced with two different engines, a gasoline and diesel engine both of about 72 hp. The manual transmission is produced by Alfa Romeo and has four ratios.

Mercedes 307D—This vehicle had been designed to integrate into a line of vehicles (versions). Three different wheel bases are available (3050, 3350, and 3700 mm) with two different types of internal combustion engines, the gasoline with about 80 hp, and the diesel with about 70 hp. More than 75 percent of all Mercedes 307 models produced have diesel engines. The total production is composed of vans with two different heights available for the roof, and pickups and platforms available with single and double cab. Note that Daimler-Benz has designed the complete class of vehicles as a group rather than a single model to improve the effectiveness of all the versions of the class. Some considerations of the 307D are:

- All side panels are symmetric in all versions.
- The roof section of the van is composed of unitized roof sections; the number of sections determine the length of the different versions.
- The cross section of the roof has a unique shape to allow a uniform height in all parts of the interior of the van.
- Rear doors are symmetric.
- Front corner panels of the body are removable (connected with nuts and bolts).
- Interior width between the two rear wheel wells is greater than other vehicles in this weight class because Daimler-Benz studied a special type of tire to avoid the use of dual tires.

- The body supporting the van is composed of a channel structure (hat section) closed by the floor while in the pickup version by similar double channels.
- The pickup truck is produced in two different models: normal or lower floor. In this second version the sides do not fold down because the wheel wells are part of the cargo bed structure.
- Front axle is rigid (steering system allows maximum turning angle of 52 deg) with shock absorber, transverse stabilizer, and leaf spring suspension (with the two leaves of the spring not in contact to improve comfort, and double wound-eyes to improve reliability).
- Rear rigid axle includes also the final drive reduction. The available subsystem weights are:

engine	200 kg
gear box and clutch	35 kg
front axle	100 kg
rear axle	150 kg

The side panel thickness (0.88 mm) represents the minimum thickness to provide for stability of this very flat panel (van version). The thickness of the metal in the chassis is 2.5 mm. To make an evaluation of the two different designs examined, in the SB2 van each component had been designed exactly for that specific vehicle, while in the Mercedes each component had been designed considering all of the other versions.

VW LT35D—This line of vehicles has been marketed in Europe by for 3 years and has already captured over half of the market for that weight class. Weight efficiency was the primary design goal in the development of this vehicle; in addition to fuel economy and cost reduction. Only the instrument panel, door and window equipment, and seats were utilized for other passenger cars and trucks; all other components including the engines and drivetrains were newly developed and were designed to be as weight efficient as possible. This vehicle was designed to meet or exceed all American safety and emission standards. The placement of the specially designed diesel engine over the front axle enables the vehicle to have a shorter body with a maximum area devoted to the cargo. The vehicle body and chassis are integrated into other vehicle series with the floor connected directly to the double hat channel chassis. The five-speed transmission coupled with the six-cylinder engine (75 din) allow the van to reach 140 km/h in road tests. The chassis members are constructed of 2 mm and the side wall of 0.8 mm sheet metal.

engine weight (gasoline)	150 kg
engine weight (diesel)	200 kg
gear box weight	60 kg

Special anticorrosion methods to allow thinner sheet metal included electroferretic coating of the entire vehicle by dipping and then hand spraying. Aerodynamic considerations have been taken into account to produce a low drag ($C_x = 0.44$).

Fiat 238—The 238 line was introduced to the market 14 years ago and has maintained its design since that time. The intended mission of these vehicles was urban delivery with some rural application for transporting agricultural products. It was one of the first LDT with front wheel drive (lighter than rear wheel drive). The high level of comfort was reached with front and rear independent suspension (leaf spring in front and torsion bar in rear). The Fiat 238 was developed as a line of vehicles and its weight efficiency is due to its integrated design and to the especially designed components. More detailed data are introduced in subsequent paragraphs.

Weight Efficiency—The vehicle that has been especially designed for only that version, and the vehicle designed as a complete line of vehicles, has been examined. The main difference is that each component is designed in one case only for one vehicle (for its curb weight, power, cargo weight) and in the other case suitable for the complete line. The principal reason for this, arises from industry's need to maintain costs at a low level. It is important to use the same components for different vehicles (short or long, van or pickup, high or low cargo weight). In this case the weight efficiency of the second class of vehicle is less than the first one because the first had been optimized to a specific mission.

Comparison of Ford F100 and Fiat 238 Pickups—In general, U.S. pickups are derived from the car designs to maintain low costs because of the high production level of cars. However, these pickups have a body structure completely different from the European LDT. The European pickup is derived, or rather designed, together with vans. Another important difference is the fact that American pickup trucks have a separate chassis from construction while many European pickup trucks have a monocoque structure. It must be noted that Fiat pickups are not currently sold in the United States and need not comply with safety and emission standards. The Fiat 238, because of its primary in-town usage, has a very light structure; lighter than the van because the under floor structure is the same both in the van and pickup versions. The Ford pickups have the frame integrated into the truck structure.

The Fiat is a front engine front wheel drive vehicle, and Ford is a front engine rear wheel drive. The Fiat has independent front suspension with transverse leaf spring and a rear torsion bar suspension. The Ford has front coil spring suspension and rigid rear axle with leaf spring suspension. Moreover, the dimensions of the Fiat cab are like a van (short and high), while the Ford is long and low like a car. The available engine powers are quite different: 136 hp for the F100 and only 52 hp for the Fiat. The transmissions have been obviously designed for the two different torques and powers. Also the seat arrangement in one case is similar to the van and in the other to the car.

At this point some considerations may arise about vehicle usage in Europe and the United States. Normally in Europe the pickup truck is not for personal use and rarely used in agriculture, but it is used extensively for commercial delivery in town. The European and American missions are quite different and it becomes diffiult to compare the usage of the two vehicles.

The best way to evaluate these differences is to look at the weights. Gross vehicle weights are the same, but there are large differences in the percentages of curb and cargo weights. For the Fiat 238 only 53 percent is curb weight versus gross vehicle weight, while in the Ford F100 it is about 80 percent. The most important differences are in the structure, engine, and drivetrain.

The engine weight differences are a result of a "power required problem" (136 hp versus 52 hp). It is the same for the transmission, excluding the difference in the propulsion shaft (absent in Fiat), that is 29 lb. Looking at the structure, the difference in weight is more than 12 percent of the gross vehicle weight, and the same 12 percent weight difference is in the powertrain. Because the gross vehicle weight is equal in both vehicles, the difference in suspension weight versus gross vehicle weight is only 2 percent. The difference in weight on the steering system is due to the power assisted U.S. system (39 lb).

Considering that the high power is needed, there still remains more than 12 percent of the gross vehicle weight that is only the structure. Comparing the teardown weights of structure elements in a monocoque structure like the Fiat 238 pickup:

- The structural sheet metal weight is the same in both vehicles.
- The movable panel weight difference is less than 3 percent of the gross vehicle weight.
- The big difference is in the body shell and in the frame that represent 10 percent of the gross vehicle weight.
- The body shell and frame of the Fiat 238 is only 53 percent of the same weight of the Ford F100.

4.3 SPECIFIC DESIGN WEIGHT REDUCTIONS

The specific weight reductions are defined in relationship to the LDT with the greatest U.S. market penetration, the personal use pickup truck defined by mission 1. This mission was described in Exhibit 1 in Section 2 and establishes the ratios of cargo volume to curb weight and curb weight to engine torque as the primary MOE. The Ford F100 pickup truck was determined to have the most favorable MOE values for this mission and therefore was used as the base vehicle for establishing component/subsystem/system weights. Although other vehicles may have exhibited a marginal improvement over the F100 in some specific areas, none met the mission criteria as presented. Partial weight data on this vehicle were obtained from the Ford Motor Company and were used in conjunction with the ARMCO teardown data shown in Table 11 to establish system and subsystem weights. Table 13 presents the basic weight data used to establish the final weight reductions.

The specific design weight reductions determined applicable to the Fiat 238 pickup truck* are presented by short narratives which are number keyed to the system and subsystem numbers identified in Section 4.1. The resulting weight reductions are summarized in two stages. First the weight changes which result from the substitution of a more powerful engine and the downsizing of the cargo box are presented. Then the additional design weight reductions are presented.

It is noted that weight allocation which results from the engine substitution and cargo box resizing will be used in Section 5 for the basis of weight reduction through material substitution. Finally, in Section 6 the combined effects of both types of weight reduction are based on this same weight distribution.

<u>Weight Changes Due to Engine Substitution and Downsizing—Cargo Box[1]</u>**: The production cargo box on the Fiat 238 may be downsized because its dimensions are greater than that required by the mission 1 specification. The current and required parameters are summarized.

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* Weights shown in Table 12.

** The bracketed numbers refer to the system numbers in Table 13.

TABLE 13. -FUNCTIONAL WEIGHT GROUPINGS FOR DETERMINING WEIGHT REDUCTION

Mission 1 ; LDT: Ford F100 Pickup (U.S. Weight Efficient)
Engine: Configuration V-8; CID 302; HP 136; Torque 245 ft/lb
Load space, in.: Length 98; Width 70; Height 19; Volume 76.8 cu ft
Weights, lb: Curb 3686; Cargo 1014; Gross 4700 (dry weight, no driver)

1. STRUCTURE		1401 lb
1.1 Nonstructural panels	482	
1.2 Frame	314	
1.3 Movable panels	270	
1.4 Structural panels	335	
2. ENGINE		709 lb
2.1 Engine assembly	556	
2.2 Starting system	22	
2.3 Exhaust system	46	
2.4 Cooling system	20	
2.5 Emission control system	21	
2.6 Fuel system	44	
3. DRIVETRAIN		402 lb
3.1 Transmission/clutch	151	
3.2 Propulsion shaft	37	
3.3 Differential/axle	214	
4. SUSPENSION		508 lb
4.1 Front suspension	142	
4.2 Rear suspension	98	
4.3 Wheels/tires (5)	268	
5. BRAKE SYSTEM		156 lb
5.1 Front brakes	90	
5.2 Rear brakes	61	
5.3 Parking brakes	5	
6. STEERING SYSTEM		61 lb
6.1 Steering gear	35	
6.2 Power assist	26	
7. ELECTRICAL SYSTEM		58 lb
7.1 Battery	36	
7.2 Alternator	16	
7.3 Misc electrical	6	
8. BUMPER SYSTEM		29 lb
8.1 Front bumper	29	
8.2 Rear bumper	0	
9. INSTRUMENTS & CONTROLS		41 lb
9.1 Instrument panel	1	
9.2 Controls	35	
9.3 Instruments	5	
10. MISC FUNCTIONAL ITEMS		321 lb
10.1 Glass	62	
10.2 Seats	88	
10.3 Heating/ventilation	28	
10.4 Wiper/washer	10	
10.5 Exterior lighting	12	
10.6 Insulation	21	
10.7 Miscellaneous (cloth, plastic and steel)	100	
11. OPTIONAL SYSTEMS		0 lb
11.1 AC system	0	
11.2 Aux packages	0	
11.3 Miscellaneous	0	

Cargo Box Parameters

Parameter	Fiat 238	Required
Length, inch	108.7	78.0[a]
Width, inch	65.0	64.0
Depth, inch	30.3	18.0
Volume, cu ft	123.9	50.0

[a] The required length is 96 inches, but with an 18 inch tailgate, the cargo box may be only 78 inches long.

The movable panel weight [1.3] may be reduced because the tailgate will be shortened in width by 1 inch and in depth by 2 inches. The thickness of the rear doors will not be reduced so that the weight reduction will be proportionate to the difference in areas. The actual area is 1969.5 sq inches and the area designated by the specification is 1152.0 sq inches. The downsized tailgate should weigh 58.5 percent of the current door, a savings of 41.5 percent. The total movable panel weight is 108 lb (Table 12) of which 32.2 lb are in the tailgates with the balance in the two cab doors. Table 14 shows the movable panel weight as 95 lb, a reduction of 13 lb which represents a 40 percent weight saving from the tailgate (it could have been as great as 41.4 percent).

Similarly, the two cargo box side panels [1.1] will be reduced in depth and length with an associated weight reduction, also proportionate to the new and current areas. The current area of one panel is 3293.6 sq inches and that for the specification truck is 1404 sq inches. Thus the side panels for the mission 1 vehicle will weigh 42.6 percent of the actual weight. This provides a 57.4 percent weight reduction. The total nonstructural panel weight shown in Table 12 is 275 lb while the comparable value in Table 14 is 206 lb, a reduction of 69 lb or 25 percent. The cargo box side wall weight of 127 lb was reduced to 58 lb, a reduction of almost 46 percent, considerably less than it could have been.

The floor [1.4] of the cargo box will have a weight reduction proportionate to the areas of the specified box and actual box

TABLE 14. -FUNCTIONAL WEIGHT GROUPINGS FOR DETERMINING WEIGHT REDUCTION

Mission 1 ; Baseline LDT: Fiat 238*
Engine: Configuration L-4; CID 122; HP 135; Torque 160 ft/lb**
Load space, in.: Length 78; Width 65; Height 18; Volume 50 cu ft
Weights, lb: Curb 2541; Cargo 1160; Gross 3701 (dry weight, no driver)

Item	Weight	Group total
1. STRUCTURE		755 lb
1.1 Nonstructural panels	206	
1.2 Frame	191	
1.3 Movable panels	95	
1.4 Structural panels	263	
2. ENGINE		384 lb
2.1 Engine assembly	291	
2.2 Starting system	10	
2.3 Exhaust system	27	
2.4 Cooling system	17	
2.5 Emission control system	21	
2.6 Fuel system	18	
3. DRIVETRAIN		195 lb
3.1 Transmission/diff	166	
3.2 Propulsion shaft	0	
3.3 Both front axles	29	
4. SUSPENSION		467 lb
4.1 Front suspension	162	
4.2 Rear suspension	80	
4.3 Wheels/tires (5)	225	
5. BRAKE SYSTEM		168 lb
5.1 Front brakes	80	
5.2 Rear brakes	79	
5.3 Parking brakes	9	
6. STEERING SYSTEM		67 lb
6.1 Steering gear	67	
6.2 Power assist	0	
7. ELECTRICAL SYSTEM		68 lb
7.1 Battery	41	
7.2 Alternator	18	
7.3 Misc electrical	9	
8. BUMPER SYSTEM		14 lb
8.1 Front bumper	11	
8.2 Rear bumper	3	
9. INSTRUMENTS & CONTROLS		46 lb
9.1 Instrument panel	7	
9.2 Controls	36	
9.3 Instruments	3	
10. MISC FUNCTIONAL ITEMS		377 lb
10.1 Glass	60	
10.2 Seats	53	
10.3 Heating/ventilation	13	
10.4 Wiper/washer	7	
10.5 Exterior lighting	11	
10.6 Insulation	15	
10.7 Miscellaneous (cloth, plastic and steel)	218	
11. OPTIONAL SYSTEMS		0 lb
11.1 AC system	0	
11.2 Aux packages	0	
11.3 Miscellaneous	0	

* with large engine, reduced size cargo box, automatic transmission, heavier front axles, and heavier steering control arms. Axle and arm strengthened for new engine with more power (torque)

** Turbocharged

floor. These respective areas are: 4992.0 and 7065.5 sq inches which indicates that the new weight will be 70.7 percent of the actual weight. This provides a reduction of 29.3 percent. The weight proportions of the rear frame [1.2] supporting the cargo box, will be the same as that for the floor. The initial weight of the structural panel [1.4] and frame [1.2] were 280 and 240 lb, respectively, as shown in Table 12. These respective weights, shown in Table 14, are 263 and 191 lb representing savings of 17 and 49 lb, respectively. The initial weights of the cargo box floor [1.4] and associated frame are 58 and 168 lb. The 17 lb weight reduction of the 58 lb floor represents a percentage of 29.3 as indicated above. That of the frame, 49 of 168 lb is 29.2 percent, as calculated.

Engine Assembly [2.1]—The base engine, as delineated by Table 12, underpowers the mission 1 LDT. The 77.4 ft-lb torque should be increased to 155 ft-lb and the horsepower from 52 to 87. A reasonable approximation of the required engine weight and performance may be obtained from the characteristics of the Saab EMS 2L, four-cylinder, fuel injected, turbocharged cast iron block engine. This engine is rated at 135 hp at 5000 rpm and 160 ft-lb torque at 3500 rpm. The engine weight is 308 lb which includes: engine, clutch,* exhaust manifold, oil filter, throttle valve housing and starter. The turbocharger and mounting weigh another 20 lb making the total weight 328 lb**. The existing comparable component weight of the base vehicle is 287 lb. This indicates a projected weight increase of 41 lb (328 - 287 = 41).

Cooling System [2.4]: The Saab turbocharged engine requires more cooling than provided for the smaller Fiat engine. In comparing the turbocharged to nonturbocharged engine, the radiator capacity was increased and an oil cooler added.# Aluminum core

* Twenty pounds of this weight is credited to the automatic transmission.

** Saab 99 Service Manual M1975-1978 USA, Saab Turbo Service Manual M1978.

Lamm, J. "Saab Turbo", Road and Track, October 1977, p 41.

radiators have been used in Corvettes and over six million units have been used by Sofica and Volkswagen.* An aluminum core radiator, compared to a copper-brass one, should provide a weight savings of one-third to one-half.** It is assumed that the radiator will be enlarged to meet the requirements for cooling the more powerful engine. The use of aluminum will preclude a weight increase which would otherwise be realized. The Fiat base cooling system weight of 17 lb will be retained.

Emission Control System [2.5]: The Fiat 238 is not provided with a U.S. certificate emission control system (as no European LDT are). It has been identified that the current state of the art can provide such a system at a weight of 21 lb. The following typical component weights are provided for reference; catalytic converter (120 g) weight is 9 lb; exhaust gas recirculation (EGR) valve weight is 2 lb; air injection pump, with GrFRP bracket weight is 9.5 lb.

Drivetrain [3]: Transmission and Differential [3.1]: This subsystem weight in the Fiat 238 is 90 lb. As indicated in the paragraph on the engine system, this subsystem will have to be strengthened to accommodate the larger engine. The increase in strength will correspond to an increase in torque which is assumed to be proportionate to the torque ratio of the base engine and substitute engine: 2.07. On this basis, the new subsystem weight will be 186 lb. This represents a weight increase of 96 lb, however 20 lb of clutch weight included with the engine may be deducted making the new weight 166 lb and the increase 76 lb.

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* Kaechele, D.A. and Heer, H.K. "Today's View of the Aluminum Automotive Radiator", Reynolds Aluminum Co., SAE Report 770830, September 1977, p 7.

** IBID SAE Report 770830, p 13.

Front Axles[3.3]: The combined weight of the front axles in the front wheel drive Fiat 238 is 14 lb. This weight is scaled up by a factor of 2.07, as was that for the transmission and differential subsystem, to reflect the greater strength required because a more powerful engine has been substituted in place of the production one. The new axle weight is 29 lb, an increase of 15 lb.

Steering Gear[6.1]: The 44 lb steering gear subassembly includes 22 lb arm links. The links will have to be strengthened because the engine has been replaced with a more powerful one. Due to the front wheel drive design the weight has been increased in proportion to the ratio of torque. Thus the linkage weight will be about 45 lb, making the total weight 67 lb.

Controls[9.2], Instruments[9.3] and Miscellaneous[10.7]: The initial allocation of 7 lb for the instrumentation and controls system seem inadequate. This value was shown in Table 12 together with a rather large "catchall" weight value for subsystem 10.7, Miscellaneous. Based upon the teardown weight data for the 1973 Ford truck (Table 11) 39 lb were redistributed from subsystem 10.7 to subsystems 9.2 and 9.3.

Summary of Engine and Downsizing Weight Changes—The required weight changes in the Fiat 238 so that it would meet the mission 1 specification (personal use pickup truck) of full potential weight reduction to 1850 lb curb weight are summarized in Table 14. The weights shown in Table 12 were adjusted to take into account weight reductions stemming from downsizing the cargo box. Weight increases associated with the substitution of the more powerful Saab engine and automatic transmission are also incorporated. Although these changes represent an increase in the base Fiat weight of 32 lb, there is a weight reduction of 1141 lb, over 30 percent, represented by the pickup truck described in Table 14 as compared to the Ford F100 described in Table 13.

Weight Reductions Due to Additional Redesign—The weight reductions presented in this subsection are those of a more conventional nature than the downsizing ones. Fourteen components have been determined suitable for this weight reduction. These represent seven vehicle systems.

Cargo Box[1]: The tailgate [1.1] can be lightened with the provisions of cutouts and the stiffeners along the inside of the side panels [1.1] can have their cross section reduced by means of a C-section replacing the hat section. These redesigns provide 16.4 and 15.5 percent reductions respectively and are to be applied to the downsized cargo box.

Exhaust System[2.3]: The weight of the exhaust system has been reduced by 50 percent based upon shortening the "piping". This shortening was accomplished by venting the exhaust gas at the truck side, just behind the cab, instead of at the very rear of the truck. This weight reduction is considered conservative because the effect of the turbocharger has not been taken into account. The turbocharger will extract considerable energy from the exhaust gas and thereby reduce the requirements for the muffler capacity.

Fuel System[2.6]: The base vehicle fuel tank contains 41 liters (11 gal.). It is fabricated from metal and estimated to weigh 13 lb. Sulfonation processed high density linear polyethylene may be substituted for the tank with redesign, retaining metallic filler tubes, etc., and obtain a 50 percent weight reduction. This provides a weight reduction of 6.5 lb and reduces the tank weight to 6.5 lb. The larger engine is turbocharged and has about the same fuel efficiency as the original one.

Wheel and Tire[4.3]: The production base truck has a combined wheel and tire weight of 45 lb. The wheel is of a conventional metallic design and the tire is specified to be 6.50-14 passenger tire, 6-ply rating. The brake drum diameter is almost 12.5 inches so that the wheel diameter cannot be reduced from the current 14 inches without a complete brake redesign which is beyond the scope of this program. The current design wheel rim width is 5 inches which could be reduced to 4.5 inches for this size tire.

Tire weights vary considerably from manufacturer to manufacturer and with the particular tire design. The current tire weight may be characterized as being 23 lb per tire. While it appears that there may be a limited potential for reducing the tire weight by 1 or 2 lb each, it is not clear that this should be considered now. Certainly the weight reduction would result from a design change rather than from a material substitution. Other than the choice between steel, fiberglass or cord fabric, there is little material choice. Currently, fiberglass belts are used in the lightest weight tires.

The 22 lb weight wheel presents a different situation. Here there are several available materials which may be substituted with redesign. HSLA, aluminum and FRP are all being considered and used in wheel fabrication. The following quotation from Automotive Engineering, June 1978, page 36 is provided as the basis for substituting FRP for metal in the wheel, "... the 1971 Citroen SM had optional wheels of glass/epoxy. Manufactured by Michelin, these were 60 to 70 percent random glass; the balance was epoxy with metal reinforcing around the bolt holes. The SM was a high-performance front wheel drive design, and its wheels featured a large positive offset typical of front wheel drive. Their bowllike molded shape differed considerably from the bidirectional flow that would be required with conventional wheel configurations. Each FRP wheel weighed about 4 kg compared to 9 kg for a steel counterpart". On this basis, a 50 percent weight reduction is taken for the current wheel if it were fabricated from FRP. This new wheel weight is taken as 12 lb, for a 10 lb savings per wheel. The total savings for the five wheels is 50 lb. Figure 29 is a photograph of a segment of the proposed wheel. Substitution of FRP wheels for steel may be feasible, but depends upon meeting truck duty cycle requirements.

A possible alternative is HSLA (GM 980X) steel. HSLA steel wheels have been produced and have passed truck duty cycle tests. The projected weight reduction with HSLA steel is about 30 percent* or about 32 lb for five wheels.

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* Ward's Auto World, SAE Materials Presentation, p89, March 1978.

FIGURE 29. 1971 CITROEN SM FIRE REINFORCED PLASTIC WHEEL SECTION

Another possible alternative is stamped aluminum. Stamped aluminum wheels are used as original equipment on some full-sized 1979 passenger cars. The weight of a 15 x 6 inch stamped aluminum wheel is 13.5 lb. Performance of these wheels on LDT cycle tests has not been determined. The projected weight reduction, with stamped aluminum wheels, is 57.5 lb for five wheels.

In addition to redesigning the wheel, a tire design change may be implemented. Tube type tires are used in Europe whereas tubeless tires are universally used in the United States. Using a tubeless tire will provide a 2 lb weight reduction, about 5 percent of the original tire weight.

Front[5.1] and Rear[5.2] Brakes: The total system weight is 159 lb. The four brakes are identical and the weight includes that for the master cylinder and four brake drums of 62 lb. The master cylinder weight is about 7 percent of the brake weight and has been assumed to be 11 lb. On this basis, each of the four identical wheel braking units weigh 37 lb. The brake drum weight is 15.5 lb making the balance of the subassembly weight 21.5 lb.

Current design technology makes it possible to use an aluminum iron composite brake drum. A 43 percent weight reduction is possible.* The cast iron is used for the liner wear surface. This drum probably requires bolt hole inserts so that a conservative estimate of the net weight savings is 29 percent. This makes the total weight savings for the four drums 18 lb or 4.5 lb per brake. Advanced technology may allow an all aluminum brake drum. The drum surface will be treated to eliminate the use of cast iron surfaces. This is expected to improve the weight reduction from 29 to 50 percent.

Parking Brake[5.3]: The Ford parking brake shown in Table 13 weighs 5 lb while that for the currently produced Fiat 238 is shown as 9 lb in Table 12. Thus it is stipulated that the parking brake subsystem weight can be reduced by 44 percent through redesign.

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* Rhee, S. K. et al, "A Comparative Study of Four Alloys for Brake Drums", The Bendix Corporation Research Lab, SAE Paper 690443.

Steering Gear[6.1]: This subassembly should be amenable to a nominal design weight reduction. Good design practice should permit at least a 10 percent reduction. This value has been assumed so that the total system weight can be reduced from 67 to 60 lb, a 7 lb savings.

Battery[7.1]: The current battery weighs 41 lb incorporating a conventional hard rubber case. It is a 12 volt battery specified as 45 amp/hour with 185 amp for cold starting. A weight saving of 7 lb may be obtained by specifying a battery with a polypropylene case.* Such a battery has the following specifications: 12 volts, 210 amp for 30 sec at 0°F, with 25 amp for 56 min at 80°F, and 42 plates. The size is 10.25 inches long by 6.875 inches wide and 8.625 inches high. Its weight is 34 lb.

Glazing[10.1](Glass): The existing glazing consists of six glass panes having a total weight of 60 lb. This glass may be made thinner to achieve weight reduction. In addition, plastic sheet may be substituted for some of the windows. In the case of the pickup truck, the rear window is the only one which may be replaced (by IITRI interpretation of the safety standards). The weight and thickness parameters for the windows as designed and as changed, with results, are shown below.

Window Material Substitution Characteristics[a]

Item	Number of Items	Thickness, inch		Item Weight, lb		
		Current	New	Current	New	Reduction
Windshield	1	0.280	0.125	29.8	14.2	15.6
Main door glass	2	0.210	0.125	11.5	7.5	4.0
Door vent glass	2	0.210	0.125	5.3	3.4	1.9
Rear Window	1	0.280	Acrylic	13.4	6.7	6.7
TOTALS				60.0	31.8	28.2

[a] References: Lucite SAR, Passenger Transport, DuPont Ad, August 1978, p 12; SAE Paper 760076, Feb. 1976, Abrasion Resistant Acrylics Glazing; Chilton's Automotive Industries, Jan. 1, 1978, Vol. 158, No. 1; R. A. Wilson, 1985 Designers Handbook, Materials; Private Communication; Libbey-Owens-Ford Company, Glass Division, Detroit, dated Sept. 8, 1978.

* Heinhold, R. H. "Weight Reduction of Automotive Parts by Use of Polypropylene", Hercules, Inc., SAE Paper 750154, Feb. 1975, p 3.

The new total weight for the glazing is 53 percent of the original weight, making the saving 47 percent.

Seats[10.2]: The Fiat 238 has two seats which weigh a total of 53 lb. The passenger seat is the larger of the two and weighs 30.8 lb while the driver seat weighs 22.2 lb. These seats are mounted on a steel frame weighing 22 lb. This frame weight is included in the body shell weight (see Table 12, item [1.1]).

The weight reduction for the seats is predicted on achieving the same percent reduction as has been obtained for the Corvette seats. A 50 percent weight reduction has been realized through material substitution.* However, in order to make the weight reducing material changes, considerable design changes were required. The weight savings and final weight are the same, 26.5 lb.

Miscellaneous[10.7]: This item is part of the Miscellaneous Functional Items weight category and includes components made of cloth, plastic and steel. The upholstery, head liner, trim, etc., compose this subweight category. Without performing any specific design analysis, it was assumed reasonable that at least 10 percent of this weight could be designed "away".

Summary Additional Redesign Weight Reductions—The system and subsystem weights shown in Table 14 have been reduced in accordance with the narrative just presented. Table 15 summarizes the component weight reductions presented thereby and Table 16 shows the comparable weight reductions at the subsystem level. These tables provide entries for 14 components representing 13 subsystems and seven systems. The weight reduction for all of these subsystems is 220 lb, an increase of 19 percent over that obtained by the initial design weight reduction. The total design weight reduction is 1361 lb from the U.S. weight efficient LDT, the Ford F100. This provides a final curb weight of 2325 lb (dry with no driver) for the design weight efficient LDT.

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* Breakthrough: Corvette's New All Plastic Seats, Ward's Auto World, Jan. 1978, Vol. 14, No. 1, p 45.

