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AUTOMOTIVE MANUFACTURING PROCESSES
VOLUME I - OVERVIEW

BOOZ-ALLEN & HAMILTON INC.
4330 East-West Highway
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FINAL REPORT

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16. Abstract

Extensive material substitution and re-sizing of the domestic automotive fleet, as well as the introduction of new technologies, will require major changes in the techniques and equipment used in the various manufacturing processes employed in the production of automobiles. The purpose of this report is to document and analyze the publically available data on current and projected motor vehicle production processes and equipment and to report on impending changes.

This volume deals with the history of automotive-related government standards and the impact on the automotive production processes and vehicle design, future trends in automotive design, and the implications of these changes on the manufacturing infrastructure. Also included is an overview of engine and emission control systems and two passive restraint systems.

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PREFACE

This report is Volume I of a series of five reports which address changes occurring in motor vehicle manufacturing processes, materials, and equipment during the period 1978 to 1980. The reports present an overview of the major manufacturing processes and materials, and a summary of historical improvements in motor vehicle fuel economy, emissions reduction, and safety. Also included are detailed discussions of vehicle components designed to improve motor vehicle fuel economy, emissions, and safety. The reports also present detailed examination of motor vehicle manufacturing process industries, trends, and issues.

The five volumes in this "Automotive Manufacturing Process" series are listed below:

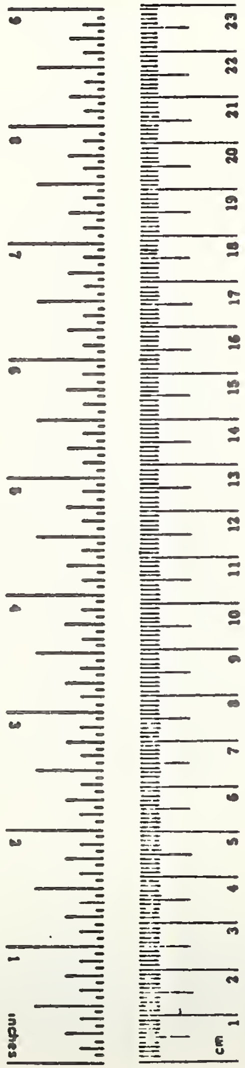
- Volume I - "Overview"
- Volume II - "Manufacturing Processes for Passive Restraint Systems"
- Volume III - "Casting and Forging Processes"
- Volume IV - "Metal Stamping and Plastic Forming Processes"
- Volume V - "Manufacturing Processes and Equipment for the Mass Production and Assembly of Motor Vehicles."

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

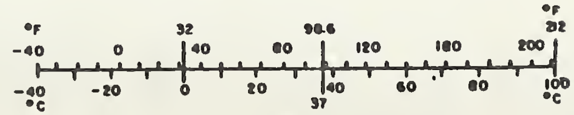
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	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

1.1 GENERAL

Since 1966, the Federal Government, through its regulatory powers, has been playing an ever-increasing role in the design of automobiles—first with the promulgation of safety regulations, then with emissions regulations, and now with fuel economy regulations. Thus, while the car of the future will undoubtedly be safer, less polluting and more efficient, the industry in complying with these regulations will undergo major changes. These include:

- Changes in the equipment used for material forming, joining, and finishing
- Changes in mass production technology
- Changes in the materials, parts and components, and machine tools utilized.

Due to these anticipated changes, an important question rises: What effect will these changes have on the manufacturing industry's requirements for labor, energy, capital and materials? To answer this question, the Transportation Systems Center (TSC) of the Department of Transportation (DOT) is conducting an in-depth analysis of the processes and equipment required to produce low polluting, fuel efficient and safe motor vehicles in the 1980's.

This chapter looks at:

- the history of government standards and their impact on automobile design
- future trends in automobile design
- the implications that these changes have on automotive manufacturing.

Subsequent chapters will address specific manufacturing processes and components, and specific issues facing the industry.

1.2 HISTORY OF GOVERNMENT STANDARDS AND THEIR IMPACT ON AUTOMOBILE DESIGN IN THE UNITED STATES

A major turning point in automotive design occurred in the mid-1960's with the publication of initial government standards for vehicle safety features. This represented a major shift in the balance of factors influencing automotive design. The industry which in the past was motivated by traditional market forces was now faced with a new challenge—that of complying with government regulations. Since the late 1960's and continuing to the present time, automotive industry resource commitments have been increasingly influenced by the requirements of federal regulations.

This section describes past and present government regulations and the impact these standards have had on automobile design. The areas covered include:

- Automotive Safety
- Automotive Emissions
- Automotive Fuel Economy.

1.2.1 Safety

The National Traffic and Motor Vehicle Safety Act of 1966 directed the Secretary of Transportation to issue Federal motor vehicle safety standards. The first such standards became effective on all vehicles manufactured on or after January 1, 1968. In general, these initial safety standards provided a stimulus for then-existing safety-related technology to be mass-produced and marketed, by eliminating the company market cost disadvantages of such additional items. Continued activities by the National Highway Traffic Safety Administration (NHTSA) since that time have served to stimulate new technology development for automotive safety. For example, standards set to date by NHTSA (see Table 1-1) have addressed areas such as brakes, tires, passenger restraints, lighting, fuel system integrity, bumpers and other safety critical systems. Additional vehicle safety standards have been added each year, and others are in the process of being developed and issued.

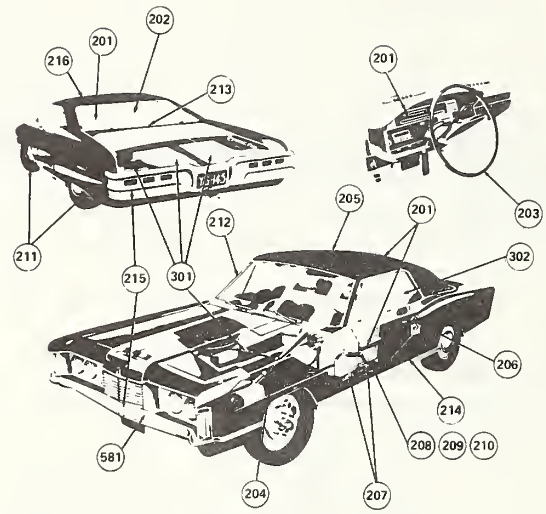
In response to these standards, major design changes have been made to assist motorists in avoiding accidents and to protect them during crashes. Figure 1-1 shows the

TABLE 1-1. FEDERAL MOTOR VEHICLE SAFETY STANDARDS RELATED TO AUTO DESIGN

ACCIDENT AVOIDANCE		CRASHWORTHINESS			
FMVSS Standard #	Description	FMVSS Standard #	Description	FMVSS Standard #	Description
101	Control location, identification and illumination	201	Occupant protection in interior impact	301	Fuel system integrity
102	Transmission shift lever sequence, starter interlock & transmission braking effect	202	Head restraints	302	Flammability of interior materials
		203	Impact protection for the driver from the steering control system		
103	Windshield defrosting & defogging				
104	Windshield wiping & washing system	204	Steering control rearward displacement		
105-75	Hydraulic brake system	205	Glazing materials		
106	Hydraulic brake hoses	206	Door locks & door retention components		
107	Reflecting surfaces	207	Seating systems		
108	Lamps, reflecting devices & associate equipment	208	Occupant crash protection		
109	New pneumatic tires (passenger cars)	209	Seat belt anchorages		
110	Tire selection & rims (passenger cars)	210	Seat belt assemblies		
111	Rear view mirror	211	Wheel nuts, wheel discs & hub caps		
112	Head lamp concealment devices	212	Windshield mounting		
113	Hood latch systems	213	Child seating systems	581	Bumper standard effective Sept. 1, 1978
114	Theft protection	214	Side door strength		
115	Vehicle identification number	215	Exterior protection		
116	Hydraulic brake fluid	216	Roof crush resistance		
117	Retreaded pneumatic tires	217	Bus window retention		
118	Power-operated windows	218	Motorcycle helmets		
119	New pneumatic tires (all except pass. cars)	219	Windshield zone intrusion		
120	Tire selection and rims (all except pass. cars)	220	School bus rollover protection		
121	Air brake systems	221	School bus body joint		
122	Motorcycle breke systems	222	School bus passenger seating		
123	Motorcycle controls & display				
124	Accelerator control systems				
125	Warning devices				
126	Truck-camper loading				

effects which vehicle crashworthiness standards have had on vehicle design. Major vehicle changes brought about by these standards include:

- Improved occupant protection through padded instrument panels, armrests, sun visors, and seat backs (to protect rear seat passengers) and glove compartment doors which remain closed during a crash (FMVSS No. 201)



FMVSS NO.	TITLE
201	OCCUPANT PROTECTION IN INTERIOR IMPACT
202	HEAD RESTRAINTS
203	IMPACT PROTECTION STEERING CONTROL
204	CONTROL REARWARD OISPLACEMENT
205	GLAZING MATERIALS
206	DOOR LATCHES ANO DOOR RETENTION COMPONENTS
207	ANCHORAGE OF SEATS
208	OCCUPANT CRASH PROTECTION
209	SEAT BELT ASSEMBLIES
210	SEAT BELT ASSEMBLY ANCHORAGES
211	WHEEL NUTS, WHEEL DISCS AND HUB CAPS
212	WINDSHIELD MOUNTING
213	CHILD SEATING SYSTEMS
214	SIDE DOOR STRENGTH
215	EXTERIOR PROTECTION
216	ROOF CRUSH RESISTANCE
301	FUEL TANKS, FILLER PIPES, AND CONNECTIONS
302	FLAMMABILITY OF INTERIOR MATERIALS
581	BUMPER STANOARD

FIGURE 1-1. AUTOMOTIVE DESIGN CHANGES RESULTING FROM GOVERNMENT-MANDATED SAFETY REGULATIONS

- Requirements for head restraints to reduce the frequency and severity of neck injuries in collisions (FMVSS No. 202)

- Collapsible steering columns which cushion the impact of the driver's chest in front end crashes (FMVSS 203)

- Windshields and windows which meet standards for retention and penetration in case of impacts. This reduces the possibility of occupants penetrating the windshield in a collision (FMVSS Nos. 205 and 212)

- Improved door latches and hinges to minimize the probability of occupants being thrown from the vehicle in an impact (FMVSS No. 206)

- Specific requirements for seat belt assemblies and anchorages, and provision of passive restraints for frontal impacts (FMVSS Nos. 208, 209, 210)

- Crush-resistant roofs and door panels to minimize the hazard of collapse and intrusion in a crash situation (FMVSS Nos. 214 and 216)

- Improved bumpers to withstand impacts of 5 m.p.h. front and rear without damage to safety or other vehicle parts (FMVSS Nos. 215 and 581)

- Fuel tanks which do not rupture or spill fuel under specified conditions of rear end impacts (FMVSS No. 301).

In general, the impact of these and other changes, while improving safety, has been the addition of weight to the vehicle and to require additional inspection and maintenance effort.

1.2.2 Emissions

A regulatory initiative that began in the late 1960's and continues to have a major impact on automobile design involves the control of emissions. A number of vehicle emissions standards have been promulgated since the adoption of the National Environmental Policy Act of 1969 and the Clean Air Amendments of 1970 (the first Clean Air Act was passed in 1955). The 1970 Amendments authorized the Administrator of the Environmental Protection Agency to establish standards for motor vehicle emissions and to regulate automotive fuels and fuel additives. The legislation originally required that emissions be reduced at least 90 percent from the 1970 levels by 1975. The standards have since been modified to allow more time for the manufacturers to comply with the standards. Present allowable exhaust emissions levels resulting from further amendments to the Act in 1977 are shown in Table 1-2.

TABLE 1-2. PASSENGER CAR EMISSION STANDARDS

Model Year	Emission Standard (Grams per Mile)		
	Hydrocarbons	Carbon Monoxide	Nitrogen Oxide
1978-79	1.5	15	2.0
1980	0.41	7	2.0
1981 and beyond	0.41	3.4*	1.0**

* Can be waived by EPA Administrator to 7.0.
** Can be waived by EPA Administrator to 1.5.
Source: Automotive News, 1978 Market Data Book.

The impact of these standards on automotive design was a sequence of modifications and additions to the conventional carbureted spark-ignition engine. First, various controls and devices were added to the vehicle, including PCV valves, EGR valves, and air injection and evaporative controls. These devices had the following effects on auto emissions:

- Crankcase ventilation systems were enclosed to prevent the escape of combustion residue into the atmosphere.

- EGR valves recirculated exhaust gases back into the combustion chamber to lower the combustion temperature. This process reduced the formation of nitrous oxides.

- Engine-driven air pumps were added to mix fresh air with the hot exhaust gases to oxidize unburned hydrocarbons and carbon monoxide into harmless carbon dioxide and water.

- Fuel evaporating from the carburetor and fuel tank were controlled by the addition of a pressurized tank filler cap and a charcoal cannister to reroute fuel vapors back through the intake manifold or to the fuel tank.

When these developments no longer would meet the requirements for maximum emission levels, changes in the basic engine were made. Compression was lowered, bore-stroke ratios changed, cylinder head designs changed, and additional controls were added. All of these changes, however, seemed to contribute to a reduction in fuel economy.

The trend of loss in fuel economy continued until it reached its apex in the 1973 and 1974 model years, when the oil embargo and resulting shortages of petroleum products focused interest on vehicle fuel economy. At that time, catalytic converters were introduced, and some of the 1975 models demonstrated a turn-around in the downward trend of fuel economy. The catalytic converter had the advantage of lowering hydrocarbons and carbon monoxide in the exhaust without affecting the efficiency of the engine.

Since the advent of the catalytic converter, electronic ignition and electronic engine controls have also been added to the engine to reduce emissions and improve fuel economy. Other design changes which have contributed to reduced emissions include modifications to the distributor, intake manifold and carburetor. A summary of these and the changes described above is presented in Figure 1-2.

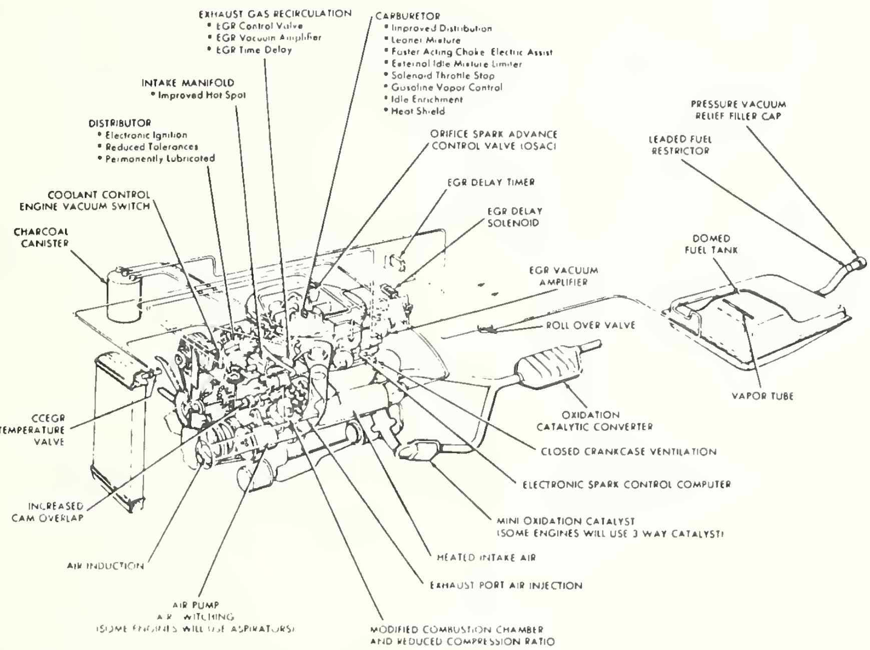


FIGURE 1-2. CHRYSLER CLEAN AIR SYSTEM SHOWING AN OVERALL EMISSIONS CONTROL PACKAGE

1.2.3 Fuel Economy

A third regulatory area which has had a strong impact on automotive design and manufacturing is vehicle fuel economy. As a result of the oil embargo of 1974 and resulting shortages of all types of petroleum products, in December 1975 the Congress passed and the President signed into law the Energy Policy and Conservation Act. The Act did two things:

- Title III, Part A of the Act, "Improving Automotive Efficiency," set forth mandatory corporate average fuel economy (CAFE)* standards for model years 1978, 1979, 1980 and 1985.

---

* CAFE refers to the average annual fuel economy (miles per gallon) for the total vehicles sold by each automobile manufacturer. It is calculated by the following formula:

$$MPG = \frac{1}{f_i \; \frac{1}{MPG\ c/h/i}}$$

where: MPG = Fuel economy for the model year
f_i = Fraction of sales of model type i
MPG c/h/i = City, highway, combined fuel economy for model type i .

- The Act amended the Motor Vehicle Information and Cost Savings Act requiring the Secretary of Transportation to implement a program for improving the fuel economy of new automobiles in the U.S. market (Title V, entitled "Improving Automotive Efficiency").

In June of 1976, authority to administer the fuel economy program was delegated by the Transportation Secretary to the Administrator of the NHTSA. The Administrator, in turn, issued mandatory fuel economy standards for the years 1981 through 1984. A summary of these standards for model years 1978 - 1985 passenger cars and model years 1978 - 1981 light duty trucks and vans is shown in Table 1-3. Model year 1982 and 1983 light truck fuel economy standards are expected to be published in 1979, followed by rules for 1984 - 1985 models.

TABLE 1-3. MOTOR VEHICLE CORPORATE AVERAGE FUEL ECONOMY (CAFE) STANDARDS (MPG) FOR MODEL YEARS 1978-1985: PASSENGER CARS AND LIGHT DUTY TRUCKS

Model Year	Passenger Cars	Vans and Light Trucks	
		2-Wheel Drive	4-Wheel Drive*
1978	18.0	No Standard	No Standard
1979	19.0	17.2**	15.8**
1980	20.0	16.0***	14.0***
1981	21.5	18.0***	15.5***
1982	23.0		
1983	24.5		
1984	26.5		
1985	27.5		

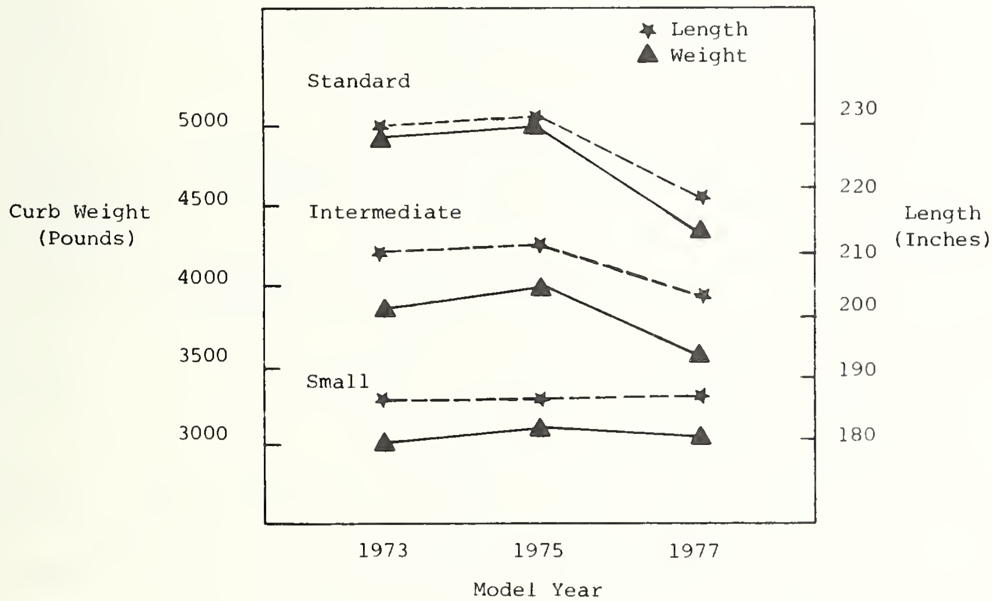
* 4-wheel drive, general utility vehicles weighing less than 6,000 lbs.

** With captive imports.

*** Without captive imports.

Source: Motor Vehicle Safety-77, published by DOT/NHTSA.

Since promulgation of the standards, the automotive manufacturing industry has been devoting large sums of capital to the development of fuel-efficient automobiles to meet these regulations. (Under the Energy Act, an auto company is fined $5 per car for each 0.1 mile that the corporation's sales weighted fleet average is below the annual mandated average.) Among the most dramatic changes made by the manufacturers has been the significant downsizing and use of lighter weight materials for weight reduction in cars. This is illustrated by the trend chart in Figure 1-3 which shows the change in vehicle size and weight by vehicle class over the years 1973 - 1977.



* Based on the average of the trends of six cars in each group.

Small cars: Pinto, Camaro, Gremlin, Hornet/Concord, Nova, Omega.

Intermediate Cars: LeMans, Torino, Coronet/Monaco, Chevelle/Malibu, Matador, Cutlass Wagon.

Standard Cars: Cadillac DeVille, Buick Electra, Oldsmobile, Chrysler New Yorker, Lincoln, Chevrolet Wagon.

Source: Automotive News Market Data Book, 1974, 1976, 1978.

FIGURE 1-3. VEHICLE LENGTH AND WEIGHT TRENDS BY MODEL CLASS 1973-1977

1.3 FUTURE TRENDS IN AUTOMOTIVE DESIGN

While the future of government regulatory actions can not be predicted precisely, one thing is certain—to comply with existing government regulations, cars will continue to get smaller and lighter and more sophisticated. According to industry sources, the cars of the future will be characterized by:

- The greater use of lighter weight materials such as aluminum, plastic and high strength, low alloy (HSLA) steel in place of conventional steel and iron to meet toughening fuel economy standards

- Sophisticated engine control systems featuring electronic ignition and fuel injection to combat emissions

- Automatically deployed occupant restraints—belts and air bags—to comply with federally mandated safety standards.

Other changes will include technological advances in engine design, drivetrain, and aerodynamics.

1.3.1 Materials Substitution

A summary of the corporate average fuel economy results to date are shown in Table 1-4. Preliminary figures indicate that the Big Four were well in compliance with the 1978 Federal standard and will also be in compliance with the 1979 standard.

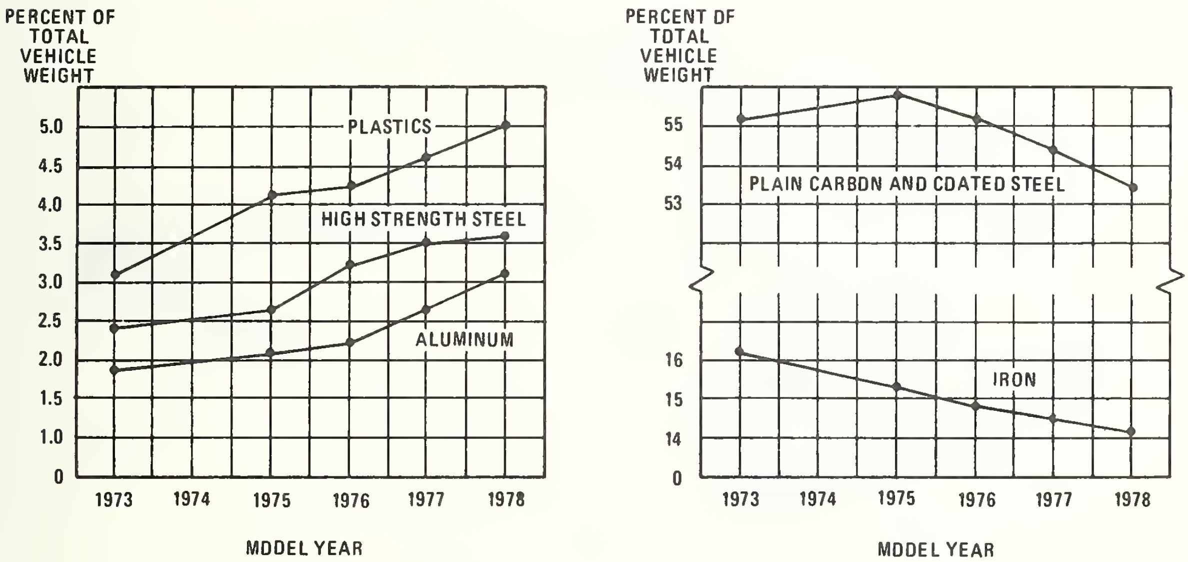
TABLE 1-4. PRELIMINARY CAFE RESULTS FOR 1978, AND PROJECTED CAFE PERFORMANCE FOR 1979*

Performing Organization	Preliminary 1978 CAFE (MPG)	Projected 1979 CAFE (MPG)		
			Trucks	
	Passenger Cars	Passenger Cars	2-Wheel Drive	4-Wheel Drive
Federal Standard	18.0	19.0	17.2	15.8
AMC	19.4	20.1	-	16.8
Chrysler	18.4	20.1	18.4	-
Ford	18.4	18.9*	18.2	-
GM	18.4	19.1	17.2	-

* 1979 data calculated by vehicle manufacturers. As of October, 1979 EPA had not published confirmed 1978 CAFE performance figures.

Source: NHTSA, Office of Fuel Economy Compliance, October 17, 1979.

However, recent events (i.e., Chrysler financial problems)* suggest that meeting the Federal CAFE standards are becoming increasingly more difficult and with a corporate average fuel economy standard of 27.5 mpg in 1985 looming on the horizon, it appears that greater measures will have to be taken in the future by the manufacturers to achieve government fuel economy standards. In all likelihood, this means continuing the trend towards use of lighter weight materials—aluminum, plastic, and high strength, low alloy steel—in cars (see Figure 1-4).



Source: Ward's Automotive Yearbooks 1974 and 1978.

FIGURE 1-4. INCREASE IN LIGHT AND DECREASE IN HEAVY MATERIALS AS A PERCENT OF TOTAL VEHICLE WEIGHT 1973-1978

Potential applications of these materials as seen by the major manufacturers are discussed below.

Aluminum

With the exception of highly-stressed parts and high temperature components, virtually every iron casting in a car is a candidate for aluminum casting. Aluminum is also

* Chrysler has stated publicly that part of their current financial difficulties are a result of large capital expenditures they have had to make to comply with government regulations.

being considered for some body and chassis parts as well, as shown in Figure 1-5. Aluminum parts are now used or are expected to be used for pump housings, the engine intake manifold, transmission housing and casings, bumpers and brakes. Other potential uses include body parts, such as the hood, chassis reinforcements, wheels and perhaps the entire engine block. In 1978 a typical U.S. made vehicle contained 39 percent more aluminum than a similar car in 1975, and total usage is expected to grow to between 200 and 240 pounds per car by 1985.*

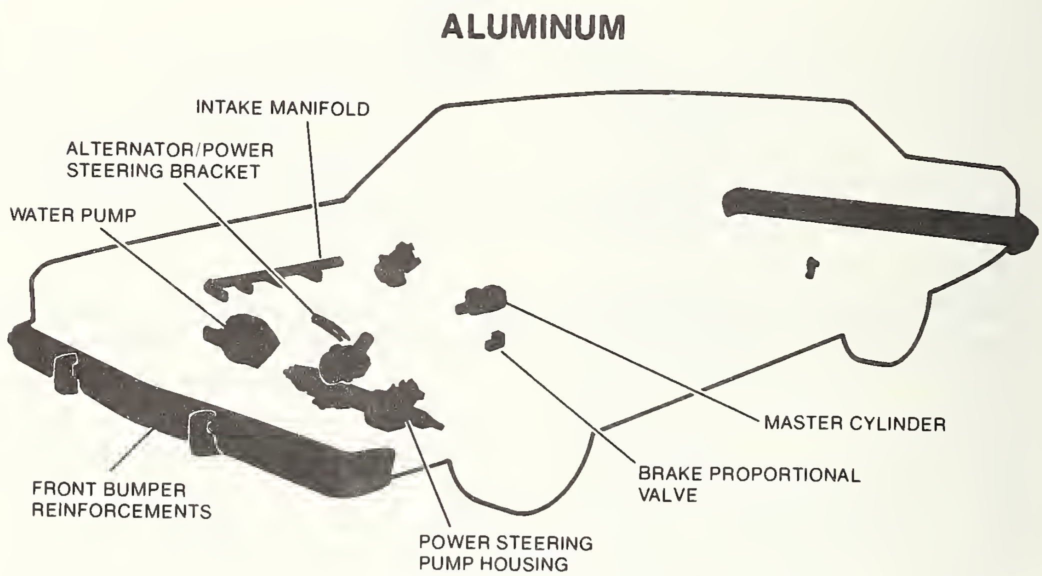


FIGURE 1-5. PICTURE OF CAR AS SEEN BY ALUMINUM MANUFACTURERS

Plastic

Plastic is another material that has been proposed for a number of uses in the car, especially body parts, rear and front ends and trimming. Not only do plastics feature weight reduction, they also offer corrosion resistance and manufacturing energy conservation.

*Source: "Materials '79 and beyond." Automotive Industries, December 1978

Plastic is already being used for interior and exterior trim, fiberglass belted tires, gas tanks and bumpers. Other possible uses include the hood, doors, fenders, wheels and windows. (See Figure 1-6).