TABLE 15. -COMPONENT REDESIGN WEIGHT REDUCTION SUMMARY

Subsystem	Selected Components	Base Design	Redesign	Reduction		Projected Percentage Subsystem Reduction
		Weight (lb)	Weight (lb)	Weight (lb)	Part (%)	
1.1	Cargo box side panel stiffeners	28.4	24.0	4.4	15.5	4
1.3	Tailgate	32.2	26.9	5.3	16.4	5
2.3	Exhaust subsystem	26.5	11.7	14.8	55.9	50
2.6	Fuel tank	13.0	6.5	6.5	50.0	40
4.3	Tire, remove inner tube	23.0	20.8	2.2	9.6	27
4.3	Wheel, for use with FRP	22.0	12.0	10.0	45.5	
5.1	Front drums, for use with aluminum and cast iron	15.5	11.0	4.5	29.0	20
5.2	Rear drums, same as front	15.5	11.0	4.5	29.0	20
5.3	Parking brake	9.0	5.0	4.0	44.4	44
6.1	Steering gear	67.0	60.0	7.0	10.0	10
7.1	Battery	41.0	34.0	7.0	17.1	17
10.1	Glass	60.0	31.8	28.2	47.0	47
10.2	Seats	53.0	26.5	26.5	50.0	50
10.7	Miscellaneous	218.0	196.0	22.0	10.0	10

TABLE 16.—DESIGN WEIGHT REDUCTION SUMMARY, SUBSYSTEM PROJECTIONS

Subsystem	Base Design	Redesign	Reduction	
	Weight (lb)	Weight (lb)	Weight (lb)	Part (%)
1.1 Nonstructural panels	206	198	8.8	4
1.3 Movable panels	95	90	5.3	5
2.3 Exhaust	27	14	13.8	50
2.6 Fuel	18	11	6.5	40
4.3 Tire/wheels (5)	225	164	61.0	27
5.1 Front brakes	80	64	18.0	20
5.2 Rear brakes	79	63	18.0	20
5.3 Parking brake	9	5	4.0	44
6.1 Steering gear	67	60	7.0	10
7.1 Battery	41	34	7.0	17
10.1 Glass	60	32	28.2	47
10.2 Seats	53	27	26.5	50
10.7 Miscellaneous	218	196	22.0	10

5. MATERIAL WEIGHT REDUCTION

The Fiat 238 pickup is the base line vehicle for the material as well as design weight reduction. The LDT described by Table 14 have been reviewed by systems/subsystems/components to determine potential weight reductions obtainable by means of material substitution. This review showed that there are three groups of systems/subsystems/components. The first of these are those which are amenable to either metallic or nonmetallic material substitutions without extensive redesign. The second group of systems/subsystems/components includes those which are amenable to metallic substitutions. Typical materials which are considered include: HSLA steel, aluminum, and stainless steel. Material strength, thickness, fabricated shape, and stiffness are important considerations. Relatively little part design change is required to obtain some benefit. However, the third group contains items which are suitable for substitution of composite materials and may require major design change to accommodate the material change.

This section of the report has four subsections; the first of which is an overall presentation of both metallic and nonmetallic material characteristics as they apply to the LDT. Thereafter specific subsections are included presenting candidate material substitutions for each material group. Finally, the specific substitutions for components and subsystems are delineated.

5.1 MATERIAL CHARACTERISTICS

Metal Alloy Considerations—There is a great potential for weight reduction in the Fiat 238 pickup truck by means of alloy substitution. However, this potential cannot be fully realized without major design changes to allow full utilization of alloy properties, while retaining low cost production methods. Direct alloy substitution for certain existing parts is possible to give minor weight savings and to prove feasibility of major weight savings by careful redesign.

Typical examples of this follow, and most sections of the vehicle are included. Without detail drawings and weights of every part of the vehicle, the study could not be fully comprehensive and should be regarded as showing conservative weight reduction possibilities by alloy substitution with some redesign.

High Strength Low Alloy (HSLA) Steels: The SAE 900 (HSLA) series represents a specific type of steel in which improved mechanical properties, sometimes with improved atmospheric corrosion resistance, are obtained by the addition of alloying elements other than carbon. Originally, the enhanced properties were accompanied by a decrease in formability, and weldability, which severely limited possible automotive uses. Formability is a particularly important attribute for automotive uses, as many parts such as frame rails, wheel rims, and control arms are formed at almost maximum severity for the ductile, low carbon steels (SAE 1008, 1010) currently used.

When the original HSLA steels are substituted for the same parts, press loads increase, stock and die tolerances must improve for better springback control, rolling speeds decrease, and additional rolling stations are often necessary. Problems encountered with parts include cracking at points of maximum deformation, wrinkling at corners when thinner sheets of equal strength are used, poor surface finish and variations in finished part dimensions caused by springback difficulties.

Furthermore, as the main purpose of using high-strength steels is so that thinner sections may be used at higher stress levels to effect weight reduction, the corrosion resistance and fatigue strength of the material becomes much more critical. Small cracks, imperfections, or mechanical damage can severely weaken or initiate fatigue cracking in a high-strength part, and loss of thickness by corrosion could cause premature structural failure. These problems remain even though the fatigue strength and corrosion resistance of HSLA steels are usually better than for low carbon steels. Design changes, together with the use of recently developed HSLA steels (such as GM 980X, YS-T50, YS-T80, USS Dual Phase 80) with fine grain structures, precipitation hardening, and spheroidized sulfide inclusions, which greatly improve formability, weldability, and toughness characteristics, can overcome many of the production difficulties, and the automotive applications of HSLA steel are steadily increasing.

Stainless Steels: For certain automotive parts, where higher temperatures or a more corrosive environment is encountered, stainless steels can show significant weight reductions, although there is a cost penalty. As it would normally be used only for minor parts and the life of these parts would be increased, the material cost penalty may be acceptable. In the Fiat 238 pickup truck, a stainless steel exhaust system has been considered as a prime example.

Aluminum Alloys: In addition to the common uses of aluminum alloy castings for automotive parts such as brackets, master cylinders, steering box and gear box castings, etc., alloy sheet can be used for body parts as a substitution for low carbon steel. However, there are several difficulties which reduce the practicable possibilities of this lightweight material. The important ones are:

1. Low modulus of elasticity
2. Special handling to avoid surface defects
3. Fastening difficulties
4. Higher cost.

Of these difficulties, the low modulus of elasticity is perhaps the key, as it leads to costly production tooling and design changes in order that a part of equivalent stiffness, dent resistance, and surface finish may be produced in quantity.

The difficulties can be offset by careful integrated design, resulting in significant weight savings, but not by direct alloy substitution. For instance, doors may have a stiff inner frame to which prepainted body panels may be attached, bimetallic parts using special fastenings can be produced, or full aluminum alloy parts can be designed with increased thickness or webbing for stiffness, and redesigned attachment points for hinges and brackets.

As the prime purpose of this study was to effect weight savings by direct alloy substitution without major redesign, the use of aluminum will be applicable only to a few minor components.

Alloy Substitution Selection: The functional groups (see Table 14) selected for the highest potential weight reduction by direct alloy substitution, together with the alloy chosen for each group, are shown in Table 17. In each case a general alloy grade has been used. Particular alloys within the grade would be determined by cost, availability, and individual part production requirements. The HSLA steels are assumed to be the new formable varieties as shown in Table 18.

Composite/Nonmetallic Material Considerations—Various approaches for achieving weight reduction using nonmetallic materials for the Fiat 238 pickup truck have been evaluated. These approaches consider the replacement of components currently fabricated of sheet steel with components fabricated of polymeric and "composite" materials. A composite material may be interpreted in the broadest sense, and not just as restricted to fiber reinforced polymer or metal matrix materials.

The methodology employed was to consider replacement of each sheet steel panel and its welded steel reinforcements with a polymeric or composite material. However, the manufacturing processes for these materials may be greatly different from the processes used in the manufacture of steel components. It was therefore felt that redesigning groups of components as one structure might afford a greater weight savings. Consequently, an overall redesign was also considered.

Several lightweight composite materials have been considered for substitution of sheet steel components. The two material categories into which these replacement parts fall are considered separately.

TABLE 17. -FUNCTIONAL GROUPS WITH ALLOY SUBSTITUTES

Functional Group	Alloy Grade	Typical Min Yield Strength, ksi	Modulus of Elasticity, psi	Elongation min in 2 inches
Body Shell	SAE 950X Steel	50	30×10^6	22-25
Frame	SAE 950X Steel	50	30×10^6	22-25
Movable Panels	SAE 950X/980X Steel	50/80	30×10^6	22-25/18-20
Structural Sheet	SAE 950X/980X Steel	50/80	30×10^6	22-25/18-20
Exhaust System	SAE 410 SS	40	29×10^6	

TABLE 18. -HIGH STRENGTH LOW ALLOY STEELS (INCLUSION-SHAPE CONTROLLED)-WROUGHT

Type[a] →	45	50	60	70	80
COMPOSITION, %	C 0.12, Mn 0.7, P 0.010, S 0.020, Al 0.06, Cb 0.015, Zr 0.09	C 0.12-0.18, Mn 0.7-1.25, P 0.01-0.04, S 0.02-0.05, Si 0.03 max, Al 0.01-0.06 See Note[b]	C 0.15-0.18, Mn 0.9-1.4, P 0.04 max, S 0.03-0.05, Si 0-0.4 max, Al 0.01 min See Note[b]	C 0.15-0.18, Mn 0.9-1.5, P 0.04 max, S 0.03-0.05, Si 0-0.5 max, Al 0.01 min See Note[b]	C 0.09-0.18, Mn 0.6-1.6, P 0.015-0.04, S 0.025-0.05, Si 0-0.06 max, Al 0-0.02 See Note[b]
MECHANICAL PROPERTIES					
Tensile Srength (min) 1000 psi	60	65[d]	75	85	90-95
Yield Strength (min) 1000 psi	45	50	60	70	80
Elongation (min) in 2 in., %	30	22-25	20	18	18
Hardness, R_B	--	80-95	--	--	--
Fatigue Strength, 1000 psi	--	26-35	30	30-34	33-43
Impact Srength (Charpy-V) ft-lb	10 (-100°F)[c]	25 (-60°F)[e]	7.5[f]	7.5[f]	20 (-100 F)[g]
FABRICATING PROPERTIES					
Formability	Superior to conventional high strength low alloy steels; little, if any, difference in being with or across grain; minimum bend radii from 0 to 1-1/2 T for "45" and "50" grades, 1/2 to 2-1/2 for higher strength grades depending on grade and gage thickness.				
Weldability	Readily weldable by all common methods; preheat and postheat generally not required; low hydrogen electrodes may be recommended for highly restrained welds or if optimum impact properties are required.				
CORROSION RESISTANCE	Generally similar to plain carbon steels; improved atmospheric corrosion resistance possible by slight compositional modifications				
AVAILABLE FORMS	Hot-rolled sheet primarily; some grades also available in hot-rolled strip and light plate. Lower strength grades also available in cold-rolled and welded tubing.				
USES	Automobile bumpers and accessories, wheel spiders, cross members, steering and suspension parts, engine mounts; roll over protection systems and other components of earthmoving equipment, truck frames and components; railroad car components; dredges; transmission towers; crane booms				

[a] Based on minimum tensile yield strength as rolled. [b] In addition to elements listed in composition, these steel contain small quantities of columbium and/or vandium, nitrogen, zirconium, titanium or rare earths. Values shown by ranges may be maximum for certain producer's grades. [c] Based on 1/4 size transverse specimens for modified grade having 42,000 psi yield strength. [d] Up to 70,000 psi on request. [e] For one grade, 0.200 inch thick, based on 1/2 size transverse specimens. [f] Typical for transition temperatures of 5°F longitudinal and 10°F transverse based on 1/3 size specimens of titanium bearing grades. [g] For one grade, based on 1/2 size transverse specimens, 0.197 inch thick

Table taken from Materials Engineering, Mid November 1977; Vol. 86, No. 6, p. 38.

Sheet Molding Compound (SMC): SMC is a composite material consisting of a polymeric matrix supporting a high strength fiber. The material, when used for fabrication, is cut from a large sheet, inserted in hot molding dies where it is formed to its final shape. The polymeric matrix may be a thermoplastic or a thermoset, in either event the cured thermoset or cooled thermoplastic holds the components shapes. There is a wide selection of fibers which the SMC may contain including: glass, graphite, metallic, and organic fibers.

The SMC selected consisted of a polyphenylene sulfide (PPS) thermoplastic matrix with 30 percent glass fiber reinforcement. Table 19 outlines the properties and cost of this material. PPS combines good chemical and solvent resistance with high stiffness. In addition, the low moisture absorption of the material indicates good dimensional stability in the wet and humid environment that a truck would experience.

TABLE 19.—PROPERTIES AND COST OF PPS/30 PERCENT GLASS THERMOPLASTIC COMPOSITE

Mechanical Properties		ASTM Test Method
Water Absorption, %, 24 hr 23°C	0.02	D-792
Specific Gravity	1.53	D-570
Impact Strength, Izod, notched, 1/4 inch	1.4	D-256
unnotched, 1/4 inch	6.0	
Tensile Strength, psi	17000	D-638
Tensile Elongation, %	1.3	D-638
Tensile Modulus, psi x 10^6	1.6	D-638
Flexural Strength, psi	28000	D-790
Flexural Modulus, psi x 10^6	1.4	D-790
Compressive Strength, psi	24000	D-695
Cost Information		
Cost per lb, cents	200	
Cost per cu inch, cents	17.8	
Cost per 1000 psi tensile, cents	11.8	

Source: Katz, H. S., Milewski, J. V., Handbook of Fillers and Reinforcements for Plastic, Van Nostrand Reinhold, 1978.

Glass and Graphite Epoxy (GR/EP) Composites: The SMC most frequently encountered is composed of short glass fibers. Though continuous fibers may be incorporated, the directionality of these fibers will probably be lost during forming. Continuous fiber composites offer greater weight savings when the fibers can be intentionally placed in the direction of principal stresses. The manufacture of these materials with directional load carrying capacity is, however, more time consuming and labor intensive than matched mold forming. In addition to this, the cost of high specific strength and modulus materials such as graphite fibers is considerably greater than the glass fibers used in the SMC material. Table 20 outlines the properties and cost of the glass and GR/EP materials used for the truck redesign.

TABLE 20.—GLASS AND GR/EP MATERIALS

Physical Properties	S-Glass Fiber	AS-Graphite Fiber	AS-GR/EP Unidirectional Composite
Specific Gravity	2.49	1.80	1.55
Virgin Tensile Strength, psi	665,000	410,000	225,000
Tensile Modulus Elasticity, psi	12,500,000	32,000,000	20,000,000
Shear Modulus, psi	---	---	1-2,250,000
Cost $/lb	6-10	32-50	---

Substitution Methodology: Replacement of steel components by polymeric or composite components has been done on a stiffness to stiffness basis. This may not be the most realistic way to redesign a component such as the headliner, but in view of the lack of specific design criteria, no other method seemed appropriate. Because of this limitation, several components which showed little weight savings when fabricated of lightweight materials may actually be fabricated with a much larger weight saving. An example of this is the door which when replacing the sheet metal with SMC on a stiffness to stiffness basis yields a

10 to 15 percent weight saving. Rockwell International has fabricated a fiberglass reinforced door which yields a 50 percent weight saving.

All calculation of material strength and stiffness represent a conservative redesign. Missing information (such as sheet metal thickness) on the Fiat 238 pickup drawings was assumed from other similar components. Information which was entirely lacking (such as the cargo side walls) has been estimated. These assumptions and estimations have been noted in the calculations when they occur.

It is noted that existing components were converted to "composite" on a one-to-one basis with the current metal components using the provided assembly drawings. Whenever possible, existing components were converted to "composite" while minimizing the total number of individual parts, e.g., converting the box floor panels and frame subassemblies to a single monocoque assembly.

5.2 CANDIDATE METALLIC MATERIAL SUBSTITUTIONS

Nonstructural Panels [1.1]* —The current body shell weight is given as 206 lb. Primary functions of this body shell are:

(a) To cover, protect and contain the contents of the vehicle.

(b) To support the windshield and various ancillaries.

(c) To present a clean and styled finish.

Generally the panels are large and pressed into shapes with rounded contours. This means that although drawing is not severe, surface finish must remain excellent, and no buckling or excessive "oil canning" should occur. Also the dent resistance of the panel must remain the same if a substitute material is used.

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* The bracketed numbers refer to the system numbers in Table 14.

To avoid increased oil-canning or buckling when a substitute material is used, stiffness must remain the same, and as stiffness depends on modulus of elasticity which is almost the same for low and high strength steels, there is no apparent advantage in going to a more expensive high strength steel for weight saving. However, if the stiffness is kept the same by a change of shape (e.g., increased curvature) or by the addition of light stiffness inside the panel, equal dent resistance may be used as a criterion for determining the weight saving possible by material substitution, (see Figures 30 and 31).

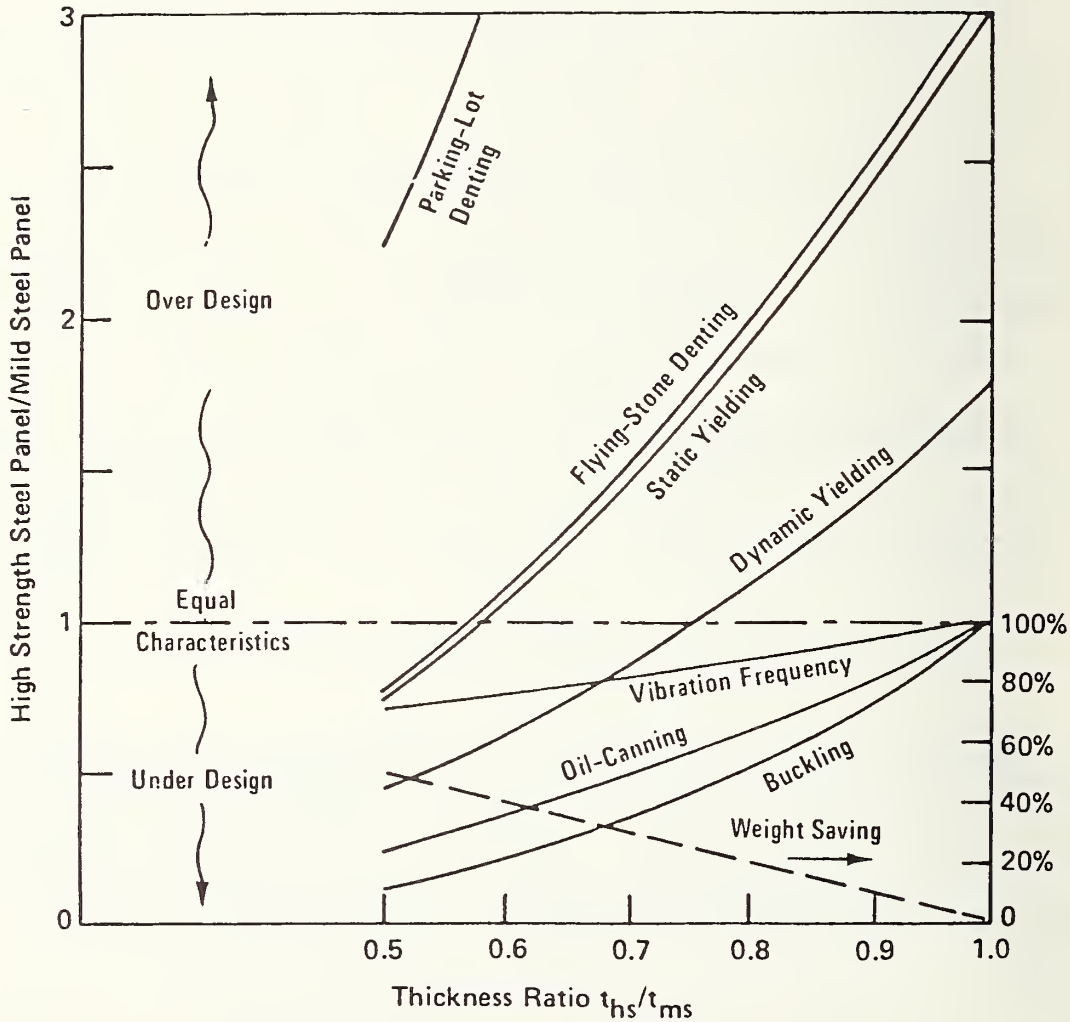

FIGURE 30. COMPARISON OF STRUCTURAL CHARACTERISTICS OF HIGH STRENGTH STEEL AND MILD STEEL PANELS

Source: "Structural Requirements in Material Substitution for Car Weight Reduction", Chang and Justusson

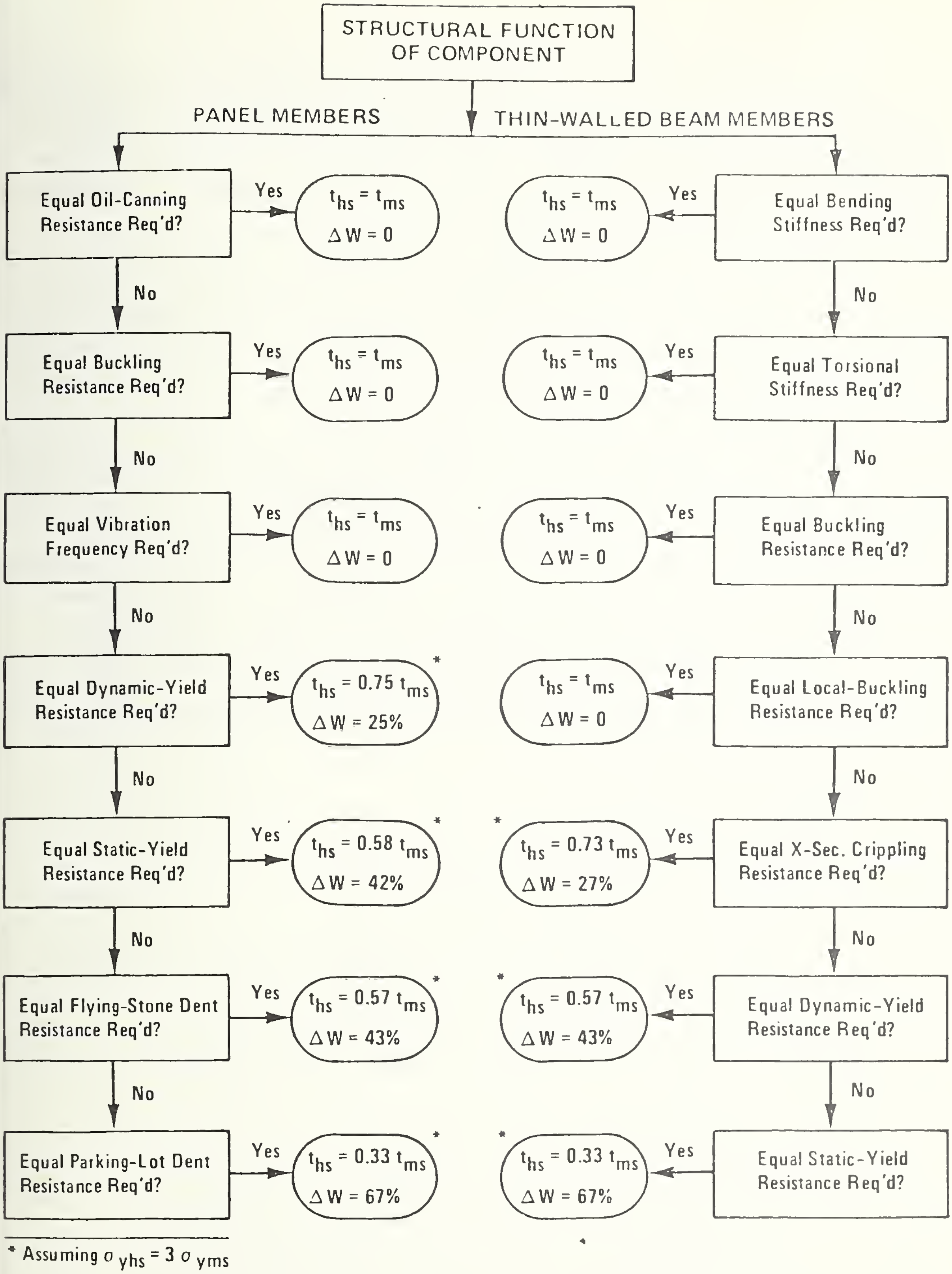

FIGURE 31. DECISION FLOW CHART FOR THICKNESS SELECTION - DIRECT SUBSTITUTION OF HIGH-STRENGTH STEEL FOR MILD STEEL

Source: "Structural Requirements in Material Substitution for Car Weight Reduction", Chang and Justusson

As strength is not as important, in general it would not be advantageous to substitute a very high strength steel with its increased production problems. The only way advantage could be taken of it would be in conjunction with some kind of composite backing to retain some rigidity in the sheet.

However, it would be possible to reduce the sheet thickness somewhat by use of a medium HSLA steel such as SAE Grade 950X where formability, weldability and surface finish would still be acceptable, and stiffness could easily be maintained.

For calculation purposes it will be assumed that the panel shape remains the same and that lightweight stiffeners have been added where necessary to maintain equal stiffness on substitution of a 950X steel. A panel thickness of 0.028 inch will be assumed (drawings not available), and the criterion for weight reductions would then be that dent resistance should remain the same.

A formula has become adopted for equivalent body panel dent resistance according to work done by DiCello and George* as

$$\frac{(\sigma_y)_1^2 \; t_1^4}{S_1} = \frac{(\sigma_y)_2^2 \; t_2^4}{S_2}$$

where S = panel stiffness

t = thickness

σ_y = yield strength

If SAE 950X steel (50 ksi yield) is used instead of carbon steel (30 ksi yield) and equal stiffness is maintained ($S_1 = S_2$ then

$$t_2 = t_1\sqrt{\frac{(\sigma_y)_1}{(\sigma_y)_2}}$$

$$= 0.28\sqrt{\frac{30}{50}}$$

$$t_2 = 0.022 \text{ inch}$$

*DiCello, J.A. and George, R.A., "Design Criteria for the Dent Resistance of Auto Body Panels", Paper 740081 presented at SAE Automotive Engineering Congress, Detroit, MI February 1974.

i.e., new panel thickness = 0.022 inch

Original body shell weight = 206 lb

Weight reduction (by thickness ratio) = $206-(206 \times \frac{0.22}{0.28})$

i.e., weight reduction in nonstructural panels = 44.1 lb

Percent weight reduction = $\frac{44.1}{206} \times 100$ = 21.4 percent

A specific example of a body shell section is the roof panel. The parts are not too deeply drawn for an SAE 950X steel, and the strength of this could be used in the edge frame, as well as the panel. The curved edge of the panel would retain its stiffness with a thinner sheet, and light stiffeners could be used to maintain stiffness at the center of the panel if necessary. Criterion for weight reduction would then be based on retaining equivalent dent resistance.

Skin panel weight = 27.5 lb (from drawing)

Skin panel thickness = 0.039 inch (from drawing)

Using the equivalent dent resistance formula

$$t_2 = t_1\sqrt{\frac{(\sigma_y)_1}{(\sigma_y)_2}} \qquad \sigma_{y_1} = 30 \text{ ksi}$$

New thickness (t_2) = $0.039\sqrt{\frac{30}{50}}$ $\qquad \sigma_{y_2} = 50$ ksi

New roof panel thickness = 0.030 inch

Weight reduction = $27.5 - 27.5 \times \frac{0.030}{0.039}$ = 6.3 lb

Percent weight reduction = $\frac{6.3}{27.5} \times 100$ = 22.9 percent

Frame [1.2]-The frame exists for strength and rigidity. Appearance and styling are of little consequence, so it would be possible to substitute a high strength alloy and accommodate necessary design changes more easily than with other parts. However, if equal bending stiffness, torsional stiffness, or buckling resistance is required, with no design or shape change, the weight will remain the same*, and there is no advantage in using a high strength alloy. If, as is often the case, the existing frame is overdesigned for stiffness and buckling, then strength may be retained while stiffness is decreased, by using thinner material of high strength alloy. This is usually possible on certain parts of the frame, but not the complete frame. With minor shape and design changes, strength as well as stiffness can be retained with thinner material.

An important additional factor with the frame is that the higher the stresses in the material, and the thinner the section, the more susceptible the part becomes to failure from corrosion. If high strength alloys are used for weight reduction on the frame they must be carefully shielded from corrosion.

The purpose of this study was to estimate potential weight saving by direct alloy substitution. In the case of the frame, there were not enough detail drawings to allow a realistic calculation of weight reduction potential. It was felt that it should be possible to use a 950X grade HSLA steel for weight reduction on certain parts, and to retain the original stiffness by small shape changes. In this case crippling resistance or dynamic yield resistance would become the criterion for weight reduction calculations. A weight saving of between 27 percent and 43 percent could be expected for various parts of the frame depending on which criterion applied (see Figures 31 and 32). On this basis it seemed reasonable to expect about 20 percent weight reduction on the frame.

Weight of frame as given = 191 lb
Weight saving of 20 percent = 38 lb
New estimated frame weight = 153 lb

<u>Moveable Panels [1.3]</u>-The current weight of a complete passenger door in 46.2 lb. Current weight of the door structure without hardware or glass is 24.7 lb. The current 0.028 inch thick material is (7/XX, which is assumed equivalent to SAE 1010 (Y.S. 30 ksi; U.T.S. 50 ksi).

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* "Structural Requirements in Material Substitution for Car Weight Reduction", D.C. Chang and J.W. Justusson, General Motors Technical Center, Warren, Michigan, February 3, 1976.

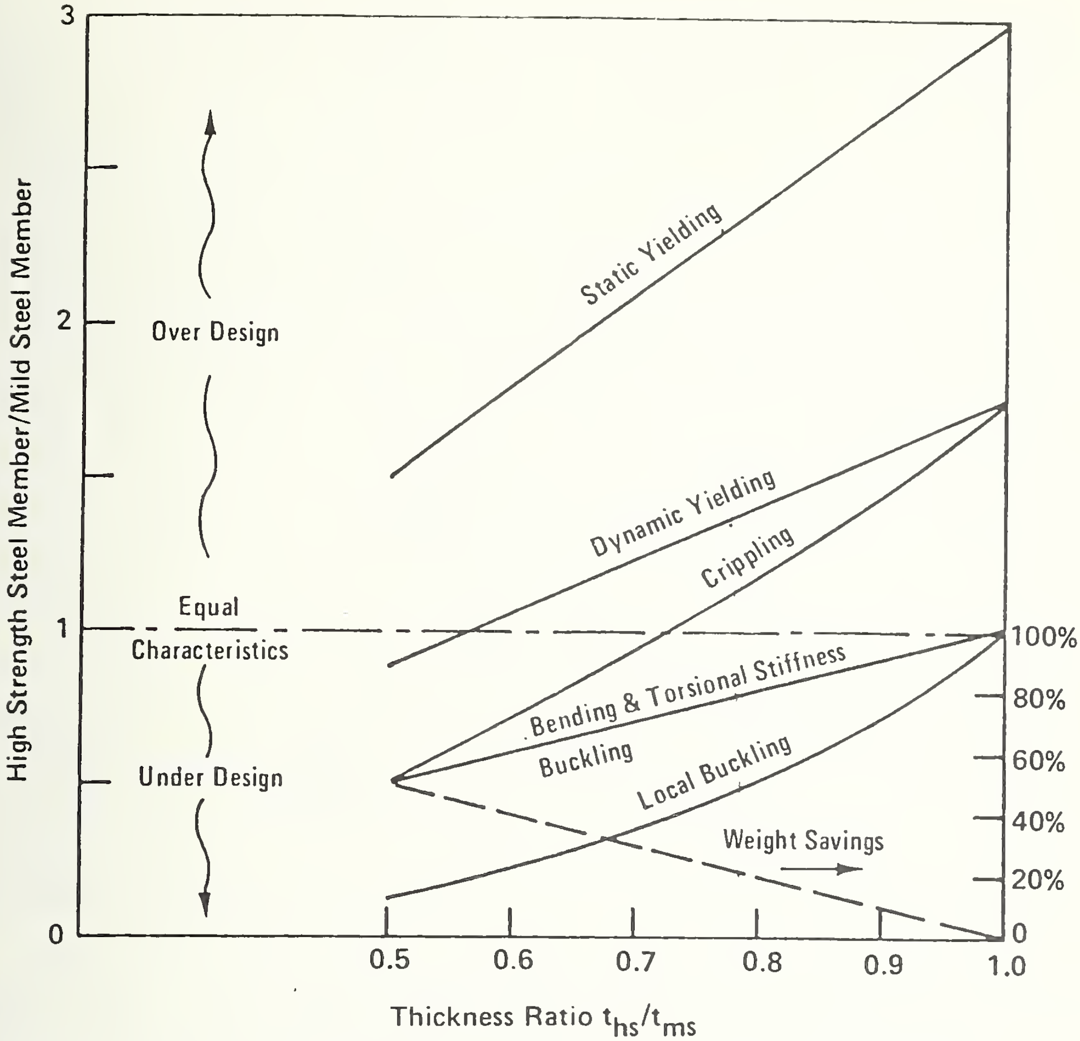


FIGURE 32. COMPARISON OF STRUCTURAL CHARACTERISTICS OF HIGH STRENGTH STEEL AND MILD STEEL THIN-WALLED BEAM MEMBERS

Source: "Structural Requirements in Material Substitution For Car Weight Reduction", Chang and Justusson.

Passenger Door Outer Skin (Estimated weight 14 lb): For this panel the essential thing is that dent resistance and "oil canning" resistance stay the same with any material substitution. Stiffness must remain the same for equal "oil canning" resistance, and this could be achieved either by minor shape changes, or by the addition of light stiffeners bonded on the inside. In addition, surface finish must be of high quality despite some severe forming. For this reason a 950X grade would be the most suitable HSLA steel to consider. As stiffness will be kept the same, the weight reduction criterion becomes dent resistant, according to the formula used previously:

$$\frac{(\sigma y)_1^2 \ t_1^4}{S_1} = \frac{(\sigma y)_2^2 \ t_2^4}{S_1}$$

$t_1 = 0.028$ inch

$S_2 = S_1$

$\sigma y_1 = 30$ ksi

$\sigma y_2 = 50$ ksi

New panel thickness $= t_2 = t_1 \sqrt{\frac{(\sigma y)_1}{(\sigma y)_2}}$

$= 0.028 \sqrt{\frac{30}{50}}$

New outer panel thickness = 0.022 inch

Hence new outer panel weight $= 14 - \frac{0.006}{0.028} \times 14$

$= 11$ lb

Percent weight reduction $= \frac{3}{14} \times 100 = 21$ percent

Passenger Door Inner Skin (Estimated weight 10.7 lb): The requirements for the inner skin panel differ considerably from the outer panel. Strength and stiffness are of prime importance, but as the appearance is of less importance (even to the extent of strain marks and wrinkling), the design could be more easily adapted to take advantage of a higher strength alloy such as SAE grade 980X. More ribbing could be used if necessary to maintain stiffness.

As the panel thickness was not given, it has been assumed to be the same as the outer panel for calculation purposes, and if equal stiffness is maintained by additional ribbing, then relating to Figures 30 and 32, if the door panel is assumed to be in a statically stressed state then the weight reduction criterion would be equal static yield resistance. The expected weight saving would be 42 percent if the yield strength ratio of the materials was 3:1.

This ratio is actually 80/30:1 = 2.7:1. For purposes of this estimate it could be assumed that the weight saving would then become 2.7/3 x 42 = 37.8 percent.

Estimated panel weight = 10.7 lb

37.8 percent weight saving = 4 lb

New inner panel weight = 6.7 lb

Combined Inner and Outer Door Panels (weight 24.7 lb): Total weight reduction for inner and outer door panel = 7 lb. Combined panel percent weight reduction = 7/24.7 x 100 = 28.3 percent. Since all doors are of similar construction, about the same weight reduction potential exists in each case. For purposes of this estimate it will be assumed that an overall weight reduction of 28.3 percent is possible with the moveable panels, excluding hardware or glass. From Table 14 total weight of existing movable panels = 95 lb. Total weight of movable panels excluding glass and hardware = 68.6 lb. Hence total weight reduction potential by change of panel material = 68.6 x 28.3/100 = 19.4 lb. Hence final weight of movable panels = 95 - 19.4 = 75.6 lb $\approx$ 76 lb. Overall percentage weight reduction = 19.4/95 x 100 = 20 percent.

Structural Sheet Metal-This group includes the cargo and passenger floor pans, the bulkhead panel, rear wheel wells and stiffness. In general, these parts show good potential for use of HSLA steel for three reasons: (1) the strength is more important than appearance, (2) there are few deep drawn sections and those could easily be modified without major design or styling changes, (3) any fall off in part stiffness because of using thinner gage material can be compensated for by increasing the section modulus of ribbing or bracing.

The parts for which drawings were available have been used as examples in order to get an indication of the overall weight reduction for the structural sheets.

Various Structural Sheet Stiffeners-As these are protected from corrosion (e.g., stiffening members inside cargo department outer skin), their shape can easily be modified, their stiffness can be maintained by increasing section modulus, and since appearance is of minor importance, these members could be roll formed from SAE 980X material successfully. This could give a weight saving of between 27 percent and 67 percent according to thin walled beam thickness charts (Figures 31 and 32), depending on which criterion is applied in each case. There are no available details on the weights of these pieces.

Bulkhead Panel-The current weight of this single skin panel, together with bracing is 28.6 lb. Current thickness is 0.031 inch. This part has several functions:

1. Isolate passenger compartment from cargo compartment safely
2. Support and stiffen cab structure
3. Support rear window
4. Help stiffen passenger floor

Material substitution must provide a sheet of equal dent resistance as the cargo should not be able to dent the panel any more than at present. As corrosion is not a major problem, the panel stiffness may be maintained by extra ribbing or increased section modulus of the stiffeners, and as the surface finish is not critical, an SAE 980X grade steel can be used. Then using the equivalent dent resistance formula, the thickness of the new panel is given by

$$t_2 = t_1\sqrt{\frac{(\sigma_y)_1}{(\sigma_y)_2}}$$

where $t_1 = 0.031$ inch

$(\sigma_y)_1 = 30{,}000$ psi

$(\sigma_y)_2 = 80{,}000$ psi

then $t_2 = 0.031 \times \sqrt{\frac{30}{80}}$

$t_2 = 0.019$ inch

i.e., new panel thickness = 0.019 inch

If this was used then new panel weight = 28.6 x 0.019/0.031 = 17.5 lb. However, with a sheet this thin, additional stiffeners would be required for cargo safety at the bottom of the panel. This would increase the weight by approximately 1.2 lb (estimate).

i.e., final panel weight = 17.5 + 1.2 = 18.7 lb

Weight reduction = 9.9 lb

Percent weight reduction = 9.9/28.6 x 100 percent = 35 percent

Rear Wheel Well-The current weight is 45.1 lb, with a panel thickness of 0.035 inch. This part serves two purposes:

1. Cover the wheel and protect the cargo
2. Anchor rear shock absorber, and accept forces from shock absorbers

The function is a combination of rigidity and strength which must be maintained for the life of the vehicle. One surface is exposed to severe corrosion as well as the possibility of mechanical damage from debris thrown up from the wheel, while the inside surface has to withstand mechanical damage as it forms part of the vehicle bed. The criterion for calculating possible weight reduction would be dent resistance except for the shock absorber tower which would be based on strength.

Not enough details were given to be able to separate the weight of the shock absorber tower from the weight of the wheel well, and so the potential weight saving will be worked out only on the basis of dent resistance. This will give a slightly conservative result, because weight savings in thin walled members on the basis of strength calculations are generally greater than those based on dent resistance in panel members.

For the purposes of this study SAE 950X material will be used, as the full potential of 980X could not be realized in this corrosive environment.

Equal stiffness would be maintained by additional ribbing, and then

$$t_2 = t_1 \sqrt{\frac{(\sigma_y)_1}{(\sigma_y)_2}}$$

$$= 0.035 \sqrt{\frac{30}{50}}$$

$$= 0.027 \text{ inch}$$

$$t_1 = 0.035 \text{ inch}$$

$$({}^{\sigma}y)_1 = 30{,}000 \text{ psi}$$

$$({}^{\sigma}y)_2 = 50{,}000 \text{ psi}$$

$$S_1 = S_2$$

i.e., new panel thickness = 0.027 inch

Weight reduction = 45.1 - (45.1 x 0.027/0.035)

Wheel well weight reduction = 10.3 lb

Percentage weight reduction = 10.3/45.1 x 100 = 22.8 percent

Passenger and Cargo Floor Pans-Although these could be made from SAE 980X grade steel as surface finish is not a problem, and production difficulties could be overcome by small design changes, these panels are structural members which see a severe corrosive environment on one side. The full potential of an SAE 980X steel could be used only if exceptional corrosion protection could be guaranteed. A better choice would be the SAE 950X steel where medium weight savings can be obtained with minor sheet thickness reductions.

Not enough information was given to isolate the individual weight of these items, but the percentage weight saving will be as for the wheel wells, at 22.8 percent.

Total original weight	=	143.9
22.8 percent weight saving	=	32.8
Hence new total weight	=	111.1

Overall Weight Reduction in Structural Sheet: The total weight of structural sheet is given as 119 kg (263 lb) with an approximate breakdown as in Table 21 together with proposed weight reductions. Substitutions of HSLA steel would not require design changes of significance and are feasible for manufacturing.

TABLE 21.—BREAKDOWN OF STRUCTURAL SHEET PARTS [1.4]

Part	Original Weight lb	Percent Weight Reduction	Weight Reduction lb	New Weight lb
Cargo Floor	84.4	22.8	19.2	65.2
Passenger Floor	59.5	22.8	13.6	45.9
Bulkhead	28.7	35	9.9	18.7
Two Rear Wheel Wells	90.4	22.8	20.6	69.8
TOTALS	263.0	23.3	61.5	201.5

Engine Assembly [2.1]-Weight reductions by means of material substitution in engine assembly will, of course, depend upon the final engine selected. However, there are a number of components which may have aluminum substituted for often-used mild steel. In the case of the air cleaner assembly this substitution may provide a 65 percent weight saving. Aluminum may also be substituted, using warm forming, in the oil pan. This will also provide a 65 percent weight reduction.

Exhaust System [2.3]-The muffler and piping of the exhaust system are treated separately in this section. The current system is fabricated from conventional low carbon steel with thicknesses of 0.039 inch to 0.1 inch. The weight is 27.0 lb. The material is changed to 410 stainless steel. The assumed/scaled current dimensions and those proposed for the stainless steel replacement for the equivalent piping are shown in Table 22.

The proposed stainless steel tubing thicknesses and diameters are nominally based on standard tubing dimensions. The length of the front and center sections is 112 inches (scaled from Fiat Drawing 4185573). The new weight of this section is (112 inches x 0.75 lb/ft)/12 = 7 lb.

The scaled length of the tailpipe is 26.5 inches. The new weight of the tailpipe is (26.5 inches x 0.54 lb/ft)/12 = 1.2 lb.

TABLE 22.—CURRENT AND PROPOSED DIMENSIONS FOR EQUIVALENT EXHAUST PIPING

Section	Inside Diameter inch	Thickness inch	Weight lb/ft
Current Piping			
Front	1.378	0.098	
Center	1.378	0.047	
Tailpipe	1.299	0.039	
Proposed for Stainless Steel Piping			
Front	1.402	0.049	0.75
Center	1.402	0.049	0.75
Tailpipe	1.430	0.035	0.54

The current muffler diameters and low carbon steel thicknesses (estimated from Fiat drawings) and the proposed equivalent stainless steel changes are shown in Table 23.

New weight calculations are as follows:

Outer casing new weight = 14.5 x 0.25 = 3.73 lb

Casing ends new weight $= \frac{2 \times \pi \times (5.9)^2}{4} \times 0.021$

= 0.14 lb

Inner tubes new weight = 16.27 x 0.045 = 0.73 lb

Weld metal and baffles estimated weight = 1.3 lb

Total weight of new muffler is 6.9 lb

TABLE 23.–CURRENT AND PROPOSED DIMENSIONS FOR MUFFLER

Current Muffler

Section	Inside Diameter inch	Thickness inch	Length inch
Outer casing	5.8	0.060	14.5
Casing ends (2)	5.8	0.060	------
Inner tube (3)	1.36	0.039	16.27

Proposed Stainless Steel Muffler

Section	Inside Diameter inch	Thickness inch	Length inch	Weight
Outer casing	5.9	0.050	14.5	0.257-lb/inch
Casing ends (2)	5.9	0.060	------	0.021-lb/sq inch
Inner tube (3)	1.4	0.035	16.27	0.0445-lb/inch

Allowing 1 lb for brackets and joints, total new weight of exhaust system is 7 + 1.2 + 6.9 + 1 = 16.1 lb.

Exhaust system weight = (16.1 lb)
Original system weight = (27.0 lb)
Hence, weight saving = 10.9 lb = 40 percent

Assuming that manufacturing methods could stay essentially the same, cost increase would be for materials only. Relative cost of 410 stainless steel over carbon steel is about 5:1 ($0.70: $0.15 per lb).

original system = 0.15 x 27.0 = $4.10
material cost of new system = 0.6 x 16.1 = $9.70

Material cost would increase about 240 percent, but this would reflect as a much lower increase for the total cost of the system.

Rear Suspension [4.2]-As with the frame, strength is a prime consideration for the two rear control arms and it appeared that HSLA could be used for these to advantage. Without more details it is not possible to determine realistic weight savings, but a conservative estimate would be 22 percent. The arms have a calculated weight of 53 lb and thus the new arms would then have a total weight of 41.3 lb for a saving of 7.3 lb.

Summary

Estimates of weight reductions in the Fiat 238 baseline LDT have been made according to current technology. The candidate items evaluated for weight reduction are listed in Table 24. The baseline truck weighs 2,545 lb. Items weighing a total of 755 lb, or about 29 percent of the LDT showed a potential for weight reductions of 23 percent. This 175 lb weight reduction amounts to 6.8 percent of the entire vehicle.

TABLE 24.—CANDIDATE METALLIC SUBSTITUTION WEIGHT REDUCTION SUMMARY

Item	Original Material	Base Line LDT Weights lb	New Material	New LDT Weights lb
1.1 Nonstructural Panel	Low Carbon Steel	206	SAE 950X	162
1.2 Frame	Low Carbon Steel	191	SAE 950X	153
1.3 Movable Panels (excluding glass and hardware)	Low Carbon Steel	68.6	SAE 950X SAE 980X	49.2
1.4 Structural Panels	Low Carbon Steel	262.4	SAE 950X SAE 980X	199.4
2.3 Exhaust System	Low Carbon Steel	27	410 S.S.	16.1
Totals		755		579.7
Percent Reduction				23.2

5.3 CANDIDATE NONMETALLIC MATERIAL SUBSTITUTION

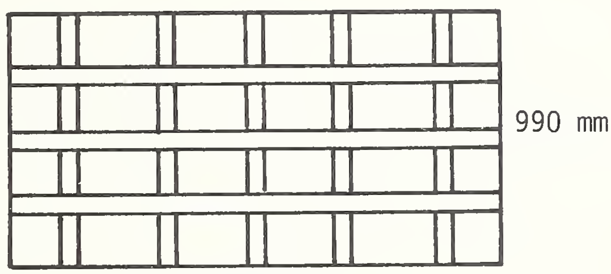
Nonstructural Panels [1.1]-Three body components are considered: the cargo area box walls, cabin roof, and the cabin front closure panel (cowling). In order to ensure design conservation redesign of these components was performed, not on the basis of equivalent stiffness, but by consideration of material strength. Both the panel walls and their reinforcements were treated in this manner. SMC is considered for these components.

For these applications the surface appearance of the panels is important. To obtain a more attractive appearance, special molding techniques may be required. This will not, however, affect the weights calculated.

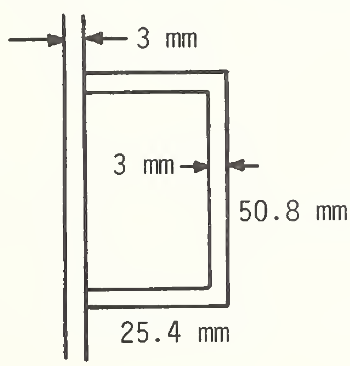
Cargo Area Box Walls: Figure 33 is the simplified box wall design used for calculation. View A depicts the location of channel reinforcements in the orginal sheet steel design. View B is a detailed section through a typical reinforcement.

Substitution of SMC for steel on an equivalent stiffness basis

$$EI_{steel} = EI_{SMC}$$



View A. Cargo Box Wall Simplified Design



View B. Cross Section Through a Typical Reinforcement

FIGURE 33. CARGO BOX WALL (SMC)

The sheet steel is 0.035 inch thick:

$$EI_{steel} = \frac{(0.035)^3}{12} \times 30x10^6 = 107.2$$

$$EI_{SMC} = \frac{t^3}{12} \times 2x10^6$$

$$t = 0.086 \text{ inch}$$

If the steel and the SMC are compared on an equivalent strength basis

σ_{steel} = 71 ksi (yield)

σ_{SMS} = 20 ksi

$$\frac{71}{20}(0.035) = 0.124 \text{ inch}$$

$$= 0.3 \text{ cm}$$

$$t_{equivalent\ stiffness} < \tau_{equivalent\ strength}$$

The 0.3 cm value is the more conservative design, it is for that reason that the equivalent strength method was used. All sections are 0.3 cm (0.118 inch) SMC.

Calculation of box wall approximate weights.

Weight of box wall panel:

(990)(2840)(3)(0.001)(1.56)(0.001) = 13.2 kg
mm mm mm cm^3/mm^3 g/cm^3 kg/g = 29 lb

Structural supports:

<u>Horizontal</u>

3[(2)(25.4)(3)(2840) + (50.8)(3)(2840)](0.001)(1.56)(0.001) =

4.05 kg = 9 lb

<u>Vertical</u>

5[(2)(25.4)(3)(990) + (50.8)(3)(990)](0.001)(1.56)(0.001) =

2.34 kg = 5 lb

Total weight of one wall box

29+9+5 = 43 lb

Total weight of both walls = 86 lb

The weight saving is 4.5 kg (10 lb).

Cowling: Figure 34 is the simplified cowling design used for calculation. Once again the material used is 0.3 cm (0.118 inch) SMC. Reinforcements in this panel have been assumed similar to the cargo box walls. Reinforcements will be required for the hinges, the grille and stiffness. The component weight has therefore been increased by 50 percent consistent with the cargo box walls. The final SMC component weight with this design is 22.7 kg (50 lb) for a saving of 15.3 kg (34 lb).

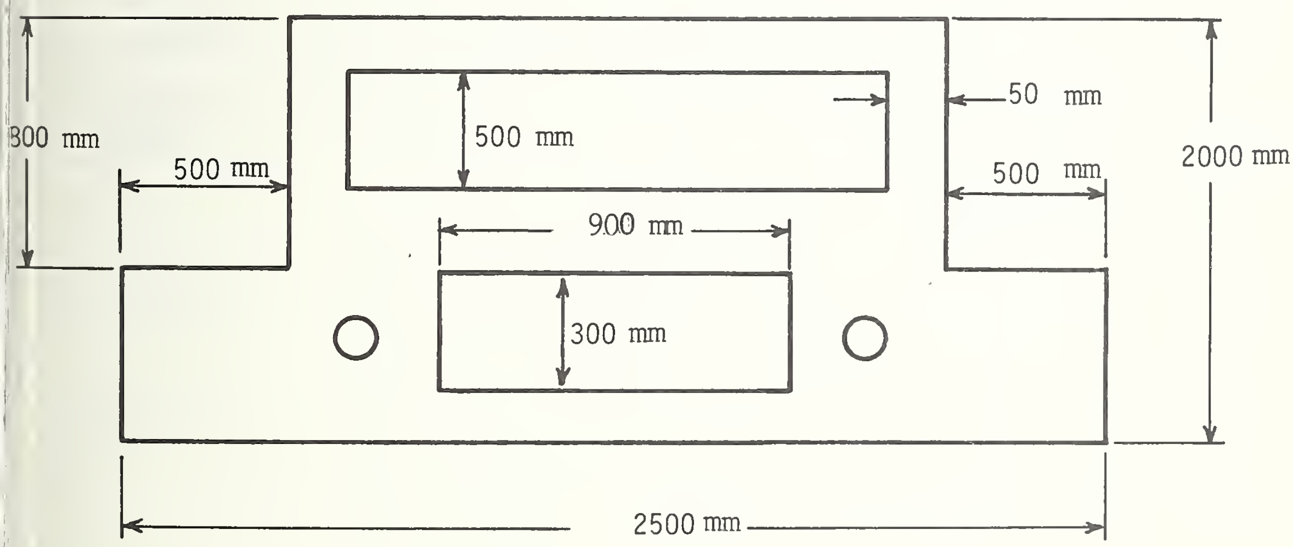


FIGURE 34. SIMPLIFIED COWLING DESIGN

Cabin Roof: The cabin roof weight reduction has been evaluated with both aluminum/honeycomb sandwich construction and SMC. Replacement was performed on an equivalent stiffness basis. This may not be the deciding design criteria for this component and panel stiffness may be reduced due to the lighter weight of the material. SMC construction provides the greatest weight reduction (36.4 percent). In addition, it may provide a more logical alternative if equivalent stiffness is not considered for calculation purposes.

Aluminum/honeycomb sandwich construction has been designed to maintain the same depth of the cabin roof, that is 2.6 cm (1 inch). Aluminum thickness required is 0.733 mm. This yields a total aluminum weight of 6.3 kg (14 lb). If Nomex is again used for the sandwich core, the total weight of the component is 10.9 kg (24 lb). This is a weight saving of 1.6 kg (3.5 lb) based on the 12.5 kg (27.5 lb) current weight.

Replacement of the cabin roof with SMC yields a weight saving of 4.5 kg (10 lb). This considers the thickness of the SMC to be 0.315 cm (0.124 inch) which is based on similar argument to the one presented for the rear wheel wells.

Second Generation Improvements: The nonstructural panels may be fabricated from second generation SMC. Two approaches are available for using this material incorporating fiberglass reinforcement: use of SMC II, or use of Genglaze in an in-mold surface coating process.

SMC II is an Owens-Corning Fiberglass product. It is a low-viscosity sheet molding compound composed of 27.3 percent glass, 29.5 percent resin, and 43.2 percent filler. It is molded at low pressure, 400 to 500 psi, as compared to conventional SMC which are molded at about 1000 psi. The low viscosity and low molding pressures provide a Class A surface finish, comparable to sheet metal.

Genglaze is a two-component urethane-based thermosetting material which is heat sensitive and has low shrinkage. It is applied to the exterior surface of SMC panels while still in the mold and fills voids, sink marks and surface flaws. It is a joint development of General Motors and General Tire and Rubber. The in-mold application of Genglaze provides a Class A finish to the exterior surface of SMC panels.

Cargo Box Frame[1.2] and Floor[1.4]—The basic design for the Fiat 238 cargo floor [1.4] and frame [1.2] is a ladder frame supporting two sheet steel floor pans. These components have been dealt with as a single unit. In redesign this unit has been fabricated from an aluminum/Nomex honeycomb sandwich.

Nomex is a nylon paper which can be formed into a hexagonal honeycomb structure. Table 25 outlines the bare compressive strength and shear modulus of Nomex and compares these values with aluminum. Figure 35 shows a photograph of the Nomex honeycomb. The light weight of Nomex compared with equivalent strength and modulus of aluminum was the reason for the choice of this material. Aluminum skins were used for weight savings and also because numerous adhesives are commercially available for bonding aluminum.

TABLE 25.—COMPARATIVE COMPRESSIVE STRENGTHS AND SHEAR MODULUS OF NOMEX AND ALUMINUM HONEYCOMB

Honeycomb	lb/cu ft	Nomex		Aluminum	
		Compressive Strength psi	Shear Modulus psi	Compressive Strength psi	Shear Modulus psi
1/8 inch	3.0	300	55		
	3.5	400	65		
Cell size	4.0	495	75		
	4.5			220	40
	6.1			405	56
	8.1			690	78
3/8 inch	1.5	50	22		
	1.6			35	8
Cell size	2.0	130	33		
	2.3			60	16

Source: Nomex: E. I. DuPont de Nemours and Company
Aluminum: Honeycomb Company of America

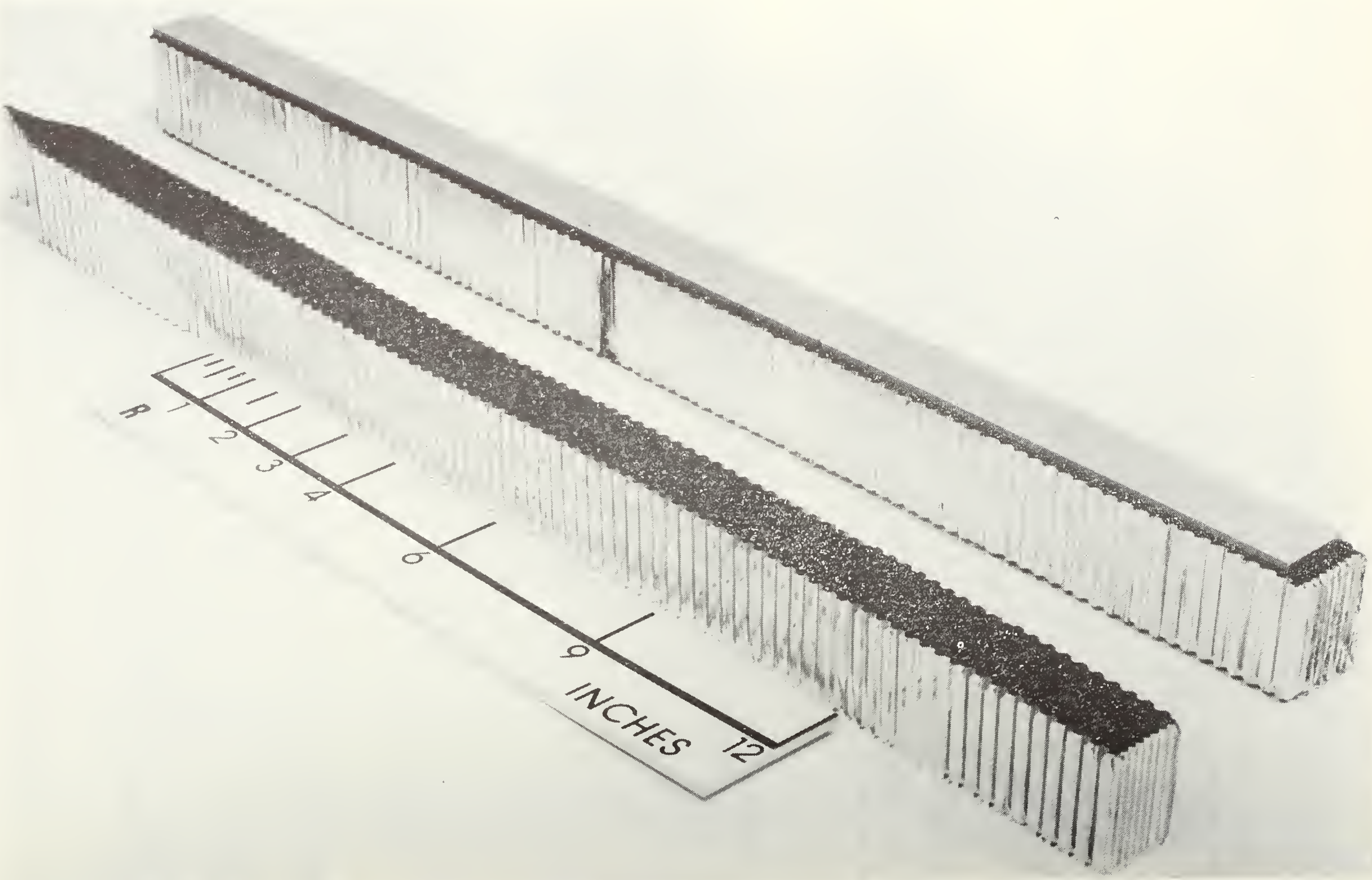


FIGURE 35. HONEYCOMB COMPOSITE MATERIAL

Aluminum does present one objectionable quality for use as a truck cargo floor, that is: poor wear resistance. This drawback could be alleviated by the attachment of stainless steel, wood or teflon runners to the cargo floor or by fabricating the entire floor of stainless steel with some attendant weight penalties associated with the heavier material.

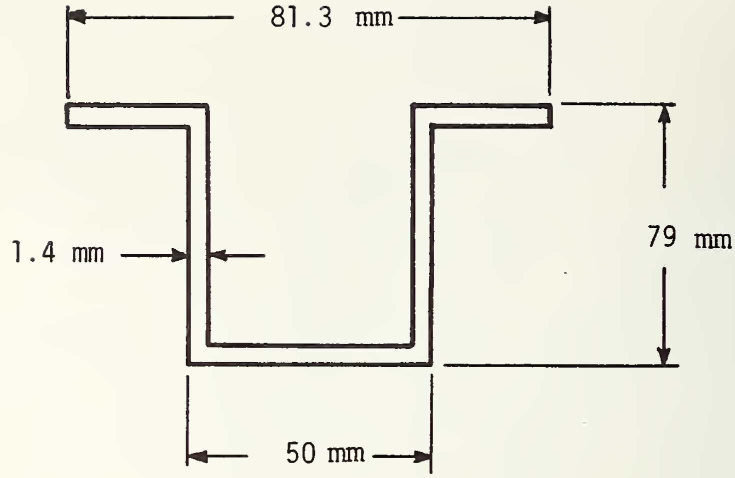
The upper skin of the Nomex honeycomb sandwich structure will double in function as the box floor in addition to being an integral stressed member of the frame assembly. The frame and cargo floor moment of inertia were calculated with assumptions that the frame rails were of the cross-sectional geometry shown in Figure 36. The moment of inertia calculated for this design is 1.78 $inch^4$. This then indicates the need for a 5.34 $inch^4$ (equivalent EI, $\frac{30 \times 10^6 \text{ psi}}{10 \times 10^6 \text{ psi}} \times 1.78 \text{ inch}^4$) moment of inertia when aluminum is used in place of steel.

The thickness of the aluminum skin was determined by using equivalent yield strengths of 1008 steel and 2024 T-4 Alclad aluminum; 1008 steel yields at 71 ksi, 2024 T-4 yields at 42 ksi. The floor pan is currently 0.9 mm (0.035 inch) which indicates an equivalent aluminum thickness of 0.152 cm (0.060 inch).