In 1978 a typical U.S. made vehicle contained 16 percent more plastic than a similar car in 1975, and total usage is expected to grow to approximately 240-300 pounds by 1985.*

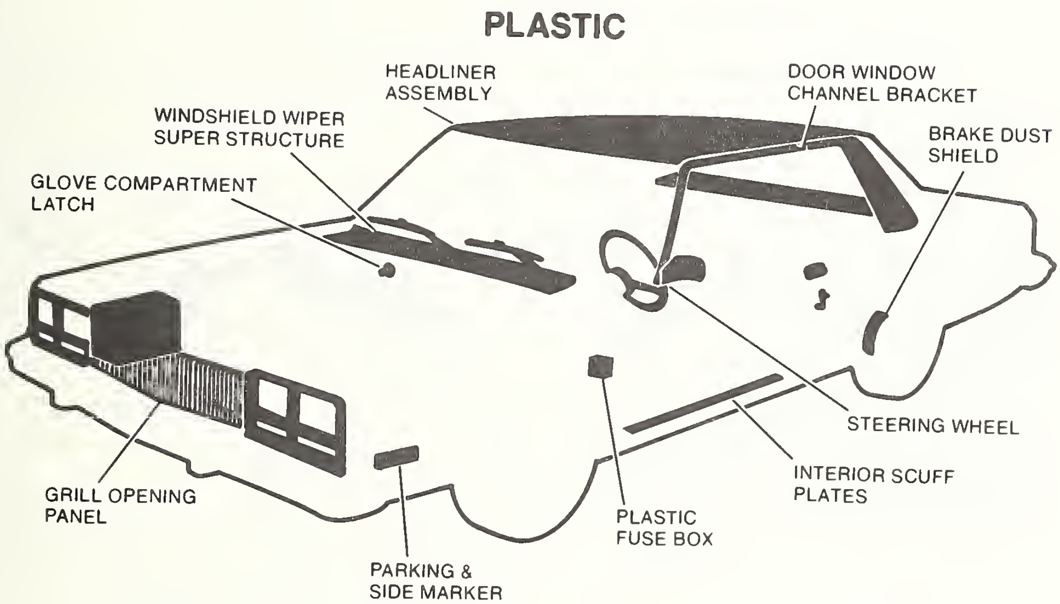


FIGURE 1-6. PICTURE OF CAR AS SEEN BY PLASTICS MANUFACTURERS

High Strength Low Alloy (HSLA) Steel

HSLA steel (made with small amounts of alloying materials possessing up to 2.5 times the breaking strength of mild steels) is finding the greatest share of substitute materials. Because of its higher strength and lower weight than conventional steels, such steels on a percentage-wise basis will probably continue to account for a greater portion of future cars. (In 1985, it is estimated that a typical U.S. made vehicle will be composed of 500 pounds of HSLA steel.)**

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* Source: "Materials '79 and Beyond," Automotive Industries, December 1978

** Source: "Steel's Surprising Comeback," Automotive Industries, December 1978

Potential applications for HSLA as shown in Figure 1-7 are as follows:

- Chassis parts and reinforcements
- Side impact beam suspension arms
- Bumper support bars
- Body panels and reinforcements.

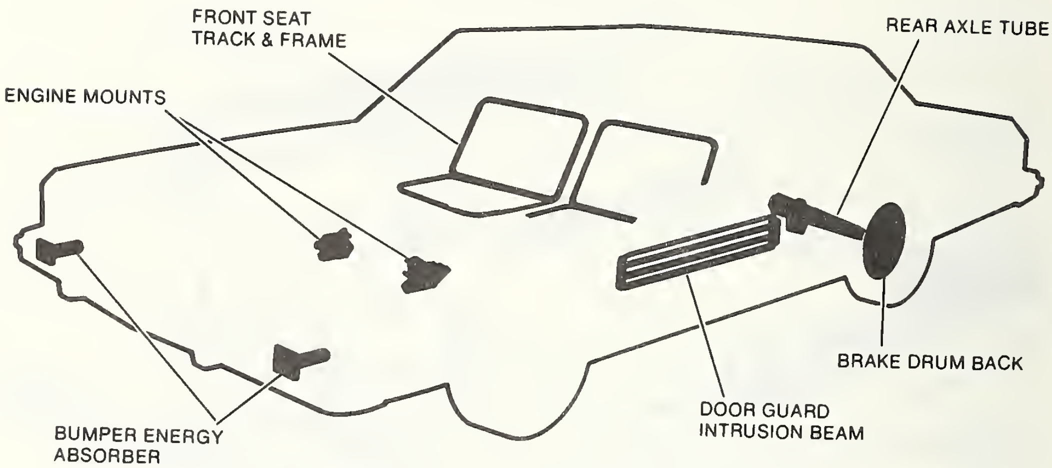
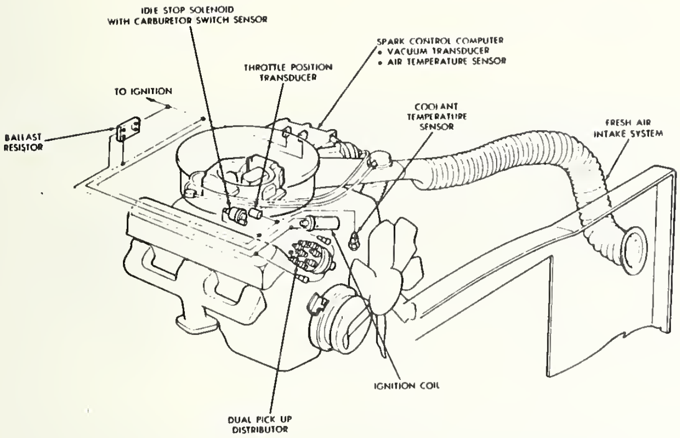


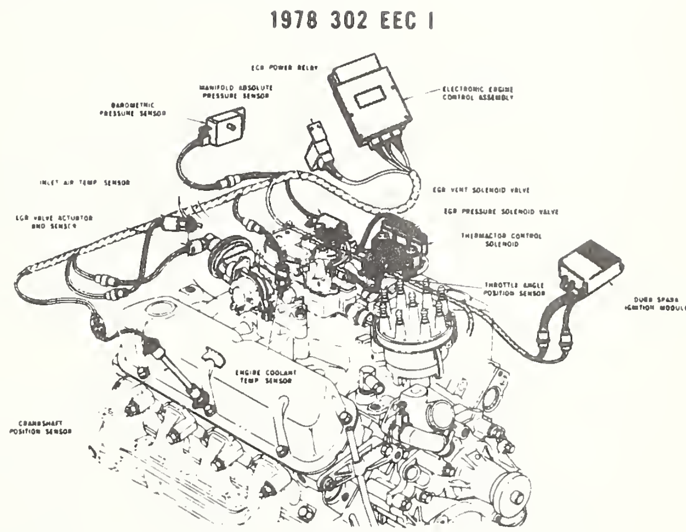
FIGURE 1-7. PICTURE OF CAR AS SEEN BY HSLA MANUFACTURERS

1.3.2 Electronic Engine Controls

Another significant change which will be seen in the automobile during the 1980's will result from the extensive use of electronics and microprocessor computers. With tightening emissions standards, the auto makers will be relying more and more on engine controls to regulate spark timing, exhaust recirculation, and air-fuel mixture. In fact, most auto makers have already started this trend, as shown in Figure 1-8.



Chrysler



Ford

General Motors

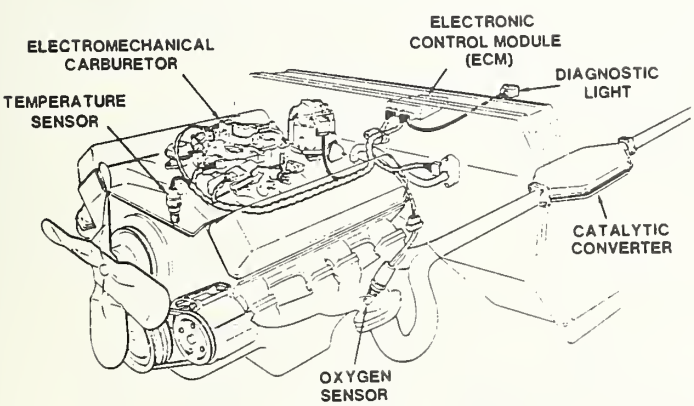


FIGURE 1-8. EXAMPLES OF ENGINE ELECTRONIC CONTROL SYSTEMS OFFERED BY THREE AUTO MANUFACTURERS

While available only on a limited number of vehicles at present, within several years, most new passenger automobiles and light trucks are likely to be equipped with some form of microprocessor control systems. Toward the latter 1980's, engine control systems featuring electronic multiplexing of engine control functions, whereby a single wire or fiber-optic cable will replace a number of wires, could also come into widespread use. Other uses of electronics include:

- Use of solid state triggering devices that require no mechanical drive systems to replace engine electrical distributors

- Use of analog or digital circuits in closed-loop engine control systems for on-board engine diagnostics, including real-time monitoring of certain critical engine, emissions, brake, and lighting systems, as well as other functions, such as low tire air pressure, air filter conditions, and catalyst condition.

1.3.3 Safety Improvements

In addition to strict fuel economy and emissions standards, the automakers will also be faced with stricter safety regulations in coming years. In fact, starting with the 1982 model year, the DOT has already mandated that all full-sized passenger cars manufactured for sale or use in the U.S. must be equipped with automatic (passive) restraint systems, i.e., passive belts or air bags. In model year 1983, all intermediate and compact cars also will have to be equipped, and by 1984, all passenger cars will be required to have automatic protection systems. The design and type of system (belt or air bag) to be used to meet the passive restraint regulations is the manufacturer's option, but certification must be made that the vehicle meets the performance requirements of Federal Motor Vehicle Safety Standard Number 208, Occupant Crash Protection.

According to NHTSA's Five Year Plan, other likely safety standards in future years include:

- Providing better protection for occupants in side impact collisions

- Extending many existing motor vehicle safety standards to cover light duty trucks and vans

- Improving braking requirements for all motor vehicles.

1.3.4 Other Technology Changes

In addition to the above-mentioned vehicle changes, other anticipated changes resulting from existing fuel economy, emissions and safety standards include the following:

- Use of alternative engines in vehicles
- Greater use of turbochargers
- More vehicles with front wheel drive
- Enhancements in aerodynamic vehicle design.

Alternative Engines

One of the major vehicle components where significant change will occur is the engine. While research is continuing on the stratified-charge, stirling cycle, gas turbine and diesel engines, it is the diesel which will be prevalent in future years. This is because of the cost and fuel economy advantages of the diesel.

General Motors has indicated that its V-8 engines may be eliminated after the 1983 models, in favor of 4-cylinder in-line and V-6 engines. However, the spark-ignition gasoline engine will not be displaced, but will evolve into a more mature power source. Diesel Engines will probably become more prevalent in passenger automobiles and light truck fleets. Sales are climbing for the newly-developed Volkswagen diesel, and General Motors expects to build about 100,000 diesel-powered passenger cars and light trucks in 1978, and 190,000 in 1979. By 1981, diesel penetration is now expected to reach at least five percent, and may climb to 25 percent or more by 1985.*

Turbocharging

Turbocharging is another innovation which should receive more widespread application in coming years. This is because turbochargers permit the use of a smaller displacement engine, thereby reducing vehicle weight while still providing adequate power at the higher engine speed ranges. Thus, through turbocharging, manufacturers can both increase fuel efficiency and reduce pollution levels.

In 1978, the largest U.S. automaker, General Motors, employed turbocharging on some of its V-6 engines. This was done to achieve fuel economy and meet emissions requirements while retaining performance in a lightweight

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* Growth of the diesel engine market might be inhibited by future emissions regulations.

package. Some foreign automakers also offered turbochargers on some of their car models. Because of this and other research, a major U.S. manufacturer of diesel engines now offers its engines only in the turbocharged configuration, with the exception of one model, to meet emissions requirements. Increased use of turbochargers can therefore be expected in the near future.

Front Wheel Drive

One problem with reducing the size and weight of automobiles is that the driver and passenger space does not shrink and a minimum number must be accommodated, even in the smallest car. Front wheel drive systems have become an important design solution to this problem.

Front wheel drive offers a small direct fuel economy advantage by decreasing weight and also offers the potential for greater passenger and luggage space for a given vehicle weight and exterior size. These space advantages are gained by eliminating the center hump in the floor and by use of another type of rear-suspension design, such as the swing axle, which can result in additional rear seat space.

This configuration has been most effective in the smallest vehicle sizes but there are plans to use front wheel drive in compact cars. Use in larger cars has been restricted to specialty luxury cars, but the concept can be applied to packages of all sizes as driveline packages of different sizes are developed.

Aerodynamic Design

In the search for enhanced passenger vehicle fuel economy, aerodynamic improvements are also becoming more and more critical. The loss of fuel economy which results from aerodynamic drag is primarily a function of vehicle body shape, the roughness of the surface, and protuberances from the surface such as door handles, hood ornaments, and outside rearview mirrors. Although considerable progress has been made in streamlining passenger cars, improvements continue to be made.

Current aerodynamic studies may contribute to changes in future vehicle designs and result in modifications to parts such as body stampings and windshields. For example, recent research has demonstrated that aerodynamic drag at some slant angles is exceedingly higher than for a squared-off shape. Thus, the hatchback shape may not be as aerodynamically sound as it has previously been considered.

Existing vehicle styles may be modified to change the aerodynamics without completely changing the vehicle's overall appearance. The VW Rabbit originally was designed with a blunt, squared-off nose which prevented a smooth airflow over the hood and roof. A slight modification was made in the body design by adding a rounded nose to the front end to optimize airflow, without changing the basic Rabbit design. Other aerodynamic styling concepts which continue to be modified and perfected by automakers include rounded side windows, sloping front windows and the feasibility of providing molded underbody panels to reduce the drag which occurs from irregular surfaces underneath the car.

1.4 IMPLICATIONS OF DESIGN CHANGES ON AUTOMOTIVE MANUFACTURING PROCESSES

The previous two sections discussed how government standards are likely to change the design of automobiles. The implications of these changes are that virtually every automotive component system, and manufacturing process used in the production of automotive components (see Figure 1-9) will be affected.

For example, the shift to lighter weight materials—aluminum, plastic and HSLA steel—will require significant improvements in existing manufacturing techniques:

- The development of thin wall aluminum castings will require a refined die casting method
- The joining of HSLA steel will require precision welding
- The forming of plastic components will require reaction injection molding.

In addition, improved process controls—often computerized—will also be needed to help eliminate excess metals from mass-produced cast components such as the engine block.

But this is not all. The trend towards increased use of electronic controls to improve fuel economy and combat emissions, and the requirement for passive restraint systems to improve safety will also have significant implications for the manufacturing industry as well. Key issues here are the supply of rhodium required to produce catalytic converters, the capacity of the semi-conductor industry and its ability to meet the increased demands for electronic engine controls, and the costs and reliability of sophisticated electronic sensors.

Thus, the implication of "bottom line" is that as automakers strive to meet federal standards in coming years, the automotive process industry can expect to devote heavy capital resources for the purchase of new equipment and for the development of new technology. For the larger organizations, such as General Motors, heavy capital deployment and extensive technological change are neither unusual nor traumatic—but for most of the industry, the heavy capitalization required to meet the changing technological demands may be a major problem.

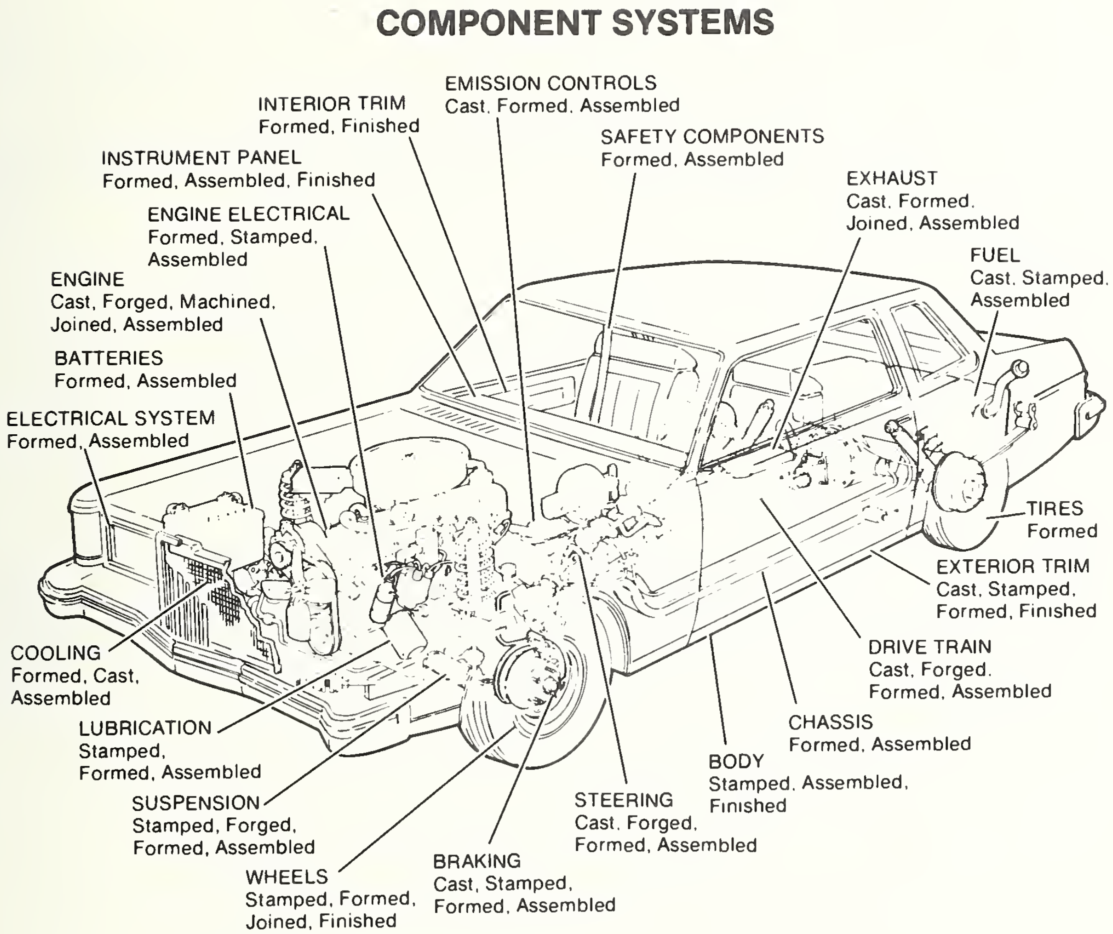


FIGURE 1-9. SCHEMATIC DIAGRAM OF AUTOMOBILE SHOWING THE VARIOUS MANUFACTURING PROCESSES EMPLOYED

2. AUTOMOTIVE MANUFACTURING PROCESSES

2.1 GENERAL

The processes used to manufacture cars today are basically the same as those used over the last twenty years. They are:

- Casting
- Forging
- Stamping
- Forming
- Machining
- Joining
- Assembly
- Finishing.

To provide a frame work for future discussions of the impact of substitute materials and other automotive design changes on the manufacturing industry, this chapter presents brief sections on each process. Included in each section are:

- A discussion of how each process works
- The principal methods, machinery and materials used in each process
- The major automotive components produced by each process
- The size and structure of each process industry
- The key issues impacting upon each process now and for the next few years.

A conceptual model showing where the various processes enter into the production of a new automobile is presented in Figure 2-1.

In presenting the above material, the sections on casting, forging, and stamping are limited solely to metals and the section on forming is limited solely to plastics. The reason for this is that the term "forming" actually encompasses a broad range of manufacturing processes—in its broadest sense, the processes of casting, forging and stamping. Since plastic is becoming more popular in automotive manufacturing, it seemed desirable to devote a separate section to the processing (forming) of plastics.

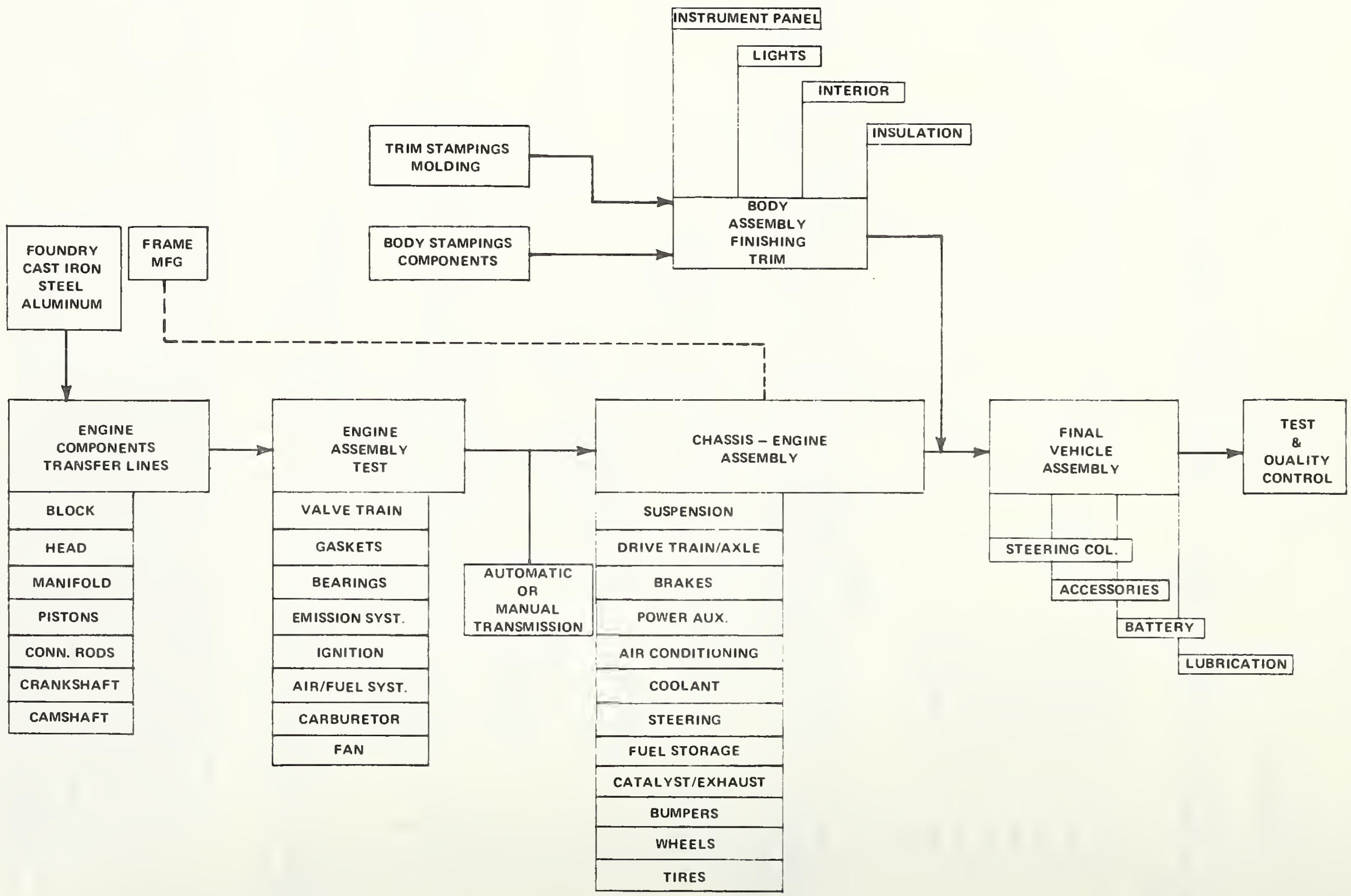


FIGURE 2-1. AUTOMOTIVE MANUFACTURING PROCESS FLOW

2.2 CASTING

Casting is one of the most common automotive manufacturing processes. Automotive parts and components that can be cast include brake drums, engine blocks, cylinder heads, oil pans, manifolds and pump housings. Simply put, casting is the entire process from introducing material in a liquid form into a mold to removing the material from the mold after it has solidified.

There are many casting processes currently in use, and many new variations are in development. Among the metals which can be cast are iron, aluminum, zinc and magnesium. A particular casting process is chosen, depending on the type of material to be used, the size of the casting, or production requirements.

2.2.1 Type of Castings

The major types of castings are:

- Sand casting
- Shell mold casting
- Permanent mold casting
- Die casting
- Plaster mold casting
- Investment casting.

Of these six types, however, only the first four—sand, shell mold, permanent mold and die casting—are used to any great extent in the automotive industry. Both plaster mold casting and investment casting are used to make high precision parts and have very limited applications in the automotive industry.

Sand Casting

Sand casting is the predominant method for casting automotive parts and components. In this casting process, expendable molds of different sands or clays are formed around a pattern into a shape. Molten metal is then poured into the sand mold which is discarded after use.

There are two principal types of sand casting: green sand molding and dry sand molding. The term "green" indicates there is moisture in the sand. Green sand molding is the predominant method in the automotive industry and is used to make such parts as cylinder heads and manifolds, brake drums and discs, universal joints and automatic transmission parts.

A summary of the steps involved in making a green sand mold is as follows:

- First, moist "green" sand is compressed around the pattern of the part to be cast, in two halves. The bottom half of the pattern, called the "drag," surrounded by a wooden flask, is placed on a board, and surrounded with sand.

- The flask is then inverted, and the upper portion of the pattern, called the "cope," which has been similarly surrounded with sand, is locked into position with the bottom half.

- Two holes, one called a "sprue," and the other a "riser," are then cut in the sand. The sprue is for the passage of molten metal into the mold while the riser is to prevent the forming of porous spots in the casting by allowing a reservoir of molten metal near the mold cavity. The flask is then separated and the pattern removed.

- The two halves of the sand casting are next put into place and the flask is firmly clamped. Molten metal is then poured to form the casting When the metal has sufficiently cooled, the casting is removed from the mold and the sprues and risers detached from the casting. The latter is often accomplished by sawing.

An overview of a green sand mold ready for casting is shown in Figure 2-2.

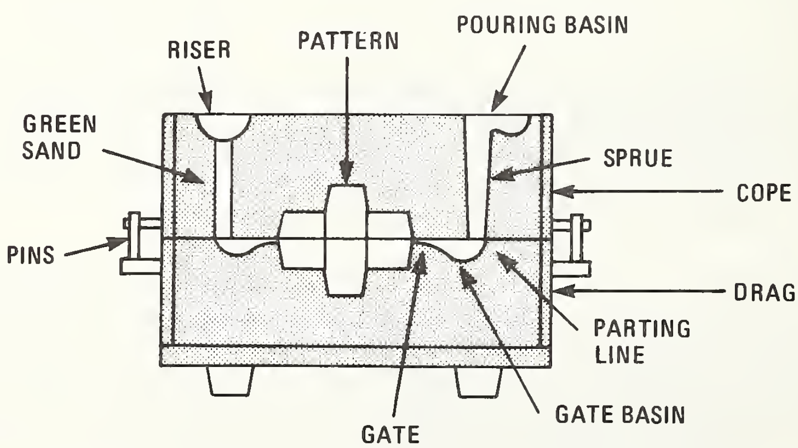


FIGURE 2-2. GREEN SAND MOLD READY FOR CASTING

The principal advantages of sand casting are low cost of pattern and low piece cost; also, intricate pieces with elaborate interior cavities can be made by the use of sand cores. The chief disadvantages are the rough surface and the low accuracy of the castings. This often means that expensive finishing and machining operations are required that might be eliminated by some other casting processes.

Shell Mold Casting

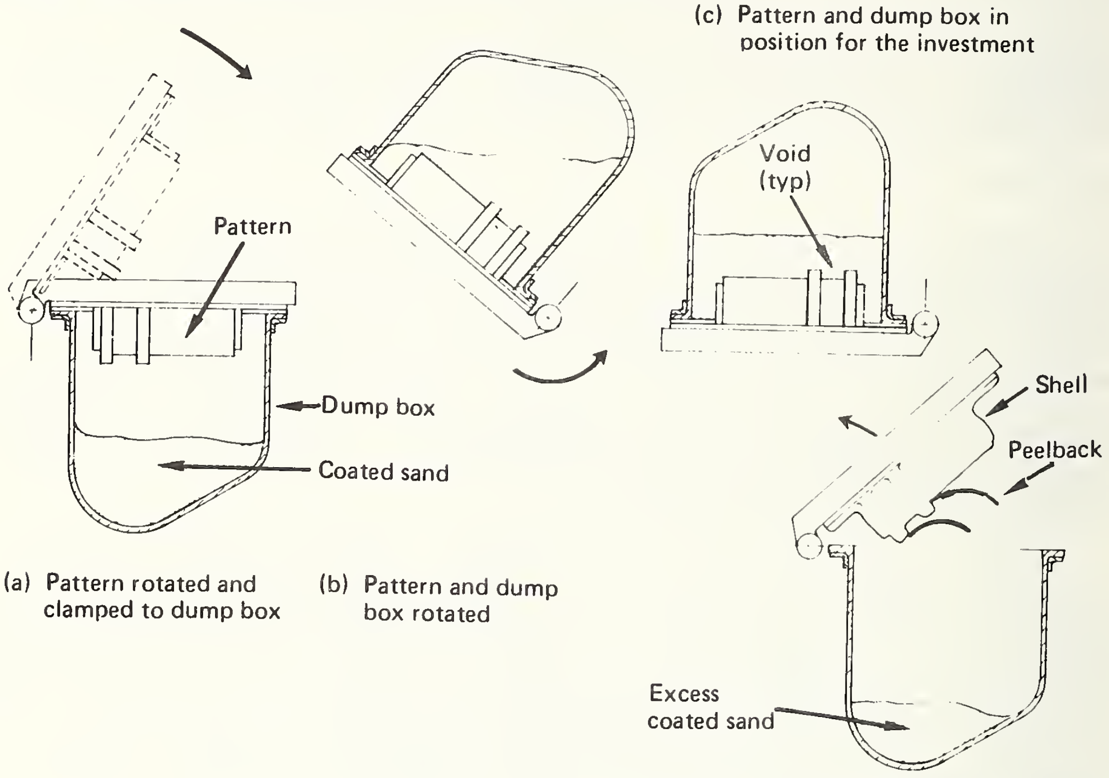
Shell mold casting is similar to green sand molding. In this casting process, however, a thin shell of sand, rather than a moist thick mold, is preformed around a pattern and baked. This thin shell is usually a resin-sand mixture. The baking of the sand forms a hard, thin shell over the pattern. When the shell has been adequately baked, it is removed from the pattern. To facilitate this removal, the pattern is coated with a release agent prior to the forming of the shell.

Two halves are formed this way, and are then pasted together with a resin glue and supported in a flask of coarse sand or metal shot for metal pouring. Provision is made on the original pattern for a gate to pour the metal. This is usually between the halves of the shell mold. The metal is then poured, and, after cooling, the shell is broken away. The gating is then cut off, and the parts are cleaned by sand blasting or tumbling.

Figure 2-3 is an overview of one commonly employed technique in making shell castings—the dump box technique. As shown, in this technique, the resin-sand mixture is placed over the heated pattern by means of a dump box. Note that the amount of sand-resin mixture is considerably greater than that needed to form the shell. This is to ensure that the pattern is completely covered.

Castings obtained by shell mold casting are characterized by sharp reproduction of the details of the original pattern, a smooth surface finish and good accuracy. Because the mold is permeable, it allows the escape of air and gases and the castings are exceptionally sound. Less sand is also required as compared to that needed for green sand casting.

The pattern cost for shell molding is, however, considerably more than that for sand casting, which means that the process is not usually economical for very small quantity runs. In general, the piece cost is also somewhat higher than that of sand casting, so the better finish, the closer tolerances, or the savings in machining or finishing time must be counted on to offset this.



(a) Pattern rotated and clamped to dump box

(b) Pattern and dump box rotated

(c) Pattern and dump box in position for the investment

(d) Pattern and shell removed from dump box

FIGURE 2-3. DUMP BOX METHOD OF MAKING A SHELL MOLD

Permanent Mold Casting

Permanent mold casting consists of filling a mold with molten metal as in sand casting, except that the mold itself is made of metal. Such a mold may be used thousands of times to produce parts with smooth surfaces and superior strength. As shown in Figure 2-4, no pressure is used other than gravity to force the metal into the mold; therefore, pouring techniques are especially important for preparation of good castings.*

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* Low pressure casting, where seven to eight pounds of pressure is applied to the flowing metal, is closely related to the permanent mold casting technique. This process is not widely used in the automotive industry.

The process is used successfully for both ferrous and nonferrous casting, although it is best applied to lower melting point alloys such as aluminum. The most widespread automotive applications of permanent mold castings are in light to medium weight aluminum components such as master cylinders and intake manifolds. Automotive applications of permanent mold castings are more restricted than for sand or shell mold casting since they must be removed without destroying the mold.

Permanent mold castings are characterized by their superior surface finish compared to sand or shell castings. The cost for permanent mold castings, however, is considerably higher than the pattern cost for sand castings; but the process can be mechanized so that the piece cost in quantities may be considerably less. Therefore, the process is adapted best to medium or large quantitites of small- or medium-size parts.

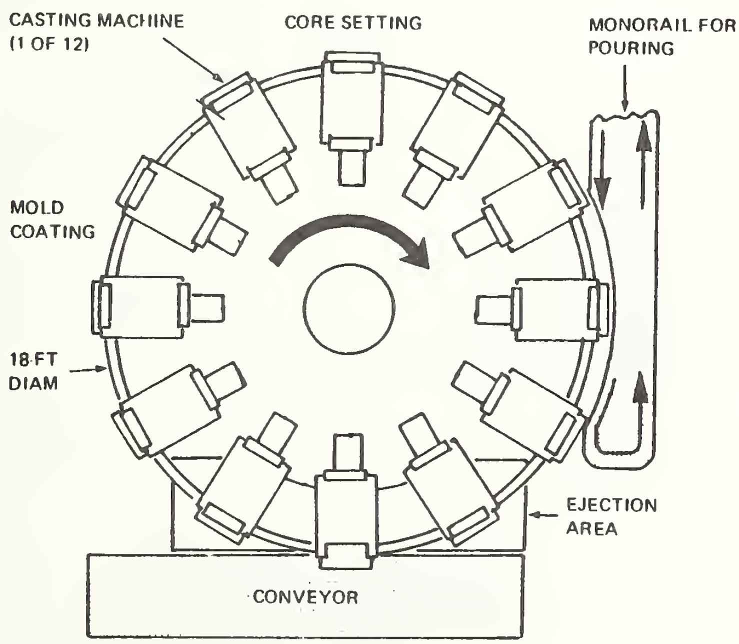
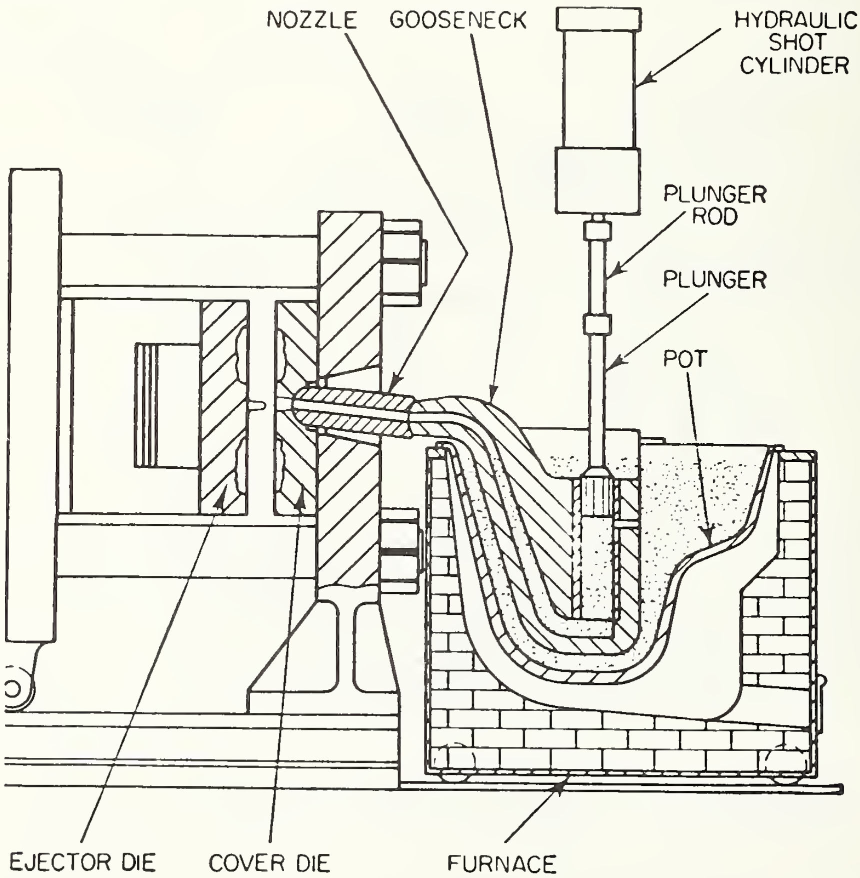


FIGURE 2-4. PERMANENT MOLD CASTING MACHINE

Die Casting

Die or pressure casting has become one of the most important of all casting processes. This is because die casting produces castings of high strength, close tolerances, and thin sections, at high production rates.

In die casting, molten metal is forced into a die cavity under extreme pressure. To accomplish this, there are two basic machines: hot chamber and cold chamber machines. In the hot chamber or "gooseneck type" machine (see Figure 2-5), the injection mechanism is immersed in a molten metal bath in a furnace attached to the machine. The molten metal is forced through the gooseneck and nozzle into the die cavity by a plunger at pressures ranging from 1,500 to 2,000 psi. Since the gooseneck and pot are made of iron, and since most metals react with iron at elevated temperatures, only low melting point alloys such as lead, zinc and tin may be cast by this method.

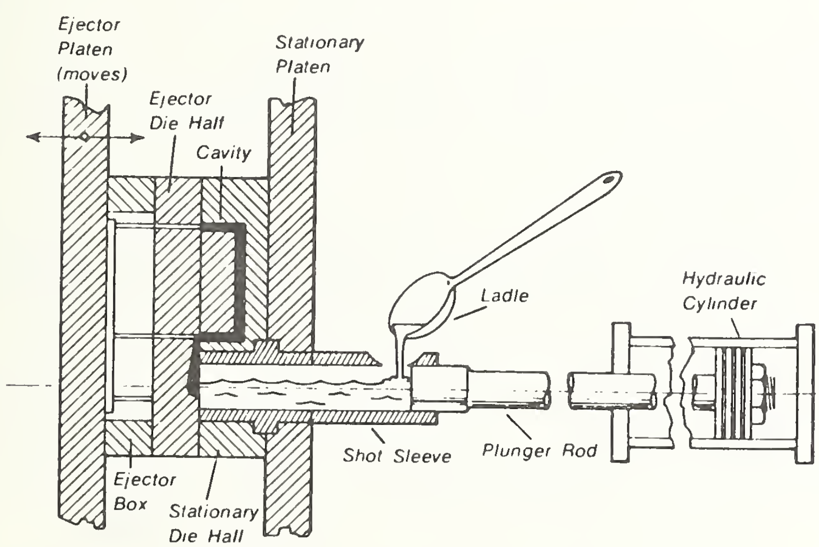


Source: American Die Casting Institute

FIGURE 2-5. HOT CHAMBERED MACHINE

The cold chamber machine is similar to the hot chamber machine, except that molten metal is poured directly into the piston chamber and forced into the die at 10 times the pressure of the hot chamber machine. As shown in Figure 2-6, the cold chambered machine uses a ladle to transfer the molten metal from a melting pot to the cold chamber of the machine. This process best suits high melting point alloys such as aluminum, magnesium, and copper-based metals. Injection pressures usually range from 3,000 to 10,000 psi for both aluminum and magnesium alloys and from 6,000 to 15,000 psi for copper-based alloys.

In both the hot and cold chamber methods, the metal is kept under pressure until it has solidified. At that time, the core is retracted, the mold is opened and the finished casting is ejected from the cavity by the ejection pins.



Source: American Die Casting Institute

FIGURE 2-6. COLD CHAMBERED MACHINE

The primary drawbacks of die casting are:

- The size of the part that can be die cast (usually restrained to under 50 pounds)
- The cost of equipment (the cost of a die cast machine ranges from $150,000 to $1,000,00 depending on part complexity and production requirements)
- The metals that can be die cast (iron and steel parts cannot be die cast).

2.2.2 Automotive Applications

Some examples of the typical automotive applications of various automotive casting processes discussed above by type of material are summarized in Table 2-1. The asterisks in the table denote potential or presently limited applications. Most of the same parts are also displayed graphically in Figure 2-7.

As shown in Figure 2-7, and in Table 2-1, many key components of the automobile, such as engine blocks, cylinder heads, intake and exhaust manifolds, and transmission and chassis components, are cast metal products. Current changes in Detroit, however, are resulting in changes in the casting industry—in its processes, products, and production rate. For example, most engine blocks, automatic transmission cases, pump bodies, and intake manifolds are being die cast in lightweight aluminum for weight reduction, and the same potential exists for other parts, such as rack-and-pinion power steering gear, rear-wheel brake drums, and ball-nut steering units. Use of other lightweight materials, such as magnesium, in parts are also being investigated as potential substitutes to the heavier iron parts.

2.2.3 Size and Structure of the Casting Industry

The following is a summary of the four major segments of the casting industry:

- Sand casting
- Shell mold casting
- Permanent mold casting
- Die casting.

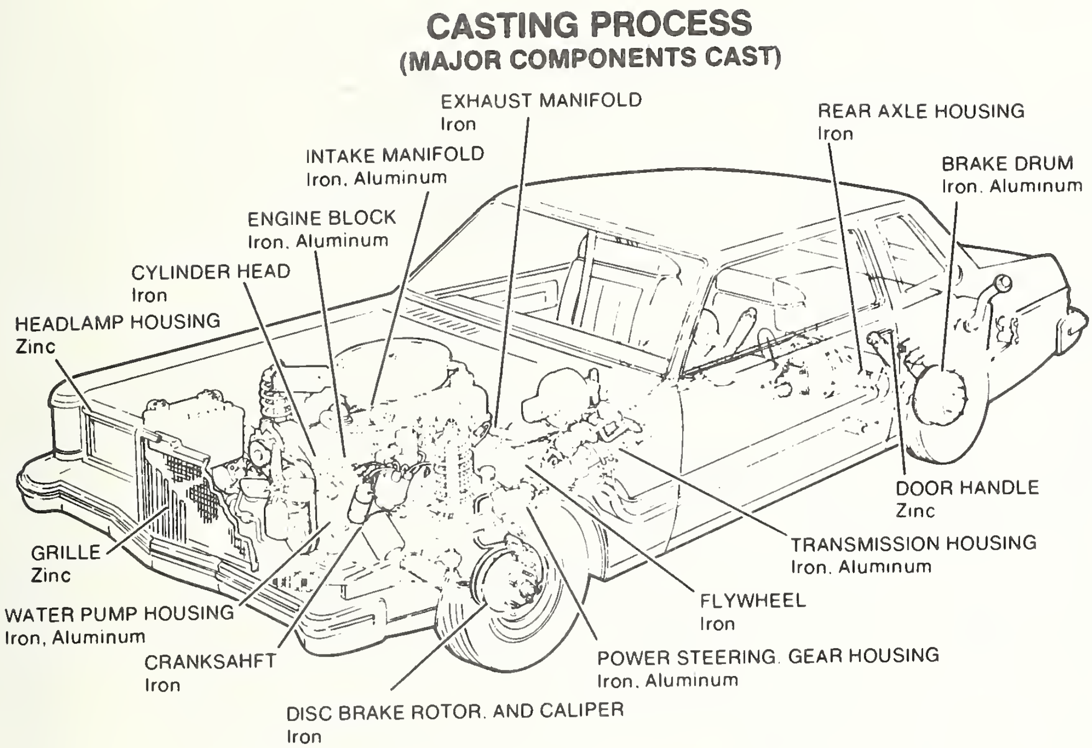


FIGURE 2-7. SCHEMATIC OF AUTOMOBILE SHOWING COMPONENTS WHICH ARE CAST

Sand Casting

Sand casting is the largest of the casting industries consisting of both iron and aluminum foundries. Each is discussed below.

- Iron Sand Casting. Sand casting of iron has a growing market, particularly in the automobile industry where 82.8 percent of all castings are sand cast iron. The automobile industry annually consumes approximately 25 percent of gray iron, 55 percent of ductile iron and 65 percent of malleable iron. This is procured from outside or "commercial" suppliers as well as from the automotive in-house or "captive" foundries. Casting foundries of General Motors, Ford, and Chrysler account for 20 percent of the entire casting industry. Commercial foundries account for 20-50

TABLE 2-1. EXAMPLES OF AUTOMOTIVE APPLICATIONS OF VARIOUS CASTING PROCESSES BY TYPE OF MATERIAL

	GRAY IRON	MALLEABLE IRON	DUCTILE IRON	ALUMINUM	ZINC	MAGNESIUM *
Sand Casting	Master cylinder Cylinder head Engine manifold Water pumphousing Engine block Brake disc/drum	Suspension parts Brake calipers Automatic transmission parts Universal joints	Front knuckle castings Disc brake caliper Steering gear housing Automatic transmission parts Differential carrier & case	Cylinder head Intake manifold Engine block Brake drum		
Sheel Molding Casting	Camshafts		Crankshaft Exhaust valves Transmission parts Hubs Carriers			
Permanent Mold Casting	Wheel Cylinders Proportioning valves Fan hub castings for engine cooling fans A/C compression bodies			Cylinder head Intake manifold Piston Master cylinder housing		
Die Casting				Rocker arm cover Cabureutor body Fuel pump body Transmission housing Piston Engine block Water pump housing Oil pump body Timing chain cover	Door/window handles Head/rear lamp bezel Hood ornaments Parking lamp housing Fender exten-sions Grille License plate frame Rearview mirror housing Rear lamp housing Exterior mirror housing Wheel trim parts Exterior moldings	Distributor diaphragm housing Case for manual transmission Steering column lock housing Mirror remote control Switch cover plate

*Existing applications of magnesium are limited to selected make/model vehicles.

percent of total automotive casting tonnage. In 1978, there were 1472 gray, ductile, and malleable iron foundries of which 90 percent employed less than 250 people. In the future, the number of smaller commercial foundries will decrease if they cannot meet new health, safety, energy, and technological regulations. However, continued growth for the sand cast iron industry is forecasted for the future.

- Aluminum Sand Casting. Aluminum sand casting accounts for 10 percent of total aluminum castings. This small percentage is due to the superior efficiency and tolerances of die and permanent mold casting. Captive operations of aluminum die casting have been growing while smaller, independent aluminum sand casters are limited to making such aluminum replacement parts for cars as manifolds and heads. None of the auto companies are expected to build new sand casting facilities for aluminum. Cast Metal Industries, the largest sand caster of aluminum, produces 8,000 manifolds a day. This company expects sand cast manifolds to decrease 36 percent as cars are down-sized and need less complex manifolds.

Shell Molding

Shell molding is a specialty molding segment of the casting industry, and can be used for both ferrous and nonferrous metals. While shell molding lines are distinct from green sand molding facilities, companies that do shell molding often also do sand casting. In addition, shell molding foundries serve the same markets and make the same parts as green sand foundries. Companies that do shell molding include Lynchburg Foundry, CWC-Textron, Eaton, and Grede.

Lynchburg Foundry, in Lynchburg, Virginia, did much pioneering work in shell molding in the 1950's, and is the leading producer of castings by this method. Lynchburg continues to be a major supplier of shell molded iron parts to the auto industry. Shell molding is rarely used in automobiles; shell molded parts account for an estimated 8 percent of cast iron parts. Most of the major auto companies have captive shell mold foundries. Captive shell mold castings include crackshafts and camshafts. Shell casting in the auto industry is presently declining according to sources familiar with the automotive foundries.

Permanent Mold Casting

Permanent mold casting is predominatly an aluminum casting industry. In 1977 permanent mold aluminum castings accounted for 22 percent of all aluminum castings. The tonnage of such castings has increased significantly in recent years. Foundries that do permanent mold castings may also do sand or other types of castings. Unlike die castings, however, permanent mold casting is not dominated by captive shops, and there is about fifty-fifty split (see Table 2-2).

TABLE 2-2. PERMANENT MOLD CASTING SALES
(Million of Pounds)

Type of Shop	1977	1976
Commercial	220	199
Captive	213	178
TOTAL	433	377

Permanent mold facilities which supply the auto industry now exist at Doehler-Jarvis, Hayes-Albion and Dayton Malleable:

- Doehler-Jarvis. The Greenville, Tennessee plant was converted to the production of permanent mold castings in 1977, and initial production began in 1978. The 115,000 square foot plant makes intake manifolds, master cylinder housings and cylinder leads.

- Hayes-Albion. The Tiffin, Ohio plant houses the permanent mold casting facilities which are targeted for 19,000 tons of aluminum capacity by 1981. The foundry will be making cylinder leads and intake manifolds for the 1981 Ford Erika.

- Dayton Malleable. The Meta-Mold and Columbia plants are presently in production of aluminum permanent mold master cylinders. Additional acreage has been purchased for expanding capacity at the Columbia plant.

Additional suppliers include Stahl Specialty Company (master cylinders), Hall Machining Company (master cylinders) and Winters Industries (intake manifolds).

Both General Motors and Ford also have permanent mold casting facilities. General Motors has a permanent mold facility in Sheffield, Alabama. Ford has also recently announced the construction of two permanent mold shops, one in Windsor, Ontario and one in Mexico. These shops will be built to give Ford hands-on experience with the permanent mold process.

Die Casting

Die casters tend to be separate from sand and permanent mold foundries but like these other industries are comprised of both commercial and captive foundries. The following is a brief summary of both types of die casters which combined, accounted for 41 percent of the aluminum casting tonnage and 50 percent of the zinc casting tonnage shipped to the auto industry in 1976.

- Commercial Die Casters. At present there are approximately 500 commercial aluminum die casters and 200 zinc die casters. Only about 100 though supply a major portion of their output to the auto industry. These shops tend to be medium-size facilities employing around 150 people. Doehler-Jarvis is the major aluminum die casting supplier to the auto industry. Others include Dupage, Superior, Heick, Midland-Ross, and Hoover Universal. Of the 460 zinc die casters, 44 percent report shipments to the auto industry.

- Captive Die Casters. All the major auto companies have die casting capabilility except American Motors. Approximately 74 percent of all aluminum automotive die casting was done by captive shops in 1976. The auto companies tend to have large machines (up to 3,000 tons) that can make large automotive parts such as automatic transmission castings. Smaller covers and castings tend to be done by outside shops. There are approximately 500 aluminum and 230 zinc captive die cast shops at present.

Since about 1962, captive shops have steadily increased their share of the market and this trend is expected to continue especially if blocks, heads, and manifolds become die cast parts in the next few years. If this happens it is very likely that they would be made on the large machines at captive auto shops. This in turn would release smaller castings now done in-house for manufacture by independents. A study released by the Aluminum Die Casting Institute projects that while both independent and captive automobile die casting output will be higher by 1980, that captive shop output will rise twice as fast as commercial shop output.

2.2.4 Key Issues Facing the Casting Industry

The principal issues presently confronting the casting issue include:

- Changing markets stemming from the downsizing and lightening of cars
- Competition from oversears
- Capital shortages
- Shortage of skilled workers.

Changing Markets

Changes in the auto industry are having important impacts on the foundry industry. The conversion of certain auto parts to aluminum has caused a decrease in gray iron sales for some companies, especially those producing parts that have been converted to aluminum, such as intake manifolds.

There is some disagreement within the foundry industry about the extent to which downsizing of parts by itself creates excess foundry capacity. Smaller parts imply less metal and it is thus reasonable that there should be excess melt capacity. However, other factors in a foundry also determine its capacity to make auto parts. The number of parts that fit into a flask will determine the capacity of the molding equipment. If parts are not downsized sufficiently to increase the number of parts in a flask, a foundry will not be able to increase its output without investing in more facilities. In addition, smaller parts still require cores and grinding. Thus, part downsizing does not necessarily increase total foundry capacity.

However, given that significant sections of plants become underutilized, capacity should increase as plants try to better utilize their facilities either by producing different parts or making selected capital expenditures.

Some companies have claimed that a result of industry excess capacity caused by downsizing the captive auto foundries have taken a greater share of casting production to the detriment of the jobbing foundries. Other foundries, especially those that produce ductile iron or produce parts that have not been downsized or switched to aluminum, report no impact from auto industry changes. The entire foundry industry is estimated to currently be operating at 70 percent of rated capacity.*

There is a question whether the large captive foundries would assume a greater share of total auto foundry purchases if there were excess industry capacity due to auto downsizing. The captive foundries are large and tooled up for the components requiring high volumes. The jobber foundries tend to be more specialized and more susceptible to change. For instance, Dayton Malleable continues to sell automotive air conditioning castings and CWC-Textron continues to sell camshafts to General Motors because the companies are able to produce the parts at less expense or with superior characteristics than GM's foundries.

It is likely that the future of aluminum in casting will primarily be with die casting. Thus, as the auto industry continues to increase its usage of aluminum parts in cars, sand casting tonnage will decrease. This is not to say that sand casting will not be used in making aluminum auto parts. Sand casting will probably be used for large aluminum parts requiring cores in complex arrangements. Die casting, however, will likely be used for most aluminum parts due to its lower cost, better finish, and thin-wall production.

There is another reason why sand casting will not be the predominant method for casting aluminum in the future. As described earlier, sand casting is primarily an iron casting industry. Such a switch from iron production to aluminum production would require major changes in the melting and cleaning areas of the foundry. In a typical sand casting foundry these parts of the foundry constitute about 20 percent of the entire capital cost of the plant, of which about 40 percent of is for installation. Thus, a foundry would have to see a tremendous potential for aluminum sand

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* American Metal Market, April 21, 1978, page 6A.

casting before undertaking such a costly change. Sand foundries have virtually no capability to change over to aluminum permanent mold casting or die casting since the equipment is different throughout the processes.

Competition From Overseas

Many foundries have found that some of their products are now being made overseas and sold at lower prices than the American foundries can charge. Castings are being imported from Japan, Brazil, and Europe. The castings are reportedly of good quality. Price has been cited as the principal reason for losing out to imports, even if quality had to be compromised. Although imports have affected the sales of foundries that serve the auto industry there have not been any reports of major auto companies purchasing castings from overseas.

Capital Shortage

A study by the Cast Metals Federation has indicated that due to predicted expansions, modernizations, and pollution abatement expenditures, the entire casting industry could need as much as $10 billion from 1978 through 1981 for capital expenditures. Further, 18 percent of the capital necessary will have to come from unknown sources.* The study indicates that low selling prices in the industry have resulted in inadequate returns to generate the capital needed. This is particularly a problem with small foundries and die casting facilities.

The die casting industry is capital-intensive, but replacement of worn-out or obsolete machinery or buildings is very difficult in the current inflationary era. Money reserves normally set aside for such purposed are suddenly insufficient. Borrowing money for new facilities is difficult and costly because interest rates are increasing rapidly in the anticipation that they will continue to rise and that loans will be paid back with cheaper dollars. In addition, foundry earnings are taxed at a high rate. This makes it difficult to pay adequate dividends to attract investors or to generate capital out of retained earnings.

The combination of inflation, high taxes and lack of investment reduces replacement or expansion of facilities, leading to obsolescence of equipment, high production costs and ultimately to loss of jobs.

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* American Metal Market, April 21, 1978, page 3a.

Inflation is forcing foundry managers to become more sophisticated in increasing productivity, cutting costs of material and labor, and increasing utilization of facilities if they intend to stay in business. The challenge of foundry managements is clear, and smaller foundries will be under great pressure to survive.

Shortage of Skilled Workers

The principal labor issue facing the costing industry, principally die casting, is the lack of skilled workers. Many of the older skilled tool and die makers and die casting operators are tied to large companies by seniority and pension benefits. These large companies are becoming very concerned, however, as the average age of their skilled work force rises over 50. Companies have been unable to attract younger people as backup for eventual replacement. Small foundries are taxed even more by their inability to match the benefits packages of the large firms in attracting skilled workers.

Automation is a potential solution to the problem but only a partial one. Integrated die casting systems will, by themselves, require additional skilled personnel to handle the systems. A survey conducted by Foundry Management and Technology magazine identified the folllowing major problems of foundrymen:

- Shortage of skilled labor for all departments
- Shortage of engineering skills in the foundry
- Absenteeism of hourly employees
- Turnover.

2.3 FORGING

Forging is the process of working heated (but not melted) and cold metal into shape by means of pressure, usually with a hammering action. Its simplest form is represented by the method of the old-time blacksmith with his forge and anvil. Most forging is now done by mechanically operated presses, but it is still the best method for developing the greatest strength and toughness from steel, bronze, brass, copper, aluminum and magnesium. In fact, within the metals industry, "high strength" and "forged metal" are somewhat synonymous terms.

Forgings are generally more expensive than castings, but there are many applications where no other process would give satisfactory results. Tie rods, U-bolts, and connecting rods, for example, are end products of the forging process requiring high strength. Each type of forging endows the forging with a new shape and contributes a new toughness to the metal as well.

2 3.1 Forging Processes

There are two major forging processes:

- Hot forging
- Cold forging.

Cold forging is a much newer and smaller contributor to the auto industry than hot forging, but it has established itself as an important branch of metalworking.

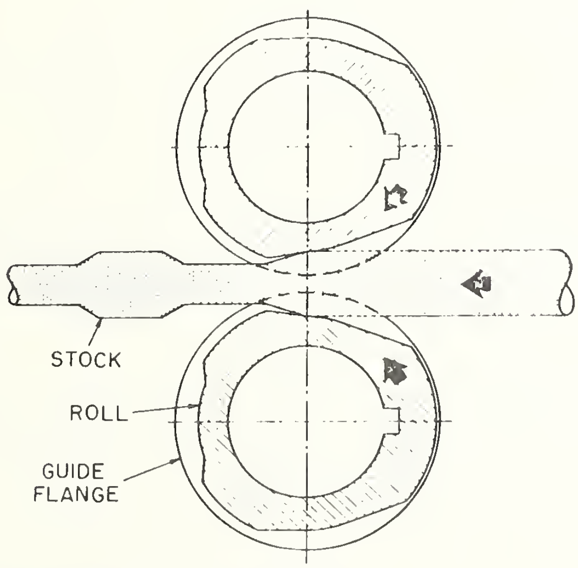
Hot Forging

Hot forging is the process of shaping a heated metal workpiece between dies by hammering, pressing, rolling or upsetting. The operation serves the dual purpose of shaping the material and enhancing its mechanical properties. The intricacy of the dies determines whether the resultant forging is a finished or semifinished product. Finished products need only to be heat treated, cleaned and occasionally ground before shipment. Semifinished products will be transferred to another forging operation or subjected to substantial machining prior to heat treatment and finishing operations. Automotive parts which are hot forged include connecting rods, steering idler levels, tie rods, and crankshafts.

The major types of hot forging are primarily categorized by the types of dies used. The major types of dies in hot forging are:

- Open Die. Open die forging is the compressing of a metal workpiece, usually an ingot or billet, between dies which impinge upon the piece tangentially and restrict the flow of metal in one direction. Open die forging utilizes crudely shaped dies; thus, its products need considerable subsequent processing. This method of forging is not suitable for high volume production and therefore is not used in the manufacturing of automotive parts.

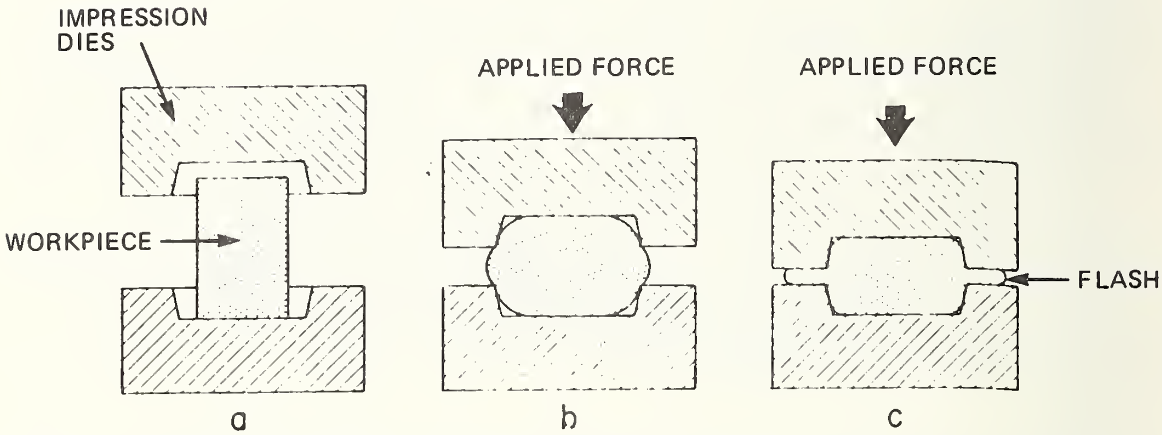
- Roll Forging. Roll forging is the shaping of metal, usually in the form of sectioned bar stock, between a pair of rolls (see Figure 2-8). Roll forging is primarily used to preshape a workpiece which will be transferred to an impression die hammer or press forging operation; however, in some cases a workpiece is sent through several sets of rolls to yield a finished product. As a result, roll forging like open die forging is not widely used in the automotive industry. Axle shafts are the predominant automotive part made via roll forging.