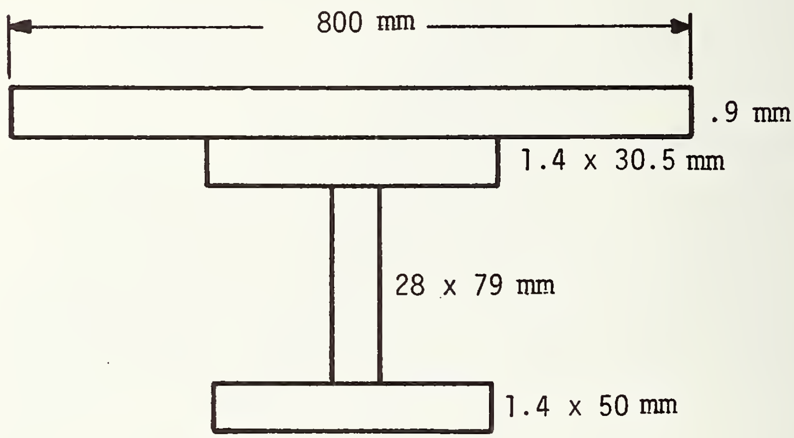
Using two 0.152-cm (0.060 inch) aluminum skins on the sandwich structure then indicates equivalent stiffness is obtained with a 6 cm (2.38 inch) sandwich depth. Honeycomb sandwich floor/frame manufactured according to the specifications and with a 6.4 cm (2.5 inch) depth weights 61.4 kg (135 lb).

The shear stress induced in a sandwich structure is frequently the cause of failure. For this reason shear calculations were performed on the structure previously described with an assumed 150 percent cargo load capacity equally distributed on the cargo floor. Load supports were considered to be the rear suspension and front frame members. The shear stress occurring at the honeycomb core/skin interface can be calculated from the equation

$$\text{Shear stress} = \frac{\text{Shear force}}{(\text{width of bonding})(\text{height})(\text{surface fraction of honeycomb contacting the skin})}$$



a) Assumed Frame Rail Cross-sectional Geometry



b) Equivalent Cross-section of Half the Cargo Floor and Frame

FIGURE 36. CARGO FLOOR AND FRAME GEOMETRY (EXISTING)

$$\tau_{max} = \frac{V_{max}}{(12)(2.5)(0.1)}$$

$V_{max} = 330$ lb (see Figure 37)

1.5 safety factor $\Longrightarrow$ $V_m = 500$ lb

$\tau = 168$ psi

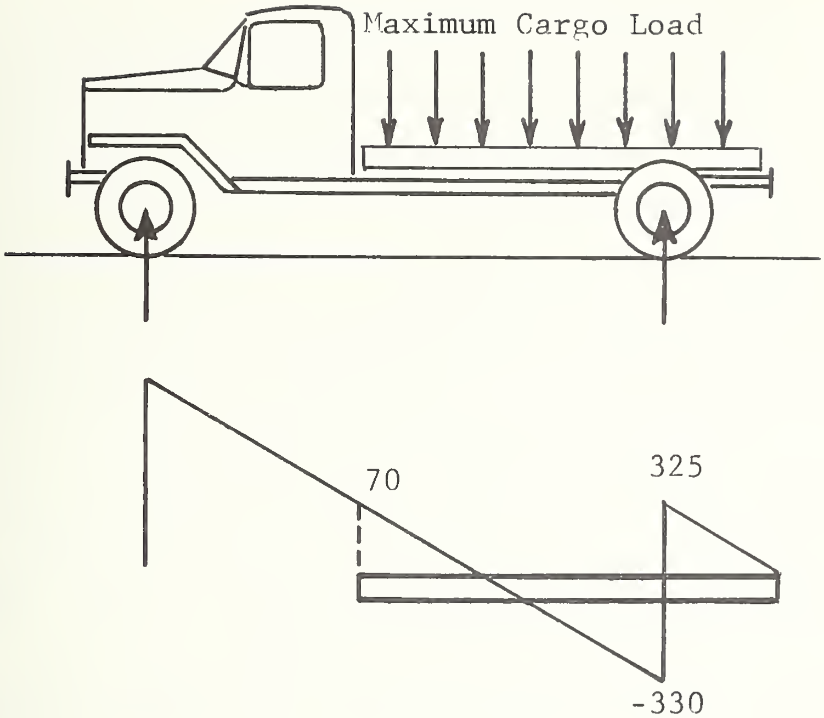


FIGURE 37. ASSUMED SHEAR FORCE DISTRIBUTION CALCULATED FROM MAXIMUM CARGO LOAD AND ATTACHMENT POINTS AT THE CARGO FLOOR (1 ft depth)

If it is assumed that the surface fraction of the honeycomb is 10 percent (90 percent of the honeycomb is voids), then the stress calculated is 42 psi. This is well below the shear strength of many adhesive systems and the honeycomb core.

Use of equivalent thickness of stainless steel for the cargo floor only, will increase approximately 8.2 kg (18 lb) or; will increase the overall weight to 69.6 kg (153 lb). From the drawings provided, the cargo bed floor and frame have a combined weight of 92.2 kg (204 lb). This still represents a 24.7 percent weight reduction.

Although the major use of honeycomb construction has been in the aircraft industry, some applications have been used in prototype racing cars. The latter was introduced by Ford Advanced Vehicles in the mid 1960's and continued in use by various other manufacturers such as Lotus. This type of construction is just entering the truck field with some experimental units and therefore it is expected that practical application is a closer reality than may be expected by the industry at large by 1985.

One of the major suppliers of honeycomb products has built and test a 40 ft long, 40,000 lb GVW enclosed semitrailer of aluminum honeycomb. The cargo floor of the trailer is made up of a top skin of 0.090 inch thick 5052 H34 aluminum, a 1/8 inch 8 lb density aluminum core and a 0.060 inch thick 5052 H34 aluminum bottom skin. Overall thickness of the panel is 3.5 inches. The trailer bogey, dolly wheels and rear suspension are adhesively bonded to this panel. This unit has accumulated over 1 million highway miles in regular commercial service between the midwest and southwest over a 5-year period without failure.

Fabrication of the aluminum/nomex honeycomb panels proposed for the LDT cargo box and driver/passenger compartment floors would be relatively straightforward. The skins would be bonded to the core in a press with heated platens using a fast-setting thermoset adhesive. Edge closures could be incorporated into the panel during the bonding process or added in a postbonding operation.

Equipment and labor costs would be low; however, material costs would be relatively high. It is estimated that these panels would cost approximately six times as much as comparable mild steel stamped and assembled components.

The 2024 T-4 Alclad aluminum skins proposed may lack satisfactory corrosion resistance, particularly when exposed to road salt and the abrasion resistance of aluminum is low. A 5000- or 6000-series aluminum alloy skin would provide improved corrosion resistance.

Another possibility would be the substitution of glass-reinforced epoxy skins for aluminum. This alternative design would include a 0.040-inch thick unidirectional (lengthwise of the cargo box) fiberglass reinforced epoxy resin laminate with a top ply of woven glass for the top skin, a 1/4 inch 4 lb nomex honeycomb core and a 0.025 inch thick unidirectional fiberglass reinforced epoxy resin laminate bottom skin. Total thickness of the panel would be 2 inches. Fabrication would involve curing the preimpregnated skins and bonding them to the core in a single process in a press with heat platens.

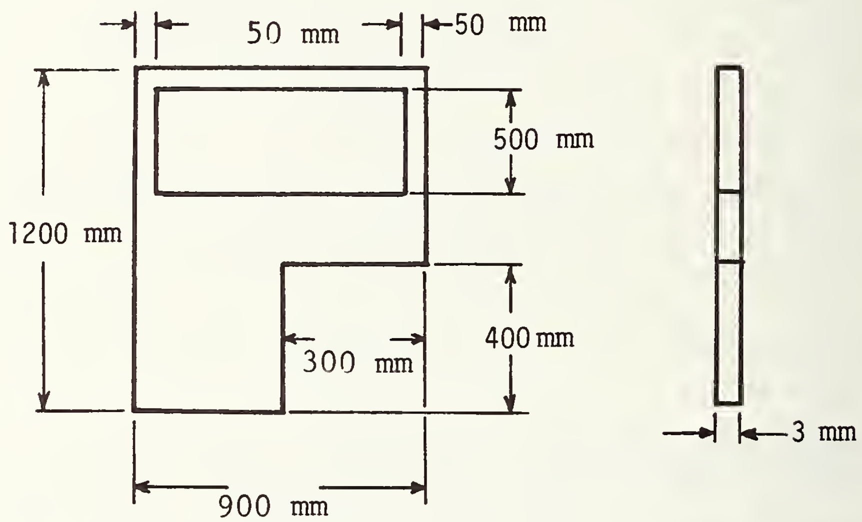
The epoxy-fiberglass/nomex panels would have several advantages over the aluminum/nomex panels. Corrosion, dent and abrasion resistance would be significantly improved. The panel weights would be about 50 percent less than aluminum/nomex panels due to the lighter weight of the epoxy-fiberglass skins, reduced core density and reduced panel thickness. The cost of the panels would be somewhat less than for the aluminum/nomex panels but still significantly more than steel stampings. It is estimated that the epoxy-fiberglass/nomex panels would be approximately five times as costly as mild steel stamped and assembled components.

Movable Panels[1.3]—Two components comprise the movable panels, these are the passenger doors and tailgate. Replacement of these panels was performed in a similar manner to that for the wheel wells. Figure 38 is the simplified design of these panels used for calculation purposes.

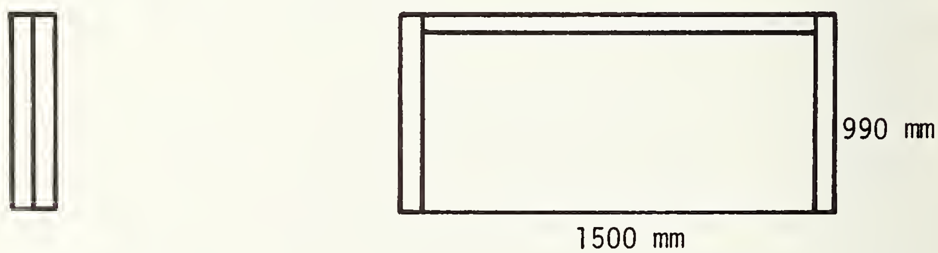
Weight calculated for the door panel in this manner is 2.6 kg (5.8 lb). This considers the outer door panel only. The windows and window and door closing mechanisms are not considered. Door reinforcements may be estimated in a manner similar to the cargo box walls. This then gives an outer panel weight of 4 kg (8.7 lb). If both inner and outer panels are constructed in a similar manner then the total door weight (without glass or closing mechanisms) is 7.9 kg (17.4 lb) or a total passenger door weight of 15.8 kg (34.8 lb). The use of glass-reinforced SMC for the cab door inner and outer panels requires redesign of the doors. However, other body components would be unaffected.

The tailgate (Figure 38b) has been dealt with in a manner similar to the passenger door outer panel. The calculation is straightforward and without closing mechanisms the component weight is 5.2 kg (19.1 lb). There is no inner panel to the tail-gate therefore this represents the final component weight.

The total weight for movable panels is then 33.0 kg* (72.8 lb). This is 76.6 percent of the original total component weight of 43.1 kg (95 lb).



a) Passenger Door Outer Panel



b) Tailgate Simplified Design

FIGURE 38. MOVABLE PANEL SIMPLIFIED DESIGN

* 12.0 kg added for the door hardware.

Graphite fiber reinforced plastic could be used for the door and tailgate hinges. The projected weight reduction with graphite fiber reinforced plastic is 70 percent. Note: a typical steel door hinge weighs about 2 lb. This material may also be used for accessory brackets on the engine [2.1] and obtain the same weight reduction. Typical brackets include: alternator, starter and air pump.

Structural Sheet Metal[1.4]—SMC has been used for replacement of the sheet steel wheel wells. Once again, equivalent stiffness was used as the design criteria. Since the properties of SMC were described in the beginning of this report, no further discussions of the materials will be presented here. Equivalent stiffness of SMC requires the SMC to be 0.22 cm (0.088 inch) thick (steel is 0.09 cm (0.035 inch)). On an equivalent strength basis the SMC must be 0.315 cm (0.124 inch) thick. Strength however, is not the design criteria.*

The weight for a 0.22 cm (0.088 inch) panel was calculated from the simplified wheel well geometry shown in Figure 39. The weight calculated is 6 kg (13.1 lb). The wheel wells are reinforced for shock absorbers and bumper pads. Figure 39 is a simplified drawing showing the geometry of these reinforcements. Weight calculated for the reinforcement only is 3.4 kg (7.5 lb) based on equivalent strength.

These reinforcements have been redesigned using aluminum first, for weight saving and secondly for attachment to the cargo frame/floor, a cross-sectional view of one possible design for this attachment is shown in Figure 40. Note in this design that the bottom skin of the cargo bed is used as the shock absorber reinforcement. The weight of the aluminum reinforcing components has been included in the wheel well, however, not in the cargo bed. The overall weight of the redesign wheel well is then 9.4 kg (20.6 lb). Compared with the original 20.5 kg (45.1 lb) sheet steel weight this represents a weight saving of 54 percent.

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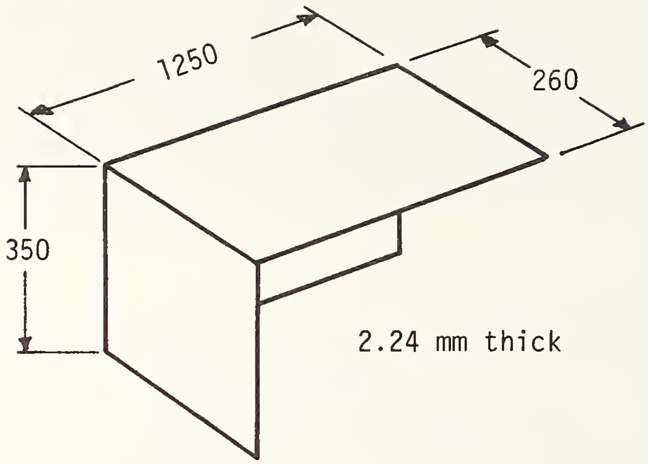
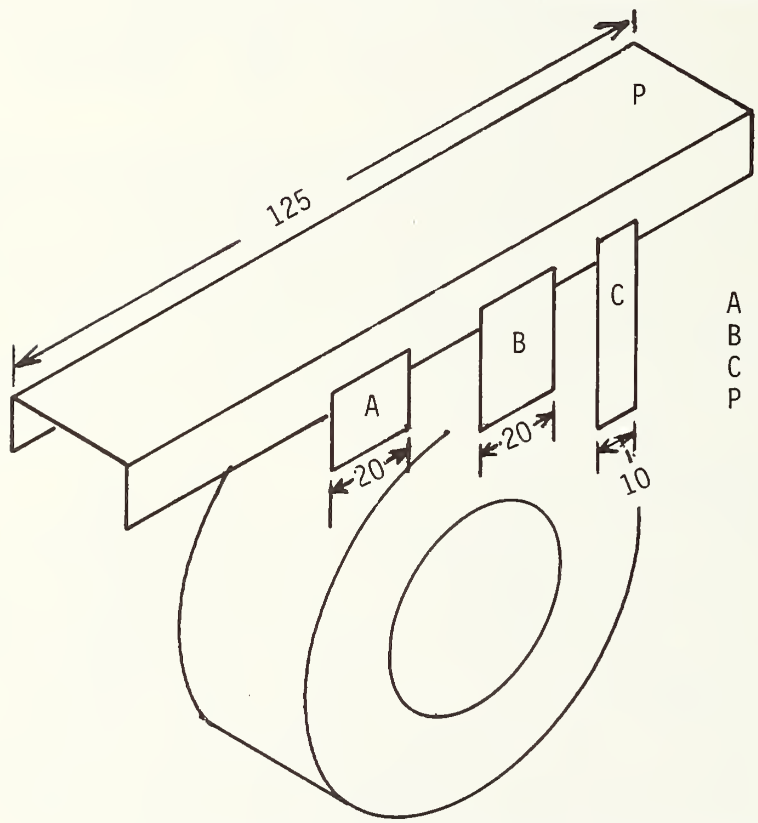
* A panel 0.124 inch thick still gives a total weight saving of 19.1 lb for both wheel wells.



Approximate Dimensions in Millimeters

a) Simplified Wheelwell Geometry



A => 20 x 20
B => 20 x 30
C => 10 x 35
P => 13 x 125

b) Simplified Wheelwell Reinforcement Geometry

FIGURE 39. SIMPLIFIED WHEEL WELL GEOMETRY USED FOR WEIGHT CALCULATIONS

Fiat 238

Frame/Box Floor/Wheelwell Assembly

Rear View

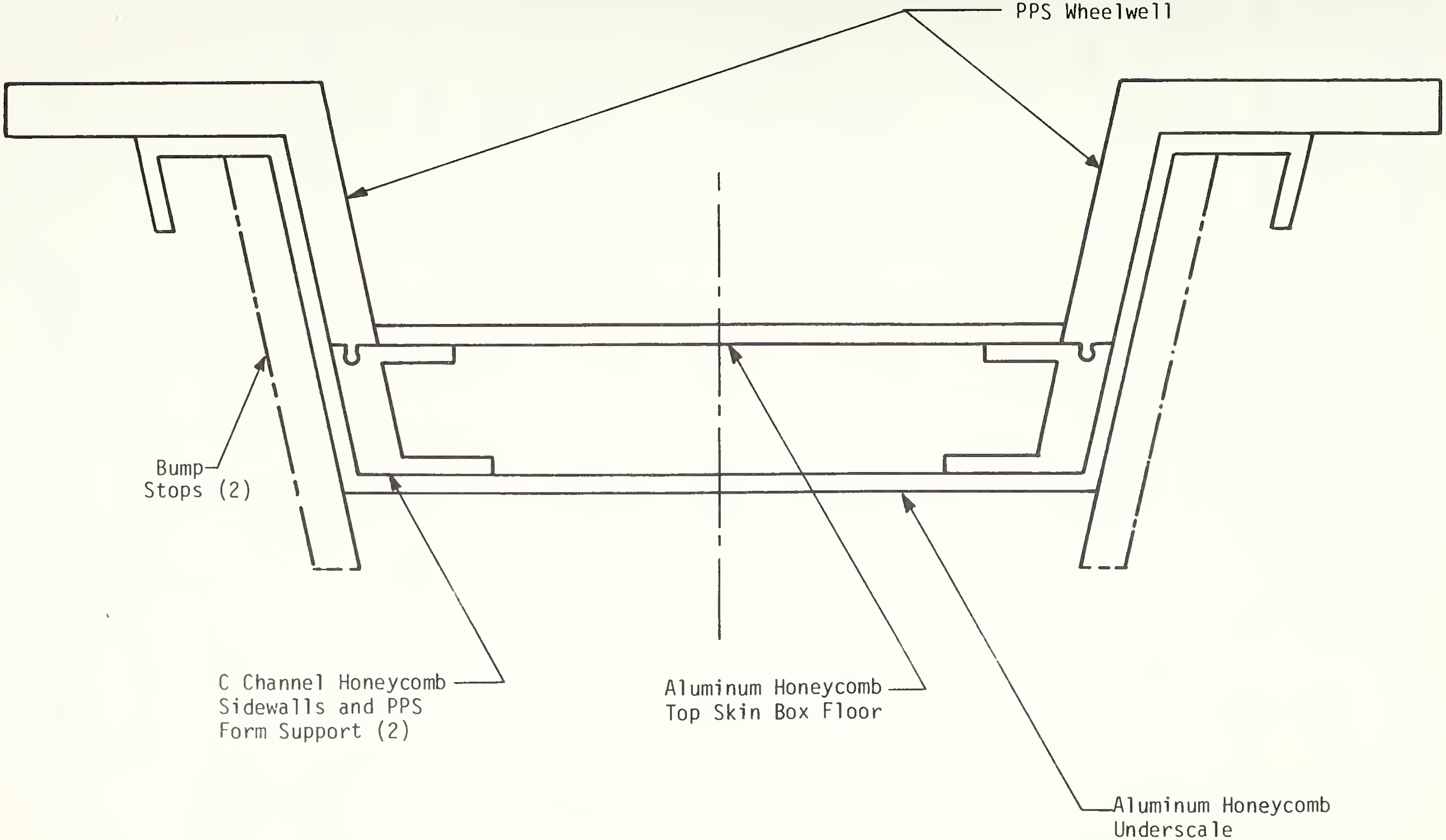


FIGURE 40. SECTION THROUGH CARGO FLOOR AT THE WHEEL WELLS

Rear Suspension[4.2]—Three components are considered in this subsystem: the torsion springs, the torsion bar anchor, and the longitudinal control arms. Two of these components, the torsion springs and the longitudinal control arms, are a direct redesign from the original components. The torsion bar anchor, however, is a different design entirely.

The torsion bar anchor transfers the torque from the rear torsion springs to the cargo frame. In the original design this anchor is mounted on a cross member of the ladder frame. In redesign of the frame, however, the ladder frame cross members have been eliminated. The replacement component must attach to the honeycomb sandwich structure, the plane of attachment has therefore been rotated through 90 deg to meet the bottom skin of the sandwich structure. In redesign of this component, the moment produced in the torsion springs was estimated.* This moment is transferred to the sandwich structure through the anchor. It is therefore necessary to design an anchor of sufficient length (lower arm) to reduce the stress concentration in the sandwich.

Torsion Springs: It was assumed that the original torsion springs are 4 cm (1.6 inch) in diameter, 76.2 cm (30 inches) long and solid. The material used for replacement was GR/EP composite and calculations were based on equivalent torsional rigidity. (The properties of GR/EP were outlined in Table 20.)

The original spring weight was calculated from the above dimensions to be 7.5 kg (16.5 lb) each. The equivalent GR/EP spring would weigh 5.6 kg (12.4 lb), this is 75 percent of the original weight and represents an overall vehicle weight saving of 3.8 kg (8.2 lb). However, the springs must be 76.2 cm (3 inches) in diameter to be of equivalent torsional rigidity.

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* This estimate was based on a 150 percent cargo capacity load, evenly distributed on the cargo floor.

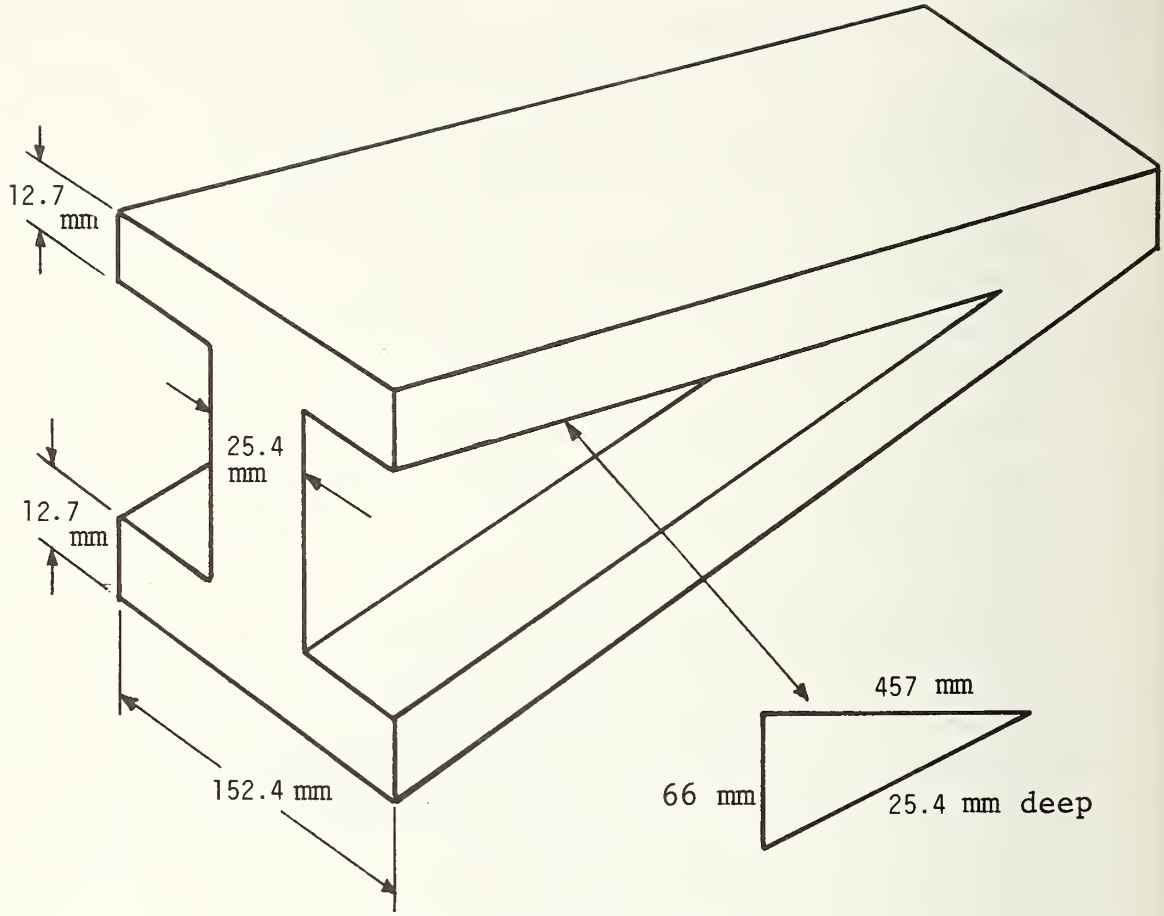
Torsion Bar Anchor: This component has been designed from PPS with 30 percent glass fibers as described earlier. Figure 41 presents the geometry and method of attachments of this component. Weight calculated from Figure 41 is 8 kg (17.5 lb). The weight for the original component is unknown.

Longitudinal Control Arms: Figure 42 presents the assumed cross-sectional geometry of the original control arm, which was used for all calculations. The component was redesigned based on equivalent stiffness. The redesigned PPS component is shown in Figure 42b. The original component weight was calculated as 5.7 kg (12.5 lb) each, the equivalent composite component as 5.4 kg (11.7 lb). This is 94 percent of the original weight and a total weight reduction of 0.7 kg (1.6 lb).

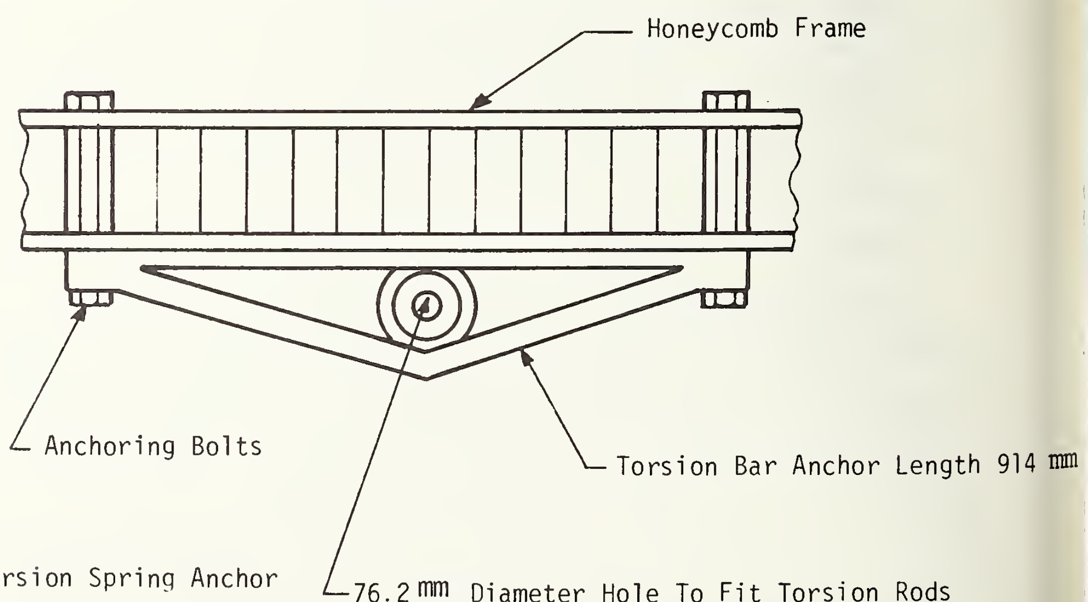
Front Suspension[4.1]—The only component in the front suspension for which a redesign was considered was the transverse leaf spring. The original leaf spring is composed of six component leaves. Each of these was considered independently in redesign. Equivalent stiffness was the design criteria used. GR/EP provides the highest stiffness to weight ratio, therefore, this material was used in redesign.

The original component weight was calculated as 20.8 kg (45.8 lb). The GR/EP spring weight is 6.2 kg (13.8 lb). This is 70 percent of the original component weight and an overall vehicle weight saving of 14.6 kg (32.2 lb). Projected weight reduction, based upon actual design experience, is 75 percent, or 34 lb.

Brake System[5]—The master cylinder/reservoir may have its weight reduced by 18 percent by means of material substitution. Aluminum and plastic may be substituted in place of the current ferrous material. The weight saving is 2 lb which reduces the item weight to 9 lb. The master cylinder weight is considered apportioned between the front and rear brakes (Section 4).