Source: Forging Industry Handbook, 1970

FIGURE 2-8. ROLL FORGING OPERATION

- Impression Die.* Impression die forging is the shaping of hot metal completely within the cavities of two dies that come together to enclose the workpiece on all sides (see Figure 2-9). This process is capable of producing a high volume of complex parts that require a minimal amount of subsequent machining and which range in size from a few ounces to several tons. Although 70 percent of all impression die forgings weigh two pounds or less, steel forgings weighing as much as 33,000 pounds and with maximum dimensions of 35 inches wide by 115 inches long have been successfully forged.



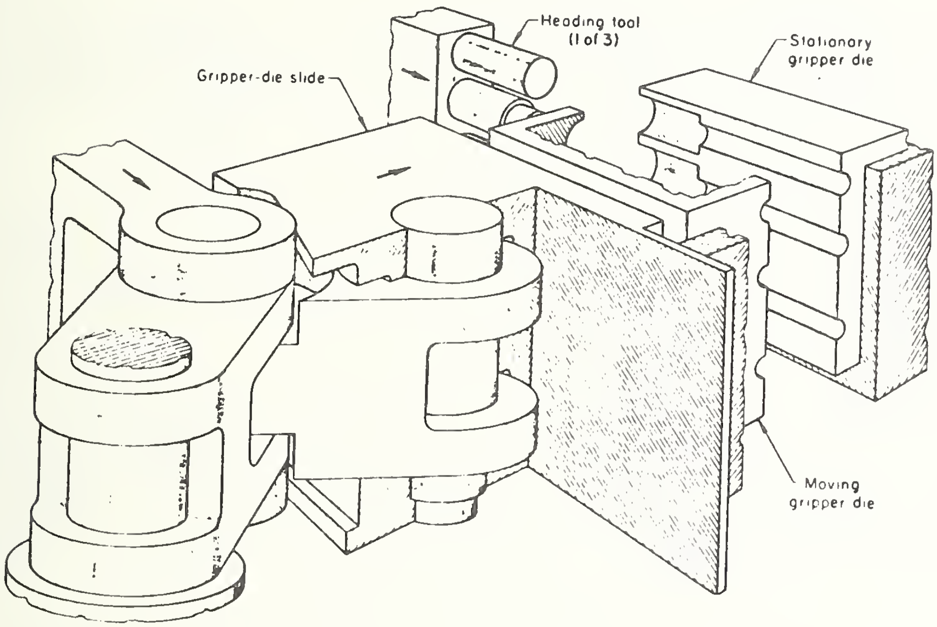
Source: Forging Industry Handbook, 1970

FIGURE 2-9. COMPRESSION IN SIMPLE IMPRESSION DIES WITHOUT SPECIAL PROVISION FOR FLASH FORMATION

- Upset Forging. Upset forging is the enlarging or reshaping of some of the cross-sectional area of a bar, tube or other product by applying a

* True closed die forging (flashless forging) is a special subcategory of impression die forging. It has limited commercial use and is totally absent in the manufacturing of automobile parts. As a point of clarification, the term closed die forging is often used in industry when impression die forging, which involves flash formation, is the technically correct terminology.

compressive force along the longitudinal axis of the workpiece. In its simplest form, upset forging involves the striking of one end of a bar with a forming die called a header while the other end of the die is held between two gripper dies, one of which is a stationary die and the other is a movable die. (See Figure 2-10.)*



Source: Forging and Casting, Volume 5 of The Metals Handbook

FIGURE 2-10. BASIC ACTIONS OF THE GRIPPER DIES AND HEADING TOOLS OF AN UPSETTER

* A clarification of forging nomenclature should be made. In forging terminology, the process of upsetting is any forging conducted with the compressive force parallel to the longitudinal axis of the workpiece resulting in shortening of the piece and the increasing of its diameter. An upsetting action can be achieved by open die forging, impression die forging and by a separate major type of forging just discussed and commonly referred to by four names: upset forging, hot heading, hot upsetting or machining forging. When reading forging literature, it is necessary to infer from context whether the part was forged in hot upset forging equipment or whether the workpiece was compressed axially during open die or impression die forging.

Impression die and upset forging operations are capable of producing relatively close tolerance parts which undergo very little subsequent processing. These two types (i.e., impression die and upset forging) are the cardinal hot forging operations used for manufacturing automobile parts.

Cold Forging

In cold forging, unheated slugs of steel are forced to flow around punches or through shape-forming dies, thus producing shapes of a desired configuration. Such parts require little or no subsequent machining.

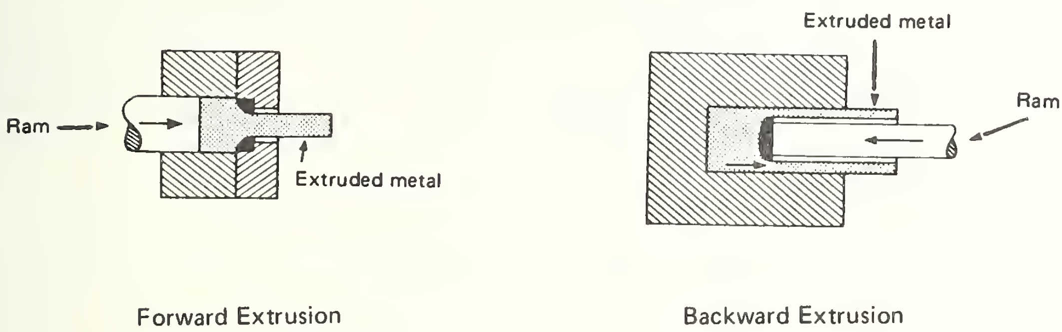
During cold forging the temperature of the metal is increased due to friction. However, it never reaches temperatures equivalent to those in hot forging, and work hardening always occurs. The improved physical properties (high tensile and yield strength) resulting from cold forging are retained in the finished parts unless they are subsequently heat treated.

Cold forging differs from most other metalworking processes in that the metal is always being pushed in compression and seldom pulled in tension. Because of this, the metal can be deformed more drastically with less chance of cracking or tearing.

Steel is the only metal used for the cold forging of automotive parts. Components which are cold forged include spark plug bodies, hydraulic valve lifters, steering ball joints and power steering shafts. Cold forging boasts less material waste, reduced machining costs and reduced labor costs compared to hot forging. Cold forging presses require more energy than hot forging presses, but a significant net energy savings is realized because no heating is required. The future trend in forging is toward greater use of cold forging of all types of auto parts requiring high strengths.

The principal types of cold forging used in the manufacture of automotive parts are as follows:

- Cold Extrusion. In the process of cold extrusion or "cold forming," metal is forced to flow through a die orifice in either a forward or backward direction. (See Figure 2-11.) In forward extrusion, the metal flows in the same direction in which the energy is being applied. In backward extrusion, the metal flows in the reverse direction in which the energy is being applied. In the latter case, the metal usually follows the contour of the punch or moving die. In combination extrusions, forward and backward extrusions are performed on the part simultaneously.

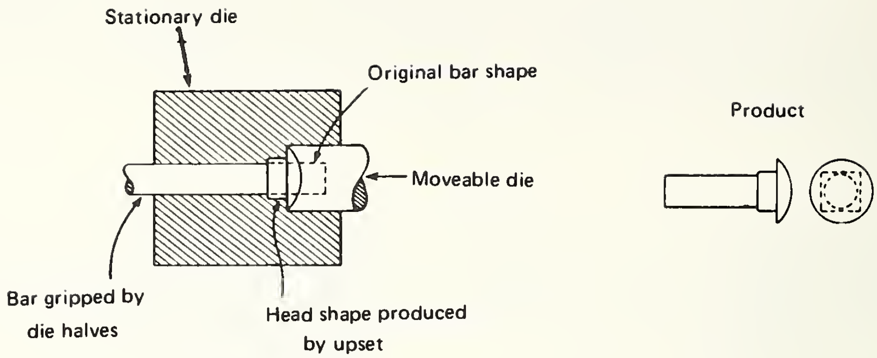


Source: Manufacturing Materials and Processes, by H.D. Moore and D.R. Kibbey, 1965.

FIGURE 2-11. DIAGRAM OF FORWARD AND BACKWARD EXTRUSIONS

- Cold Upset Forging. Cold upset forging is similar to hot upset forging with two exceptions: (1) the metal is not heated and (2) a zinc phosphate coating is required on the cold metal to aid lubrication of the piece before processing. In the upset forging process (see Figure 2-12), a rod is gripped by a stationary die, and the moveable die, containing the cavity of the desired shape, is forced against the protruding part of the rod. The action is one of squeezing pressure rather than hammering action.

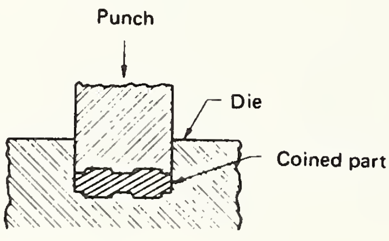
- Coining. Coining is essentially a sizing operation where pressure is applied to all or some portion of a forging's surface in order to obtain closer tolerances and smoother surfaces. The process,



Source: Manufacturing Materials and Processes, by H.D. Moore and D.R. Kibbey, 1965.

FIGURE 2-12. COLD UPSETTING

illustrated in Figure 2-13, is used in producing coins and medals and in numerous other cases where exact size and fine detail must be obtained. Coining may be used either before or after extrusion. Cold extruded steering linkage parts are examples of components that are coined as a finishing operation.



Source: Materials and Processes in Manufacturing, by E.P. DeGarmo, 1974.

FIGURE 2-13. THE COINING PROCESS

2.3.2 Automotive Applications

Automobile parts made from forgings generally require better tensile strength, toughness, fatigue resistance or hardness properties compared with other automobile parts. In most instances, these are the load-bearing components of the car. Structural components which are not forged, such as the frame, are made from rolled products which have a wrought structure similar to that of forgings. A summary of some typical automotive applications of forging by type (cold vs. hot) is provided in Table 2-2. A graphical representation of these applications is shown in Figure 2-14.

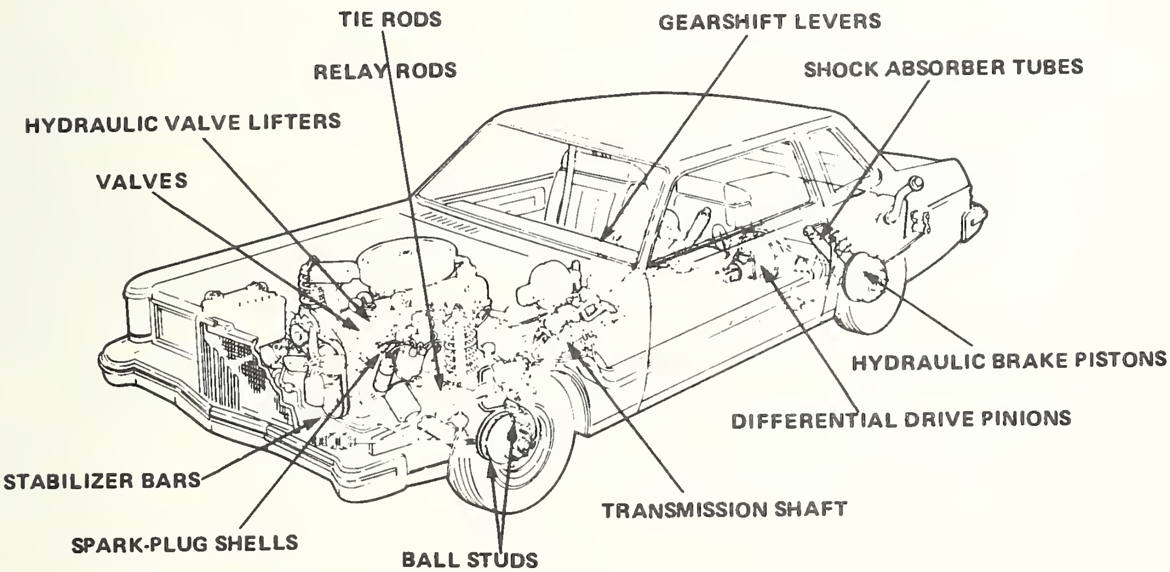


FIGURE 2-14. SCHEMATIC OF AUTOMOBILE SHOWING PARTS AND COMPONENTS WHICH ARE FORGED

TABLE 2-3. SELECTED AUTOMOTIVE APPLICATIONS OF HOT AND COLD FORGING

Forging Process	Automotive Components
Hot Forging	
• Impression Die	Connecting rods, steering idler lever, camshaft, piston rings, clutch fork, differential spiders, universal joint gross fittings, pitman arms, wheel hubs, ball joints, steering knuckles
• Upsetting	Stabilizer bars, valves, tie rods, relay rods, gearshift levers, differential drive pinions, ball studs
Cold Forging	
• Extrusion	Spark plug bodies, hydraulic valve lifters, engine valves, shafts, steering linkages
• Upsetting	Piston pins, steering ball joints, power steering parts (shaft, gears, etc.), alternator pole pieces
• Coining	Rotors, hot forged connecting rods, cold extruded steering linkages

2.3.3 Size and Structure of the Forging Industry

While the basic forging process is easily and appropriately divided into hot and cold forging, the forging industry itself cannot distinctly be divided into hot and cold forging. Cold forging processes, for the most part, were introduced by the large manufacturing firms, often as a substitute for machining processes. Thus, cold forge operations are found integrated into the large machining and manufacturing facilities of the major auto makers. One of the important captive cold forge shops is General Motor's facilities at Saginaw, Michigan.

In characterizing the forging industry, it is more appropriate to break down the industry into commercial and captive forge shops, as discussed below.

Commercial Forge Shops

The Forging Industry Association has counted 500 to 600 commercial or non-captive forge shops. Of these, approximately 250 are considered to be viable, modern, automated forging facilities and of these 250, approximately 30 percent are estimated to send a significant portion of their production to the auto industry. In 1978, the commercial forging industry had sales of approximately $2.2 million of which 19 percent was for passenger vehicle related parts. Approximately 40 percent was for motor vehicles (trucks, buses, trailers, cars) related parts.

Important independent hot forge shops include Columbus Forge, Columbus, Ohio; Atlas Forge, Lansing, Michigan; Wyman and Gorman, Worcester, Massachusetts; and Pittsburgh Forgings, Coraopolis, Pennsylvania.

Important cold forge shops include Braun Engineering in Detroit and Masco Corporation, Taylor, Michigan. Braun claims to be the world's largest independent cold extruder. Ninety-five percent of the company's 1978 revenues of $52.3 million were generated by sales to the auto industry. Braun makes constant velocity joints used with front wheel drive cars and five to six million piston pins per month. Forge shops have tended to cluster in certain locations due to the crucial role of die design in the forge process. Dies wear out after 20,000 to 50,000 impressions and, depending on output rate, this can occur in less than 30 hours. Thus forge shops are constantly in need of new dies. Important forging centers have the manpower and facilities to supply forge shop needs. Key centers include Lansing, Michigan; Toledo and Cleveland, Ohio; and Pittsburgh, Pennsylvania. Many forging facilities are therefore tied closely to machine shops located nearby.

Commercial forge shops tend to be medium to large size shops (i.e., employ 100 to 400 people) although it is not uncommon to find some commercial forge shops which employ less than 10 people. These shops are actually closer to blacksmith shops.

Captive Forge Shops

The importance of the auto industry in forging is quite large. It is estimated that the captive auto forge shops by themselves forged as much as the entire commercial forging industry in 1978. Thus, approximately 80 percent of automotive forgings are done in captive shops.

Captive shops tend to be large (employ 600 people or more), use many presses and hammers and do high volume, standard weight forgings. Commercial shops tend to be much smaller and do runs under 500 per day, or pieces under 5 pounds or over 25 pounds. Truck parts thus are often done outside.

The auto industry, in its attempts to build lightweight cars, however, is moving away from interchangeability of truck and car parts. This may create more short-run truck part jobs for commercial forge shops.

2.3.4 Key Issues Facing the Forging Industry

The major issues confronting the forging industry are:

- Competition from cold forging and powder metallurgy
- OSHA noise levels for workplaces
- The poor machinability of forged aluminum
- The tendency of aluminum forgings to crack under impulse loading.

Competition from Cold Forging and Powder Metallurgy

One trend to watch is movement away from hot forgings to cold forgings. Cold forging boasts less material waste, reduced machining costs and reduced labor costs compared to hot forging. The limiting factor in cold forging is the high energy requirements. Newer cold forging equipment, however, has the clamping power necessary to make larger parts by cold forging than were previously made.

The use of Powder Metallurgy (P/M) is another potential competition to conventional means of forging automobile parts. At present, there are 8 to 15 pounds of P/M parts in the average automobile in the form of automatic transmission parts and sprockets for camshafts, crackshafts, and water pumps. Additional automotive parts which are candidates for P/M are all gears ranging in size from two inches to nine inches and ranging in weight from 1/2 to 7 pounds. In Germany, Porsche executives are pleased with the cost savings, energy savings and improved fatigue performance being realized with a P/M steel connecting rod. The rod weighs slightly less than 2 pounds and is used in the Porsche 929 V-8.

The powder mettalurgy process involves compressing a mixture of metal powder and a lubricant at room temperature in a mechanical or hydraulic press with up to 60 psi to form a green compact material which has a density of 75 to 80 percent. The part is then sintered* at 2,000 to 2,050 F. After sintering, the part is considered complete, except for applications requiring greater strength. To increase strength, the sintered part is heat treated to increase density. The chief competitive advantage of the P/M process is reduced cost. A P/M gear can be manufactured with a 30 percent equipment and labor savings over a conventionally forged part.

OSHA Noise Level Limits for Workplaces

Another major issue facing the hot forging industry is noise. The equipment used for hot forging will probably be affected significantly by OSHA's noise level limits for workplaces. At present, hammers are needed for thin webbed and high profiled forgings. In the future, these forgings will probably be made in screw presses which can provide a loading more similar to impacting than other forging presses. At present there are about 20 screw-type presses in the United States; however, there are no manufacturers of such equipment in this country.

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* Heating without melting.

Need for Improved Machinability in Forged Aluminum Parts

Aluminum and other non-ferrous forgings are enormously less machinable than steel and they tend to wear out traditional carbide cutting tools very quickly. To reduce the high costs encountered with these aluminum forgings, improvements are needed which will add to their machinability. In the case of one aluminum alloy, number 7050, the use of a synthetic quenchant of polyalkylene glycol in the heat treatment process is helping to produce forgings which are more amenable to machining operations.

The quenchant, it should be noted, is a cooling liquid poured over the heated forging after shaping. The quenchant accelerates the solidification of the forged metal parts. Ideally, the forging will be cooled rapidly enough to develop its full strength but not so fast as to distort the forging or increase the amount of residual stress within the part itself. Researchers at the Convair Division of General Dynamics Corporation report, for example, that conventional water quenching of aluminum alloys can result in the distortion of parts and in the development of high residual stresses. More solutions, such as this synthetic quenchant, are needed to reduce the machinability problems encountered in aluminum forgings.

Low Resistance of Aluminum to Stress

Aluminum is traditionally sensitive to fracturing and up to recently its use on the automobile has been restricted to comparatively low-stress areas. As the use of aluminum is projected for more components, new methods of developing stress-resistant aluminum alloys will become critical.

A relatively new alloy with greater resistance to stress-corrosion cracking has been developed through the use of a process called Intermediate Thermal - Mechanical Treatment (ITMT). By the application of this heat treatment process, the fracture roughness and fatigue properties of this alloy, number 7475, are improved by at least 20 percent over those of the conventional 7075 aluminum forging materials without any loss in tensile strength and resistance.

Further development of methods to raise aluminum's resistance to stress-corrosion cracking will assist the forging industry in supplying low-weight, high-strength components to the auto manufacturers.

2.4 METAL STAMPING

The stamping of automotive parts and components—primarily sheet metal which is stamped into a myriad of shapes from small washers to large body panels—is one of the most diversified and critical areas of automotive production. In the stamping process, metal stock in the form of sheets, strips, and coils is pressed between matching dies under large amounts of pressure in presses. Usually each piece is pressed or stamped a number of times before the final shape of the auto part is achieved. This is accomplished by moving the metal stock through a series of presses or a press "line." The press line is the heart of every stamping operation.

2.4.1 Major Stamping Operations

The major stamping operations used in the automotive industry are blanking, piercing, forming, drawing, coining, and bending. Each is described in detail below. Other stamping operations which are used in the automotive industry but to a lesser degree include:

- Embossing which is essentially a light forming operation used to produce a pebbled surface or a raised pattern in low relief. The identification plates on an automobile which carry the serial number and other data are embossed.

- Louvering which is a specialized form of piercing (described below) that produces a series of hooded slots. Typical applications include radio and stereo housings, air conditioning, and heating vents.

- Spinning, while not true stamping, is often combined with stamping to produce cylindrical parts. Typical applications include wheel covers and reflectors.

Blanking

Blanking (see Figure 2-15) is a relatively simple process in which a desired shape is cut from a sheet or coil of material. Usually the blank will be further processed, either in the same piece of equipment or as a secondary operation. A typical application of blanking is in producing a round disk from which a cover may be drawn or spun.

Piercing

Along with blanking, piercing (see Figure 2-16) is the most common press operation. The purpose is to produce accurate, precisely located holes, usually for assembly purposes. As with blanking, piercing (also referred to as perforating) is rarely performed alone. It is usually combined with another operation or operations. The applications of piercing are many. Mounting holes in automobile radio mounting brackets is a typical piercing operation.

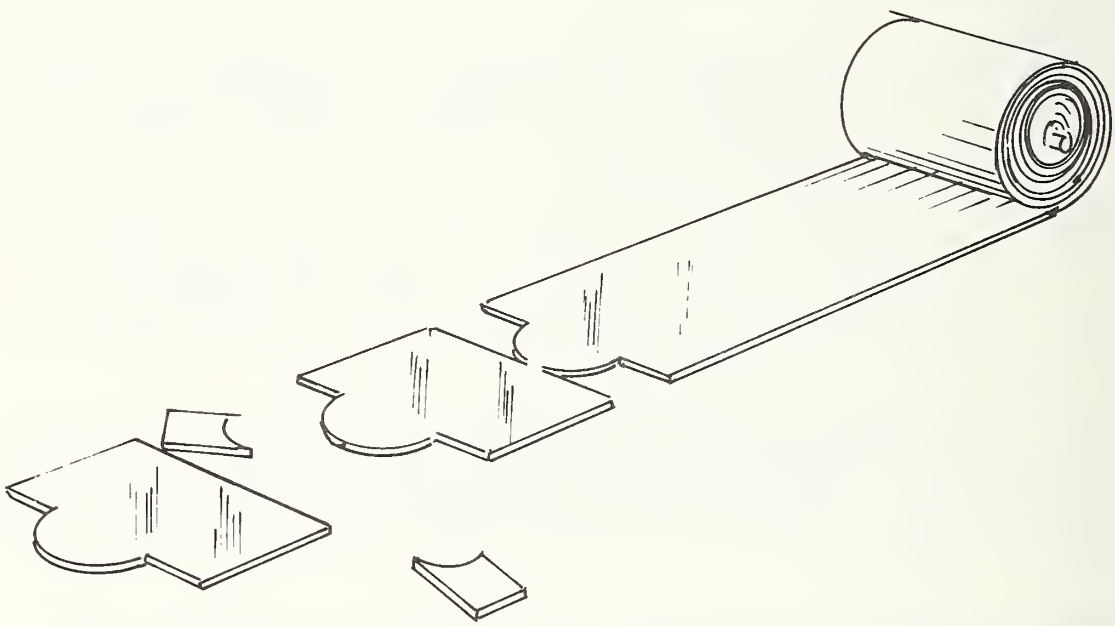

FIGURE 2-15. BLANKING OPERATION

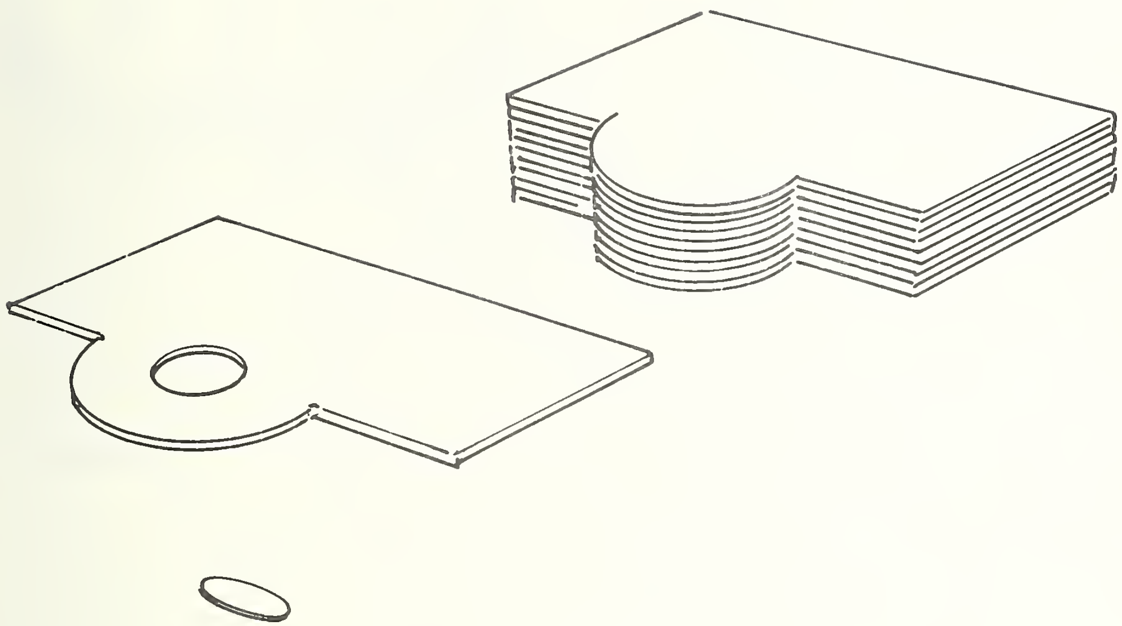

FIGURE 2-16. PIERCING OPERATION

Forming

Forming (see Figure 2-17) is a process that transforms a flat piece of metal into a three-dimensional part without exceeding the plastic flow limits of the metal. It may involve simply turning up one edge of the blank to produce a right angle. Making a "bead" in a flat piece of metal to make it stiffer is forming. About 50 percent of all automotive stampings are formed to some extent. Forming is usually combined with blanking and piercing but it is often a stand-alone operation. A forming operation adds considerably to the cost of a metal stamping die. Some typical forming applications include radiator, crankcase, and transmission filler caps. The applications are numerous.

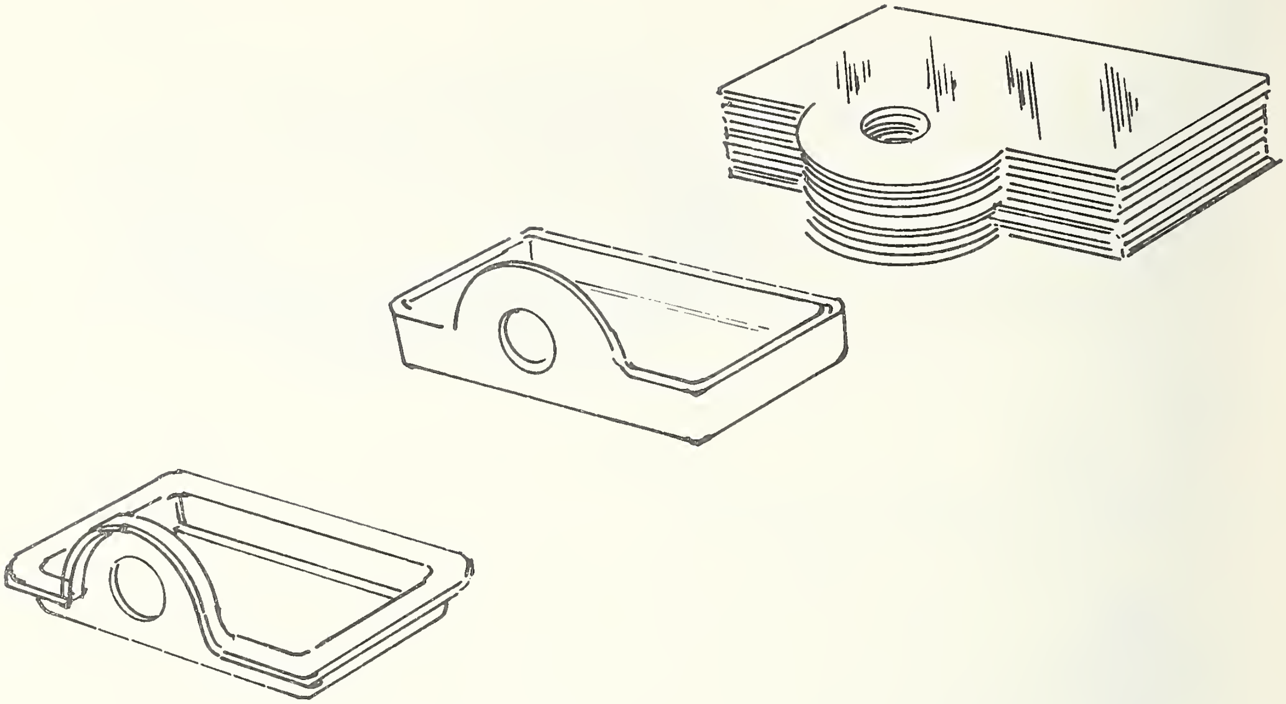

FIGURE 2-17. FORMING OPERATION

Drawing

Drawing (see Figure 2-18) is the most difficult of all stamping operations and one of the most expensive in terms of total cost. In drawing, a flat blank is transformed into a cylinder or box shape—there are infinite variations—by forcing the metal beyond its yield point. Usually a double or triple action press or a press with air cushions is required. Applications of drawing include rocker arm covers, valve covers, and crankcase oil pans.