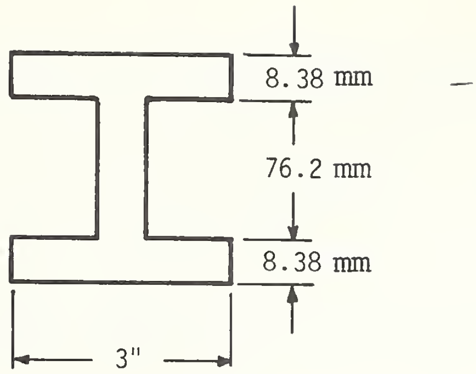


View a. Torsion Bar Anchor

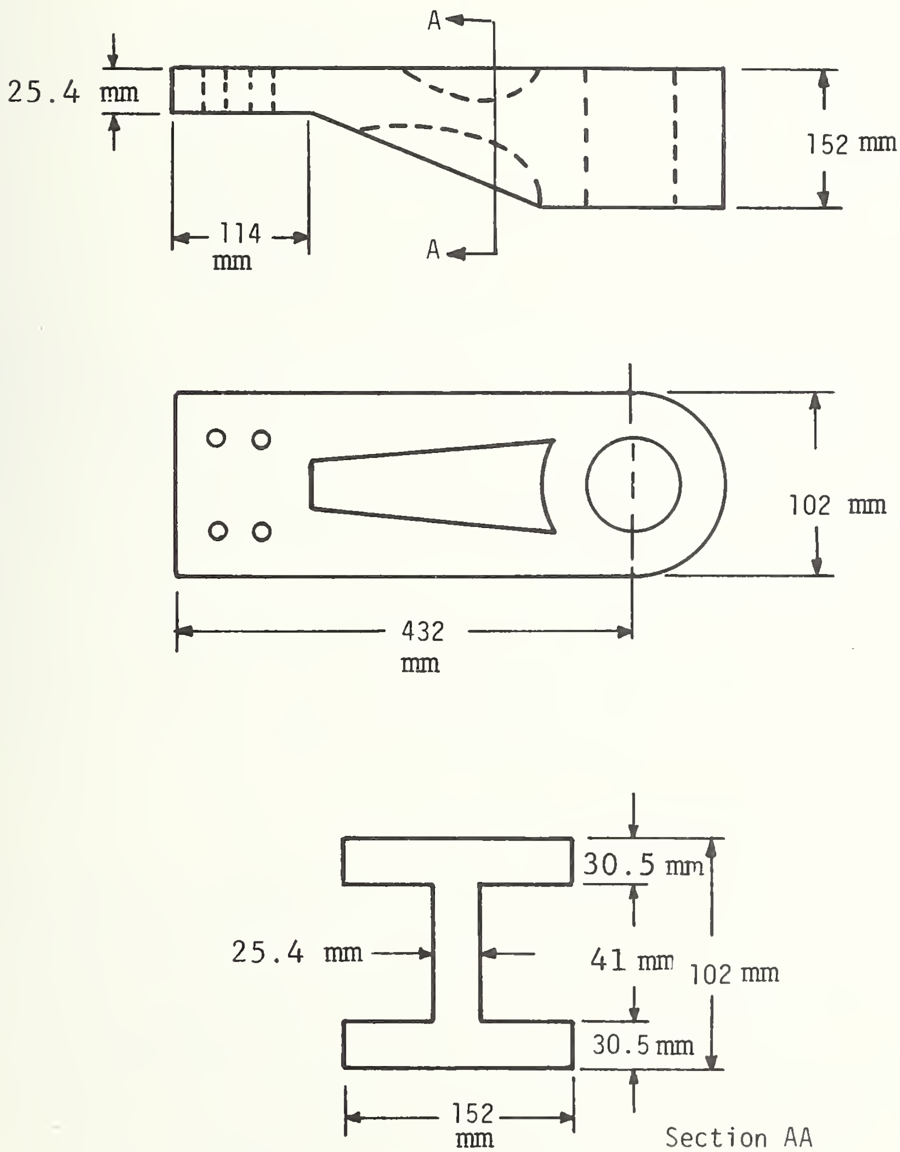


View b. Torsion Spring Anchor

FIGURE 41. TORSION BAR ANCHOR GEOMETRY AND ATTACHMENTS



a) Cross-section of Original Steel Arm



b) Polyphenelen Sulfide Redesigned Arm

FIGURE 42. DESIGN OF REAR SUSPENSION CONTROL ARMS

Controls[9.2]—Graphite fiber reinforced plastic may be substituted effectively for steel in many control components. Brake pedals, brackets, and levers are typical items in which direct material substitution may be made. This substitution will provide a 70 percent weight reduction.

SMC Component Characterization, Material, and Manufacturing Cost—The SMC components suitable for the LDT pickup include:

Doors (inner and outer panels)	-- SMC II
Front end	-- SMC II
Roof	-- SMC II
Seat support	-- SMC II
Cargo box sides	-- SMC-R50
Tailgate	-- SMC-R50
Bulkhead panel	-- SMC-R50
Rear wheel wells	-- SMC-R50

SMC II is a new SMC with low molding viscosities. It can be molded at 400 to 500 psi, about one-half the pressures needed for conventional SMC. It can also be molded at higher pressures to form large, complex parts. The lower molding pressures provide significant cost advantages for presses and tooling. Mechanical properties of SMC II are similar to conventional SMC. SMC II has the potential to yield automotive class A finishes when molded at high pressure; however, SMC II systems have not yet been developed to produce such finishes at low molding pressures. Material costs for SMC II are equivalent to conventional SMC--about $0.38 per lb.

Structural SMC, such as SMC-R50, contains a higher glass content than conventional SMC--up to 65 percent, as compared to 20 to 30 percent. This material offers mechanical and physical properties which are superior to conventional SMC. SMC-R50 (50 percent glass, randomly oriented fibers), for example, shows the following advantages over conventional SMC:

	SMC-R50	Conventional SMC
Flexural strength	41×10^3 psi	28×10^3 psi
Stiffness	2.2×10^6 psi	1.9×10^6 psi
Tensile strength	23×10^3 psi	10×10^3 psi

Molds and molding pressures for structural SMC are comparable to those used for conventional SMC. Surface finish of structural SMC is satisfactory; however, a low profile resin system is usually not used. Therefore, sink marks at ribs, bosses, etc., are more evident than with conventional SMC. Material costs are somewhat higher--about $0.50 per lb. Material costs for SMC compounds are significantly higher than for steel. Even on a weight-adjusted basis of 2 lb of steel for 1 lb of SMC, the steel raw material cost is lower. Conventional compression molding of SMC components has greater labor content and is more labor intensive than steel stamping and assembly.

The capital required to construct and tool-up a typical steel panel stamping/assembly line far exceeds that needed for an SMC molding operation. However, when investment is adjusted for capacity difference, the capital requirements for conventional SMC compression molding exceed that of steel.

An alternative to conventional SMC molding is the high throughput or movable-mold process. This process involves a series of identical molds for a part which are sequentially cylced through a single press. Charging of the molds with raw SMC, postforming cure of the part and part removal from the mold all take place outside the press. Thus, the press facility is utilized to its maximum capacity. Mold handling is done by simple transfer line automation.

The high throughput process can significantly reduce the labor intensity of SMC molding. Typically, a sixfold increase in production can be attained with less than a 15 percent increase in crew size over conventional compression molding. For a typical automotive component, the labor cost per unit with the high throughput SMC process is about one-third that of steel.

Similarly, the high throughput process shows a significant advantage over steel in equipment investment. The capital investment required for the high throughput process, on an adjusted capacity basis, is about one-third that of steel. Typically, the investment for tooling alone for steel parts stamping/assembly is equal to or slightly greater than the entire investment for a high throughput SMC operation of equivalent capacity.

These significantly lower capital and labor costs nearly offset the higher material costs for SMC components. Thus, the SMC II parts in this study would cost approximately 0.92 times their steel counterparts and the SMC-R50 parts would cost about 1.18 times equivalent steel parts. Proportioning these cost factors to the weights of SMC II and SMC-R50 components in the LDT pickup would result in an overall cost penalty for all SMC components of 1.06 times the cost of comparable steel parts.

A less satisfactory cost position would ensue if surface finish requirements of certain components were to preclude the use of SMC II and instead require adoption of the in-mold or Genglaze surface coating process. This process requires that the mold be opened slightly after forming and partial curing of the part to permit injection of a thermosetting urethane surface coating between the part exterior and the mold, followed by closing of the mold and curing of the finish coat.

Since this process essentially doubles the time required to mold each part and molding pressure must be applied twice during each part cycle, more facilities are required than for conventional SMC molding processes. A modified high throughput process could be employed whereby each mold was cycled through two presses, one for initial molding of the part and the second for injection of the finish coat.

The in-mold finishing process increases material cost to about $0.45 per lb of SMC. Additional facilities and tooling are required to provide a production rate equivalent to SMC II and SMC-R50 molding. Labor requirements are comparable in either process. Thus, the in-mold finished SMC parts would cost approximately 1.12 times equivalent steel parts.

In-mold finishing would be required on only highly visible exterior surfaces and would be used on the front end, roof and door exterior panels. Proportioning cost factors between in-mold finished SMC parts, SMC II parts and SMC-R50 parts would result in an overall cost penalty for all SMC components of 1.13 times the cost of comparable steel parts.

In summary, a judicious choice of SMC materials and processing methods would yield components at a 6 to 13 percent cost penalty compared to mild steel parts, with a significant weight saving.

<u>Composite Monocoque[1]</u>—In vehicle design when a series of component parts are unitized about a central chassis member, a monocoque is realized. The earliest application of this construction technique was in open wheeled "formula" type road racers. Here, a central tub making up the frame and body surfaces is made onto which such subsystems as suspension members and engine are attached. The basic advantage of this design is the minimization of parts since the stressed skin of the monocoque resists load applications instead of requiring a bulky ladder or complicated space frame.

The application of a monocoque bears many advantages over replacing existing steel parts on a one for one basis. First, the number of total parts and subassemblies is reduced. In the monocoque design, see Figure 43, the frame, box floor, front pan, wheel wells, and box walls are combined in a single structure.

Second, the truck has greater structural integrity since the number of parts joining locations is reduced. This fact also helps to minimize material degradation due to corrosion from trapped moisture.

Finally, the monocoque design is an inherent application of composite material fabrication techniques. Composite material structures are limited in size only by the size of the curing

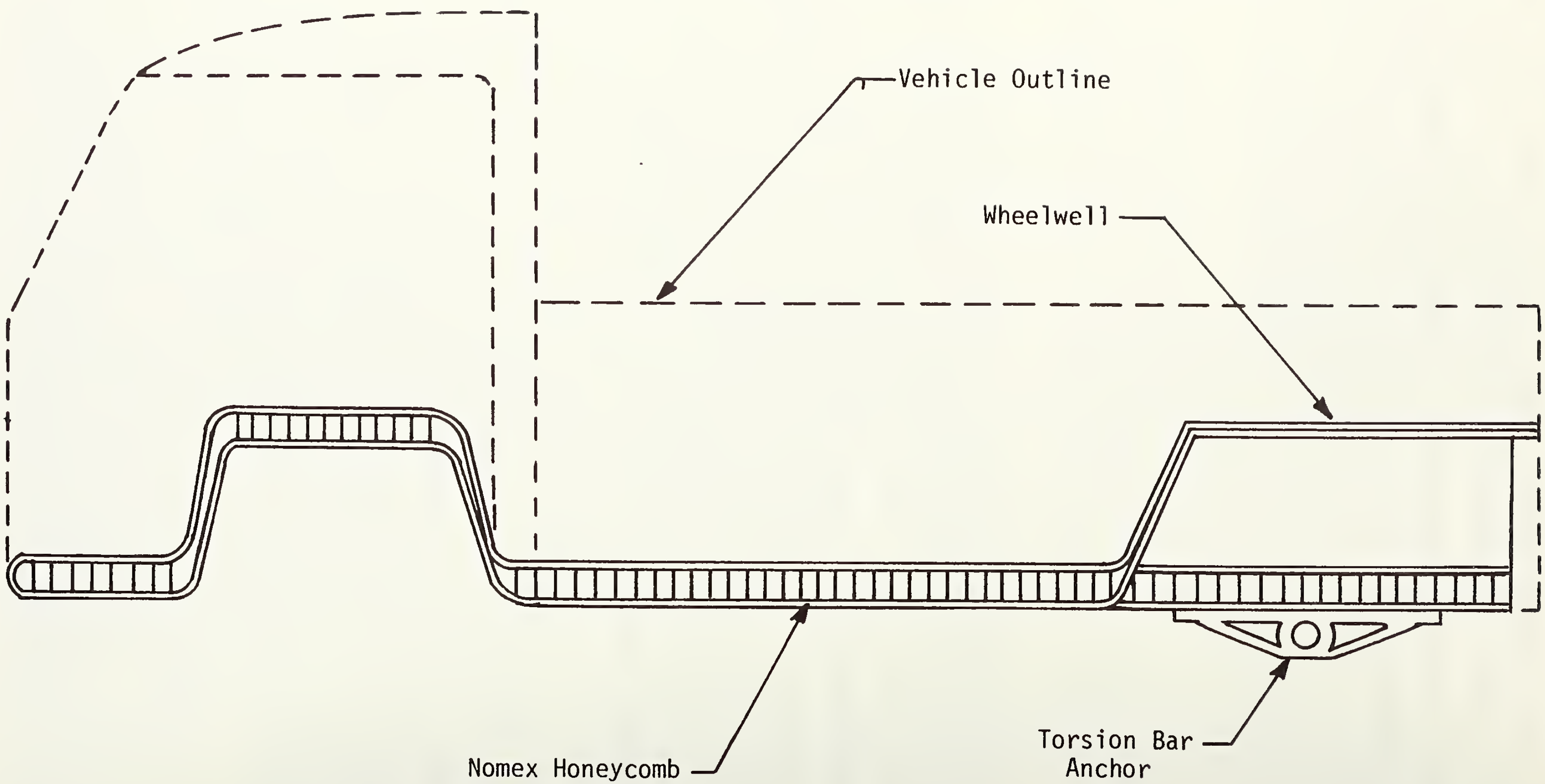


FIGURE 43. ILLUSTRATIVE MONOCOQUE FRAME FOR THE FIAT 238

oven available, whereas: sheet steel parts are limited in size by the size and power of the forming equipment available. A recent example of this size capability of composite structures was the making of a single piece composite wing for a U.S. Marine Harrier jet fighter. Therefore, the technology is available and has seen practical application.

For this design study it was determined that for a commercially, mass produced vehicle such as the Fiat 238, the number of basic structure components can be reduced to two, see Figure 44. These are the monocoque frame and the bulkhead/cab roof assembly. This two-piece concept is an optimization of weight saving, fabrication technique, structural integrity and other design parameters. Table 26 shows the weights for this design. These weights are approximations calculated from design specified dimensions whenever possible. They are in no way an approximation of vehicle curb weight.

TABLE 26.—MONOCOQUE DESIGN WEIGHT ESTIMATES

Component	Conventional Design, Mild Steel		S-Glass Sandwich		GR/EP Sandwich	
	kg	(lb)	kg	(lb)	kg	(lb)
Cargo box frame and floor	92.4	(204)	42.1	(91)	35.4	(78)
Cab floor and frame	59.5	(131)	34.5	(76)	29.5	(65)
Bulkhead	13.0	(29)	9.9	(22)	8.5	(19)
Cab roof	12.5	(28)	9.1	(20)	5.9	(13)
TOTALS	177.4	(392)	95.6	(209)	79.4	(175)
Percent Reduction:						
on components	0		46.1		55.2	
on vehicle	0		7.1		8.5	

Summary of Direct Substitution Weight Reductions—Nonmetallic material substitutions currently available to the industry were applied to truck components having a total weight of 323.1 kg. Excluded from these candidate substitutions was the composite

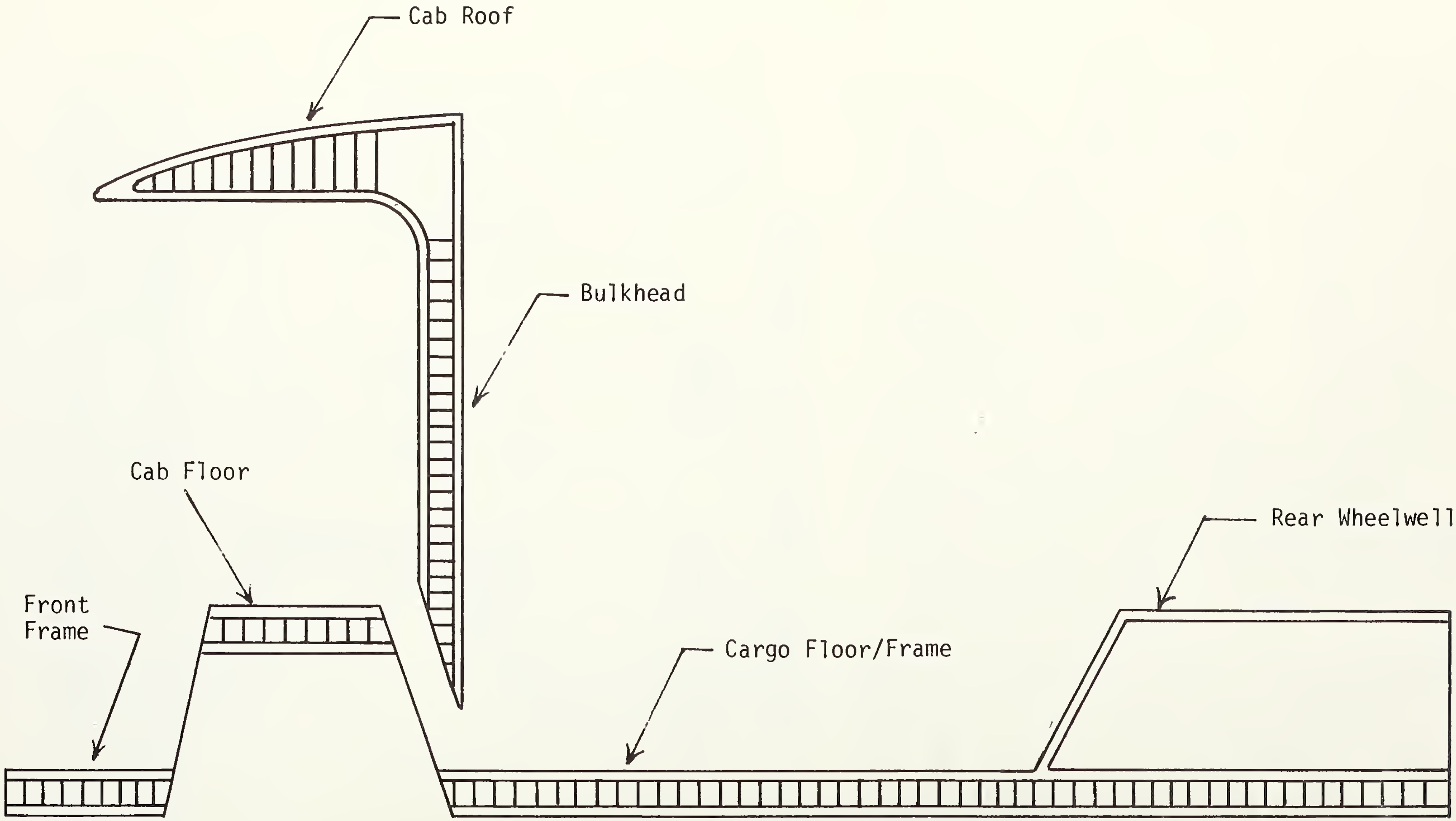


FIGURE 44. CONCEPT FOR MASS PRODUCIBLE HONEYCOMB MONOCOQUE VERSION OF MISSION 1 PICKUP LDT

monocoque. This substitution, although presenting great potential for weight saving, was judged not to be feasible for any segment of the industry by 1985. These reductions are summarized in Table 27. As shown, a 33 percent weight reduction in this weight (106.7 kg) was achieved. Amortizing this reduction over the total base line vehicle weight of 1154.4 kg indicates a saving of 9.2 percent, almost four times as much as achieved through metallic substitutions.

TABLE 27.—CANDIDATE DIRECT SUBSTITUTION OF NONMETALLIC MATERIAL WEIGHT REDUCTION SUMMARY

Item	Weights: Base Line LDT kg	Weights: New LDT kg
1.1 Nonstructural panels	93.4	46.3
Cab roof skin	12.5	8.0
Coweling	38.0	22.7
Box walls	42.9	15.6
Frame and Floor		
Cargo box	92.5	69.6
1.3 Movable panels	43.1	33.0
Two front doors	34.4	27.8
No hardware	22.4	15.8
Hardware	12.0	12.0
Tailgate	8.7	5.2
1.4 Structural panels		
Two wheel wells	41.0	18.8
4.1 Front suspension		
Transverse leaf spring	20.8	14.6
4.2 Rear suspension		
Two torsion bars	15.0	11.2
Two control arms	11.4	10.8
Torsion bar anchor	0.9	8.0
5. Master cylinder	5.0	4.1
TOTALS	323.1	216.4
Percent Reduction		33.0

A direct indication of the increased weight saving obtainable by the monocoque design may be obtained by comparing the additional weight saving projected for the cargo box combined floor and frame. Table 28 shows the weight of this item to be 69.5 kg (153 lb) as a result of direct material substitution. In Table 27, the monocoque design for this subassembly is 42.1 kg (91 lb) in S-glass and 35.4 kg (78 lb) in GR/EP. The respective increases in weight reduction are 39.5 and 49.1. When these savings are amortized over the total LDT weight of 1154 kg (2545 lb), the increased saving amounts to 2.4 and 3.0 percent, respectively. This projects an increase in the total weight saving for the LDT of almost one-third more than achievable by direct substitution. For this reason serious consideration should be given to implementing the monocoque design at the earliest possible time.

5.4 SPECIFIC MATERIAL SUBSTITUTION WEIGHT REDUCTIONS

The specific weight reductions are presented in two steps. First, the component which is reduced by material substitution is listed with the current and new materials and weights. The weight reduction, both in pounds and by percent of the part weight is shown. Finally the percent weight reduction which is to be applied to the subsystem is shown. This percent may be the same as that for the component or it may be greater or smaller. The value depends on the engineering judgment of the part weight reduction relationship to the subsystem as a whole. The second step in the summary process is quite similar to the first, but is performed at the subsystem level rather than the component level. The material designations are not repeated in this step.

Fifteen components from 14 subsystems representing seven of the 11 systems (shown in Table 14) are shown in summary Tables 28 and 29. From the total of 1658 lb of subsystem weight 453 lb were removed. This represents a 27.3 percent weight reduction in the applicable subsystems and 17.8 percent of the total base

TABLE 28. -COMPONENT MATERIAL SUBSTITUTION WEIGHT REDUCTION SUMMARY

Subsys-tem	Selected Components	Base Line		Substitution					Projected Percent Subsystem Reduction
						Weight, lb			
		Material	Wt lb	Basis	Material	New	Saved	% of Old	
1.1	Roof Skin	Mild Steel	28	Equal Stiffness	SMC	14	14	50	40
1.2	Total Frame	Mild Steel	191	Equal Stiffness	950X HSLA	149	42	22	22
1.3	Four Doors	Mild Steel	95	Equal Stiffness	SMC	47.5	47.5	50	50
1.4	Cargo Floor	Mild Steel	58	Equal Stiffness	HSLA	45	13	22.4	22
4.1	Transverse Front Leaf Spring	Mild Steel	45.8	Actual Experiment	GR/EP	11.8	34	75	40
4.2	Control Arms	Mild Steel	53	Equal Stiffness	HSLA	41	12	22	18
4.3	Wheels	Mild Steel	22	On some '79 pass. cars	Stamped Aluminum	12	10	46	27
5.1	Brake Drums (2)	Cast Iron	40	Literature	Alum. w/Cast Iron	27	12	30	20
5.2	Brake Drums (2)	Cast Iron	40	Literature	Alum. w/Cast Iron	27	12	30	20
7.2	Alernator Bracket	Mild Steel	2	Tanner	GR/EP	1.4	0.6	30	17
9.2	Brake Pedal	Mild Steel	4	Tanner	GR/EP	1	3	75	40
10.1	Windows	Glass	60	Literature	Thin Glass and Plastic	30	30	50	50
10.2	Seats	Metal & Misc	53	Corvette	Various Plastics	27	26	50	50
10.7	Miscellaneous	1/2 Steel (assume various materials)	109	Equal Stiffness	Various HSLA	85	24	22	11

line truck weight. The material substitution weight reduction is just a little greater than double that obtained by redesign of the Fiat 238 after substituting a larger engine and downsizing the cargo box.

TABLE 29.—MATERIAL SUBSTITUTION WEIGHT REDUCTION SUMMARY—SUBSYSTEM PROJECTIONS

	Total Weight		Reduction	
Subsystem	Base* Line lb	With Material Substitution lb	lb	%**
1.1 Nonstructural panels	206	124	82	40
1.2 Frame	191	149	42	22
1.3 Movable panels	95	47	48	50
1.4 Structural panels	263	205	58	22
2.3 Exhaust system	27	16	11	42
2.6 Fuel system	18	11	7	40
4.1 Front suspension	162	97	65	40
4.2 Rear suspension	80	66	14	18
4.3 Wheels/tires (5)	225	164	61	27
5.1 Front brakes	80	64	16	20
5.2 Rear brakes	79	63	16	20
7.2 Alternator	18	5	3	17
9.2 Controls	36	2	14	40
10.7 Miscellaneous	218	194	24	11

* From Table 14
** From Table 28

6. VEHICLE WEIGHT PROJECTIONS

This section presents an overview of the methodology and limitations implied by the methodology, used to predict the weights for each of the mission vehicles. These weights are then used to provide comparisons to the U.S. base line (weight efficient) mission LDT. This comparison illuminates the predicted and potential achievable weight reductions.

6.1 METHODOLOGY OVERVIEW

The potential for weight reduction has been based on the results of two different types of studies. The first evaluated the current design for opportunities for weight reduction by means of design, exclusive of materials. The second study identified various materials which could be substituted for those currently being used in the Fiat 238 pickup truck. Some of the material weight reductions proposed could be considered as design weight reduction, or vice versa. This potential overlap has occurred in different components of the vehicle, and when the results of both studies are combined, will not be identifiable or of significance. There has been no overlap or multiple weight reduction presented in the predictions.

The materials chosen for substitution were selected upon a somewhat comparative basis. For example, it seems clear that a honeycomb structure could be incorporated into the design of LDT for large flat surfaces such as the cargo bed floor and cab floor. There still seems to be some problem with the reliability of the bond between the core and the sandwiching surface plates of this type of material/structure. The availability of adequate production and repair facilities was not definable, so that it was considered conservative to not specify a honeycomb composite. Although SMC could be specified for many structural panels and GR/EP for many others, these materials were used more conservatively in the substitution effort. HSLA steel was specified as the substitute material for structural panels and SMC for nonstructural panels. GR/EP was specified for small structural items such as hinges and levers. Because of the large positive offset associated with front wheel drive wheels, a stamped aluminum wheel was specified, rather than a fiber reinforced plastic, to be conservative.

The curb weight for the baseline LDT and the final weight predicted as being potentially achievable do not explicitly include fluids. The curb weight is for a "dry" pickup truck without a driver. The following is a summary of Fiat 238 LDT fluids.

Fluid	Weight, lb
Gasoline	65.0
Miscellaneous (brake fluid, hydraulic fluid, etc.)	19.0
Oil	6.5
Windshield washer fluid	4.4
Total	109.0

The engine selected for mission 1 was the Saab EMS turbocharged L-4 engine. The specifications for missions 3 through 6 required a more powerful engine than that used in mission 1. The General Motors turbocharged V-6 engine was selected for these missions. Table 30 summarizes the driveline (engine and drivetrain) data applicable to these engines.

All of the selected LDT for missions 3 through 6 had larger cargo volumes and corresponding cargo loadspace dimensions than required for the respective specifications. Therefore downsizing these vehicles could be performed. Reduction in curb weight corresponding to reduced loadspace requirements could not be predicted as it had been for mission 1. Cargo box drawings were available for the mission 1 LDT but not for the others. The method used to predict the weight reductions was based, in part, on unit weight data provided in SAE Report 780132.* These two factors were developed:

- weight reduction per inch of vehicle width and pound of CuW: 0.0035 lb/(inch-lb)
- weight reduction per inch of cargo space length and pound of CuW: 0.0018 lb/(inch-lb)

These relationships were applicable to the length and width of the cargo space, but not to reductions in height. This type of weight reduction was accomplished by approximating the weight of a "band of sheet metal" which corresponded to the width and length of the reduced cargo space with the third dimension being the reduction in height. The thickness of the steel sheet metal was taken as 0.035 inch.

TABLE 30.—BASIC DRIVELINE DATA

Item	Saab	GM V-6
Engine:		
CID	122	232
HP	135	175
Torque, ft-lb	160	245
System weight, lb	384	596
Drivetrain: with automatic transmission		
Dry weight, lb	195	298
Used for LDT missions	1	3, 4, 5[a], and 6

[a] The mission 5 LDT, the Bedford, has an automatic transmission which is considered used.

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* Hanson, E. K., "An Overall Design Approach to Improving Passenger Car Fuel Economy", General Motors Corp., Buick Motor Div., February 27 to March 3, 1978 (ASME Technical Paper Series 780132).

The projected weight reductions for material substitutions, whether from direct substitution or integrated design with material substitution, has been based on having the totality of new material technology available. It is recognized that this technology is highly fractionated and does not actually reside in total with any single manufacturer. In fact the technology is distributed over more than just the vehicle producing firms. The component and material supply houses have accumulated considerable experience independently and in cooperation with the vehicle producers.

Sample and limited or prototype production is not a sufficient background on which to base a decision to enter mass production with a technologically new part or subassembly. Considerable preproduction tool and process development is required before even limited production runs are made. Generally serviceability of a new item can only be determined through public use.

The subsystem weight reduction predictions provided by means of redesign and by material substitution are summarized in Tables 16 and 29, respectively. These weight reductions were then aggregated, by system, to determine a projected percentage weight reduction. The system weight reduction was determined by subsystem weight averaging. That is, the total of the weight reductions for the system, obtained from the subsystems, was determined and defined as a percent of the base line system weight. In the case of mission 1, the base line LDT was defined as a modified Fiat 238 with the weight distribution as shown in Table 14.

The percent weight reductions for each system were determined for redesign potential first. Then the potential obtainable by material substitution was determined. Finally the potential weight reduction from combining these two methods was determined. The material weight reduction percentage was applied to the subsystem reduced weight obtained by redesign and then weight averaging, as described above, was accomplished. This then provided three predictions for weight reduction.

Table 31 summarizes the above described weight reduction results. The first column in the table identifies each system of the mission 1 LDT. The next four columns show system and total LDT weights as a result of each step in the described prediction process. The first column shows the initial weights, before the reduction process was started. The second and third columns show, respectively, weights obtained through redesign and material substitution. The fourth column is for the combination of both these weight reduction methods. The second portion of Table 31 summarizes the weight changes which were used to calculate the projected weight reductions. The first two columns report the weight reductions in pounds and percent of the base line system weight due to material substitution. The next pair of columns summarize the same data, but for design weight reductions and the last set of columns are for the combined effect of both weight reductions.

6.2 MISSION VEHICLE PROJECTIONS

The weight reductions determined for the Fiat 238 LDT form the basis for predicting weight reductions for all the other mission vehicles. Each vehicle selected as the most weight efficient (refer to Table 10) was analyzed in a similar manner as the mission 1 LDT. First the engine was upgraded as required by the applicable specification. Then the cargo volume (load space) was resized to meet the specification and an automatic transmission substituted for the manual one, as required. The resulting vehicle is defined as the "base line" for the applicable mission. Then the weight reduction percentages determined for the mission 1 vehicle, as shown in Table 31, were applied to each system of the other LDT to determine similar weight reductions. Tables 32 through 35 summarized these calculations for missions 3 through 6.

TABLE 31. WEIGHT REDUCTION SUMMARY-PERSONAL USE PICKUP LTD

Mission 1 ; Base LDT Fiat 238; Base Curb Weight 2541 lb; Base Engine 52 hp; 77.4 torque, ft/lb;
Potential LDT: Engine 4 cylinder; Turbocharged yes; CID 122; 135 hp; 160 torque, ft/lb;
Weights: Curb 1891 lb; Cargo 1160 lb; Gross 3051 lb; Curb Weight Ratio: Spec/Base 0.728

System	Total Weight, lb				Changes					
					Material		Design		Total	
	Base Line	With Design	With Material	Final	Pound	Percent	Pound	Percent	Pound	Percent
1. Structure	755	742	525	516	230	30.5	13	1.7	239	31.7
2. Engine	384	364	366	347	18	4.7	20	5.2	37	9.7
3. Drivetrain	195	195	195	195	0	0.0	0	0.0	0	0.0
4. Suspension	467	406	327	284	140	30.0	61	13.1	183	39.1
5. Brakes	168	136	136	110	32	19.1	32	19.1	58	34.5
6. Steering	67	60	67	60	0	0.0	7	10.4	7	10.4
7. Electrical	68	61	65	58	3	4.4	7	10.3	10	14.2
8. Bumper	14	14	14	14	0	0.0	0	0.0	0	0.0
9. Instruments & Controls	46	46	32	25	14	30.4	0	0.0	14	30.4
10. Miscellaneous Functional	377	301	353	282	24	6.4	76	20.2	95	25.3
11. Optional Systems	0	0	0	0	0	0.0	0	0.0	0	0.0
12. Total	2541	2325	2080	1891	461	18.1	216	8.5	643	25.3

TABLE 32. -WEIGHT REDUCTION SUMMARY-COMMERCIAL USE PICKUP LDT

Mission 3; Base LDT 307DT; Base Curb Weight 3109 lb; Base Engine 64 hp; 101 ft-lb Torque;
Engine: V-6 cylinders; Turbocharged yes; CID 232; 125 hp; 245 ft-lb Torque;
Load space: Volume 75 cu ft; Length 76.5 in.; Width 73.5 in.; Height 19.5 in.;
Weights: Curb 2437 lb; Cargo 2100 lb; Gross 4537 lb; Curb Weight Ratio: Spec/Base 1.054

System and Subsystem	Total Weight, lb				Changes					
					Material		Design		Total	
	Base Line	With Design	With Material	Final	Pound	Percent	Pound	Percent	Pound	Percent
1. Structure	1181	1118	821	777	360	30.5	63	5.3	404	34.2
2. Engine	597	596	569	568	28	4.7	1	0.2	29	4.9
3. Drivetrain	274	298	274	298	0	0.9	-24[a]	-8.8	-24	-8.8
4. Suspension	525	525	368	368	158	30.0	0	0.0	157	39.9
5. Brakes	136	136	110	110	26	19.1	0	0.0	26	19.1
6. Steering	53	53	53	53	0	0.0	0	0.0	0	0.0
7. Electrical	50	45	43	39	7	14.4	5	10.3	11	23.0
8. Bumper	25	25	25	25	0	0.0	0	0.0	0	0.0
9. Instruments & Controls	34	34	24	24	10	30.4	0	0.0	10	30.4
10. Miscellaneous Functional	234	187	219	175	15	6.4	47	20.2	59	25.2
11. Optional Systems	0	0	0	0	0	0.0	0	0.0	0	0.0
12. Total	3109	3017	2506	2437	604	19.4	92	3.0	672	27.6

[a] minus means increase not reduction

TABLE 33. -WEIGHT REDUCTION SUMMARY-PERSONAL USE VAN LDT

Mission 4; Base LDT 2528; Base Curb Weigh 3541 lb; Base Engine: 71 hp; 108 ft-lb Torque;
Engine: V-6 cylinders; Turbocharged yes; CID 232; 175 hp; 245 ft-lb Torque;
Load space: Volume 108 cu ft; Length 55 in.; Width 68 in.; Height 50 in.;
Weights: Curb 2384 lb; Cargo 1780 lb; Gross 4164 lb; Curb Weight Ratio: Spec/Base 0.895

System and Subsystem	Total Weight, lb				Changes					
					Material		Design		Total	
	Base Line	With Design	With Material	Final	Pound	Percent	Pound	Percent	Pound	Percent
1. Structure	1481	926	1029	644	452	30.5	555	37.5	837	56.5
2. Engine	434	596	414	568	20	4.7	-162[a]	-37.3	-134	-30.9
3. Drivetrain	302	295	272	266	30	10.0	7	2.3	37	12.1
4. Suspension	589	589	412	412	177	30.0	0	0.0	177	30.0
5. Brakes	136	136	110	110	26	19.1	0	0.0	26	19.1
6. Steering	53	53	40	40	13	25.0	0	0.0	13	25.0
7. Electrical	59	53	51	45	8	14.4	6	10.3	14	23.1
8. Bumper	50	48	40	38	10	20.0	2	4.0	12	23.2
9. Instruments & Controls	40	40	28	28	12	30.4	0	0.0	12	30.4
10. Miscellaneous Functional	397	317	292	233	105	26.4	80	20.2	164	41.2
11. Optional Systems	0	0	0	0	0	0.0	0	0.0	0	0.0
12. Total	3541	3053	2688	2384	853	24.1	488	13.8	1158	32.7

[a] minus means increase not reduction

TABLE 34. -WEIGHT REDUCTION SUMMARY-COMMERCIAL USE VAN LDT

Mission 5 ; Base LDT CF280; Base Curb Weight 2986 lb; Base Engine: 80.5 hp; 124 ft-lb Torque;
Engine: V-6 cylinders; Turbocharged yes; CID 232; 175 hp; 245 ft-lb Torque;
Load space: Volume 215 cu ft; Length 114 in.; Widht 68 in.; Height 48 in.;
Weights: Curb 2308 lb; Cargo 2300 lb; Gross 4617 lb; Curb Weight Ratio: Spec/Base 1.009

System and Subsystem	Total Weight, lb				Changes					
					Material		Design		Total	
	Base Line	With Design	With Material	Final	Pound	Percent	Pound	Percent	Pound	Percent
1. Structure	1005	851	698	591	307	30.5	154	15.3	414	41.1
2. Engine	499	596	476	568	23	4.7	-97[a]	-19.4	-69	-13.8
3. Drivetrain	312	312	281	281	31	10.0	0	0.0	31	10.0
4. Suspension	584	589	409	412	175	30.0	0	0.0	172	29.4
5. Brakes	168	168	136	136	32	19.1	0	0.0	32	19.1
6. Steering	48	48	36	36	12	25.0	0	0.0	12	25.0
7. Electrical	59	59	51	51	8	14.4	0	0.0	8	14.4
8. Bumper	11	11	11	11	0	0.0	0	0.0	0	0.0
9. Instruments & Controls	40	40	28	28	12	30.4	0	0.0	12	30.4
10. Miscellaneous Functional	260	207	243	194	17	6.4	53	20.2	66	25.3
11. Optional Systems	0	0	0	0	0	0.0	0	0.0	0	0.0
12. Total	2986	2881	2369	2308	617	20.7	110	3.7	678	22.7

[a] minus means increase not reduction

TABLE 35. -WEIGHT REDUCTION SUMMARY-PERSONAL USE UTILITY LDT

Mission 6 ; Base LDT K10; Base Curb Weight 4122 lb; Base Engine: 165 hp, 255 ft-lb Torque;
Engine: V-6 cylinders; Turbocharged yes; CID 232; 175 hp; 245 ft-lb Torque;
Load space: Volume 80 cu ft; Length 66 in.; Width 54 in.; Height 37 in.;
Weights: Curb 2972 lb; Cargo 1200 lb; Gross 4172 lb; Curb Weight Ratio: Spec/Base 0.549

System and Subsystem	Total Weight, lb				Changes					
					Material		Design		Total	
	Base Line	With Design	With Material	Final	Pound	Percent	Pound	Percent	Pound	Percent
1. Structure	1379	1256	958	873	421	30.5	123	8.9	506	36.7
2. Engine	753	596	718	568	35	4.7	157	20.8	185	24.6
3. Drivetrain	761	744	685	670	76	10.0	17	2.2	91	12.0
4. Suspension	493	435	345	305	148	30.0	58	11.8	189	38.2
5. Brakes	161	161	130	130	31	19.1	0	0.0	31	19.1
6. Steering	61	61	46	46	15	25.0	0	0.0	15	25.0
7. Electrical	58	52	50	45	8	14.4	6	10.3	13	23.3
8. Bumper	58	49	46	39	12	20.0	9	15.5	19	32.4
9. Instruments & Controls	41	41	29	29	12	30.4	0	0.0	12	30.4
10. Miscellaneous Functional	357	285	334	267	23	6.4	72	20.2	90	25.3
11. Optional Systems	0	0	0	0	0	0.0	0	0.0	0	0.0
12. Total	4122	3680	3341	2972	781	18.9	442	10.7	1151	27.9

6.3 WEIGHT REDUCTION COMPARISONS

The overall weight reduction potential is predicted based upon U.S. weight efficient LDT. The predicted reductions presented thus far have been for European vehicles, except for mission 6. Our methodology is based upon the assumption that the basic European design represents a first (and significant) design weight reduction. Therefore the total weight reductions should be related to the U.S. fleet for comparative purposes.

To this end, the basic data used to predict system potential weight reductions have been applied to the appropriate U.S. vehicles. Tables 36 through 40 represent the data from Tables 31 through 35, but are based upon U.S. selected vehicles.

Comparing the specified weights for the U.S. LDT and the predicted reduced weights resulting from design and material substitution shows that significant results should be obtainable. For all practical purposes the specification weights were achieved except for mission 6. This latter mission was the only one for which no comparable European vehicle was identified. The predicted mission 1 LDT came within 5 percent of achieving the specified weight reduction. The other three mission vehicles exceeded the specified weight reductions by more than 50 to 100 percent.

It is interesting to note that the greatest poundage weight reduction was achieved for the mission 1 pickup truck followed closely by the mission 3 pickup truck. On the order of 25 percent less weight was predicted removable from the vans than from the pickup trucks. About 35 percent less weight was predicted removable from the personal use utility vehicle.

There are several possibilities related to the lesser actual poundage weight reductions obtained for vans--over and above the consideration that actual study of van LDT was not undertaken. Firstly, these vehicles could be better designed for weight efficiency. In general the van is a more "gentile" vehicle than the "rough and ready" pickup.

TABLE 36. WEIGHT SUMMARY-PERSONAL USE PICKUP TRUCK

System	Total Weight, lb				Weight Changes from U.S. LDT Due to:					
	U.S. LDT[a]	Only Design[b]	Only Material	Material and Design	Only Design		Only Material Substitution		Design/Material Substitution	
					Pound	Percent	Pound	Percent	Pound	Percent
1. Structure	1401	742	974	516	659	47	427	31	885	63
2. Engine	709	364	676	347	345	49	33	5	362	51
3. Drivetrain	402	195	402	195	207	51	0	0	207	51
4. Suspension	508	406	356	284	102	20	152	30	224	44
5. Brakes	156	136	126	110	20	13	30	19	46	29
6. Steering	61	60	61	60	1	2	0	0	1	2
7. Electrical	58	61	55	58	-3[c]	-5	3	4	0	0
8. Bumper	29	14	29	14	15	52	0	0	15	52
9. Instruments & Controls	41	46	29	25	-5	-12	12	30	16	39
10. Miscellaneous Functional	321	301	300	282	20	6	21	6	39	12
11. Optional Systems	0	0	0	0	0	0	0	0	0	0
12. Total	3686	2325	3008	1891	1361	37	678	18	1795	49

[a] Ford F100

[b] Fiat 238

[c] Minus means increase not reduction.

TABLE 37. -WEIGHT SUMMARY-COMMERCIAL USE PICKUP TRUCK

System	Total Weight, lb				Weight Changes from U.S. LDT Due to:					
	U.S. LDT [a]	Only Design [b]	Only Material	Material and Design	Only Design		Only Material Substitution		Design/Material Substitution	
					Pound	Percent	Pound	Percent	Pound	Percent
1. Structure	1575	1118	1095	777	457	29	480	31	798	51
2. Engine	796	596	761	568	200	25	35	5	228	29
3. Drivetrain	452	298	448	298	154	34	4	1	154	34
4. Suspension	572	525	400	368	47	8	172	30.0	204	36
5. Brakes	174	136	141	110	38	22	33	19.0	64	37
6. Steering	70	53	70	53	17	24	0	0	17	24
7. Electrical	66	45	56	39	21	32	10	14	27	41
8. Bumper	33	25	26	25	8	24	7	0	8	24
9. Instruments & Controls	46	34	32	24	12	26	14	30	22	48
10. Miscellaneous Functional	361	187	338	175	174	48	23	6.4	186	52
11. Optional Systems	0	0	0	0	0	0	0	0	0	0
12. Total	4145	3017	3367	2437	1128	27	778	19	1708	41

[a] Dodge D200

[b] Mercedes-Benz 307DT

TABLE 38. -WEIGHT SUMMARY-PERSONAL USE VAN

System	Total Weight, lb				Weight Changes from U.S. LDT Due to:					
	U.S.[a] LDT	Only[b] Design	Only Material	Material and Design	Only Design		Only Material Substitution		Design/Material Substitution	
					Pound	Percent	Pound	Percent	Pound	Percent
1. Structure	1353	926	940	644	427	32	413	30.5	709	52
2. Engine	709	596	676	568	113	16	33	4.7	141	25
3. Drivetrain	402	295	362	266	107	27	40	10.0	136	34
4. Suspension	508	589	356	412	-81[c]	-16	152	30.0	96	19
5. Brakes	156	136	126	110	20	13	30	19.1	46	29
6. Steering	61	53	46	40	8	13	15	25.0	21	34
7. Electrical	58	53	50	45	5	9	8	14.4	13	22
8. Bumper	50	48	40	38	2	4	10	20.0	12	24
9. Instruments & Controls	41	40	29	28	1	2	12	30.4	13	32
10. Miscellaneous Functional	432	317	318	233	115	27	114	26.4	199	46
11. Optional Systems	0	0	0	0	0	0	0	0.0	0	0
12. Total	3770	3053	2943	2384	717	19	827	22.0	1386	37

[a] B100 Sportsman

[b] Volkswagon LT28

[c] minus means increase not reduction

TABLE 39. -WEIGHT SUMMARY-COMMERCIAL USE VAN

System	Total Weight, lb				Weight Changes from U.S. LDT Due to:					
					Only Design		Only Material Substitution		Design/Material Substitution	
	U.S. LDT[a]	Only Design[b]	Only Material	Material and Design	Pound	Percent	Pound	Percent	Pound	Percent
1. Structure	1368	851	951	591	517	38	417	30.5	777	57
2. Engine	709	596	676	568	113	16	33	4.7	144	20
3. Drivetrain	402	312	362	281	90	22.1	40	10.0	121	30
4. Suspension	513	589	359	412	-76[c]	-15	154	30.0	101	20
5. Brakes	156	168	126	136	-12	- 8	30	19.1	20	13
6. Steering	61	48	46	36	13	21	15	25.0	25	41
7. Electrical	58	59	50	51	-1	- 2	8	14.4	7	12
8. Bumper	50	11	50	11	39	78	0	0.0	39	78
9. Instruments & Controls	41	40	29	28	1	2	12	30.4	13	32
10. Miscellaneous Functional	257	207	241	194	50	19	16	6.4	63	25
11. Optional Systems	0	0	0	0	0	0	0	0.0	0	0
12. Total	3615	2881	2890	2308	734	20	725	20.0	1307	36

[a] B200 Tradesman

[b] CF280

[c] minus means increase not reduction

TABLE 40. -WEIGHT SUMMARY-PERSONAL USE UTILITY VEHICLE

System	Total Weight, lb				Weight Changes from U.S. LDT Due to:					
					Only Design		Only Material Substitution		Design/Material Substitution	
	U.S. LDT[a]	Only Design	Only Material	Material and Design	Pound	Percent	Pound	Percent	Pound	Percent
1. Structure	1379	1256	958	873	123	9	421	31	506	37
2. Engine	753	596	718	568	157	21	35	5	185	25
3. Drivetrain	761	744	685	670	17	2	76	10	91	12
4. Suspension	493	435	345	305	58	12	148	30	188	38
5. Brakes	161	161	130	130	0	0	31	19	31	19
6. Steering	61	61	46	46	0	0	15	25	15	25
7. Electrical	58	52	50	45	6	0	8	14	13	22
8. Bumper	58	49	46	39	9	16	12	20	19	32
9. Instruments & Controls	41	41	29	29	0	0	12	30	12	29
10. Miscellaneous Functional	357	285	334	267	72	20	23	6	90	25
11. Optional Systems	0	0	0	0	0	0	0	0	0	0
12. Total	4122	3680	3341	2972	442	11	781	19	1150	28

[a] GM K10 Blazer

Alternatively as a class of vehicles, they weigh less so that the application of relatively fixed percentages of weight reduction would result in lesser weight reduction. This shows up in both pounds reduced and percentage reduction.

The personal use utility vehicle is a special case unto itself. It is the heaviest of all the vehicles after redesign, even though it weighed about the same as the commercial pickup. This may not be surprising as it has four-wheel drive which was assumed uneffected by either design or material substitution. Examination of the data shows that the design weight reduction is much less for this vehicle than the others. As pointed out in the previous subsection, there was no parallel European LDT and as a result an important design weight reduction component was missing. This situation may be considered an argument for integrated design applied to specific vehicle designs. True this could effect producibility and therefore cost, but careful across-the-board family-of-vehicle design could provide compensations.

7. INTEGRATED CONCEPTUAL DESIGN

The Fiat Research Center in response to the mission criteria as presented in the preceding sections has developed an integrated conceptual design (ICD) LDT. This ICD was chosen to maximize potential impact on the existing fleet. The vehicle selected is the personal use pickup truck corresponding to approximately 50 percent of total LDT usage in the United States based upon the U.S. Bureau of Census 1972 Truck Inventory and Use Survey.

7.1 GENERAL DESIGN PHILOSOPHY

The ICD is based upon projecting the existing LDT specifications into the 1985 time frame and incorporating European design philosophies into the construction of an American specification vehicle. The design methodology utilizes the detailed mission specifications for the personal use pickup as presented in Section 2 of this report. Based upon these specifications the following design considerations were undertaken.

The cargo volume, and more significantly the length and width of the cargo box, established specific design requirements for the ICD. The propulsion system was required to provide a specific level of power as related to design weight of the vehicle. It was also necessary to incorporate an automatic transmission into the design. Therefore, the first task was to select a propulsion system from the existing vehicles currently available at Fiat which provided the necessary design requirements and which were capable of being utilized in the ICD. The second task was to provide a space allocation for the propulsion system in the ICD. The first propulsion system selected was chosen from the Lancia Beta automobile which has a four-cylinder transverse engine coupled to an existing automatic transmission. The second propulsion system selected was from a Lancia Gamma automobile with the propulsion system located longitudinally in the vehicle. However, the second solution required incorporation of a new design automatic transmission which is currently not in production for U.S. vehicles.

Proceeding from the general layout of the propulsion system, the next step encompassed the development of overall specifications for the width and length of the vehicle. The 50 inch dimension between the rear wheel wells, coming from the mission specifications, provided a minimum design goal. It was possible, from this dimension and the identification of suitable tires and suspension components, to specify the rear track for the vehicle. Similarly, the front track for the vehicle was established from the required shoulder space as indicated in the mission specifications. This shoulder room dimension was obtained from the requirement to provide one driver and one passenger seat with an occasional seating position between. The chosen solution was to provide a single seat for the driver and a second seat of additional width for one or two passengers as required in the vehicle.

The overall length of the vehicle was established from the requirement for the location of the propulsion system, the passenger compartment, and the minimum cargo space as defined by the mission specifications. Within this length constraint it was necessary to establish a characteristic dimension for the wheelbase of the vehicle. Based upon the experience of the Fiat designers, it was not considered feasible to provide a wheelbase of less than 24 mm in order to assure handling stability for the vehicle, as well as providing a minimum level of ride comfort.

In developing the length for the cargo box, the first design attempt was based upon using the tailgate in a horizontal position to provide the necessary load space length of 96 inches. Depending upon the requirement for rear overhang and wheelbase, in one solution it was necessary to provide a cargo box wherein the length of the load space did not require using the tailgate in a horizontal position. In establishing the floor height of the vehicle the design goal was to maintain the height as low as possible to promote easy loading. Obviously the position of the floor height was constrained by the drivetrain placement and the suspension of the vehicle plus the consideration of minimum required ground clearance. However, within these constraints the floor height was designed as low as possible.

All of the ICD solutions developed are based upon a front wheel drive configuration to maximize the weight efficiency. The cargo weight as required in the mission specifications is low enough that the vehicle can be designed with a high inherent weight efficiency. Of the three design solutions developed two basic configurations were utilized for the drivetrain placement. One with a transverse engine, ahead of the driver and two with a longitudinal placement of the drivetrain either ahead of or below the driver compartment.

All of the ICD solutions utilize a front suspension derived from the existing Lancia Beta automobile. This design consists of a McPherson strut with a coil spring for control of the front driven wheels. The rear suspension is derived from Lancia Fulvia rigid axle with elliptic leaf spring. However it was necessary to revise the position of the leaf spring to minimize the floor height of the vehicle.

The body and structure for the ICD have been modified from the existing Fiat 238 pickup truck to satisfy the new propulsion system and suspension configurations. Provisions for existing U.S. safety standards were integrated into the design development process. The rear suspension was specifically developed around a leaf spring configuration instead of the torsion bar assembly as utilized on the Fiat 238 because of the low cargo weight requirements. If a torsion bar suspension were required, increased weight structural members would have to be added into the cargo bed structure to provide for anchoring of the torsion bar system. Therefore, the leaf spring suspension was chosen as an optimum design.

The longitudinal members of the chassis were substantially stiffened in order to provide the necessary crush resistance and make possible adaptation of impact bumpers in the vehicle. This requirement indicated additional modifications to the vehicle structure. The structural members for the cargo box are constructed from 1 mm thick low carbon steel, the same material as used in the cargo box floor. The longitudinal members for the frame are constructed from 1.5 mm thick material and the external sheet metal components are 0.8 mm material.

7.2 DESIGN METHODOLOGY

The specific methodology used in developing the new vehicle design is discussed herein. From the presentation of the mission specifications, functional design characteristics have been developed. These functional specifications identified specific design limitations that had to be incorporated in the ICD vehicle. Additionally, much of the design was based upon existing available technology to minimize extraneous design problems. Therefore, the foremost issue confronted was the arrangement of the powertrain and cab into the structure of the vehicle to satisfy U.S. safety standards.

Beginning from the existing known components for the powertrain, specific design dimensions were established. These dimensions included location of: principal functional masses for the vehicle; design points for component attachment; and power transmission shafts. One of the functional specifications provided from the mission analyses was the projected GVW for the final ICD vehicle. This projection allowed for immediate selection of an appropriate wheel and tire design.

The design commenced by determining the wheel centerline positions and principal propulsion system component placement within a structure constrained by propulsion shaft angle limitations. With the propulsion system incorporated into the design, the next problem to be dealt with was the development of the specific passenger compartment layout. The seat position relative to the steering wheel and pedals; the top of the cab related to seat position; and the windshield position relative to steering wheel and seat placement, were treated independently in order to arrive at a functional solution within the mission specifications. Based upon the development of interior passenger compartment dimensions, the cab structure was placed onto the powertrain layout previously defined. The integration of these two design features provided the skeleton structure for the development of the vehicle.

The selected suspension designs were placed into the developing vehicle structure. Depending upon the specific suspension type selected for investigation and attachment points for the propulsion system, the frame structure underneath the passenger compartment area was next defined. This structure was then extended back to the cargo area to provide main support for the cargo box.

The basic configuration for the ICD was defined by the preceding method and additional detail is prepared, as necessary, to incorporate specific required design features. One typical issue encountered was the provision for achieving an acceptable level of front impact safety. The placement of the pedal position relative to the front axle had been identified early in the design development, however, to provide sufficient crush area to withstand frontal impact the location of the front bumper was selected approximately 18 inches forward of the defined pedal position. The vertical positioning of the longitudinal support members have been defined and now it is necessary to develop the plan view for this support structure. From a design standpoint it is necessary to maintain these members in as straight a position as possible.

The preliminary design layout is prepared at this point, and additional development now implemented in order to finalize a specific ICD concept. This design methodology, using functional specifications developed directly from the mission analysis, ensures that all design criteria are met for the final developed design.

After the design is prepared, an estimation of the subsystem and total vehicle weights was made. The methodology utilized during the evaluation of weight projection for the three solutions is as follows:

Vehicle is broken down into four main categories or assemblies

- Engine and transmission
- Chassis
- Body Frame
- Electrical System

For each of them a further breakdown is developed through the system and subsystem level down to the component level such as:

- Engine and transmission: case, piston rods, gear box, gears, bearings, shafts,.....
- Chassis: tank, transmission levers, mufflers, steering system, front and rear suspensions, brakes, propulsion system suspension, wheels,.....
- Body frame: front rear lateral roof frame, internal and external panels, floor, windshield, glasses, doors, radiator, seats,.....
- Electrical equipment: generator, starting motor, voltage regulator, battery, lights, instruments, wiper,.....

Based upon this components list, the available drawings and component weight data were collected and a component weight list prepared.

In the specific cases, we went down only to the component level for those components completely new (body - structure components) while for instance the engine weight was already available at Lancia. As far as the body weight is concerned, material type, thickness, dimensions and, in general, drawings were utilized to prepare each component weight. Moreover some corrections were made, based upon our experience, comparing weights of similar groups with the estimated ones. Using this process the normal level of accuracy achieved is 90 percent.

7.3 CANDIDATE ICD SOLUTIONS

Three closely related design solutions have been developed and are presented in the following material. The first solution has been developed in greater detail than the subsequent two due to the longer development time available. Initially, this first solution was thought to be the optimum configuration for the ICD vehicle. However, subsequent evaluation indicates that the alternative solutions offered the best possible tradeoff between vehicle design and required performance.

Solution Number 1—Referring to Figure 45 a general layout of solution 1 is presented. The general mechanical components selected for this configuration include the 2 liter opposed four-cylinder Lancia Gamma engine coupled, through a torque converter, to a four-speed automatic transmission. For this solution the engine is placed in the cab of the vehicle, under the seats in a longitudinal position, with the transmission trailing behind. The differential is integrated into the transmission and the output shafts are directly coupled to the front wheel hubs. The attachment points for the powertrain are connected to a small subframe that supports the principal powertrain components and front suspension of the vehicle. This subframe has been attached to the chassis body shell of the vehicle as an integral unit.

The front suspension is a McPherson type, with coil spring over shock absorber, developed from the Lancia Beta. The steering system utilizes a rack and pinion actuating system coupled directly to the front wheel drive hubs. The rear suspension is derived from a Lancia Fulvia with the elliptical spring reversed for its position in the ICD. This suspension consists of a rigid axle with leaf springs incorporating a panhard bar and shock absorber system.

The driver seat is adjustable fore and aft, with the passenger seat rigidly fixed atop the engine compartment. Due to the minimum 2400 mm wheelbase dimension, the resultant cargo box length (because of the placement of the rear attachment points for the suspension) was increased to 2390 mm without tailgate.