Coining

Coining (see Figure 2-19) involves striking a blank with great force to reduce its thickness and improve its physical properties. Most often it is a final sizing operation following other processes to uphold critical tolerances. A variant of the process is called swaging and the purpose is to flatten the end of a round rod to produce a flat section of much greater diameter. Coining applications include rod ends and valve lifters.

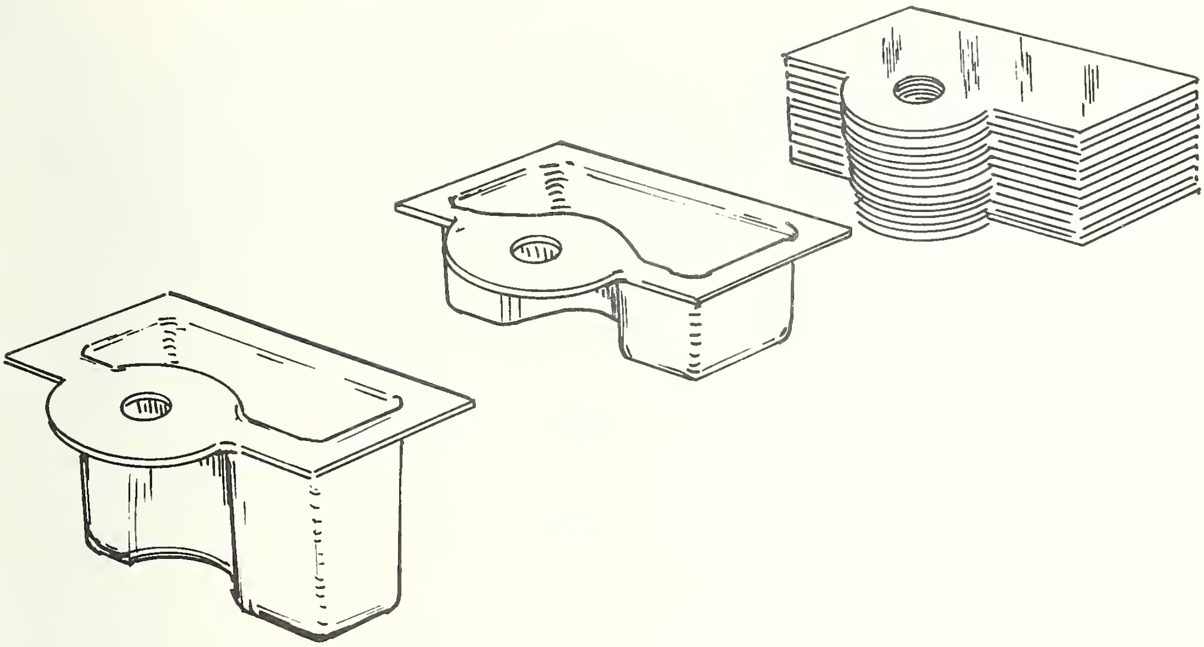

FIGURE 2-18. DRAWING OPERATION

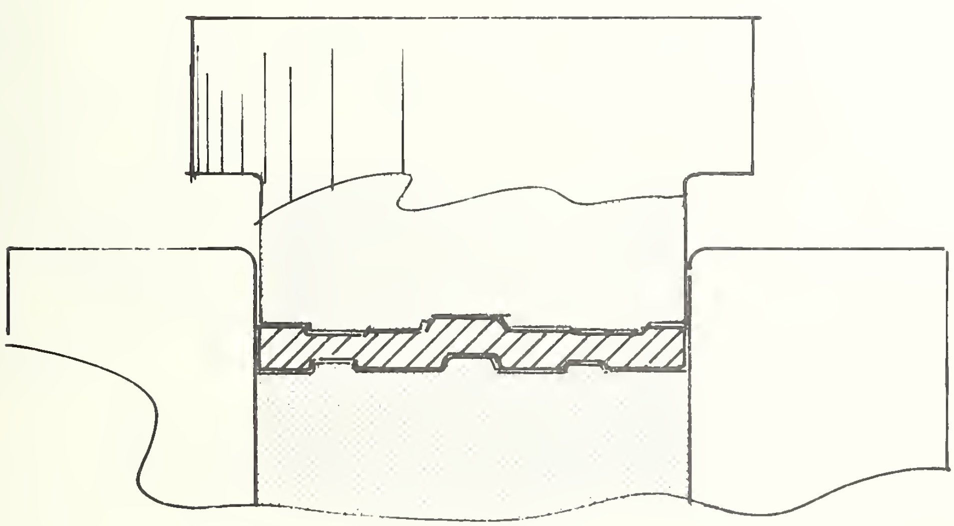

FIGURE 2-19. COINING OPERATION

Bending

Small parts are formed by bending (see Figure 2-20) on a press. Larger parts may be bent on a press brake. This is a relatively simple operation. The tolerances are usually generous. Usually bending is combined with other operations. There are hundreds of applications. For illustrative purposes, consider an automotive ash tray which is usually made up of one member bent into a U-shape to which side pieces are attached by tabs or by welding.

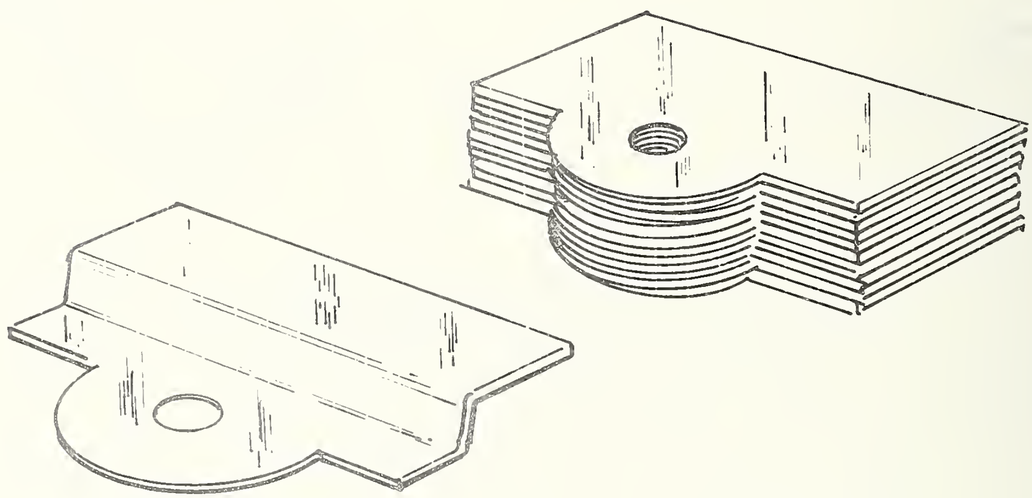

FIGURE 2-20. BENDING OPERATION

2.4.2 Automotive Applications

It is difficult to determine just how many automotive applications there are for stampings. The average automobile contains between 2,500 and 3,000 stampings. As shown in Figure 2-21, they range from such large parts as the hood, fenders, doors, truck lid and roof, to such smaller parts as the oil pan cover, timing chain cover, valve cover, fan and wheels. Other stamped parts include laminations in the starter and the alternator and the brackets that support them—not to mention the key that turns on the ignition. There are also a great many stamped components in the new electric engine control devices and because of the many advantages of stamping over other manufacturing processes, other components (e.g., engine crankcase breather, rocker cover, oil pan, turbocharger manifold) are being redesigned for stamping.

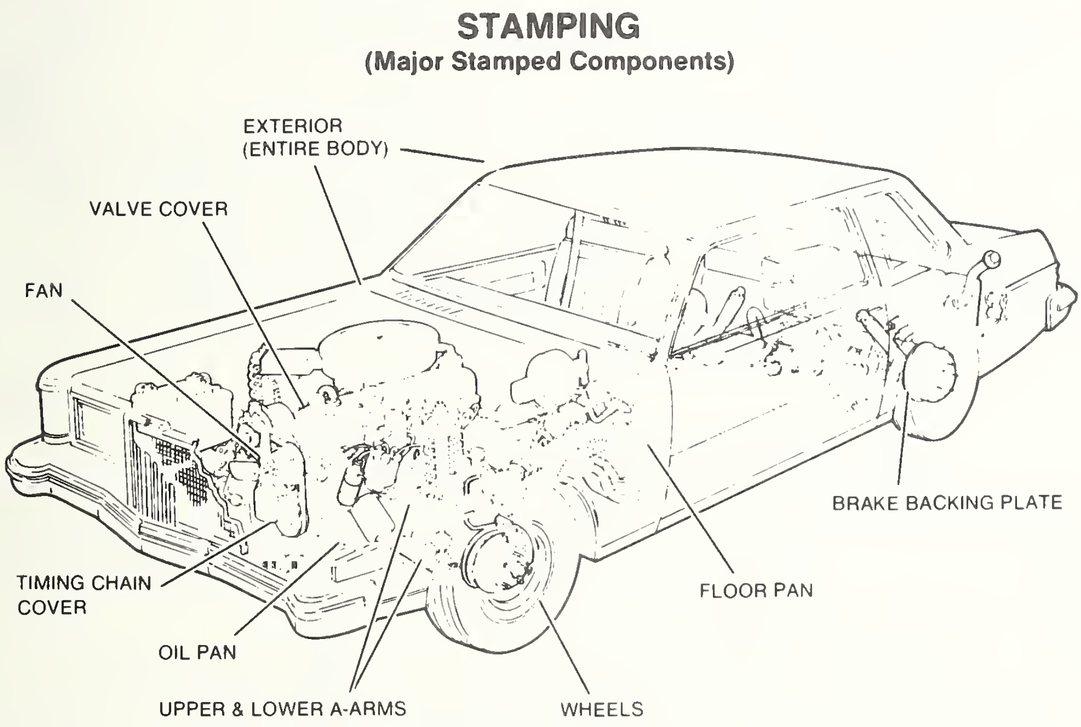

FIGURE 2-21. SCHEMATIC OF AUTOMOBILE SHOWING COMPONENTS WHICH ARE STAMPED

2.4.3 Size and Structure of the Metal Stamping Industry

Like other manufacturing industries which serve the auto industry, the stamping industry is comprised of two major types of operations:

- Contract operations, where the parts and components are made by independent companies and sold to the auto industry
- Captive operations, where the parts and components are made in-house by the auto company, usually by a separate division or plant of the company.

Each is discussed below.

Contract Operations

The contract segment of the stamping industry is a major supplier to the auto industry. It is estimated that of the 2,500 to 3,000 stampings used on an automobile approximately 2,000 are bought outside by the auto industry. These stampings are primarily the smaller stampings found in an automobile, i.e., valve cover, oil pan, fans, etc.

The contract segment of the industry includes about 3,000 individually owned businesses with sales of approximately $14 billion annually. Each individual company tends to specialize. It may have expertise in high volume production of small parts, it may specialize in deep drawing or it may concentrate on assembly as well as stamping. Most companies, however, as shown in Table 2-4, do not tie themselves totally to the automotive market.

TABLE 2-4. NUMBER OF CONTRACT COMPANIES BY PERCENT OF AUTOMOTIVE BUSINESS

Percent Automotive Business	Number of Companies	Percent of Total	Cumulative Percent
75 to 100%	150	5%	5%
50 to 75%	300	10%	15%
25 to 50%	800	27%	42%
0 to 25%	1,750	58%	100%
Total	3,000	100%	

The industry is widely scattered. Where once it was concentrated in major industrial centers—Detroit, Cleveland, Chicago, etc.,— it has dispersed itself pretty much across the country. In some cases it has followed other industries—IBM, GE, etc. More often it has set up plants in areas where the climate, the tax incentives and, above all, a non-hostile labor attitude were considerations. Except for the extreme Northwest—Idaho, Montana and North Dakota—contract stamping industry services are available everywhere in the U.S.

Captive Operations

Approximately 60 percent of all stamping in terms of weight are produced by the auto manufacturers themselves. These include the larger body and frame stampings. All four of the major domestic automobile manufacturers—GM, Ford, Chrysler and AMC—own and operate plants which make these stampings.

2.4.4 Key Issues Facing the Metal Stamping Industry

As in all areas of automotive production, it is the ever-present need to reduce the weight of the automobile that is the prime issue behind most others affecting the stamping industry. Other key issues include:

- OSHA Regulations
- Foreign competition
- Competition from plastics
- Liability and workmens compensation
- Unavailability of skilled workers.

Weight Reduction

Faced with the problem of weight reduction, the automobile makers have turned to the HSLA (high strength low alloy) steels. The theory is that if you use a steel with a tensile strength of 75,000 psi to replace a carbon steel with a tensile strength of 50,000 psi, you can use thinner material.

The theory, in fact, has proved to be tenable although not without problems. The HSLA steels are difficult to form because of their strength and they tend to crack if the necessary deformation is severe. Several auto builders have backed off on the HSLA steels and returned to the conventional materials.

This is a temporary retreat—a pause while the steel makers improve their product and the suppliers of heavy stampings develop their technology. The HSLA steels are a formidable weapon in the war against weight and their use in heavy stampings will continue to widen.

The use of titanium, graphite composites and other sophisticated materials has been suggested as a weight reduction measure. The use of these materials would present severe problems to the stamping industry since they cannot be formed on conventional equipment. The costs would be prohibitive and these materials are not forseen as a threat during the next decade.

OSHA Regulations

Over the last seven years, the stamping industry has spent about $1.2—billion dollars in compliance measures with OSHA regulations—installing air clutches, brake monitors, guards, sensing devices, improved controls, acoustic enclosures, vibration movements, etc.

Whether this investment has decreased the number of injuries is debatable. OSHA figures are not specific and GAO figures would indicate no significant change in either direction. There can be no doubt, however, that the meeting of OSHA requirements has led to an overall upgrading of equipment and a measurable improvement in productivity on the order of 5 percent across the industry. This is primarily because older presses, which could not economically be brought into compliance, have been phased out.

The OSHA noise exposure standard of 90 Db for eight hours has worked hardships. A proposed OSHA standard which is expected to call for an 85 Db level is also generally regarded as unworkable.

Currently, most OSHA citations in the stamping industry are for noise violations. The industry has taken the stand that personal hearing protection is the only effective solution and, in general, the courts have supported this stand.

Foreign Competition

Foreign competition has affected the stamping industry in direct relationship to the number of foreign cars that are imported and that otherwise would have been produced in this country.

There has been little effect on a one-on-one basis except in the case of fasteners and some fractional horsepower electric motors. In other words, the automotive industries do not buy stampings abroad although they do buy stamping from Canadian sources.

At least two foreign car producers have set up U.S. manufacturing facilities. Because U.S. labor rates are lower than those of Japan, Germany and several other countries and because of the declining value of the dollar, it is believed that this trend will continue and that it will be to the benefit of the domestic stamping industry.

Competition from Plastics

The stamping industry has faced competition from plastics for many years. With the need for lightweight components and the development of high strength engineering plastics such as PPG's AZDEL and Allied Chemical's STX, competition will continue to be strong.

However, these plastics are petroleum based and their rising cost is rapidly eroding their economic advantage so that their only real advantage is their light weight. In general, the production of plastic parts in larger sizes is extremely slow as compared with metal forming processes. For this reason STX is often formed on metal forming presses rather than by sheet molding processes.

There will be a continuing encroachment by plastics on traditional metal stamping applications but it will be very slow, very selective and by no means catastropic. And in some applications the trend has reversed, primarily for reasons of cost, esthetic and reliability reasons.

Liability and Workmens' Compensation

There are scattered incidents where metal stampers have been named as third-party dependants in liability actions. These are rare incidents, however, and are not an indication of a trend.

The proliferation of liability actions has had an effect on the stamping industry, however. Increasingly the automotive industries are requiring rigorous quality control and the documentation thereof. In general the automotive industries have accepted the additional costs.

The costs of workmens' compensation insurance have tripled over the last five years. There are indications that the additional costs are totally unjustified. No conjecture can be made at this time as to future implications because bills before the House and the Senate which are generally expected to be enacted, will sharply alter the picture.

Unavailability of Skilled People

The single most serious problem affecting the stamping industry today is the lack of skilled personnel, particularly tool and die makers.

The industry graduates about 2500 journeymen from registered apprenticeship programs each year as against an annual requirement of 4600, based on Labor Department figures. The actual shortfall is much higher in the opinion of knowledgeable people in the industry. To compound this problem, more than half of the tool and die work force is over 50 years old and will be retiring over the next seven years.

The shortage is even more surprising in view of the fact that a class A tool and die maker can expect to earn more than $20,000 per year.

There are many reasons ranging from the erosion of the work ethic to the failure of the educational establishment to recognize the opportunities the stamping industry offers.

The industry, together with the tool and die industry and the Bureau of Apprentice Training (Department of Labor) has undertaken a crash program to encourage young people to enter the industry; however, the problem is grave and will hamper the industry for the foreseeable future. It will only be partially alleviated by developments in technology such as NC, CNC, and Wire EDM.

2.5 PLASTIC FORMING

In its broadest sense, the term "forming" denotes a process whereby a desired shape is imparted to plastic through the carefully planned application of pressure and/or heat. The automotive industry uses over five percent of plastic production and this figure is expected to increase over the next ten years.

2.5.1 Major Types of Plastic Forming

The major plastic forming processes used in the automotive industry are:

- Injection molding
- Compression molding
- Reaction injection molding.

Each is discussed below. Other plastic forming processes used in the automotive industry, but to a lesser extent, include:

- Calendering, which is used to process thermoplastics into sheets.
- Blow molding, which is used to hollow plastic products such as gas tanks.
- Extrusion, which is used to form continuous sheeting, tubes, or rods.

Injection Molding

The basic concept of injection molding revolves around the ability of a thermoplastic material to be softened by heat and to harden when cooled. In most injection molding operations, granular material (the plastic resin) is fed into one end of the cylinder (usually through a feeding device known as a hopper), heated, softened, and forced through a nozzle (where it is still in the form of a melt) into a relatively cool mold held closed under pressure. Here, the melt cools and hardens (cures) until fully set-up. The mold then opens and the molded part is removed.

The newest and most popular injection molding machine sold today is the in-line reciprocating screw injection machine shown in Figure 2-22. To force the plastic melt into the mold, the machine uses a rotating screw which moves back and forth within the heating cylinder. As the screw rotates, the granules are conveyed forward and melted. The melt flows from the last flight of the screw through the non-return valve. As the material comes off the end of the screw, the screw moves back to permit the plastic material to accumulate. At the proper time, the screw is forced forward, acting as a plunger and propelling the softened material through the nozzle and sprue into the mold cavities. The size of the charge is regulated by measuring the back travel of the screw.

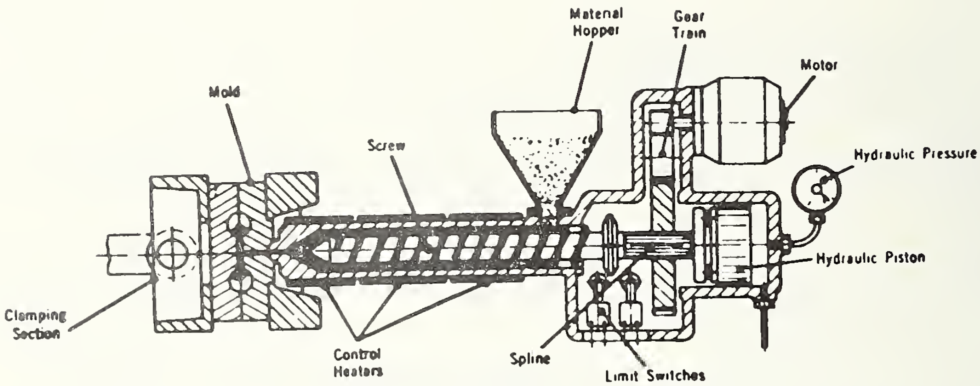

FIGURE 2-22. IN-LINE RECIPROCATING SCREW UNIT

The injection molding process makes possible the production of highly finished and detailed plastics at very high rates. Injection molding is used for thermoplastics, i.e., polypropylene, polyethylene, and others. It is estimated that the 1985 car will include 300-400 pounds of plastic, much of it injected molded.

Compression Molding

Compression molding is used to form plastic components through the application of heat and pressure in a closed mold. It is used almost exclusively for shaping thermoset plastics. The plastic molding material, usually in powder or granule form, is loaded into a mold cavity. The mold is closed, squeezing the molding material throughout the cavity. The application of heat triggers a chemical reaction in the plastic compound that permanently hardens the material in the shape of the mold. Compression molding typically uses hydraulic presses to force the sections of the mold together. A basic two-part compression molding process is illustrated in Figure 2-23.

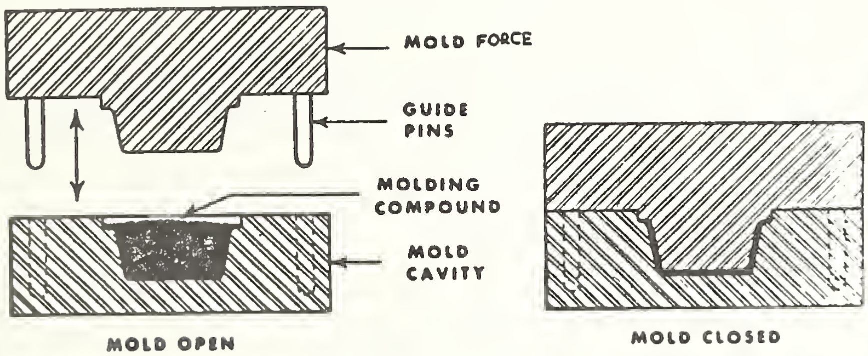

FIGURE 2-23. BASIC COMPRESSION MOLDING PROCESS

In the automotive industry, compression molding is most commonly used with reinforced polyester compounds. These are compounds that combine thermosetting polyester plastic and, in most cases, glass reinforcing materials called fiberglass. They are strong and have exceptional strength to weight. The most commonly used reinforced polyesters usually come in rolls of thick sheet called sheet molding compound (SMC). Their automotive applications include front fascia, spoilers, grille opening panels, fender skirts, and side rails.

Reaction Injection Molding

Reaction injection molding (RIM) is a process for molding polyurethane elastomers or foams into end-products with solid integral skins and cellular cores. Two or more streams of highly reactive liquid components are impinged together under high pressure in a mixing chamber. The resulting mixture is then injected, under low pressure, into a mold where the component materials react until the mixture has formed into a solid, finished product.

The plastic most commonly molded by RIM is polyurethane, formed by combining an isocyanate with a polyol. The basic equipment for RIM processing includes material tanks for storing, heating, and recirculating the reactive liquids; high output pumps for delivering the liquids to the mixing head; mixing heads with adjustable opposing orifices for liquid streams; molds made from steel, aluminum, or non-ferrous alloys; clamps for holding the molds; and a molding press.

The heart of the system is the mixing head. The impingement mixing chamber is very small--1 to 5 cubic centimeters--and impingement pressures run between 1500 and 3000 psi. Once the mixed components are injected into the mold, usually at pressures below 60 psi, they begin to react immediately.

The RIM process is viewed as possibly offering the most potential benefits to the auto industry in the future. The advantages of RIM over the other plastic forming processes, particularly injection molding, are as follows:

- RIM components offer a cost per part advantage consistently 20 to 30 percent lower than alternative methods.

- Less injection pressure is required with RIM. In conventional injection molding, thermoplastic pellets must be melted and injected into a mold at pressures as high as 4000 psi. RIM injection is performed at only 50 to 100 psi.

- Clamping pressures of RIM molds are much less than injection molds and thus less expensive machines are needed. Clamping pressures for injection molding machines are usually between 2500 and 3000 tons. RIM clamping pressure is less than 100 tons.

- The RIM process takes up one-tenth of the floor space required for the injection molding process and a single RIM metering machine can serve up to 12 RIM molding machines.

- The RIM process consumes about one-fiftieth of the energy required for other plastic-forming processes.

2.5.2 Automotive Applications

Figure 2-24 shows the major automotive parts and components which are manufactured using plastic forming processes. These parts and components include:

- Fascia
- Lamp lens and housing
- Storage battery housing
- Instrument panel
- Camshaft timing gear
- Seatbelt components/head restraints
- Seatback and cushion pads.

Examples of plastic automobile components by plastic forming process and material are given in Table 2-5.

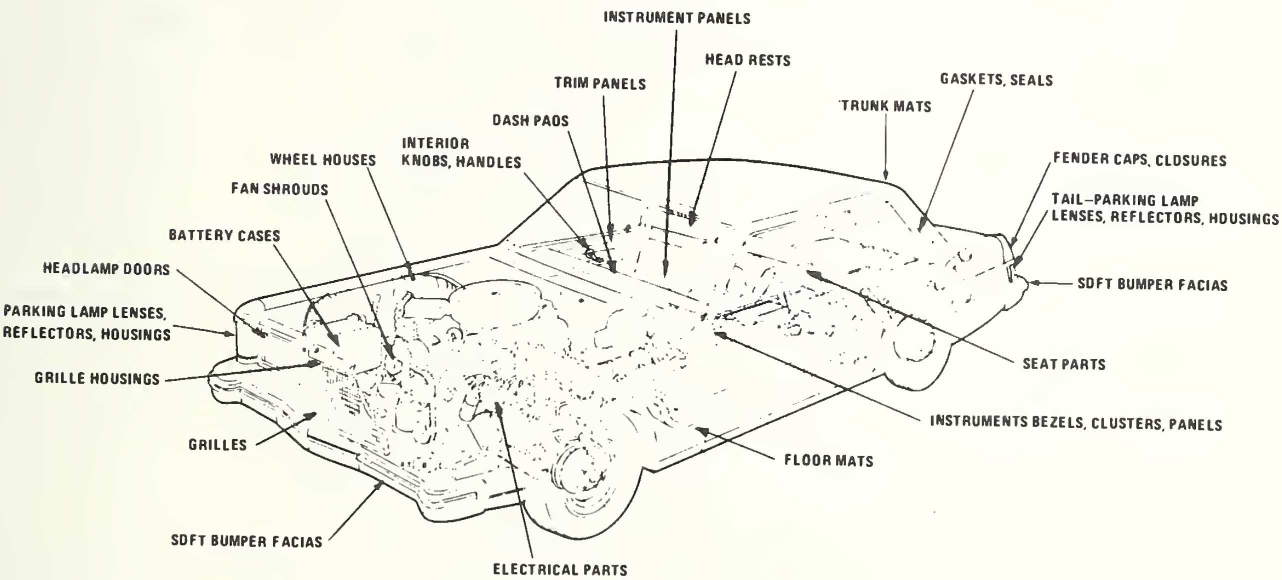

FIGURE 2-24. AUTOMOTIVE APPLICATIONS OF PLASTIC FORMING

TABLE 2-5. EXAMPLES OF PLASTIC AUTOMOTIVE PARTS BY TYPE OF PROCESS

FORMING PROCESS	AUTOMOTIVE APPLICATIONS
Injection Molding	Tail-Parking lamp lenses, Reflectors, Housings Interior Knobs, Handles, Buttons, Escutcheons Instrument Bezels, Clusters, Panels Headlamp Doors Grilles Electrical Parts
Compression Molding	Fender caps, Grille Housings, Closures Trunk Mats Floor Mats Trim Panels Soft Parts Fan Shrouds Battery Cases
Reaction Injection Molding	Head Rests Wheel Houses Soft Bumper Facias Gaskets, Seals Instrument Panels Fan Shrouds Dash Pads

2.5.3 Size and Structure of the Plastic Forming Industry

The plastic forming industry is one segment of the plastic production industry. The other segment is the resin producing industry. In 1977 total U.S. plastic production was over 33.9 billion pounds and sales were more than $8.6 billion. Over 400,000 people were employed by the plastics industry. Of total industry shipments in 1977, plastic resins accounted for about 14 percent while fabricated plastic products accounted for the rest.

Broadly speaking, the plastic forming (processing) segment of the plastic production industry is divided into three rather diverse categories:

- Resin producers—Many of the large resin producers* process a portion of their plastics and make such products as film, textiles, or calendered plastics. In the auto industry this situation occurs for parts like vinyl seat covers or urethane foam seats but is much less likely to be found in specialized plastic automotive parts like bumpers or grilles. Approximately 20 percent of resin production is processed within the producers' own companies.

- Processors captive to end users—Many end users have their captive shops that make plastic parts. Industries that process plastics for their own use include the automotive, communications, film, packaging, pipe, appliance, and recording industries. Approximately 50 percent of resin production is processed by captive shops.

- Independent plastic processors—Independent processors purchase resin and manufacture plastic parts which are sold to other companies. This industry is very fragmented, consisting of many companies of varying sizes. The approximately 5,550 custom or independent processing plans process about 30 percent of resin production.

Selected plastic processing plants which serve the auto industry are listed in Table 2-6 together with information on the principal processes and principal plastics employed by the plant.

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* Resin producers are companies which make the basic plastic materials from feedstocks.