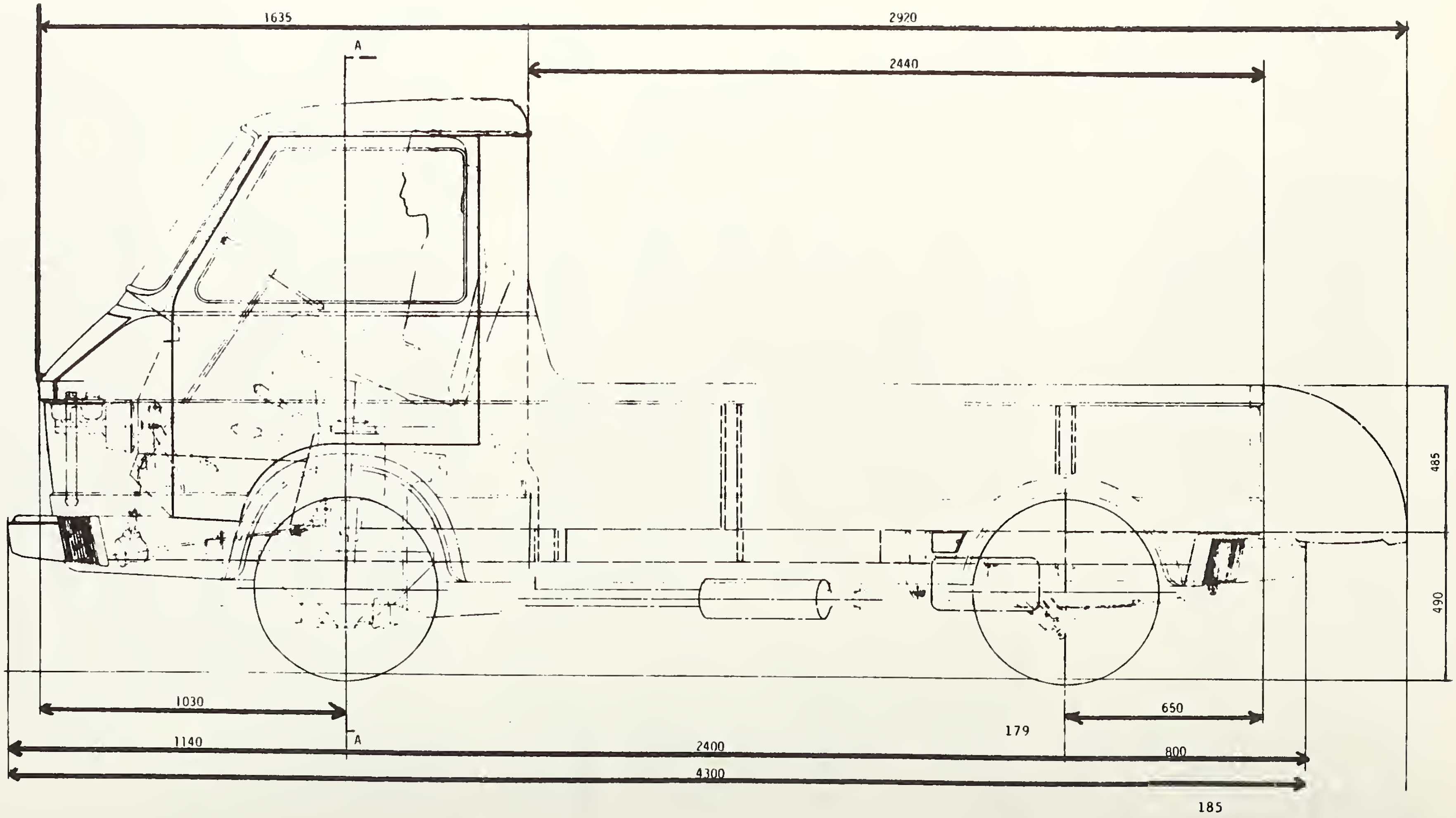

FIGURE 45A. ICD SOLUTION 1 GENERAL VEHICLE LAYOUT

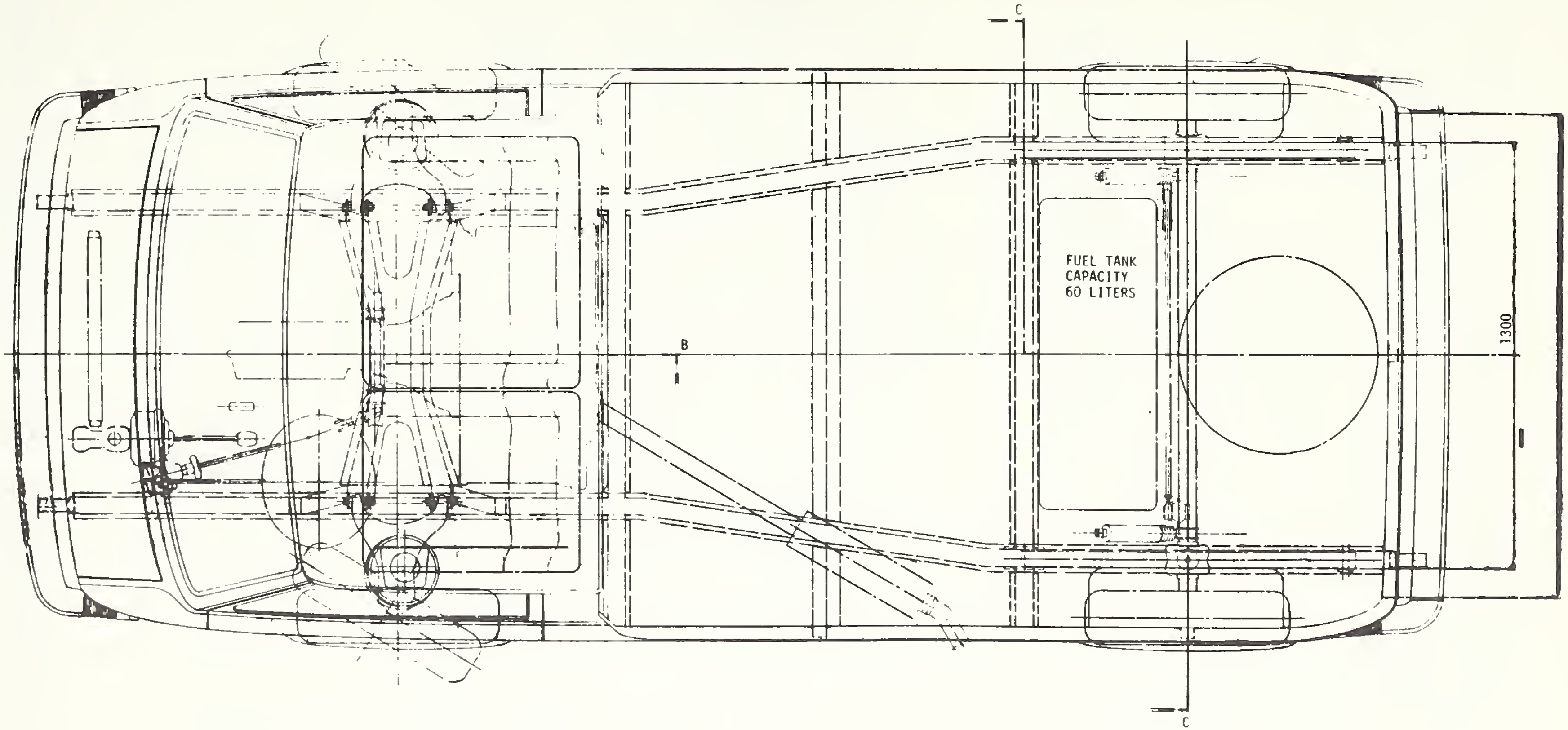

FIGURE 45B. ICD SOLUTION 1 PLAN VIEW

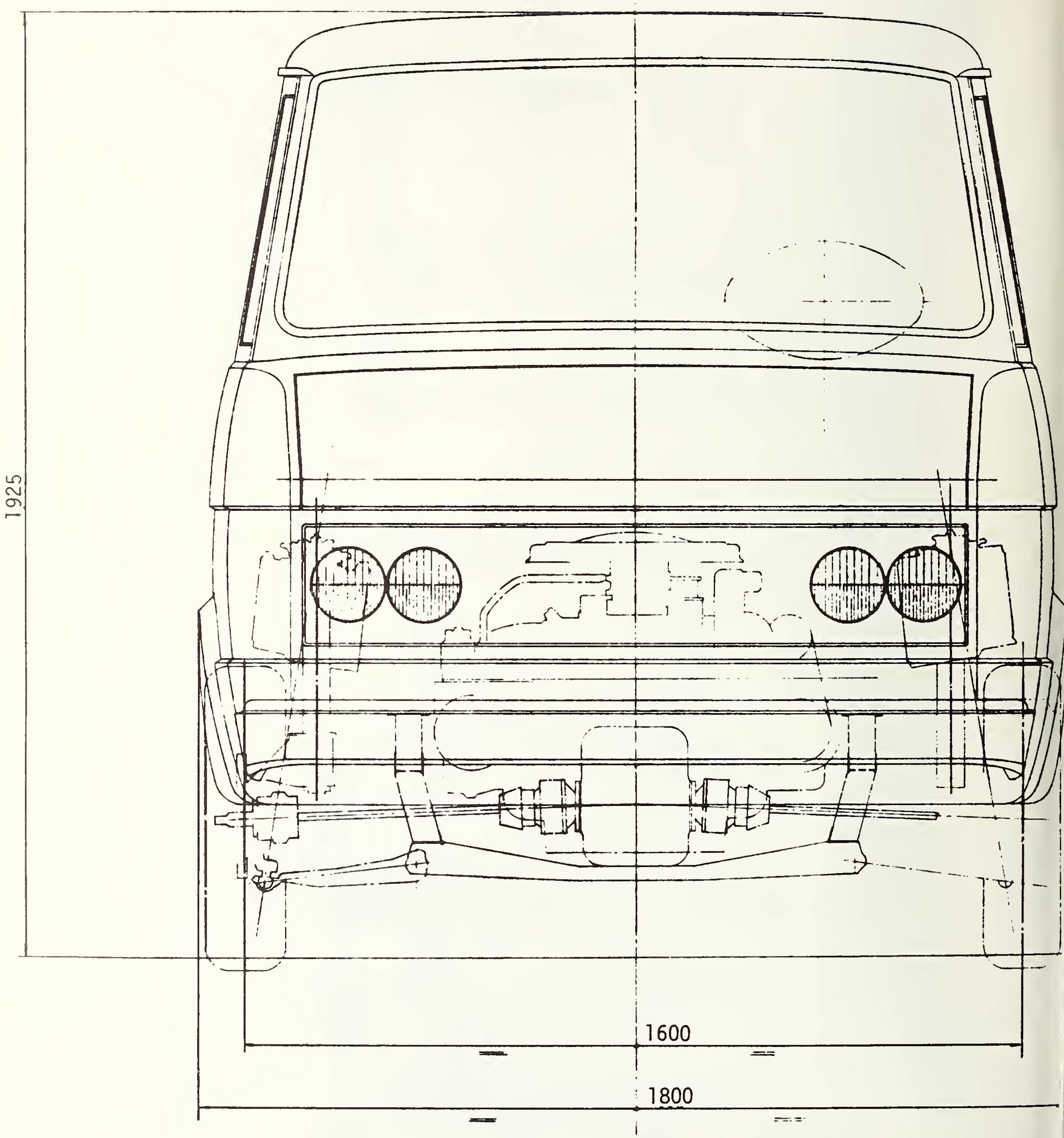

FIGURE 45C. ICD SOLUTION 1 CAB CROSS SECTION AND POWERTRAIN LAYOUT

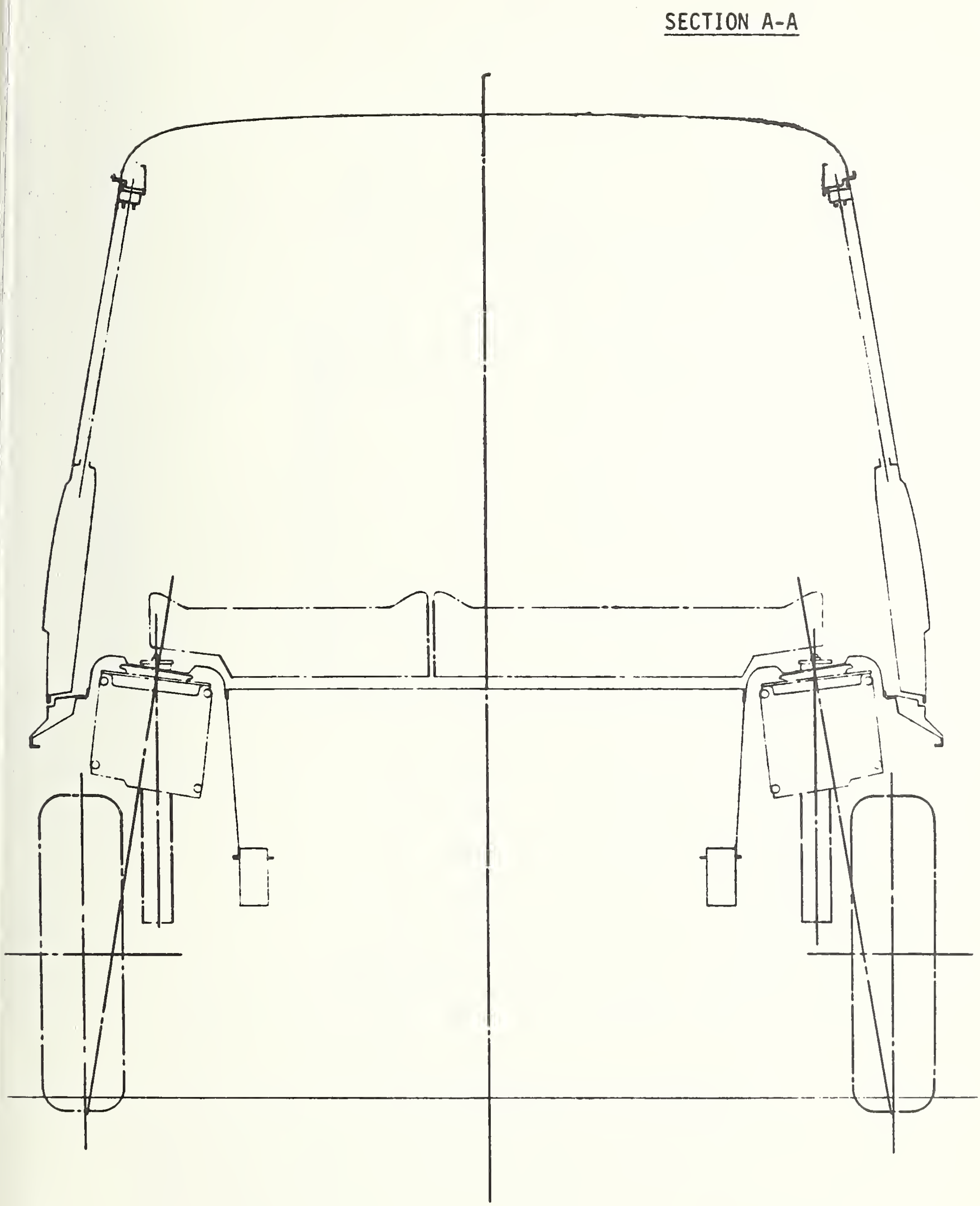

FIGURE 45D. ICD SOLUTION 1 FRONT SUSPENSION GEOMETRY

SECTION C-C
(SPREAD OUT FLAT 90°)

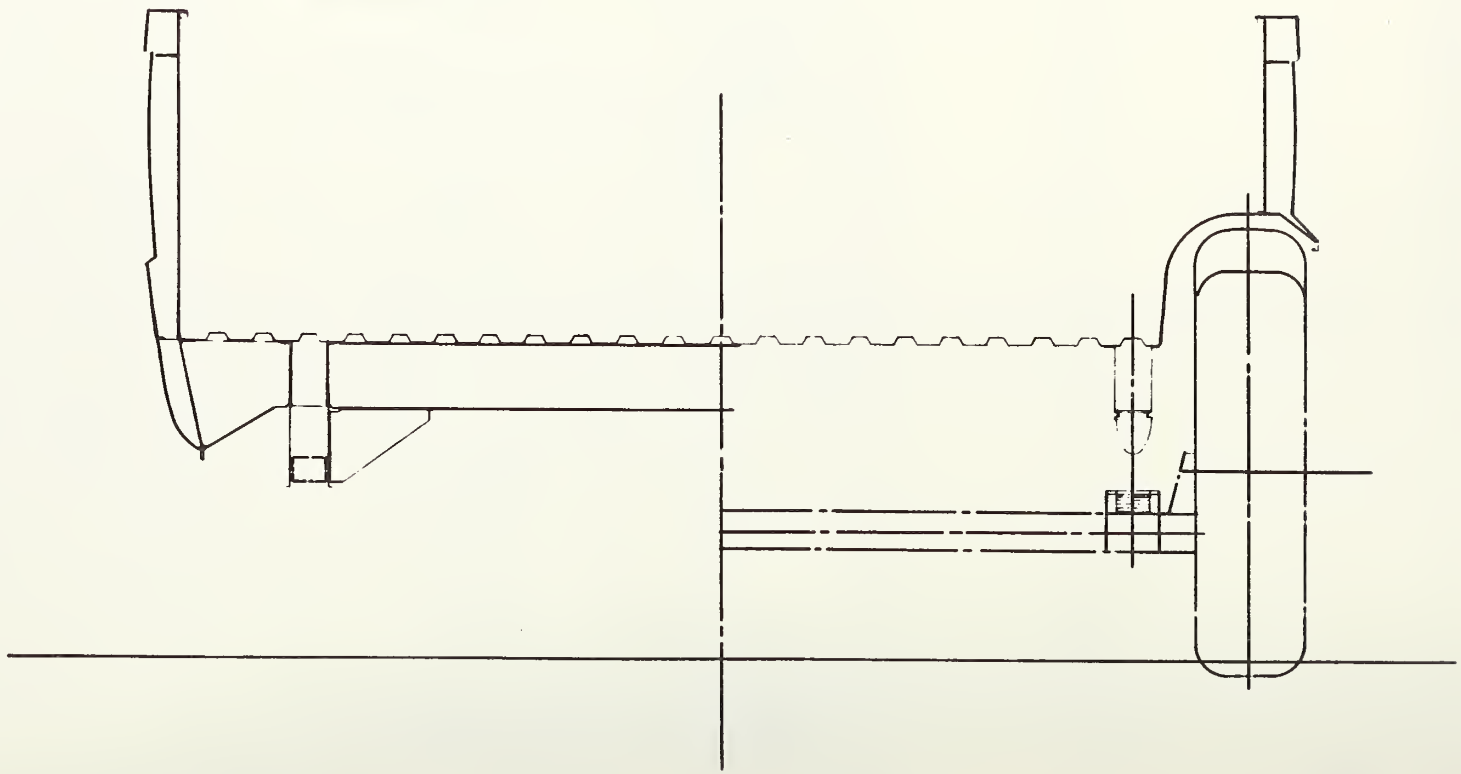

FIGURE 45E. ICD SOLUTION 1 CARGO BOX CROSS SECTION AND REAR SUSPENSION DETAIL

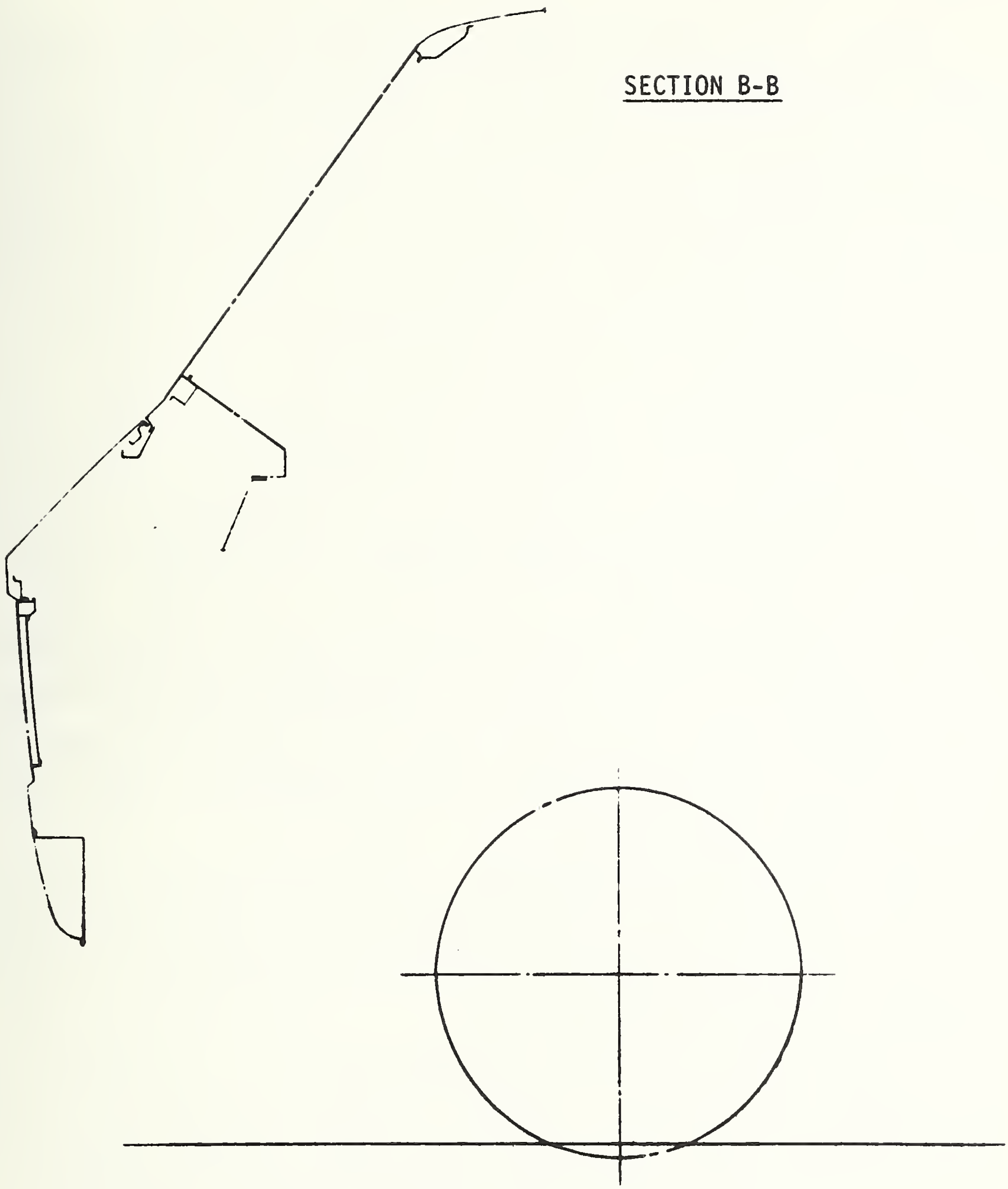

FIGURE 45F. ICD SOLUTION 1 FRONT END SHEET METAL LAYOUT

The powertrain location and required crush space dictate that the cab of the vehicle must have a large front overhang.

The fuel tank has been located close to the rear axle to minimize weight transfer as fuel is used form the tank. The spare wheel is located in the rear overhang below the cargo box and may be removed from the vehicle through a rear opening. The profile of the vehicle has been developed incorporating suitable aerodynamic considerations to minimize vehicle drag. Particular contours were prepared for the leading edge of the vehicle and front grill in order to maximize aerodynamic penetration.

This first solution presents several features which may not be considered as ideal. Specifically, the engine position in the cab in proximity to the driver provides an unsuitably high noise level and temperature environment. Furthermore, the engine position behind the front wheel centerline and behind the driver's foot position may present a problem during collision. The substantial mass located in this position could move forward during a crash and increase injury level. Therefore, appropriate design solutions would have to be found to attach the powertrain in such a manner as to mitigate the possibility of engine dislocation during collision.

The characteristic dimensions for the solution 1 vehicle are presented in Table 41. Of particular note for this vehicle is the cab proportion of the overall vehicle length which presents a forward-weighted vehicle style.

Utilizing current design technology, only as available for existing Fiat production, a weight evaluation for design number 1 is presented in Table 42. This preliminary weight evaluation does not take into account any advanced material applications either as available within Fiat or available within the industry outside Fiat. Therefore this weight evaluation presents the initial design weights to which the vehicle could be built. Additional weight reductions would be achievable utilizing more advanced material applications.

TABLE 41.—SOLUTION 1 VEHICLE DIMENSIONS

Overall length, mm	4300
Front overhang, mm	1140
Overall width, mm	1800
Overall height, mm	1925
Wheelbase, mm	2400
Rear overhang, mm	800
Front and rear track, mm	1600
Load space length, mm	2390(2920)*
Load space width, mm	1300
Load space height, mm	485
Floor height, mm	490

* With tailgate in horizontal position

Note that the weight distribution for the empty vehicle at its curb weight places 69 percent on the front axle and 31 percent on the rear axle. This vehicle when loaded to its maximum GVW, transfers the weight to the rear of the vehicle. Therefore, the weight distribution changes to 55 percent on the front axle and 45 percent on the rear axle. This forward weight biasing may present some problems with the handling characteristics of the vehicle in transient conditions.

Solution Number 2—The first alternative solution developed from the preceding design was to modify the drivetrain position within the vehicle. The selected drivetrain was taken from a Lancia Beta 1.8 liter automobile. This engine is coupled through a torque converter to a three-speed automatic transmission. This is the drivetrain that is normally used in the U.S. certified Lancia Beta automobile. Referring to Figure 46, the transverse positioning of the drivetrain, ahead of the front axle and forward of the passenger compartment is shown. This design presents a more conventional European truck design. With the exception of the drivetrain itself, all of the mechanical components for this solution are identical to the preceding one.

TABLE 42.—SOLUTION 1 WEIGHT EVALUATION

	kg
- Engine and transmission complete with oil and water	253.0
- Chassis for engine and suspension connections	20.0
- Battery	20.0
- Electric system	10.0
- Front suspension complete with brakes, axles, two wheels, two springs	100.0
- Rear suspension complete with brakes, axles, wheels	94.0
- Steering system and power assist brakes	21.0
- Pedals	4.0
- Radiator with water	10.5
- Brakes and shift system	5.0
- Wiper/washer	3.5
- Instrument panel	42.0
- Heating	8.5
- Seats	20.0
- Glasses	26.0
- Locks	4.0
- Fuel system complete with fuel	57.0
- Exhaust system	21.0
- External lights	6.0
- Front bumper system	14.0
- Cab complete with insulation and painting	175.0
- Cargo box complete with under-structure, rear bumper and painting	210.0
- Spare wheel	20.0
Total weight	1144.5 (2460 lb)

Values derived for design weight analysis

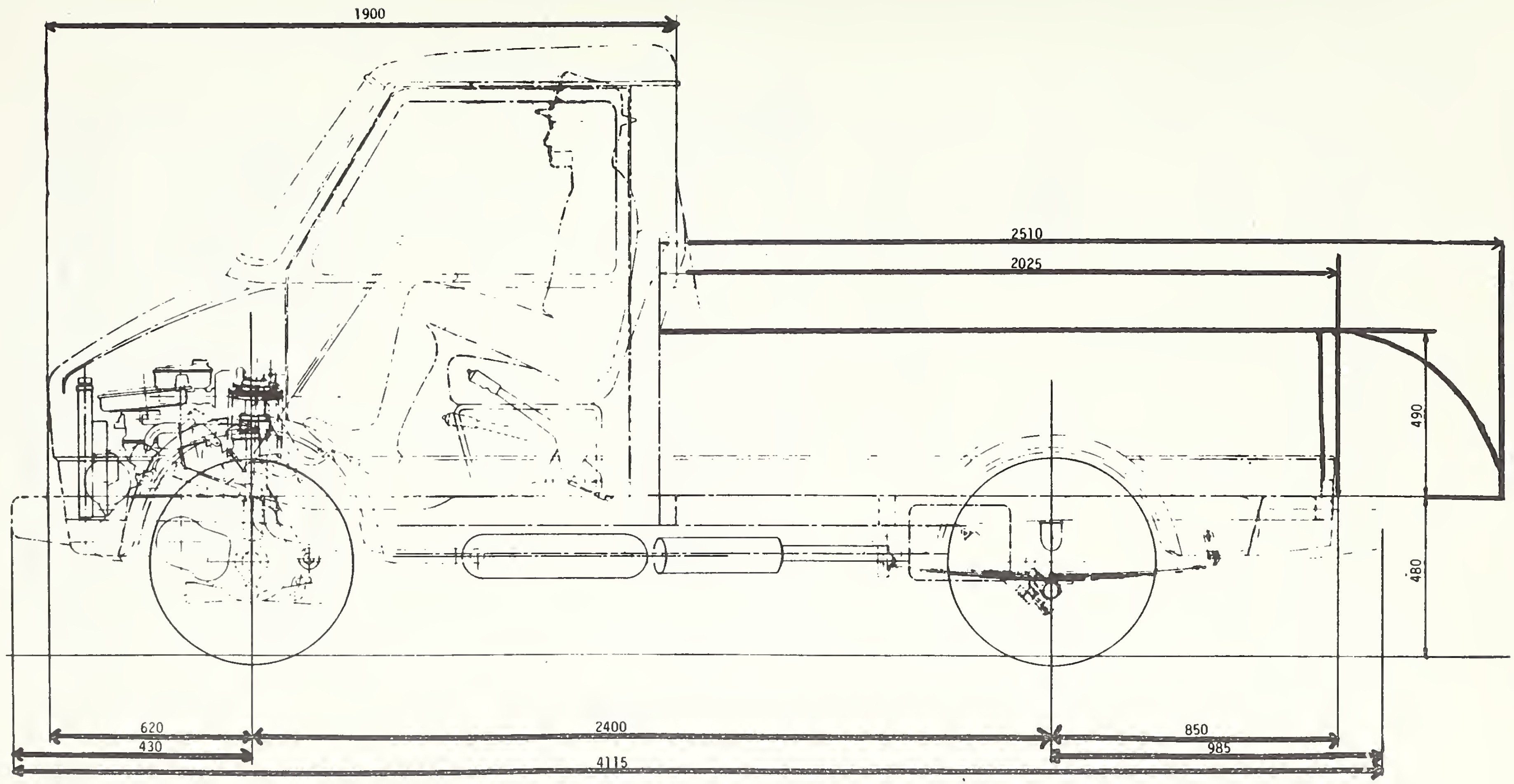

FIGURE 46A. ICD SOLUTION 2 GENERAL VEHICLE LAYOUT

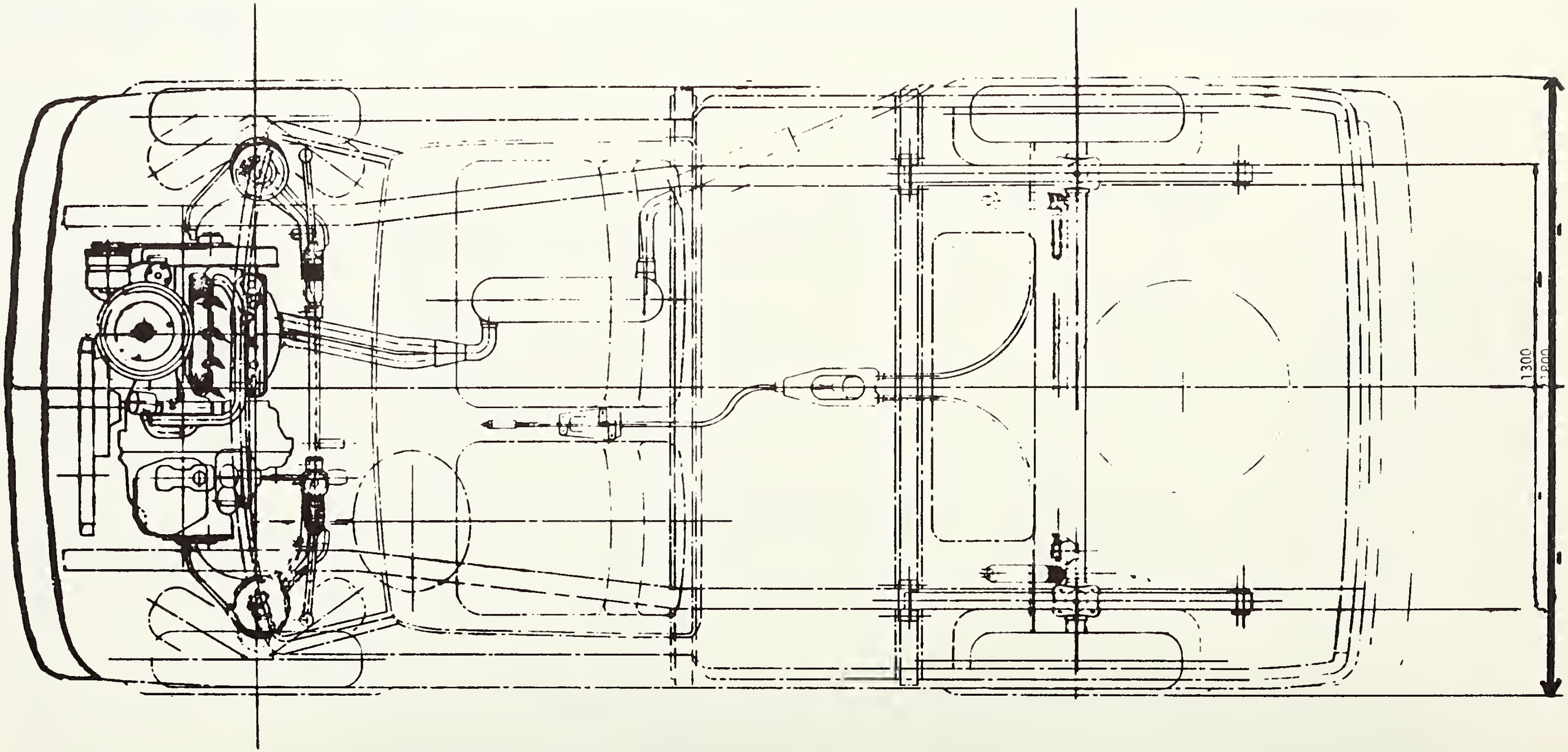

FIGURE 46B. ICD SOLUTION 2 PLAN VIEW

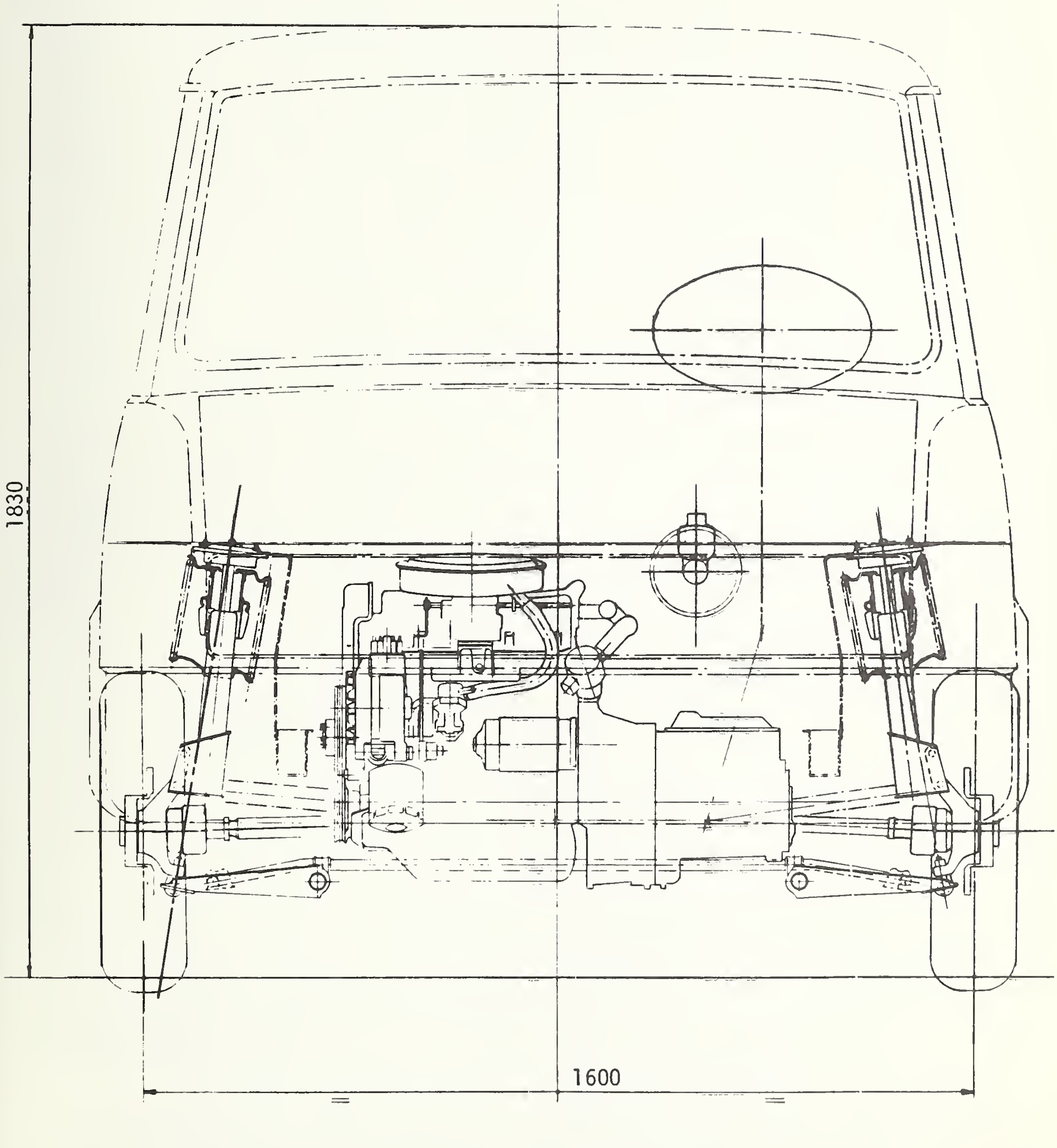

FIGURE 46C. ICD SOLUTION 2 CAB CROSS SECTION AND POWERTRAIN LAYOUT

Based upon the wheelbase minimum design value of 2400 mm, this vehicle locates the cab more conventionally behind the front axle. Therefore to maintain an equivalent cargo box, the rear overhang of the vehicle must increase. The rear overhang for solution 2 is 985 mm instead of the 800 mm as presented in the preceding solution. In this solution note the design of the bulkhead between the passenger compartment and the cargo box. It is designed in such a manner that there is a foward offset of the bulkhead below the belt line of the vehicle to increase the cargo volume available, taking into account the dead space behind the driver seat. Additionally, interior space is provided under the passenger seats in the position formerly occupied by the propulsion system in solution number 1.

The characteristic dimensions for this ICD solution are presented in Table 43. The overall length of the vehicle has been shortened to approximately 4115 mm. This shortening of the vehicle is possible due to better integration of the drivetrain with the passenger compartment. Similarly, the front overhang has been decreased approximately 400 mm while the rear overhang has increased 185.

TABLE 43.—SOLUTION 2 VEHICLE DIMENSIONS

Overall length, mm	4115
Front overhang, mm	730
Overall width, mm	1800
Overall height, mm	1830
Wheelbase, mm	2400
Rear overhang, mm	985
Front and rear track, mm	1600
Load space length, mm	1975(2510)
Load space width, mm	1300
Load space height, mm	490
Floor height, mm	480

An estimate of the weight of this vehicle for the conventional design solution was made and the resultant curb weight for the vehicle is approximately 1061 kg. The weight distribution of the vehicle in the empty condition is improved with 62 percent on the front axle and 38 percent on the rear. Fully loaded at the maximum GVW, 44 percent of the weight is on the front and 56 percent on the rear axle.

Solution Number 3—The third solution was developed from the initial one by repositioning the propulsion system within the vehicle. The drivetrain, still in line and placed longitudinally in the chassis, has been reversed. In this design (Figure 47) the engine is placed in front and the transmission under the passenger compartment floor. For this reason the cab structure may take on a design more similar to solution number 2. That is, one in which the passenger compartment is located between the two axles of the vehicle. With this placement of the passenger compartment substantially improved crashworthiness is provided.

Since all of the engine weight is placed in the front overhang of the vehicle the wheelbase of the vehicle had to be increased over the minimum of 2550 mm. With this wheelbase an improved weight distribution was obtained while maintaining the same cargo space as for solution number 2. Again, for this design, the convoluted shape for the passenger compartment bulkhead has been adopted in order to maximize cargo box volume. Space is also provided under the seats as in the previous solution.

Characteristic dimensions for the vehicle are presented in Table 44. The overall length of 4260 mm falls between the two previous ICD solutions. However, the integration of the passenger and cargo compartments is believed to be improved in this particular design.

The weight analysis based upon current conventional material design provides a curb weight of 1075 kg. The weight distribution is 68 percent front/32 percent rear at the curb weight. Fully loaded at gross vehicle capacity 57 percent is on the front axle and 43 percent on the rear.

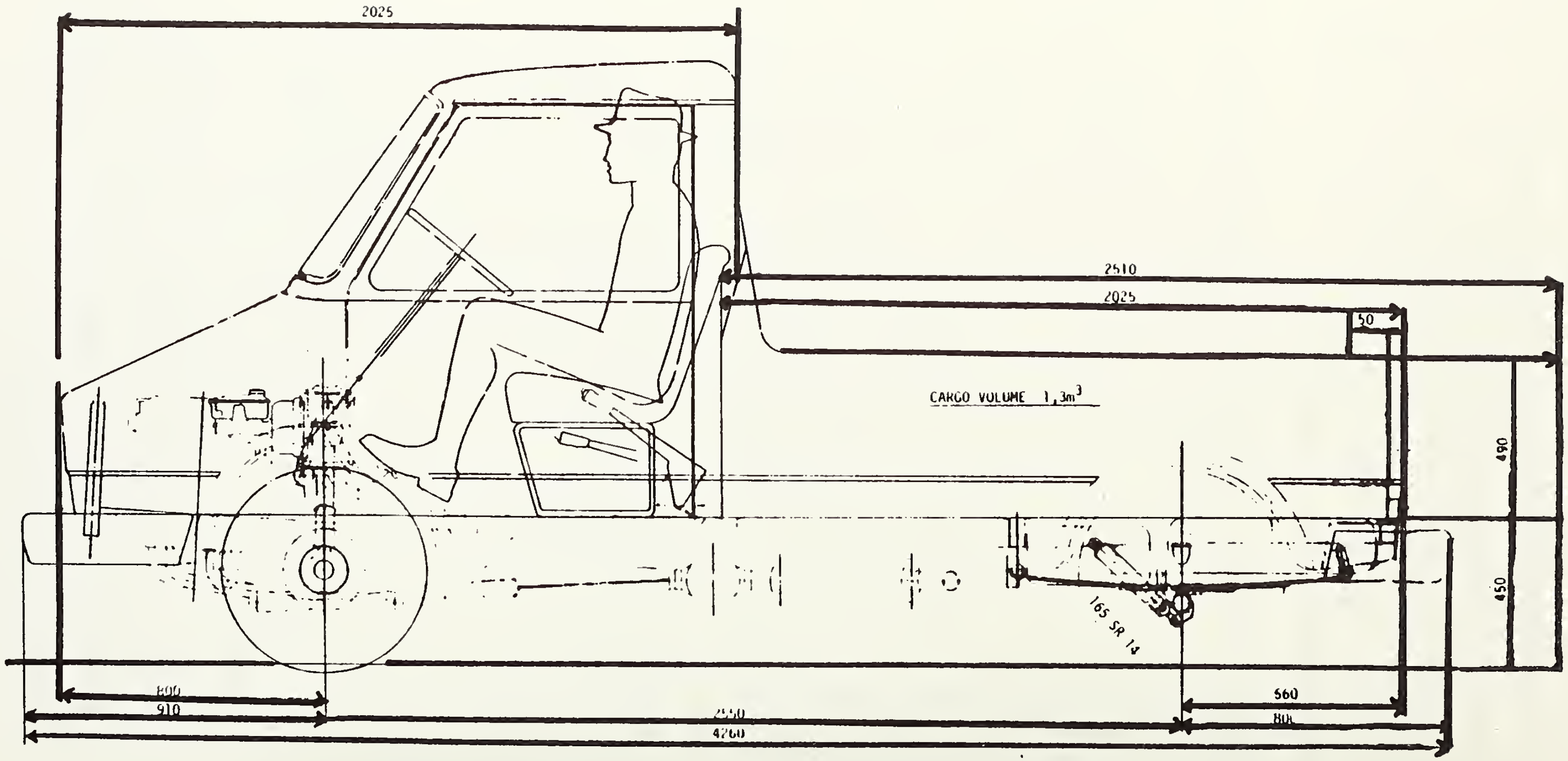

FIGURE 47A. ICD SOLUTION 3 GENERAL VEHICLE LAYOUT

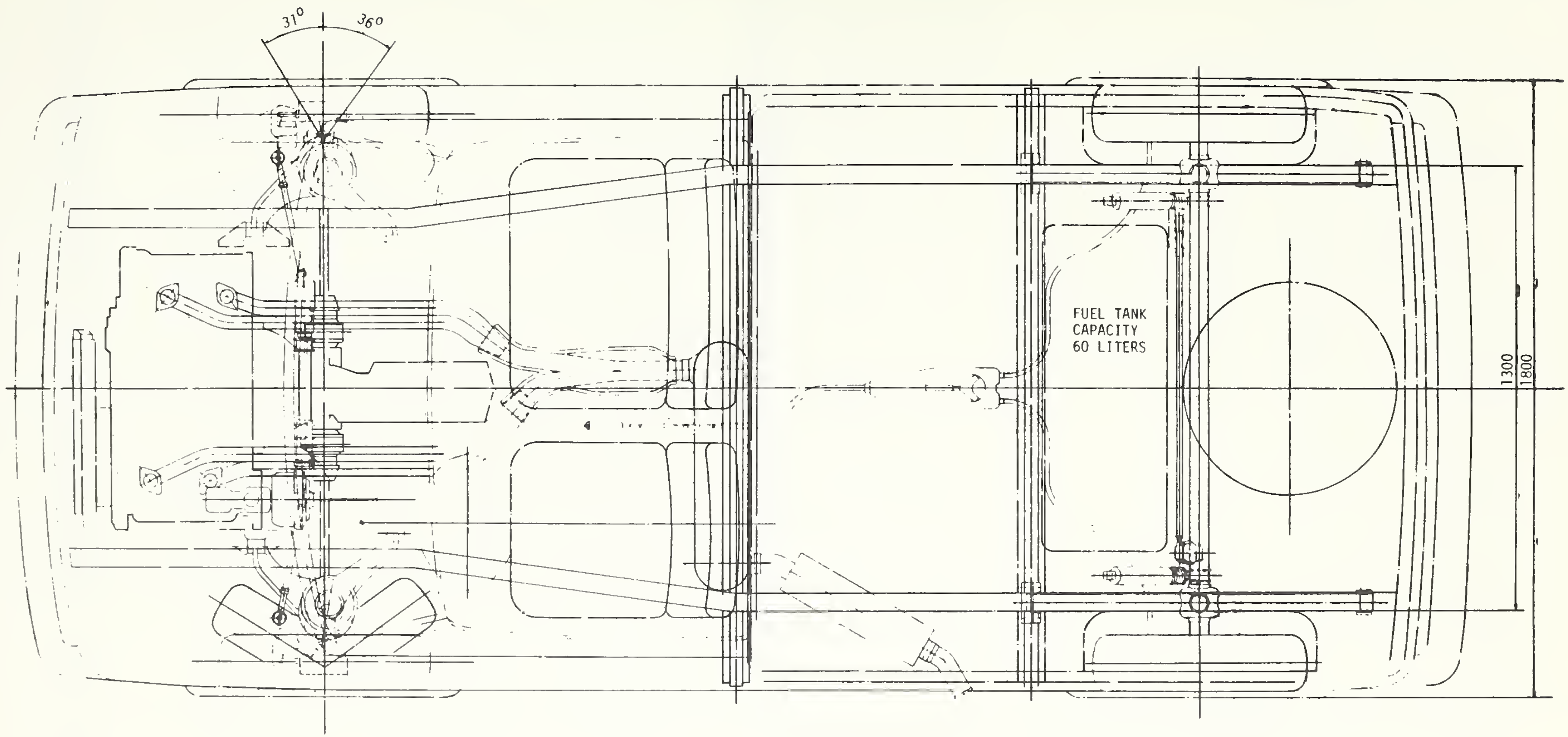

FIGURE 47B. ICD SOLUTION 3 PLAN VIEW

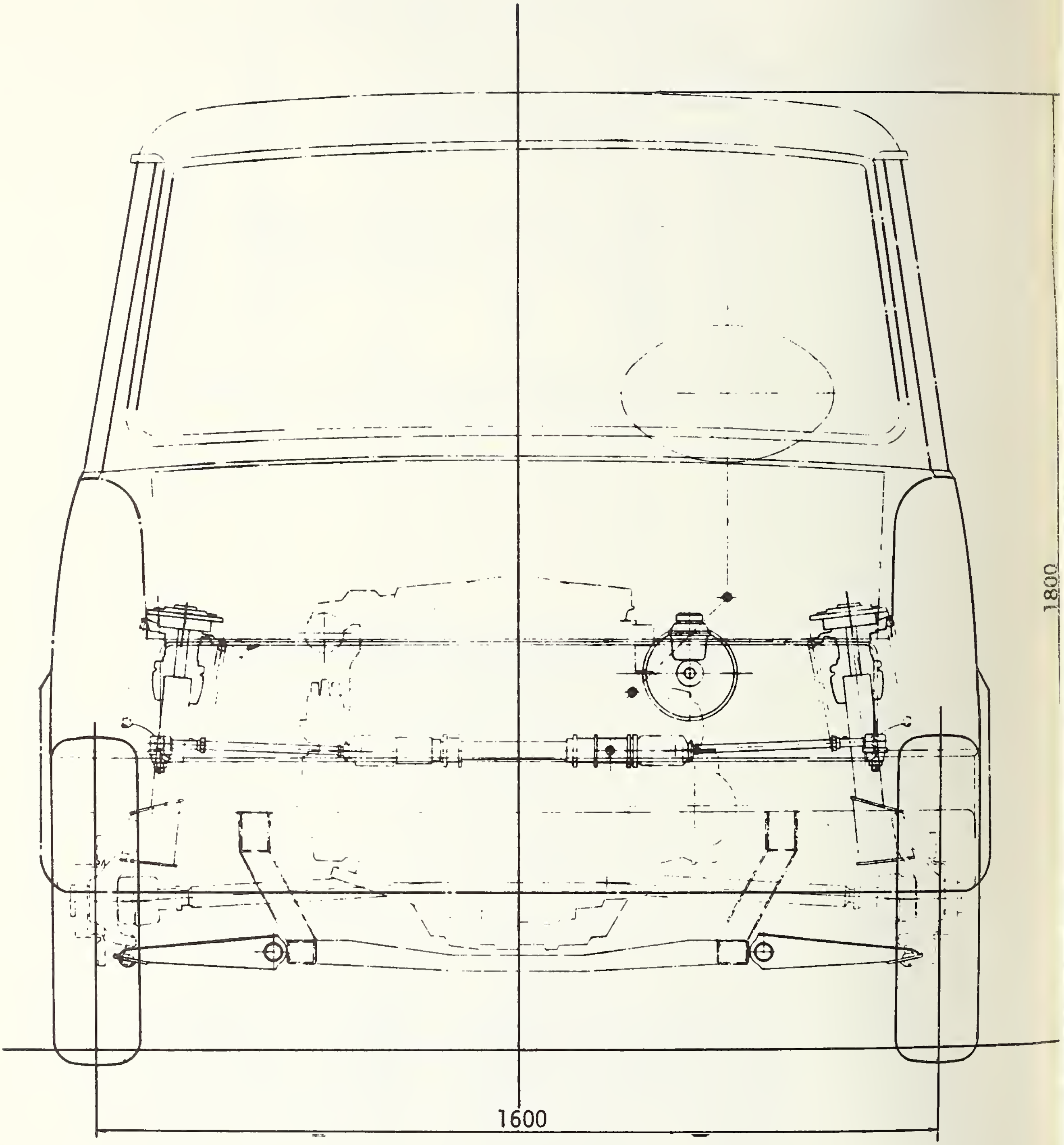

FIGURE 47C. ICD SOLUTION 3 CAB CROSS SECTION AND POWERTRAIN LAYOUT

TABLE 44.—SOLUTION 3 VEHICLE DIMENSIONS

Overall length, mm	4260
Front overhang, mm	910
Overall width, mm	1800
Overall height, mm	1800
Wheelbase, mm	2550
Rear overhang, mm	800
Front and rear track, mm	1600
Load space length, mm	1975(2510)
Load space width, mm	1300
Load space height, mm	490
Floor height, mm	450

Design Comparison—

- In general the curb weights for the vehicles are approximately equal. That is, about 1060 kg.
- The weight distributions for solutions 1 and 3 are approximately identical with solution 2 providing a somewhat more uniform front and rear distribution.
- Concerning the collision protection of the vehicle solutions number 2 and 3 are approximately equal with the placement of the major engine mass ahead of the driver compartment and in the forward crush area of the vehicle. Solution number 1 provides somewhat less crush resistance.
- From a styling standpoint solutions number 2 and 3 are better due to the more conventional proportioning of vehicle volumes.
- From an aerodynamic standpoint the profile of each of the vehicles is identical. However, the frontal area of solutions number 2 and 3 is slightly improved.

From these general observations it is possible to conclude that solutions 2 and 3 provide a satisfactory initial design attempt for the development of an ICD vehicle.

7.4 MATERIAL APPLICATIONS

Based upon the initial design solutions for the ICD vehicle it is possible to make projections for the application of more advanced materials into the vehicle structure. This analysis will present two levels of material application, the first being material that is currently available within the Fiat automotive group but not commonly used for current automotive production. The second level of analysis presents the material applications as determined in Section 5 of this report. These latter materials, while available within the industry, do not represent materials currently producible at Fiat.

The first weight reduction based upon the usage of nonconventional materials for each vehicular subsystem develops a weight reduction as indicated in Table 45. All of these materials under examination are commonly used in current production but for components other than are specified in Table 45. Therefore, this projection represents an increased production cost or additional capital investment to institute these changes on the scale indicated. The weight reductions shown in the table represent suitable reductions applied to any three of the ICD previously discussed. Assuming as a reference weight, the ICD solution number 1 with an initial weight of 1052.5 kg, these material applications would result in a new weight of 979 kg, corresponding to an additional 6 percent weight reduction.

In applying these indicated material substitutions no design changes had to be made into the structure because the ICD vehicles have already incorporated the necessary requirements for these materials.

<u>Final Weight Reduction Projection</u>—Based upon material technology currently available throughout the world, though not necessarily from any single manufacturer, a final weight reduction prediction has been developed. These final weight predictions are based upon the potential weight reduction achievable, suitable for production applications, within the 1985 time frame.

Obviously since all of the technology is available, although not necessarily in a production level, prototype vehicles may be currently fabricated.

TABLE 45.—WEIGHT REDUCTION BASED ON MATERIAL SUBSTITUTION ACCORDING TO PRODUCTION METHODS AVAILABLE TODAY IN FIAT

	kg
Engine (aluminum case and stainless steel exhaust manifold)	25.0
Engine and front suspension chassis (HSLA)	2.0
Battery (improved battery)	3.5
Five wheels (aluminum)	20.0
Fuel tank (high density polyethylene)	3.0
Radiator (aluminum)	2.0
Pedals (HSLA and plastic material)	1.0
Suspension arms and connections (HSLA)	8.0
Brake and shift (HSLA)	1.0
Heating system (redesign and plastic material)	1.0
Glasses (thickness and material)	4.0
Seats (plastic components)	3.0

The designs, as presented in the previous sections, might require slight redesign in order to incorporate all of the material recommendations as indicated in Table 46. The following additional material substitutions were provided to reduce the weight as indicated in the final column of Table 46:

- structure (composite passenger compartment doors, tailgate and roof; HSLA frame and floor)-42 kg reduction
- drivetrain (composite propulsion shafts)-4.5 kg reduction
- suspension (composite leaf spring)-20 kg reduction
- brakes (aluminum drum with cast iron liner)-12 kg reduction
- bumper assembly (HSLA and aluminum or composite material)-7 kg reduction

- miscellaneous systems (molded urethane seats)-
  5.5 kg reduction
- total weight reduction is 91 kg

TABLE 46.—ICD WEIGHT SUMMARY

		Total Weight Dry, kg	
System	ICD	Current Material and Design	Advanced Material and Design
1. Structure	405.0	403.0	361.0
2. Engine	196.0	166.0	166.0
3. Drivetrain	87.5	87.5	83.0
4. Suspension	155.0	127.0	107.0
5. Brakes	60.0	60.0	48.0
6. Steering	21.0	21.0	21.0
7. Electrical	36.0	32.5	32.5
8. Bumper	26.0	26.0	19.0
9. Instruments & Controls	7.5	5.5	5.5
10. Miscellaneous Functional	58.5	50.5	45.0
11. Optional Systems	0.0	0.0	0.0
12. Total	1052.5	979.0	888.0

The total weight projection for a vehicle as presented in ICD solution number 1 is 956.5 kg (wet curb weight) or 888.0 kg dry. In summary, the integrated ICD material weight reductions result in a 6 percent weight saving for the currently available material substitutions and an additional 9 percent for the advanced materials usage (for a total of 15 percent).

8. CONCLUSIONS AND RECOMMENDATIONS

8.1 CONCLUSIONS

The preceding analysis has indicated that a significant level of weight reduction potential is achievable utilizing state of the art technology available to the industry through 1985. The analysis, as presented, has indicated that either independent or combined downsizing, redesign and material substitutions can achieve substantial weight reductions.

Several key issues impact upon the ability to manufacture vehicles designed at reduced weights. The analysis has been based upon utilizing technology that is available throughout the automotive industry. This assumes that technology is equally available to all producers of LDT. In actuality, the mix of technology is highly stratified for each LDT manufacturer. Furthermore, the ability to design the vehicle is impacted by the available in-house expertise of the respective LDT design staffs. To the manufacturer the technological feasibility of the presented solutions are much less critical than are the impact of economic considerations.

The analysis presented previously in this report has indicated that there is an identifiable material cost, production cost, and operating cost impact. These impacts are dependent upon the selected technology and the market acceptance of that technology. A cost effective solution for a 100,000 vehicle production may be highly uneconomical for a 30,000 vehicle production. Therefore before specific conclusions relative to the economic feasibility of the selected designs may be made, it is necessary to perform analysis of the extent to which the design will penetrate the fleet. Since this activity was outside the original scope of work, we therefore have made no attempt to present more economic analysis than at the material/production level.

Presented for comparative purposes, in Table 47, are the existing and projected weights for each of the specified LDT. From this table it can readily be determined that significant weight

TABLE 47. -WEIGHT REDUCTION POTENTIAL SUMMARY

Weight	Mission		Personal Use Pickup	Commercial Pickup	Personal Use Van	Commercial Van	Utility Vehicle
Dry Curb Weight	U.S. Weight Efficient LDT	lb	3686	4145	3770	3615	4122
	LDT Redesign	lb	2325	3017	3053	2881	3680
	LDT Material Substitution	lb	3008	3367	2943	2890	3341
	LDT with Redesign and Material Substitution	lb	1891	2437	2384	2308	2972
Dry Curb Weight Reduction	Design	lb	1361	1128	717	734	442
		percent	37	27	19	20	11
	Material Substitution	lb	628	778	227	725	781
		percent	18	19	22	20	19
	Design and Material Substitution	lb	1795	1708	1386	1307	1150
		percent	49	41	37	36	28

reductions are possible at each design level. Furthermore, the integrated material and redesign weight reductions can achieve weight reductions in excess of 40 percent for selected mission purposes. These analyses are based upon technological feasibility considerations for designing and manufacturing selected lines of vehicles. The assumption that a specific vehicle can be designed to a specific mission should be thoroughly evaluated before the indicated weight reductions can be deemed probable within the constraints of the real world LDT manufacturer.

As was often recounted to us during meetings with LDT manufacturers, both American and European, the weight efficiency of selected LDT is primarily determined by the cost to which the vehicle is designed. The economic considerations of improved weight efficient LDT must be evaluated to determine the impact upon the consumer and ultimately the marketability of specific vehicles. As the industry develops more weight efficient designs for its automotive line, technology transfer from automotive to LDT is possible. Therefore, the assumption that more weight efficient components will be available for application to the LDT is a valid one. Furthermore, as the automotive and LDT market becomes more highly structured in its model selection, and vehicle owners become more selective of vehicles to serve a specific purpose, the feasibility of designing vehicles to a highly specific mission becomes a more suitable solution.

In summary, we conclude that the weight reductions, as presented in Table 47 provide no technological barrier to their implementation, and that taking into account economic and producibility considerations, significant weight reduction potential is possible within the existing LDT fleet. Further, based upon the documented cost impacts for implementation, the proposed 1985 design and material improvements, as delineated in Sections 4 and 5, the weight reduction potential may be achieved, to a large extent, within normal facilities replacement.

8.2 RECOMMENDATIONS

The project team believes that the technological feasibility of the weight reduction potential has been demonstrated in this program. However, the extent to which the specific reductions are achievable with market acceptable vehicles is open to judgmental evaluation. Therefore, two specific recommendations are indicated with which a quantification of the market feasibility may be obtained.

The mission analysis effort undertaken in this program identifies specific market segments and mission applications for LDT within the American market. The mission analysis was significant to the rest of the program in that, to deal effectively and equally with the American market, and derive more efficient vehicles for the 1982 to 1985 time frame, it was first necessary to conceptualize what the U.S. market is currently buying and the use to which these vehicles are placed. Within the limited scope and monetary constraints of this current research effort, the team strove to identify industry's perception of what special uses and in which environments their LDT must operate, and what "boundaries" on the physical and performance characteristics were necessitated by the vehicle missions.

The mission analysis, as undertaken in this program, was based upon the industry's perception of what the LDT fleet should be. The team believes the manufacturer oriented data collection revealed the types of information which were required, and also it is our opinion that these indications were biased toward existing model production. To eliminate this built in bias, we believe it is necessary to undertake an assessment of the market requirements from within the consumer sector which established specific mission limitations on LDT.

Particularly, it would be interesting to evaluate the LDT fleet as currently being produced, as to whether or not it fulfills all of the consumer's needs, or whether the fleet as provided only optimizes the manufacturer's producibility and manufacturing constraints. Significantly, whether or not the LDT currently available in the United States satisfies the market for such vehicles, or whether an entirely alternative structure may be proposed including vehicles with substantially revised mission characteristics, has not been resolved. The significance of this proposed study would be to indicate the extent to which U.S. manufacturers are providing wanted and needed vehicles for the consumer, or whether the manufacturers are only providing vehicles which they can manufacture.

The second area in which we would like to recommend additional work concerns the technological considerations of manufacturing a lightweight vehicle. Results have indicated the design feasibility for a weight efficient LDT at the preliminary design level. To fully establish the feasibility of such a design, particularly within the context of justification at the manufacturer's level, it is necessary to establish the design potential in hardware items. Therefore it is our opinion that it is necessary to begin to formulate specific hardware solutions to weight efficient designs which are readily acceptable on the part of industry. The selection of material applications for the weight reduced LDT had to be very conservative to stay within the manufacturing constraints that are identifiable for the LDT manufacturers. However, this conservatism may have been overstressed and some more advanced materials could be applied based upon their demonstration in a hardware context. Particularly some of the materials that were identified in limited production for heavy duty trucks, i.e., some composite or honeycomb materials, might be readily applied to the LDT fleet if manufacturability in large-scale production could be demonstrated.

The extent to which the weight reduced LDT may achieve the safety standards as required by law has been demonstrated at the preliminary design level. To go beyond this evaluation it would be necessary to carry the design into a more finalized state. Therefore, some of the questions concerning the suitability of the vehicles as constrained by the Federal Motor Vehicle Safety Standards must be dealt with. Additionally, the extent to which the LDT may achieve a fuel economy improvement over the existing fleet vehicles would conceivably be demonstrated through the development of prototype powertrain and vehicle configurations.

In summary, two significant issues must be dealt with. The first is an evaluation of the extent to which the market may accept more optimally defined vehicles, suitable for specific user-oriented missions. Second, is the extent to which the technologically feasible design and material solutions may be translated into a producible and market acceptable vehicle.

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APPENDIX

REPORT OF NEW TECHNOLOGY

No invention is achieved during the performance of work under this contract. This study identifies the potential for improving the weight efficiency of the light duty truck fleet while maintaining the utility and marketability of the vehicles. Analysis shows that a significant level of weight reduction is achievable utilizing state-of-the-art technology available to the industry through 1985.

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