TABLE 2-6. SELECTED PLASTIC PROCESSING PLANTS PRODUCING OVER 15 MILLION POUNDS PER YEAR

Company Name and Location	Principal Plastics	Principal Processes
General Motors Corp., Delco Remy, Anderson, IN	PMMA,PP	Injection molding
General Motors Corp., Packard Electric, Warren, OH	PP,PS	Injection molding
General Motors Corp., Saginaw Steering, Saginaw, MI	PP,PS	Injection molding
General Tire & Rubber Co., Ada, OK	PUR,PVC	Injection molding
Davidson Rubber Co., Dover, NH	PUR	Reaction injection
General Motors Corp., Fisher Body, Elyria, OH	ABS	Injection molding
General Motors Corp., Fisher Body, Syracuse, NY	PP	Injection molding
General Motors Corp., Guide Div., Anderson,IN	PPMA	Injection molding
Ford Motor Co., Saline, MI	ABS,PP	Injection molding
Budd Co., Madison Heights, MI	UP	RP molding
Goodyear Tire & Rubber Co., Jackson, OH	UP	RP molding
Molded Fiber Glass, Ashtabula, OH	UP	RP molding
American Motors Corp., Evart Products Co., Evart, MI	PS	Injection molding
Erie County Plastics Corp., Corry, PA	PS	Injection molding
Millington Plastics Div., Buckeye, Upper Sandusky, OH	PS	Injection molding
Ronther Div., Evans Products, Social Circle, GA	PS	Injection molding
Armco Composites, St. Charles, IL	UP	RP molding
Chrysler Plastic Products, Michigan City, IN	HDPE	Injection molding
Premix Inc., North Kingsville, OH	UP	Compression
Mercury Plastics Co., Div., AMC, Mt. Clemens, MI	PS	Injection molding

Abbreviations for plastics:

ABS	Acrylonitrile-butadiene-styrene	HDPE	High-density polyethylene	TPP	Thermoplastic polyester
POM	Acetal	HIPS	High-impact polystyrene	PF	Phenolic
PPMA	Acrylic	LDPE	Low-density polyethylene	UP	Thermoset polyester
CA	Cellulose acetate	PA	Nylon	PP	Polypropylene
		PE	Polyethylene	PS	Polystyrene
		PUR	Polyurethane	PVC	Polyvinyl chloride

* Plastics World, January, 1979.

2.5.4 Key Issues

The major issue facing the plastic forming industry is the requirement for new equipment. A barrier to the expanded application of plastics is the large capital outlay required for retooling and the purchase of new plastic forming equipment. Machinery used for forming metals is not applicable to plastics. One major reason is that the forming of plastics requires split second timing and higher levels of accuracy than in forming metals. Greater control is therefore required to assure that the formed plastic components do not develop flaws as a result of the forming process. While the forming industry is working on the development of new processes and materials to cope with the challenges of forming plastic, the capital investment requirements facing the forming industry remain a principal issue.

Other issues which are confronting the plastics industry as a whole include:

- Low profits
- New markets
- Environmental and energy concerns.

Low Profits

Much of the plastics industry produces commodity or tonnage plastics characterized by very large volumes and indistinguishability of product. Thus many companies in the industry tend to compete on the basis of price. In recent years the plastics industry has been faced with the situation of overcapacity and low prices. Rates of return for plastics companies have been low.

As a result, many companies, such as Hercules, are attempting to switch their product mix toward higher value products. The specialization of products can insulate the companies from downward pressure on price.

In the next decade capacities are expected to be much tighter as demand catches up with supply and construction of new capacity proceeds at a slower rate. Thus, prices are expected to improve over the next few years.

New Markets

Use of plastics has been growing faster than the overall economy and this trend is expected to continue. New markets are emerging for plastic companies, such as lightweight automotive components, structural components, and new insulation markets. The plastics industry increasingly is formulating specialized plastics that will meet the needs of particular market segments.

For the automobile, particular plastics are competing with metals and with other plastics to create lighter vehicles. The changes that are taking place in the automobile have forced the auto companies to look for new materials and processing methods. Thus, plastics companies with strong research and development capabilities have an advantage in capturing the growing automotive plastics market. Hercules is hopeful that a polypropylene-metal system it has developed will be used by Detroit. DuPont and General Electric are aggressively pushing new engineering plastics. Major producers of graphite fiber parts for the aerospace industry, such as Union Carbide and Hercules, are trying to develop the graphite-reinforcement market in Detroit. Plastics processors are working with the auto companies to develop new parts that can be made out of plastic. For instance, PPG has developed a plastic gas tank and works closely with General Motors engineers.

Companies with existing markets in the automotive industry are also seeking to preserve their position. General Tire, for one, has as a high priority the production of vinyl upholstery with less weight than current products.

Growth for most plastics in the auto industry seems assured to some degree. Not only is plastics usage expected to increase in each car, but the number of cars manufactured each year is supposed to increase significantly over the next few years. However, right now the best plastic growth prospects seem to be for polyurethanes and reinforced plastics. These plastics have the potential for replacing major parts of cars—such as body parts and engine parts. If either of these materials succeeds in becoming widely used as a replacement for sheet metal parts, volumes purchased would be quite large. Key companies to watch, therefore, are Union Carbide, Mobay, PPG, and Owens-Corning.

Environmental and Energy Concerns

The chemical industry has been affected by several environmental regulations regarding the quality of the chemical environment of company plants and with the toxicity of the chemicals produced. The Government has required all chemical companies to list the chemicals they produce, where they are produced and in what volume. Concern exists about the effect of these chemicals on workers, on the environment, and on consumers. The Food and Drug Administration also is looking carefully at the effect of plastic packaging on food.

These various investigations by the Government and other groups have increased the importance of testing and toxicology within the plastics industry.

Concern has also been raised about the effects of plastics in waste disposal systems such as dumps or sanitary landfills. The plastics industry emphasizes that the use of plastics in sanitary landfills creates a stable non-settling base, and that this helps make the land more quickly recoverable.

Finally, since plastics are derived from petroleum products, the country's current energy problems significantly affect the plastics industry. It is not likely that rising oil prices will make plastic less competitive versus other materials, such as steel. In many cases, plastics actually use less total energy to manufacture, including the energy in the feedstock, than competing materials. Rising oil prices will affect the relative importance of raw material prices in the petrochemical industry. Eventually, rising oil prices may lead to a switch to coal as the basic feedstock, and this would cause considerable changes in the industry. Already the shortages of natural gas have led plastics companies to increase their dependence on refinery products for raw materials. This trend is expected to continue.

2.6 MACHINING

Machining operations are among the most precise in the entire automotive manufacturing process, and are basically the cutting off of excess material from a casting or forging by using specialized machinery. The cutting operation gives the piece being machined a particular shape or finish. While some machine tools cut material off as shavings, pieces, or large chips, others saw, drill, hone or grind by cutting away fine particles of the material. The equipment itself ranges from large, automatic, multioperation machine tools to small, handheld drilling or grinding devices.

2.6.1 Types of Machining

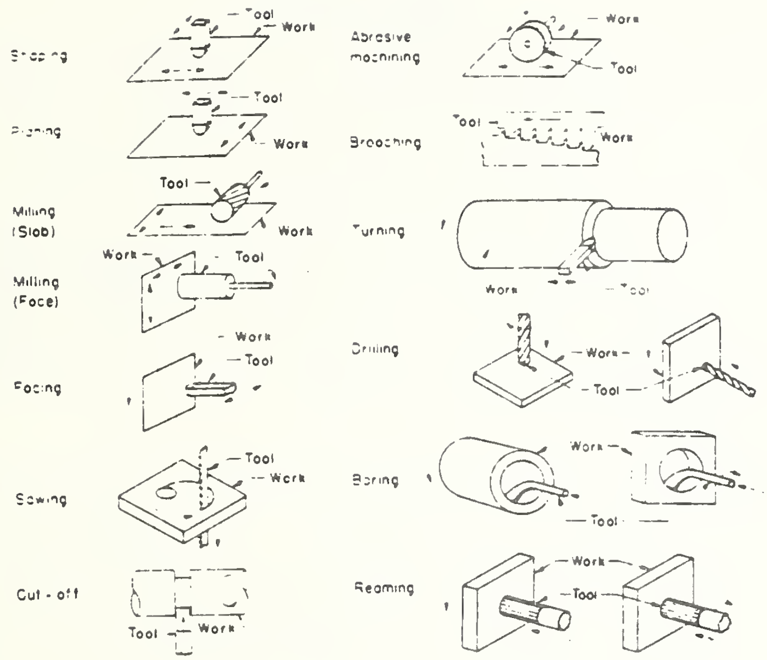
The basic determinants in selecting a machine tool for a particular assignment are the desired configuration of the component to be machined, and the surface characteristics of the material being machined. For machining purposes, surfaces are considered to be flat, flat contoured, curved, externally cylindrical (turned), or internally cylindrical (bored). As such, machine tools are divided into three basic groups:

- <u>Cylindrical Surface Machine Tools</u> - Machine tools intended primarily for cylindrical surfaces include drilling and boring machines, vertical and horizontal lathes, grinders and broaching machines.

- <u>Flat Surface Machine Tools</u> - Machine tools intended primarily for flat surfaces include milling machines, vertical and horizontal planers, shapers, surface grinders, and nibbling machines.

- <u>Trimming and Parting Machines</u> - Machines intended primarily for trimming or parting of material include circular and band saws, and flame cutters.

Many machine tools can handle more than one surface classification, although each is intended primarily for a particular application. A schematic representation of the basic machining processes is shown in Figure 2-25.



Source: Materials and Processes in Manufacturing, 4th edition, E. Paul DeGarmo, 1974.

FIGURE 2-25. SCHEMATIC REPRESENTATION OF BASIC MACHINING PROCESSES

2.6.2 Automotive Applications

Machining operations of some kind are needed on most mechanical automotive components. Figure 2-26 shows examples of major machined components and their location on the automobile. Included are:

- Carburetor body
- Valves
- Cylinder head
- Camshaft
- Engine block cylinder bores
- Crankshaft
- Pistons
- Disc brake rotors
- Transmission case
- Rear axle housing
- Brake drums.

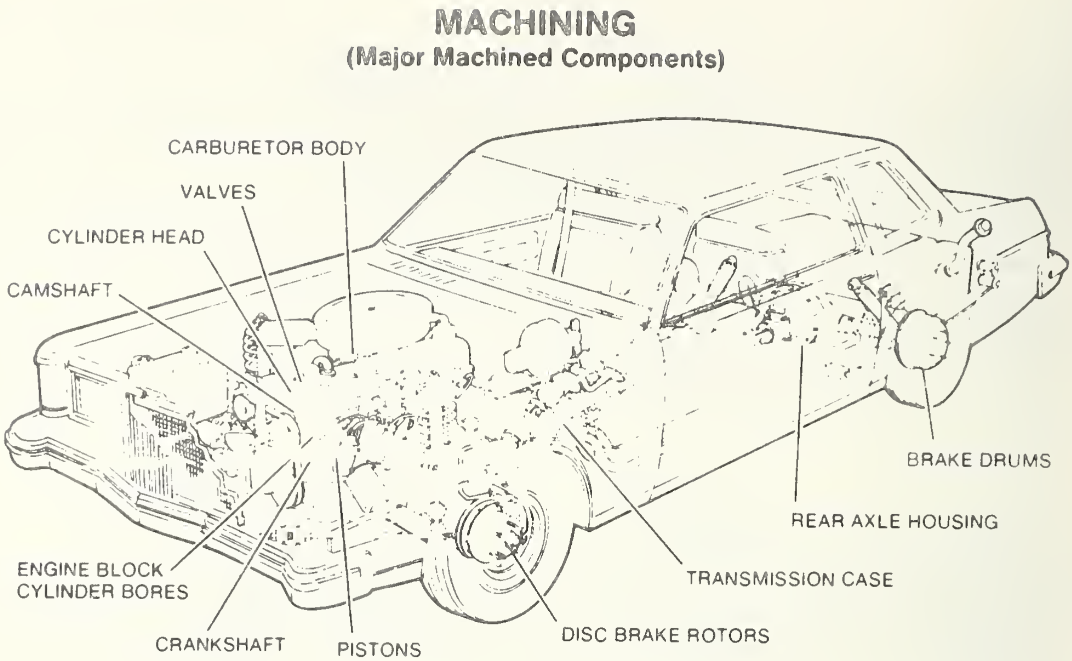


FIGURE 2-26. SCHEMATIC DIAGRAM OF AUTOMOBILE SHOWING PARTS AND COMPONENTS WHICH ARE MACHINED

2.6.3 Size and Structure of the Machining Industry

The "machining industry" is not in reality a single entity—it is fragmented among nearly all the other manufacturing processes. The principal types of machine shops are captive shops, which function as one of many operations within a larger manufacturing facility, and job shops, whose sole business is the machining of parts and components. Many of the captive machine shops, for example, are part of a foundry or one of the automaker's own plants. Thus, it is difficult to determine the total annual value of machining shipments from captive shops.

Table 2-7 presents an estimate of the total number of machining plants in the U.S., the number of production workers in machining, the capital investment and total assets. Machining is not an energy-intensive industry and its energy usage is unmonitored by industry associations or the Federal government.

2.6.4 Key Issues Facing the Machining Industry

Although machine tools have played a pivotal role from the very beginnings of the automotive industry, the machine tool supplier industry is not a large one—annual sales of all machine tool suppliers are less than four billion dollars, less than the annual gross sales of many of the top 100 corporations in this country. This limited but steady demand for machine tools, combined with the heavy capital expenditure required when any machine tool supplier gears up for a new order, results in the machine tool supply industry working at or near full capacity whenever possible, with little slack and long lead times required when new machine tools are needed.

This situation takes on considerable significance as Detroit tools up to meet the stringent new model requirements, and it is the suppliers' capacity, or lack of capacity, to meet the automakers' machine tool demands over the next few years that is the single most pressing issue in the automotive machining area. This strained capacity is expected to continue at least through 1980, according to a survey of machine tool suppliers published in January, 1978 by *Iron Age* magazine.

TABLE 2-7. MACHINING INDUSTRY STATISTICS: 1976

Industry Segment	Number of Establishments	Value of Shipments ($ Millions)	Number of Production Workers	Capital Investment ($ Millions)	Total Assets ($ Millions)
Captive Machine Shops	28,000	N/A	200,000	$ 3,000.0	$ 15,201.0
Machining Job Shops	27,000	$ 1,852.5	74,000		$ 9,875.0

2.7 JOINING

In the manufacture of automobiles, the joining process is intimately related to the assembly process, in that both operations necessitate the holding together of two or more components. The basic distinction is that components joined are more permanent, and less likely to be taken apart than components assembled.

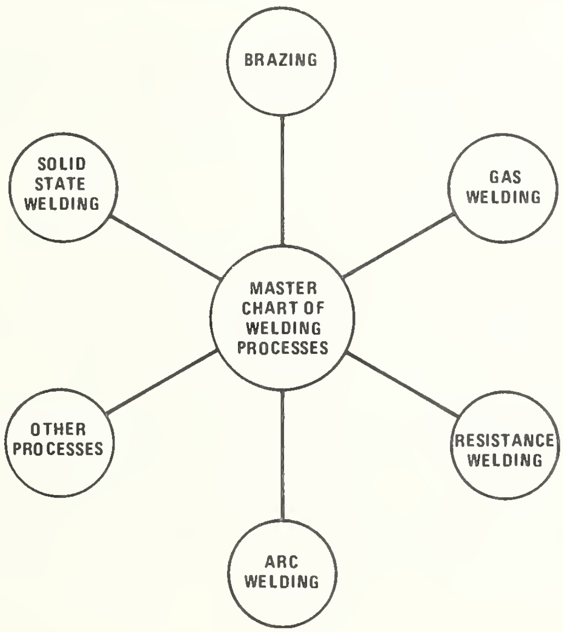
2.7.1 Types of Joining

The main types of joining are:

- Welding
- Adhesive and solvent bonding
- Mechanical fastening.

Welding

Welding is the joining of components by heating material, and either melting extra material into the joint or forcing the objects together, whereupon they solidify and form a permanent bond. A master chart of welding processes is shown in Figure 2-27.



Source: Society of Manufacturing Engineers, Tool and Manufacturing Engineering Handbook

FIGURE 2-27. MASTER CHART OF WELDING PROCESSES

One of the innovative welding techniques coming into greater and greater use in the automotive industry is electron beam welding. This welding technique welds materials by heating them to pliancy with kinetic energy transter. That is, electrons collide with atoms on the surface of the part when the beam is applied, thus forming a bond between the two parts.

Though requiring a capital outlay of $100,000 to $800,000, electron beam welding holds many benefits over conventional welding practices. The main benefit cited is speed. Electron beam machines can weld 300 to 400 inches per minute or more for high production rates. In addition, material savings can be obtained through process substitution, such as increased and economical use of joined stampings instead of single-piece forged components. Distortion is at a minimum, eliminating the need for straightening and machining operations.

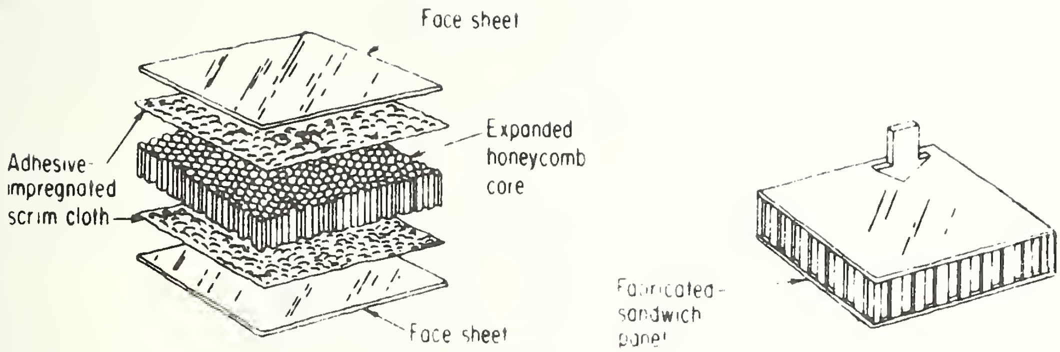
Adhesives

Adhesive and solvent bonding is the joining of materials with an adhesive or solvent material such as glue or cement in a bond designed to be permanent.

The use of adhesives in the automotive joining process is increasing rapidly. Reasons cited include low cost, relative convenience, and performance. In addition, materials such as plastic and glass, can be more easily joined without cracking or splitting.

Adhesives distribute loading stress uniformly across the entire joint area, which increases the life of the joint by providing resistance to buckling, cracking, and other fatigue. This differs substantially from the localized stressing of spot-welding and mechanical fastening.

Figure 2-28 shows the elements of an adhesive bond where two metal sheets are sandwiched together with the adhesive material in the center. As shown in the example, two layers of adhesive-impregnated cloth surround an expanded honeycomb core between the metal.



Source: Society of Manufacturing Engineers, Tool and Manufacturing Handbook.

FIGURE 2-28. ILLUSTRATION OF THE ELEMENTS OF AN ADHESIVE-BONDED SANDWICH

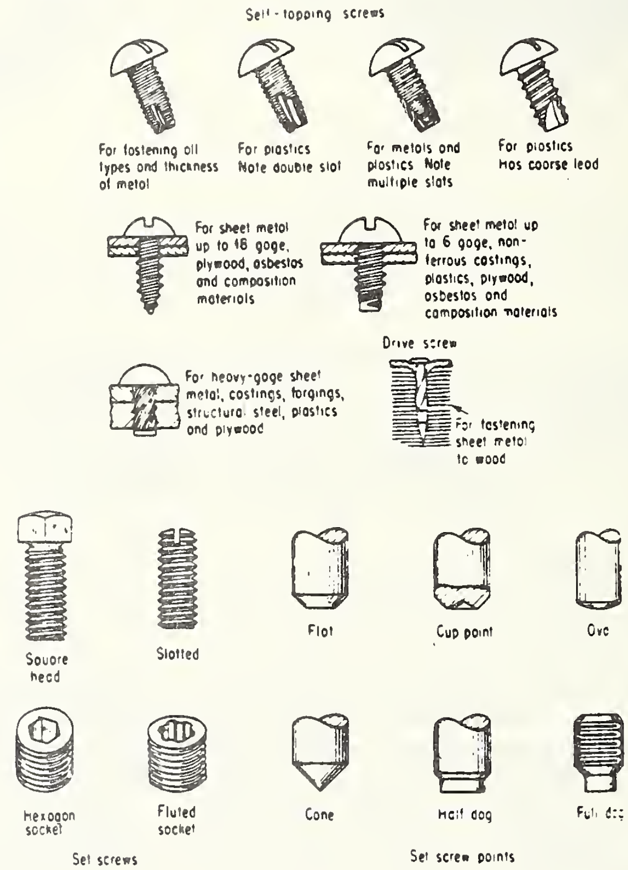
Mechanical Fastening

Mechanical fastening itself has undergone changes for the better, in particular with the development of new tension control systems. Tension control systems measure the clamping force generated in a joint more precisely and accurately than torque control can. While torque control, still most commonly used, can only measure 60 percent of the proof load of a bolt, tension control can enable 100 percent of a mechanical fastener to be applied, which means more reliable, quality products.

An advantage is that tension control will allow the design engineer to take a close look at the efficiency of his mechanical fasteners. Full use of a fastener can cut down on the number of fasteners needed. For example, four Grade Four fasteners applied by tension control could provide the same joint strength as six Grade Five fasteners, thus saving the vehicle manufacturer money.

An illustration of common types of mechanical fasteners is shown in Figure 2-29. These include:

- Self-tapping screws
- Drive screws
- Set screws.



Source: Society of Manufacturing Engineers: Tool and Manufacturing Engineering Handbook.

FIGURE 2-29. COMMON TYPES OF MECHANICAL FASTENERS

2.7.2 Automotive Applications

The joining process can be applied to almost every component in the automobile. Applications for adhesive bonding include sealed vinyl roofs, bonded brake shoes, hoods and other exterior panels, rear view mirrors, body molding and carpeting. Welding can be used for exhaust manifolds, chassis construction, transmissions, flywheels, and much more. Mechanical fastening is used in engines, wheels, and powertrain components, as well as body parts and chassis components. A summary of the major components that are joined is presented in Figure 2-30.

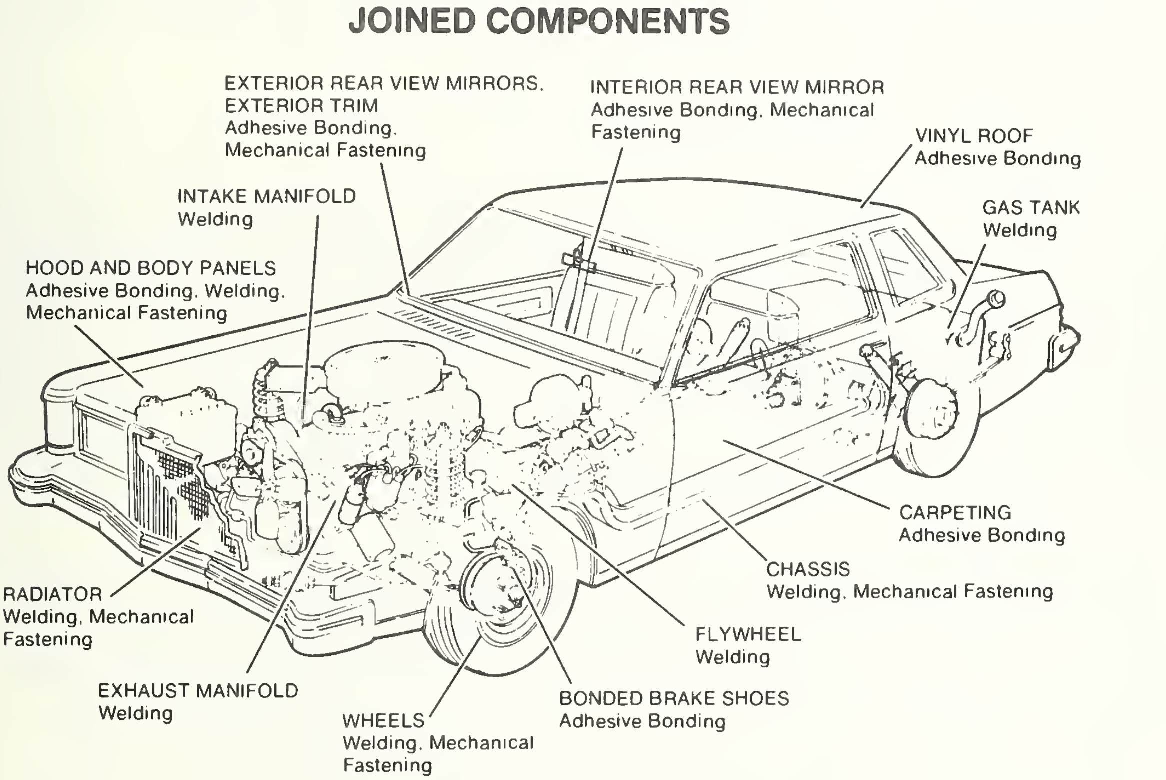


FIGURE 2-30. SCHEMATIC DIAGRAM OF AUTOMOBILE SHOWING PARTS AND COMPONENTS WHICH ARE JOINED

2.7.3 Size and Structure of the Joining Industry

The joining processes are integrally related to the assembly process, and statistics maintained by the Motor Vehicle Manufacturers Association and the Department of Census tend to combine both industries. Information on the number of production workers, capital investment and total assets in the joining industry may be found in the next section on assembly processes.

2.7.4 Key Issues Facing the Joining Industry

Current problem areas facing the joining industry relate to the use of new materials in auto components, principally aluminum and HSLA, and efforts to reduce costs through greater use of adhesives.

New Welding Techniques and Equipment Are Needed for Aluminum and HSLA

Both aluminum and HSLA are more difficult to weld than steel. In the case of aluminum, alloys are selected principally with formability and strength in mind, depending on the location of the component on the automobile. However, some alloy combinations and component surface qualities affect the durability of spot welds. In general, aluminum alloys require new equipment and different techniques than for steel. Thus, the need for new equipment is placing a burden of capital investment on joiners as the use of aluminum increases.

HSLA requires more care in welding than steel in order to obtain a component of consistent quality with steel. Although HSLA welding does not require new equipment, it does require alterations in the normal welding techniques as well as greater quality control. In addition, HSLA has shown a higher frequency of weld failure than other materials. Kelsey-Hayes, for example, found that HSLA wheels would not successfully hold hot welds, and consequently the company had to substitute aluminum wheels to meet their production schedule.

The Use of Adhesives is Limited Despite Lower Costs

Adhesives offer considerable advantages as a joining material. The process is less expensive than any other joining process and it does not contribute to noise or air pollution as welding does. The drawback to increased use of adhesives is that adhesive materials have not been shown to withstand comparable amounts of pressure and stress as weldings or mechanical fastenings. If methods could be found to increase the bonding strength of glues and cements, the joining industry could reduce manufacturing costs.

2.8 ASSEMBLY

Assembly is basically "the concept of joining two or more parts to perform a concerted function." It is closely related to the joining process, in that some parts are joined in a bond meant to be permanent, and others are fastened, hooked, snapped, bolted, or placed together in a manner in which they can be taken apart again for repair or replacement. Assembly is also related to the machining and finishing processes, all of which are part and parcel of preparing the car for the road.

2.8.1 Types of Assembly

Two basic types of assembly operations are performed in automobile manufacturing:

- The assembly of component parts along feeder lines and by individual component suppliers in their own plants

- The final assembly of the automobile along the main assembly line.

Feeder Lines

As noted above, assembly is first carried out in the feeder lines to produce many of the component parts. One feeder line, for instance, clamps together body panels, welds them, and solders, grinds and finishes them to form a smooth body shell. Another feeder line takes an assortment of gauges and switches and assembles them into instrument panels, which are then fed to the main assembly line for final assembly. Another line assembles the entire engine. Often, of course, many of the components—from engines and transmissions to carburetors and waterpumps—are fully assembled at another plant and simply placed on the feeder lines supplying the main line.

Main Assembly

The main assembly line actually consists of two separate lines: a chassis assembly line and a body assembly line. On the chassis line, axles and wheel suspensions are "hung" on the frame, as are the completed and fully tested engines, transmissions, and other components from other feeder lines. On the body line, body panels are welded together, doors and windows installed and the body painted and trimmed.

The completed chassis and body meet at the "drop" point, and are joined. From there, the car receives minor adjustments, the steering column is connected, the gas and brake pedals are connected, minor accessories are added, and fluid levels filled. Checks and adjustments are made all along the main assembly line, and in the end, a completed car rolls off the line.

2.8.2 Automotive Applications

As shown in Figure 2-31, assembly encompasses almost the entire automobile. Examples of parts and components which may

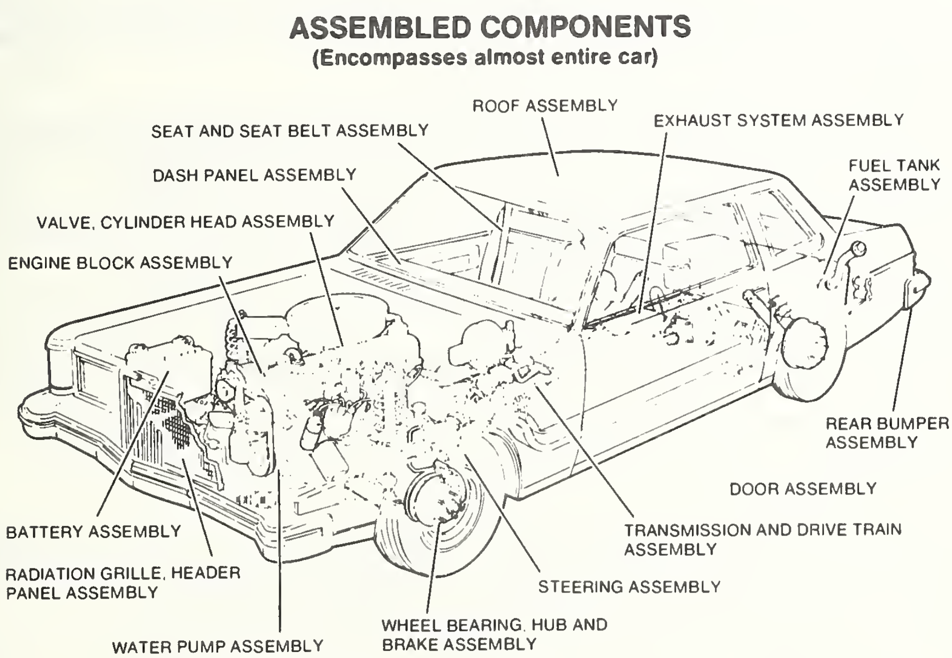


FIGURE 2-31. SCHEMATIC DIAGRAM OF AUTOMOBILE SHOWING PART AND COMPONENTS WHICH ARE ASSEMBLED

be seen on the assembly line include:

- Seat and seatbelt
- Dash panel
- Valve, cylinder head assembly
- Engine block
- Roof
- Exhaust system
- Fuel tank
- Rear bumper
- Door
- Transmission and drive train
- Steering assembly
- Battery
- Water pump
- Radiator grille.

2.8.3 The Size and Structure of the Joining and Assembly Industries

Joining parts to form components, subassemblies, and complete vehicles is an integral step in the assembly process. For this reason, statistical information on the joining and assembly industries are combined.

Table 2-8 presents the total number of assembly plants, production workers, capital investment and total assests of the joining and assembly industry.

TABLE 2-8. ASSEMBLY AND JOINING INDUSTRY STATISTICS: 1976

Industry Segment	No. of Estab-lishments	Value of Shipments	No. of Pro-duction Workers	Capital Invest-ment	Total Assets ($ Billions)
Assembly and Joining	101	$45 Billion	157,600	$890 Million	$25.2*

* Includes tooling and equipment costs for components including those supplied by vendors, and the cost for buildings and land.

The joining and assembly industries annually consume $29 billion in materials. Energy usage by this electricity-powered industry is 33.9 trillion BTUs annually.

2.8.4 Key Issues Facing the Assembly Industry

Because of the integral nature of assembly in the production of automobiles, the assembly process is one which is immediately affected by each change in the automobile.

A change in material, for example, may necessitate a change in fasteners, while a change in size has major tooling implications. Major issues facing the assembly industry at present, however, do not relate to changes in materials or automobile size but rather:

- Increasing production through automation
- Minimizing vibration on the assembly line
- Improving quality control
- Improving efficiency.

Increasing Productivity

One key issue affecting the automotive assembly process is increasing automation in attempts to raise productivity all along the line. Programmable assembly lines are on the horizon, and robots are part of this change. One example of this trend is the utilization of reprogrammable, computer-controlled manipulators, built for General Motors. Plans call for this robot to "bridge the gap between manual assembly and hard, special-purpose automation" by being "virtually interchangeable with a human being in the same workplace and working at the same speeds." This particular robot has been designed with human size, moves, and speeds for small-parts assembly. It has a carrying capacity of seven and a half pounds, since most parts weigh three pounds or less.

Automotive manufacturers are also utilizing robots for painting, welding, assembling instrument panels and other units, feeding parts to various machines, and many more functions. Robots, however, are not yet human. Since most robots are programmed only for specific movements, they have no adaptive capacity. Therefore, parts must be presented in the precise order and location, and the unit to which the part is applied or the task is performed, must be in exact position.

Chrysler has developed one solution to this problem, with its "Robogate" spot-welding system at the Belvedere Assembly Plant. Major body components, such as the engine compartment and body panels, are loosely assembled with "toy tabs." When this body moves down the line, it is automatically grabbed and positioned, every component tab located properly, and the robots make tack welds. Further down the line, final spot welding is done.

Combating Vibration

Vibration, a major factor in the failure of automotive components, is being combated at the assembly line by the increased use of electronics. As in the joining of specific components, the use of electronic tension control is helping by maximizing fastener clamping force.

There are many different types of electronic tension control. British Leyland, for instance, is using a U.S. manufacturer's joint control system in the bolting of cylinder heads during engine assembly. Electronic control precisely measures the torque and angle through which the bolt is turned. A torque/rotation curve is plotted and, based on this data, the bolt is tightened to the exact point at which metal starts to yield; this utilizes the absolute maximum tightening capacity of the fastener.

Improving Quality Control

Quality control is another area where improvements continue to be made. Ford Motor Company, for example, has a new computerized monolithic engine-timing hot test for its Fiesta engines, for more accurate setting of the distributor before the engine ever leaves the assembly line. Ford also plans to cold test its Erika engines with computerized instrumentation to detect the noise and vibration which is symptomatic of flaws in the engine.

Cold test systems check out engines for defects while running them on compressed air, hydraulic motors, or electric motors. Cold testing not only conserves gas, but is also regarded as a faster, more accurate testing technique. Ford's cold testing system will be used in conjunction with a more conventional hot testing system, which tests engines while they are running on gasoline. These testing procedures, and many more, are steps toward improved quality control.

Improving Efficiency

Other recent improvements in assembly line techniques are devoted to improving efficiency. Included are:

- Certified Power Tools. These new tools are intended specifically for precise torque control and tool durability. These are also quieter and easier to operate, increasing labor efficiency and meeting OSHA requirements.

- Breakstream Riveting. This new system lowers inventories and gives uniform results because it is insensitive to both hole diameter and material thickness "within limits."

2.9 FINISHING

Finishing, as its name implies, is the last operation performed on each automobile before it is ready for final assembly and market availability. It is during this stage that all of the rough edges are smoothed down and the protective coatings applied.

Unlike the majority of other automotive manufacturing processes, some type of finishing is necessary for almost every component in the car, from the interior all the way to the chassis itself. It is important to note, however, that these components do not necessarily go through each phase of the entire finishing operation.

2.9.1 Types of Finishing

The finishing processes include:

- Metal cleaning
- Mechanical finishing
- Electroplating
- Nonmetallic coatings
- Cleaning and finishing of stainless steel, heat resisting alloys and nonferrous metals.

Metal Cleaning

The choice of one of the wide variety of metal cleaning processes—alkaline cleaning, emulsion cleaning, solvent cleaning, salt bath descaling, etc.—depends on the type of soil to be removed. The various types of soil are:

- Pigmented drawing compounds
- Unpigmented oil and grease
- Chips and cutting fluids

- Polishing and buffing compounds
- Rust and scale
- Surface contaminants such as residue from magnetic particle inspection.

Emulsion cleaning is one of the most effective and, therefore, frequently used forms of metal cleaning. The concentrated emulsion is mixed with a certain amount of water, varying with the type of soil to be removed. After mixing, the emulsion can be applied through spraying, soaking or dipping. All of the emulsion methods must be followed by a thorough water spray rinse. The performance of emulsion cleaners can sometimes be improved by using them in conjunction with alkaline solutions, particularly in spray washers.

Mechanical Finishing

Mechanical finishing, which includes such operations as polishing and buffing, barrel finishing, shot peening, and power brush cleaning and finishing, is the process during which scratches, pits, mold marks and other surface blemishes are removed, leaving a smooth, reflective, scratch-free surface.

Polishing is an abrading operation performed with either a belt or a wheel to which an abrasive is bonded. The process removes metal and causes some plastic working of the surface. The resulting polished surface usually has a finish of 16 microinches or less.

The major purpose of shot peening is to increase fatigue strength. It is a method of cold working in which compressive stresses are induced in exposed metallic surfaces by the impingement of a stream of shot, directed at the metal surface at high velocity and under controlled conditions.

Electroplating

During electroplating, various components of the automobile are treated with such different kinds of protective plating as zinc, nickel, chromium, tin, silver, gold, etc. This process helps guard against corrosion and decomposition. In addition, there are several forms of metallic and non-metallic coating processes that perform the same protective function.

Chromium plating is one of the most frequently used electroplating operations. The two types of chromium plating, decorative and hard, differ in several ways, the most prominent of which is that hard, or industrial, chromium is usually applied directly to the base metal and is usually ground to a finish. Decorative chromium, on the other hand, is applied over undercoats of nickel or of copper and nickel, and is buffed to a high lustre.

Nonmetallic Coatings

Nonmetallic coatings include organic powder coating and painting. Organic powder coating is used to give a protective coating to the metal and to prepare the surface for the application of paint. The painting process includes the application of both primer and finish coats.

Cleaning and Finishing of Stainless Steel, Heat Resisting Alloys, and Nonferrous Metals

As discussed under metal cleaning, there are various techniques employed in the cleaning and finishing of stainless steel, heat resisting alloys, and nonferrous metals. Cleaning is required for the removal of surface soils before these components are ready for finishing.

The cleaning methods—polishing, abrasive bath cleaning, salt bath descaling, etc.—are the same methods utilized in the previously discussed metal cleaning operations. Usually, more than one method of cleaning is employed in this cleaning process.

2.9.2 Automotive Applications

As shown in Figure 2-32, selected automotive parts and components which go through the finishing processes include:

- Headlight rims
- Fender
- Grille
- Valve cover
- Air cleaner
- Selected dash components
- Rearview mirror interior
- Steering wheel and columns
- Bumpers
- Door handles
- Wheels and wheel covers.

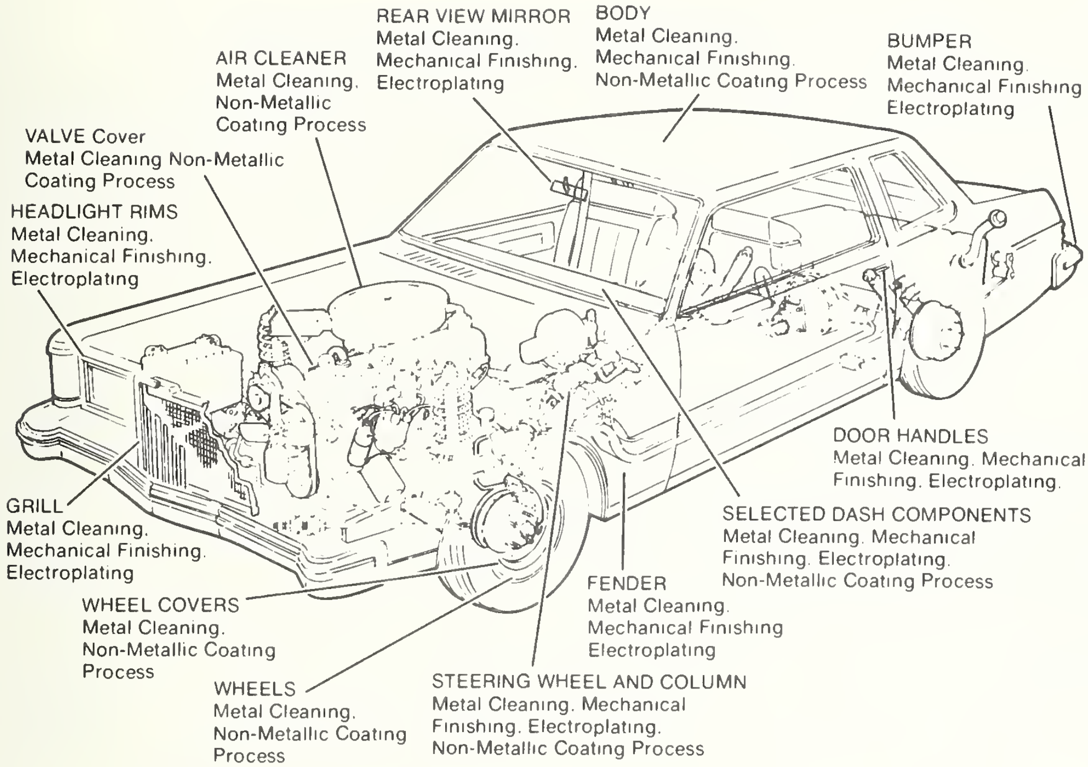


FIGURE 2-32. SCHEMATIC DIAGRAM OF AUTOMOBILE SHOWING PARTS AND COMPONENTS WHICH ARE FINISHED

2.9.3 Size and Structure of the Finishing Industry

A summary of the size and structure of the finishing industry in terms of the number of establishments, number of workers, and value of shipments is presented in Table 2-9. Of the 4,700 establishments shown in the table, 3,200 specialize in polishing and plating and 1,500 specialize in coating. A summary of the materials used by this industry is shown in Table 2-10.

TABLE 2-9. FINISHING INDUSTRY STATISTICS

Industry	Number of Establishments (1972)	Number of Production Workers (1974)	Value of Shipments in Millions (1973)
Finishing	4,700	90,000	$ 2,000

TABLE 2-10. MATERIALS USAGE: FINISHING (MILLIONS OF POUNDS)

Nickel	Copper	Tin	Zinc	Chromium
80	30	70	800	15

2.9.4 Key Issues Facing the Finishing Industry

The major problem confronting the finishing industry at the present time is that of corrosion. While Detroit and automotive finishing producers have upgraded their anti-corrosives to increase the lifespan of a car's "finish," the increasing use of aluminum and plastics presents new problems.

Plastics

Although not subject to the same forms of corrosion as most metals, plastics have their share of problems. The difference between plastics and metals is that metal corrosion is basically a result of weather conditions, whereas destruction of plastic material is caused by microorganisms. This decomposition manifests itself in stains and molds that appear on the plastic components. Thus, the protective treatment for plastics and metals differs. To protect plastic products from the deterioration caused by microorganisms, it is necessary to treat the original material with an antimicrobial agent.

There is a greater difference between the corrosive properties of metal and those of plastic that becomes obvious when comparing electroplating metal on metal to electroplating metal on plastic. In this application plastics do not appear to experience any kind of corrosion or to need any corrosion protection. They do, on the other hand, make the protection of electrodeposit more difficult because the corrosion will move laterally causing pits and blisters. When electroplating metal to plastics, a wet or corrosive environment could cause this adhesion to suffer. Whether the loss of adhesion results from corrosion or from water displacement, tests indicate that adhesion failure occurs when chemical nickel is the initial deposit, but not when chemical copper is used.

Aluminum

The major problem here is that when two dissimilar metals are connected, a galvanic reaction occurs and one of the two metals will start to corrode. Depending on the type of metals used, aluminum may be the one that begins to corrode first. Eventually the high luster of the decorative aluminum becomes cloudy and dull.

As with plastics, manufacturers began to experiment with various combinations in an attempt to find a metal that could work with, instead of against, aluminum. The result was that a combination of aluminum and stainless steel was developed. This combination, stainless clad aluminum, has apparently solved the problem of aluminum corrosion.

When it is attached to carbon steel, the galvanic action once again works against the aluminum. The difference here is that when this action corrodes the aluminum (which has a very thin layer of stainless steel inseparably bonded to it forming the exterior surface), it "bleeds" white and washes away unnoticed. There is no damage to the car body underneath.

3. AUTOMOTIVE ENGINE AND EMISSION CONTROLS

3.1 GENERAL

With the advent of emissions standards in 1968, a new era in automotive design began. The first modifications made by the manufacturers to meet the standards were relatively minor with little impact on automobile manufacturing. However, as emissions standards tightened, the manufacturers started to develop advanced technologies to further control vehicle pollutants and make the gasoline engine more thrifty with fuel.

Among the major improvements in engine and related engine control were the following new technologies:

- Catalytic converters
- Electronic engine control
- Turbochargers
- Fuel injection
- Electronic ignition.

Compared to the older methods of engine/emissions control, these new controls require considerable accuracy in all of the manufacturing processes, particularly since replacement of some of them may be necessary upon failure of a single component.

This chapter provides a detailed discussion of new manufacturing processes related to engine and emission control. Included in each section are:

- A description of each process and how it works.
- The basic components produced by each process.
- The size and structure of each process industry.
- The key issues facing engine manufacturing today, and the solutions needed for its future.

3.2 CATALYTIC CONVERTER

A catalytic converter is simply a metal chamber in the exhaust system which contains a catalyst. The purpose of the converter is to change the pollutants in exhaust gases into harmless compounds before passing out through the tail-pipe. This is accomplished through a chemical reaction which takes place when the pollutants pass over the catalyst en route to the muffler.

3.2.1 Types of Catalytic Converters

There are two basic types of catalytic converters: a two-way catalyst and a three-way catalyst.

A two-way catalyst contains platinum and palladium and transforms hydrocarbons (HC) and carbon monoxide (CO) into carbon dioxide and water. A three-way catalyst, more recently developed, contains both of these elements plus rhodium, and controls HC, CO and oxides of nitrogen (NO_x).

There are also two forms or ways the catalyst is contained inside the metal housing. General Motors and American Motors use the pellet form, in which loose pellets are packed into the converter and can be emptied out and changed, if necessary. Ford and Chrysler use the honeycomb catalyst, which is built into the converter shell and is not replaceable.

A schematic diagram of a two-way, pellet-type catalytic converter used by GM is shown in Figure 3-1. The major components of the converter, as shown in the figure, include:

- The converter shell
- The catalytic pellet compound
- Insulation.

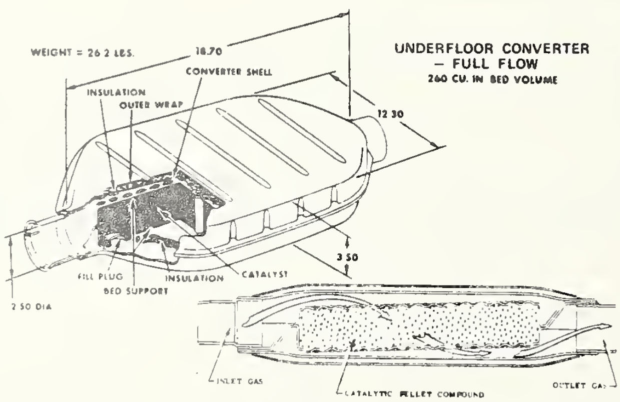


FIGURE 3-1. GM 2-WAY CATALYTIC CONVERTER

3.2.2 Manufacturing Processes

To illustrate the manufacturing processes and assembly for catalytic converters, a detailed discussion of the manufacture of a pellet-type converter is presented below. Except for the manufacture of the pellets or the honeycomb, both types of converters are essentially made the same way.

Figure 3-2 summarizes the manufacturing steps and assembly of the principal parts of a pellet-type converter: the container, substrate (pellets) and catalyst. Each is described below:

- Container. The converter container is made of several layers. The inside layer is called the retainer and is stamped in two pieces from stainless steel, shaped and pierced. Following metal cleaning, the two layers of the retainer are complete. The inner cover is pressed from the same kind of stainless steel and also separated into two layers. The two layers of the retainer are joined to the two layers of the inner cover with four studs and then electron-beam welded. The outer layer or "cover" of the container is made by stamping aluminized steel.

- Substrate. The substrate, or pellets, are made from ceramic powder (alumina) through the processes of extrusion and chopping, or dropping. The pellets must then be baked hard, before they are ready for the application of the catalyst.

- Catalyst. To make the catalyst material itself, U.S. manufacturers start out with refined platinum, palladium and rhodium imported from South Africa. These elements are placed in liquid suspension and then sprayed or otherwise applied to the ceramic pellets. The object of the application technique is to obtain maximum possible coverage of the ceramic surface.

Once the container assembly is complete, it is then filled with the pellets through a filler hole. The hole is then capped and the container with the pellets is covered with ceramic fiber insulation and placed within the outer cover. The two outer covers are tack welded, and then the catalytic converter is ready for the attachment of piping components.

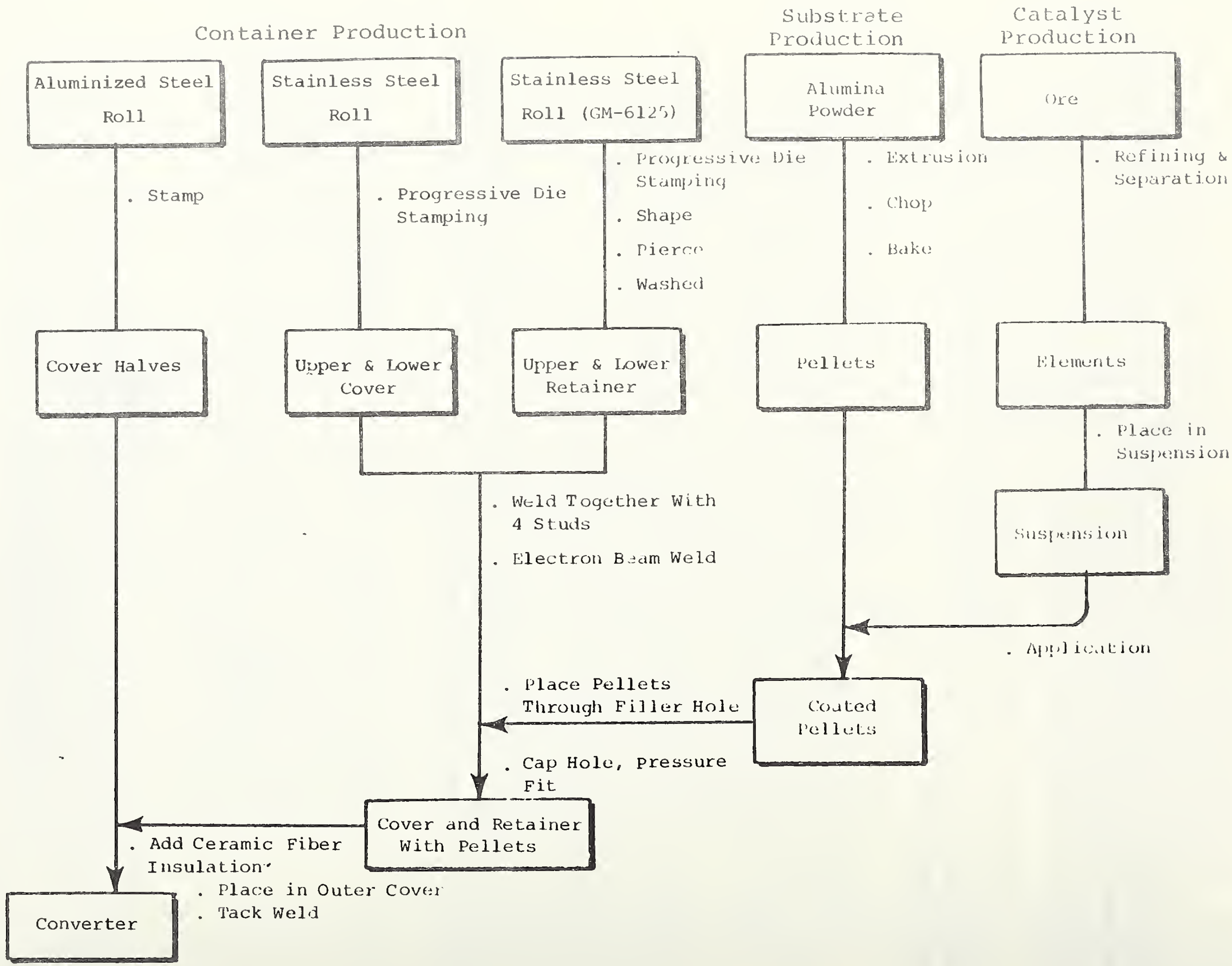


FIGURE 3-2. CATALYTIC CONVERTER PRODUCTION

3.2.3 Size and Structure of the Industry

Three industries are involved in the production of catalytic converters:

- Companies which provide the ceramic substrate which holds the catalyst. These include Rhone-Poulenc and Corning.

- Companies that put the catalyst on the substrate. These include W.R. Grace, Engelhard, Air Products, and The Catalyst Company.

- Companies which put the catalyst-coated substrates in stainless steel containers. The largest of these companies is the A.C. Spark Plug Division of General Motors which also supervises the entire production of catalytic converters and provides them to GM, AMC, and International Harvester.

While limited statistics are available which characterize this industry, the total production of catalytic converters for U.S. auto manufacturers in 1977 is estimated to be approximately 9.3 million based on the number of U.S. cars sold in that year. With catalytic converters costing $80-100, estimated domestic market for catalytic converters in 1978 was 800 million dollars.

3.2.4 Key Issues

A key problem facing the manufacturers of catalytic converters at present is the supply of rhodium. Rhodium, one of the three elements in the three-way catalytic converter (the other two are platinum and palladium), is presently mined at a ratio of 1 part rhodium to 19 parts platinum. The requirement for rhodium in the three-way converter is 7 parts platinum to 3 parts rhodium in General Motors' 2.5-litre, L-4 engine, and 15 parts platinum to 6 parts palladium to 1 part rhodium in General Motors' 3.8-litre, V-6 engine. Thus, as can be seen, the problem is that the three-way converters now in use require more rhodium relative to platinum than is presently mined. If engineers fail to develop combinations of catalysts that meet the 50,000 mile requirements, while using rhodium at a rate proportional to its extraction from the ground, rhodium will become the limiting element for converter production in the United States.

3.3 ELECTRONIC ENGINE CONTROLS

Electronic engine control refers to the continuous electrical control of engine settings which affect fuel consumption and emissions. When an engine's operating environment changes, the electronic system detects the change and adjusts the engine back to optimum operating levels. Among the engine conditions which are monitored electronically are the following:

- Crankshaft position
- Exhaust oxygen concentration
- Engine vacuum
- Exhaust manifold pressure
- Coolant temperature
- Inlet air temperature
- Distributor signal
- Throttle position
- EGR valve position
- Carburetor idle switch position.

3.3.1 Components of an Engine Control System

As shown in Figure 3-3, the control system consists of three major parts:

- Sensors, which sense the engine condition

- An electronic module, which receives the signal that engine condition is changing and dictates the necessary corrective action

- The actuator, which makes the adjustment to the engine.

There are many applications and unique constructions for engine electronic control systems. The components discussed in this section have been combined by the manufacturers into total control systems such as shown in Table 3-1.

Sensors

Sensors or "transducers" are simple devices which respond to a physical stimulus (as heat or a particular motion) and transmit a resulting impulse. Sensors are designed and constructed differently for each application, but generally they are small elements with a metal or plastic housing, electrical terminals, insulating material and wire, and are directly connected to the part of the engine which is being monitored.

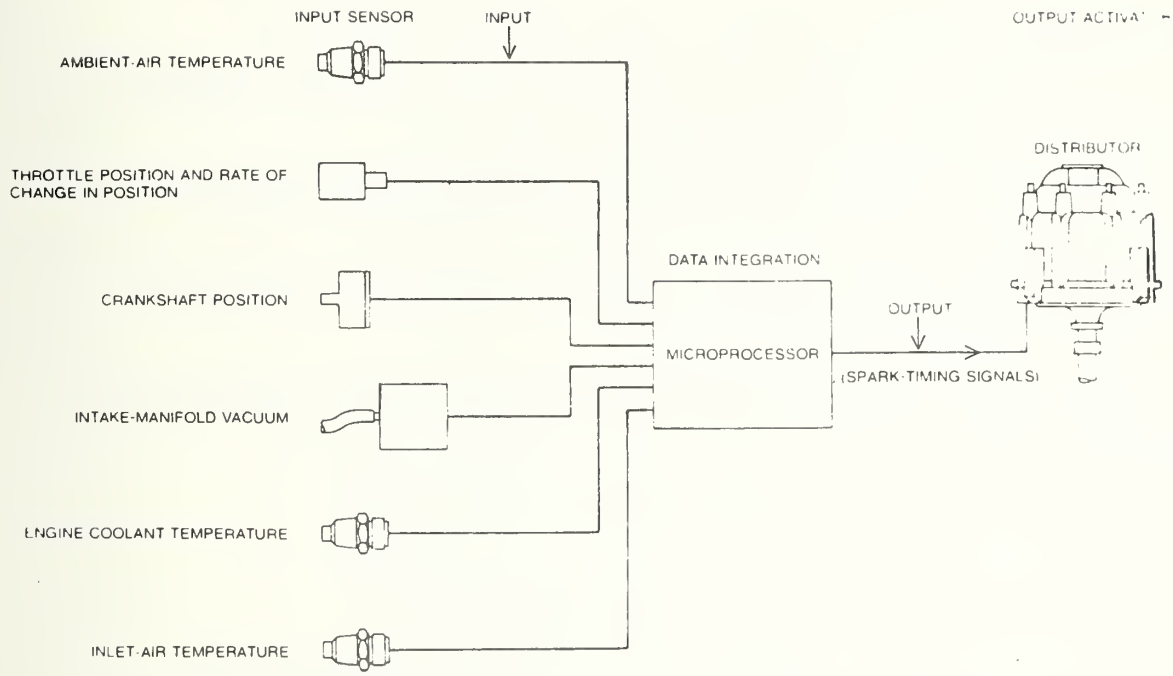


FIGURE 3-3. DIAGRAM OF ELECTRONIC ENGINE CONTROL SYSTEM

TABLE 3-1. CHARACTERISTICS OF SOME EXISTING ELECTRONIC ENGINE CONTROL SYSTEMS

SYSTEM	MANUFACTURER	CONTROLLED FUNCTIONS				SENSORS									
		IGNITION TIMING	EGR FLOW RATE	THERMACTOR AIR FLOW	AIR/FUEL MIXTURE	MANIFOLD PRESSURE	BAROMETRIC PRESSURE	COOLANT TEMPERATURE	INLET AIR TEMPERATURE	CRANK SHAFT POSITION	DISTRIBUTOR PICK-UP	THROTTLE POSITION	EGR VALVE POSITION	OXYGEN	CARBURETOR SWITCH (IDLE/NO)
LEAN BURN	CHRYSLER	●				●		●			●	●			●
EST	GM	●				●	●	●			●				
EFI	GM				●	●		●	●		●	●			
EEC-I	FORD	●	●	●		●	●	●	●	●		●	●		
EEC-II	FORD	●	●	●	●	●	●	●	●	●		●	●	●	

Among the many useful automotive sensors are:

- The pressure sensor which measures the pressure inside the intake manifold.

- The crankshaft position sensor which provides information on engine speed and position.

- The oxygen sensor which measures the amount of oxygen.

Detailed illustrations of the crankshaft position sensor and oxygen sensor are shown in Figures 3-4 and 3-5, respectively.

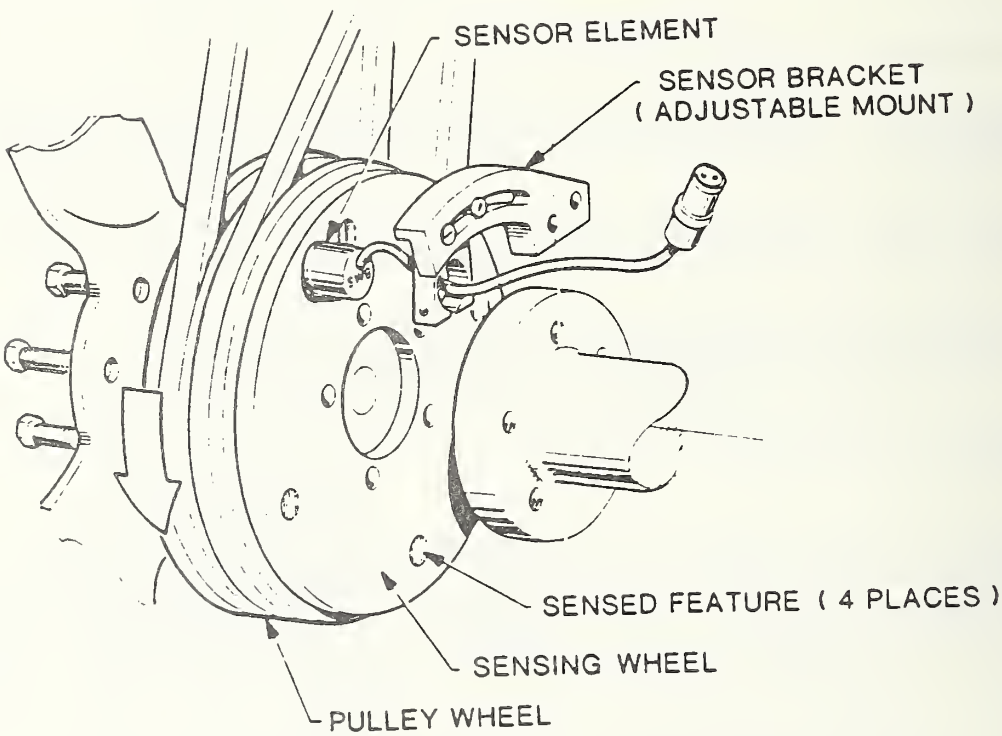


FIGURE 3-4. CRANKSHAFT POSITION SENSOR

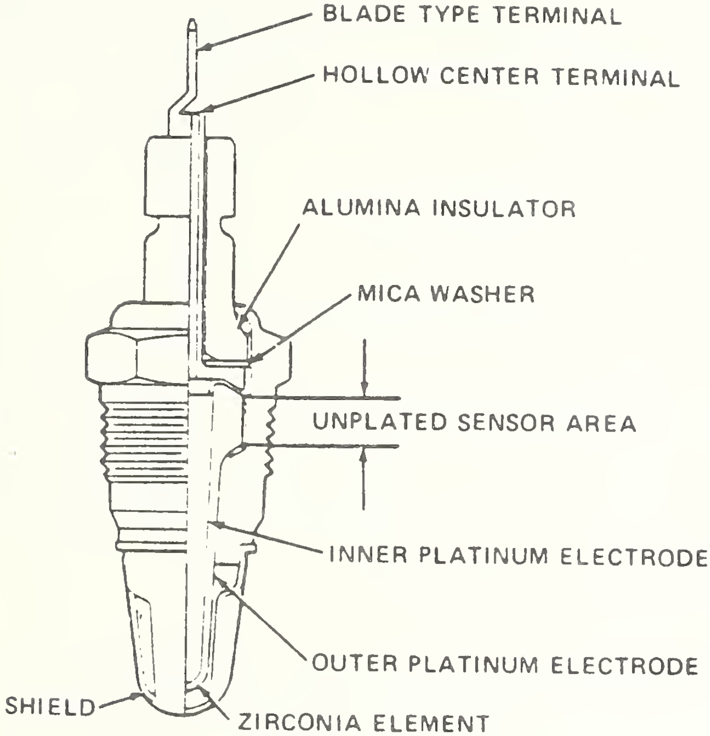


FIGURE 3-5. EXHAUST OXYGEN SENSOR

Electronic Module

The electronic module is the device that accepts information from the sensors, processes the information and sends signals to the actuators. It is essentially a small computer. The module may use either analog circuitry in which information is transmitted in terms of the magnitude of some electronic parameter (voltage, for instance), or digital circuitry where the information is transmitted as pulses. The use of digital circuitry involves the new microprocessor technology. This technology tends to use fewer parts and provides greater flexibility than analog technology. Major parts include silicon chips, integrated circuits, capacitors and resistors.

Actuators

Actuators are simple devices which have traditionally been used to exert mechanical or hydraulic pressure to change various engine settings. Typically, an actuator consists of a coil and rod in a steel housing. Actuators help to modify engine operation by continually adjusting the spark advance, carburetor setting, EGR value setting and thermactor flow setting.

3.3.2 Manufacturing Processes

As described above, the engine control system consists of three basic parts or subassemblies: the sensors, the control module and the actuators. These subassemblies of the control system are generally manufactured by independent companies and supplied to the auto manufacturers for final assembly. A description of the basic processes used in the manufacture of these subassemblies/components is presented below.

Sensors

The following is a summary of the manufacturing processes for the three sensors described earlier: the pressure sensor, the crankshaft position sensor and the oxygen sensor:

- Pressure Sensor. The working element of the pressure sensor is made from two thin pieces of an insulating material. The assembly process is shown in Figure 3-6. Two pieces of a ceramic material such as alumina are constructed with their faces slightly hollowed out (bowl-shaped). This can be done by molding and machining. The faces are plated with a metal, such as platinum or aluminum. The two alumina diaphragms are then placed together and the air is evacuated between them. The edge is bonded by a glass band. This becomes the basic operating unit of the sensor. Changes in pressure change the spacing between the two plates and this results in a change in the output of the electronic signal from the sensor.

- Crankshaft Position Sensor. The assembly process for the crankshaft position sensor is shown in Figure 3-7. Copper wire is wound on a molded plastic bobbin. This is placed in the housing

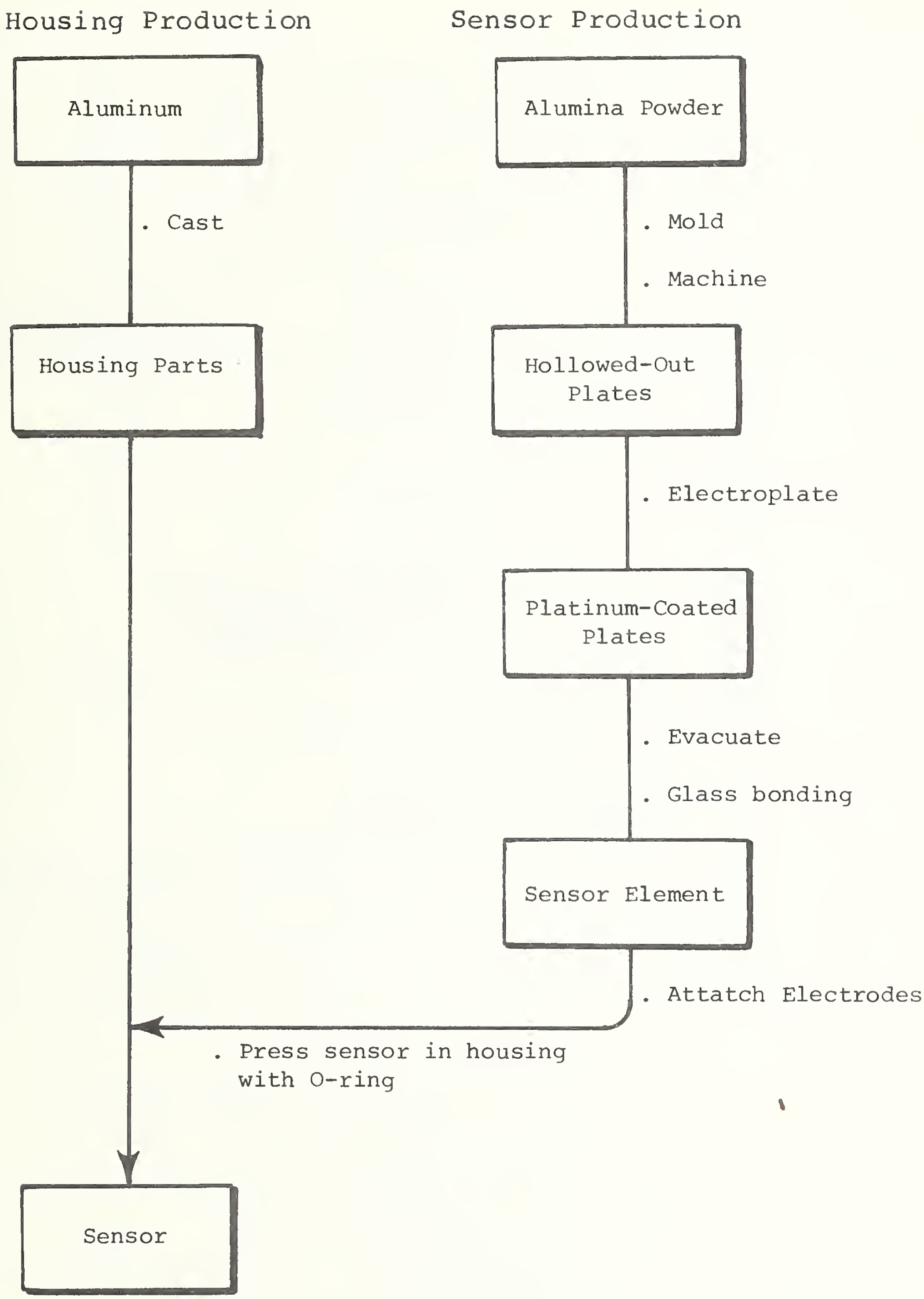


FIGURE 3-6. PRESSURE SENSOR ASSEMBLY

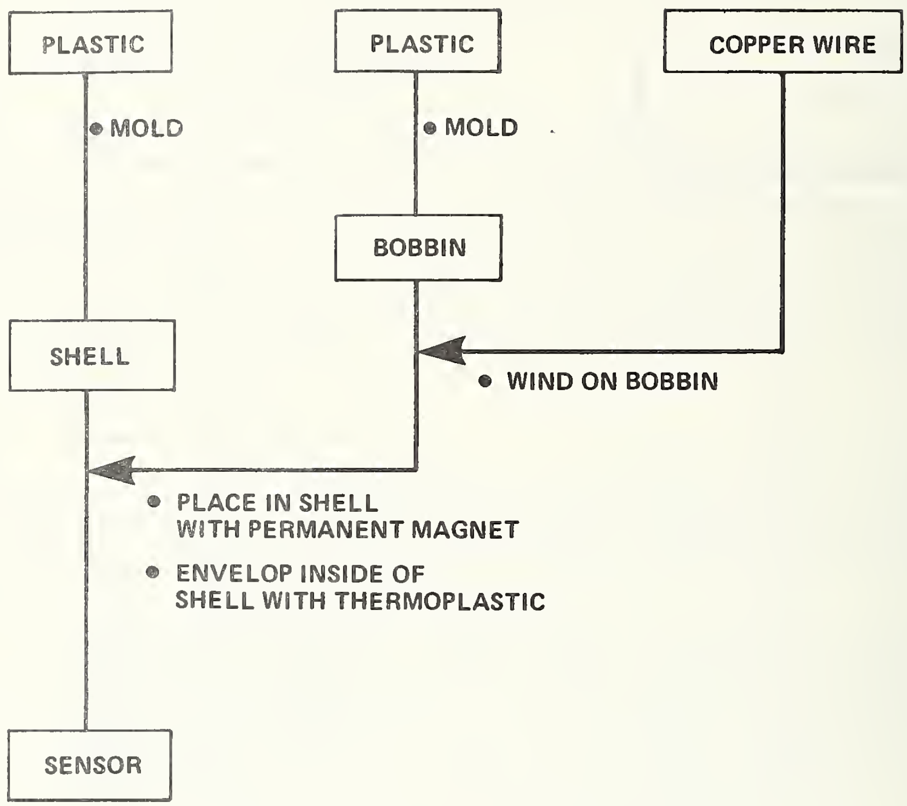


FIGURE 3-7. POSITION SENSOR ASSEMBLY

with a permanent magnet, usually made of a nickel alloy. A thermoplastic is put inside the shell and completely envelops the electric components inside. This is done to protect the device from the harsh automotive environment. The sensor is able to detect the passage of steel protrusions rotating with the crankshaft by detecting magnetic field changes.

- Oxygen Sensor. The assembly process for the oxygen sensor is shown in Figure 3-8. The compound that "senses" the oxygen is a zirconia compound. This material composes the lower thimble-shaped part at the bottom of the sensor. On the inside is a platinum coating which can be put on by an electrolytic process. Electrodes are attached to this assembly and then placed in the molded ceramic casing. The bottom part of the "thimble" region is exposed to the exhaust gas and the inside of the "thimble" region is exposed to outside air from a hole through the center of the device. Abundant oxygen in the exhaust indicates a lean fuel ratio, and an oxygen-deficient exhaust stream indicates the engine is running with excess fuel.

Electronic Module

Figure 3-9 presents a diagram of the manufacturing and assembly process associated with electronic modules. Four sub-assemblies will be defined: chip production, integrated circuit casing production, circuit board assembly, and housing production. Other components of the electronic module include transistors, resistors and capacitors which are not described here.

- Chip Production. The basic element used to construct a chip is silicon. This natural element is grown into long crystals which are ground and cut into small "wafers" approximately 3-4 inches in diameter and half a millimeter thick. Next, a process called photolithography is used to put a complex pattern on the wafer. The wafer, with the pattern, is then broken into hundreds of square pieces, less than a quarter inch on each side. These pieces are called chips. They form the basis of the integrated circuit.

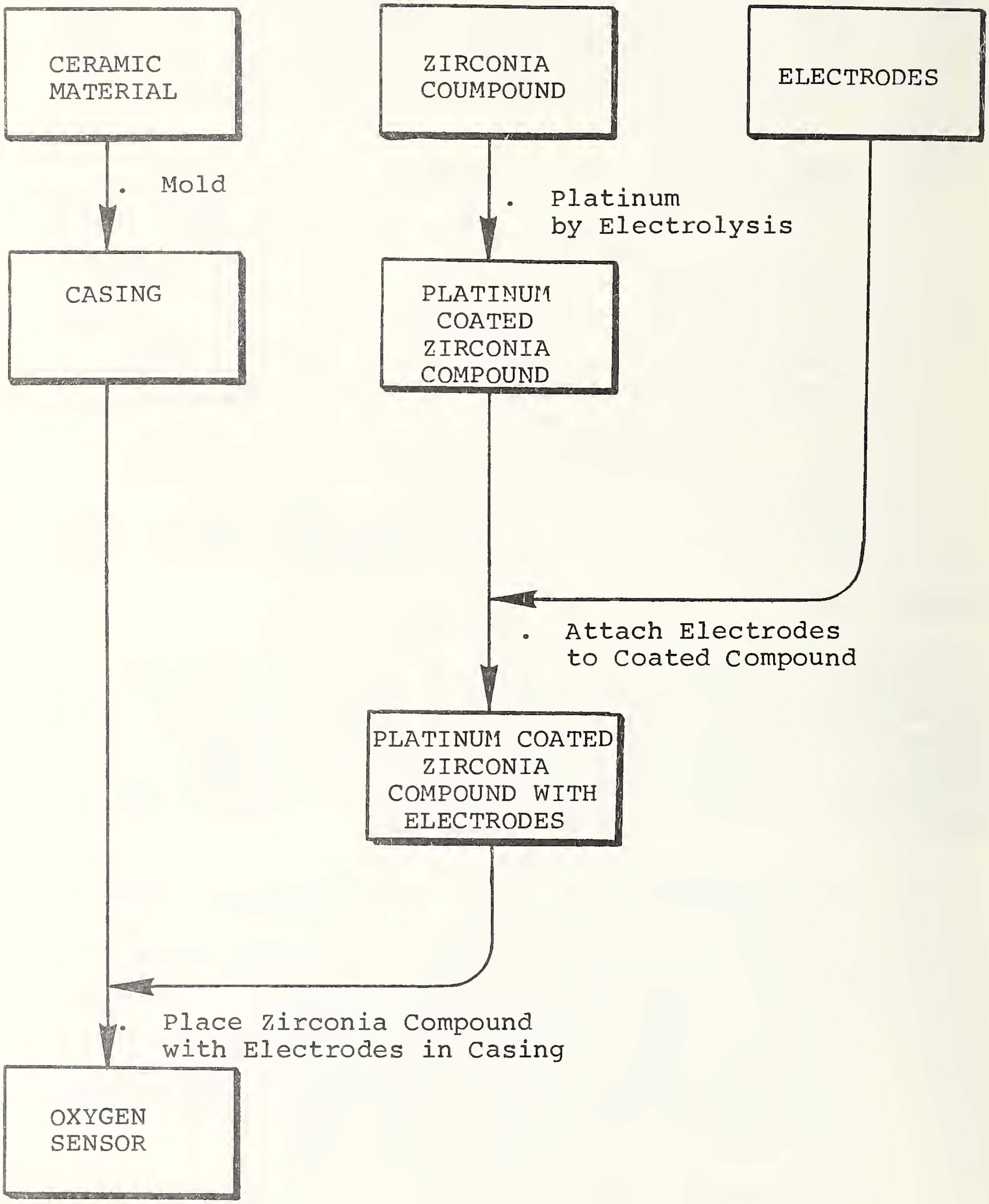


FIGURE 3-8. ASSEMBLY PROCESS FOR THE OXYGEN SENSOR

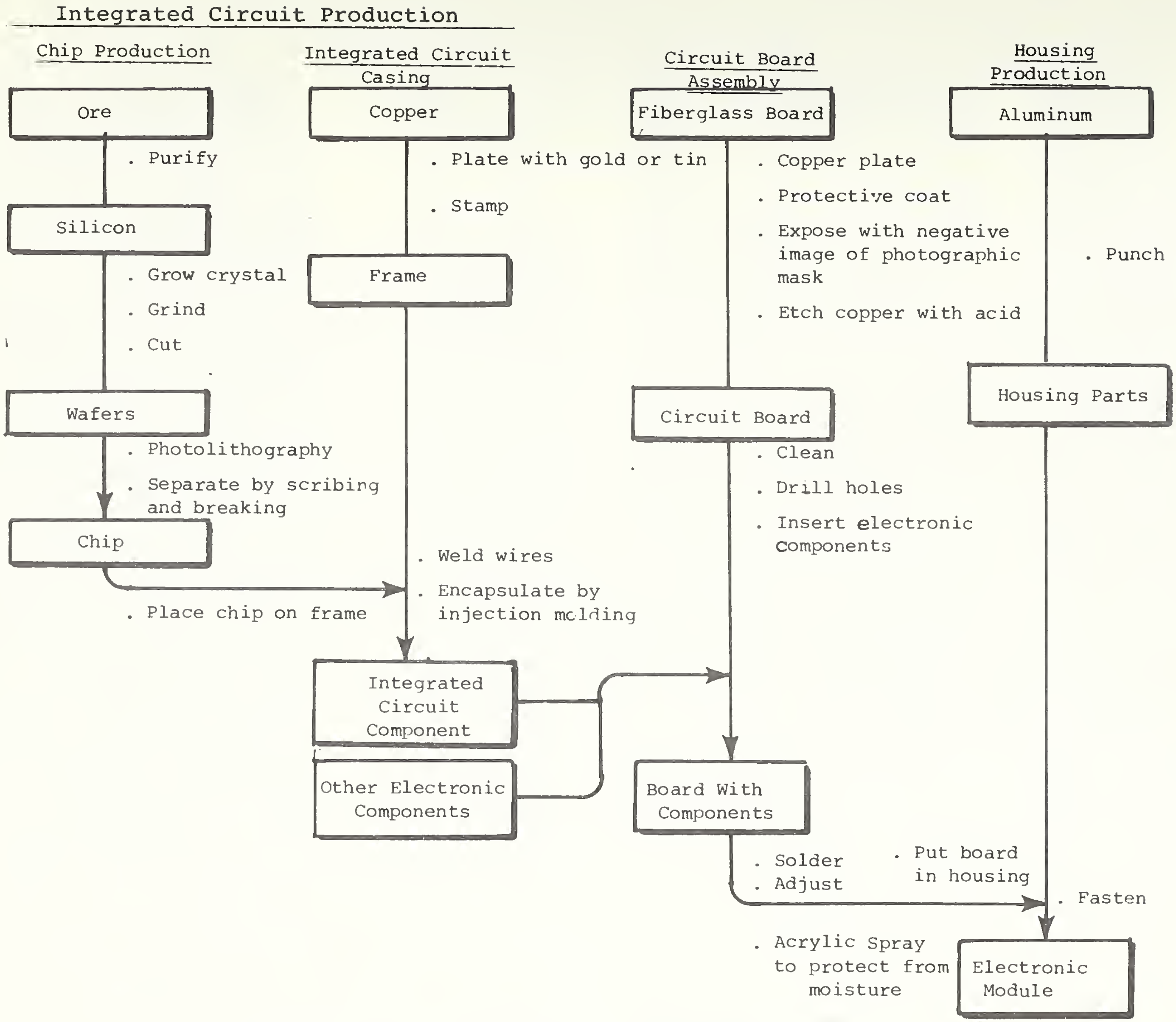


FIGURE 3-9. ELECTRONIC MODULE ASSEMBLY

- Integrated Circuit Casing Production. The integrated circuit casing assembly starts with gold or tin plated copper which is stamped into a frame. A chip is placed on the frame and connection wires are ultrasonically welded on. Finally the assembly is encapsulated by plastic injection molding. The casing is now ready for placement, along with the transistors, resistors and capacitors on the circuit board.

- Circuit Board Assembly. As shown in Figure 3-7, circuit board manufacture starts out with a fiberglass board which is coated with copper on one side. An acid then etches out the unwanted copper, leaving a pattern of electronic connection on the board. The board is cleaned, holes are drilled, and the electronic components are inserted. Solder is used to attach the electronic components to the board both physically and electrically. The board is then tested and final adjustments are made to the electronic components using computer technology. Finally, the board is sprayed with an acrylic to protect it from moisture in the automobile environment.

- Housing Production. The final step in the manufacturing of electronic modules is the production of the housing. The housing is punched out of aluminum, and the circuit board which was manufactured previously is attached to the housing using hardware fasteners.

Actuators

As described in the previous subsection, actuators are simple mechanical or hydraulic devices composed mostly of metal parts. There are two basic methods used to provide electronic actuation. The first is through electronic vacuum regulation and the second is through the use of electronic stepping motors. Both systems utilize a coil placed around a rod connected to a spring. These are placed in a steel housing. The electronic vacuum regulation utilizes electronic signals from the control module to actuate a rod which changes pressure in the attached vacuum lines. The stepping motor utilizes a rod to move a control directly according to instructions from the electronic module. Both systems of actuation present no new manufacturing or material problems and use the basic manufacturing processes described in the previous chapter, i.e., stamping, forming, casting, etc.

3.3.3 Size and Structure of the Industry

In 1978, the total automotive electronics market was approximately 282 million dollars. Of this amount, emission control systems accounted for 102 million dollars, electronic ignition for 115 million dollars, and fuel injection systems for 23 million dollars. Estimates are that the 1982 automotive electronics market will be over 1 billion dollars.

The largest suppliers of integrated circuits to the auto industry include Motorola, Intel, Texas Instruments, RCA, Fairchild, National Semiconductor and Sprague. There are also a host of smaller electronics companies, bringing the total number of electronics suppliers to date to more than 40. Motorola, which was recently awarded large contracts for the development of electronic modules for both GM and Ford, will clearly be one of the major electronic component suppliers for the 80's.

3.3.4 Key Issues

The major issues presently facing the electronics industry are:

- The ability of the semiconductor industry to meet the increased demand for microcomputer chips
- The availability of low-cost, reliable electronic sensors.

Each is described below.

Capacity of the Semiconductor Industry

As engine controls are coming into more widespread use, it is estimated that the auto industry will require 100 million microcomputer-type chips and 4-5 million, 3-inch silicon wafers by the early 1980's. This means that the semiconductor industry operating at peak capacity will need 10 new fabrication plants to meet this demand. If such demands cannot be met, the United States semiconductor industry will be faced with significant design, production and delivery troubles in the 80's.

Reliability and Cost of Electronic Sensors

While a variety of sensors are now available, many of them were developed and produced for high-performance aerospace and industrial applications at premium costs.. The electronics industry now faces the challenge of developing inexpensive sensors that still have the sensitivity and reliability that are required for use in automotive applications. The current lack of accurate and low-cost sensors is causing a serious problem in the development of efficient automotive energy management and control systems.

At the present time, the oxygen sensor is the most significant sensor with reliability problems. Since this device is placed in the automobile exhaust system, it is subject to considerable chemical contamination. Because of this, oxygen sensors now in use have only been guaranteed to 15,000 miles, although the electronics industry hopes to manufacture oxygen sensors that will last throughout the 50,000 mile test period.

The sensor field is still in a developmental stage, and potential solutions to the low-cost reliability problems are evident. One potential solution is likely to come through close interaction between automotive and semiconductor designers. The semiconductor industry for example has suggested to some electronics manufacturers that low-cost, reliable sensors can be developed from semiconductor technology with greater reliability pointing to the progress which has already been made in improving the reliability of pressure (piezoresistive strain gauge) and temperature (spreading resistance) sensors.

3.4 TURBOCHARGERS

Turbocharging like supercharging is used to increase the power of engines. Turbocharging, however, accomplishes this goal without many of the disadvantages of supercharging such as changes in the hood to accommodate supercharging and driving the supercharger at high rpm under most road conditions, thereby wasting fuel. Although turbochargers have found their most popular application among farm equipment and machinery such as forklifts, their use in small displacement and diesel engines is increasing.

3.4.1 The Turbocharging Principle

A turbocharger basically is a unit containing a turbine, a compressor and air ducts which use exhaust gas to increase the engine power output. The increased engine power results from the turbine and compressor forcing a greater and more compacted amount of air and fuel into the cylinders. Thus, with each stroke of the piston, a large amount of air/fuel mixture is compressed, exploded and translated into torque. Figure 3-10 illustrates the connection of a turbocharger in a gasoline engine.

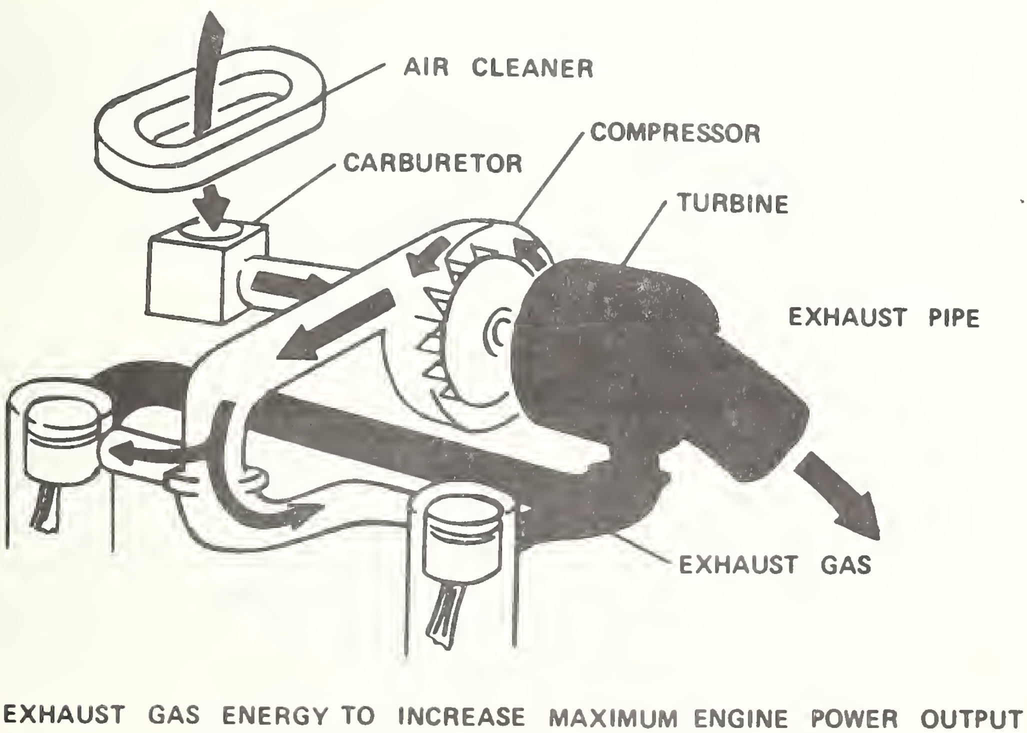


FIGURE 3-10. TURBOCHARGER CONNECTION

3.4.2 Manufacturing Processes

There are four subgroups in the assembly of turbochargers. These are the housing, compressor wheel, impeller blades, and the shaft. The manufacturing steps are shown in Figure 3-11 and are described below.

- Shaft. The shaft is made from two pieces of extruded steel which are inertia welded together.

- Impeller Blades. The impeller blades are made from high temperature nickel alloy. This material is necessary due to the high temperature exhaust gases that contact the impeller. The blades are made by a process called investment casting which uses wax and sand.

- Compressor Wheel. The compressor wheel is made from aluminum. The blades are cast and then ground, cleaned and machined.

- Housing. The turbocharger housing is made from cast iron or aluminum.

After the impeller blades are made they are sandblasted, cleaned and machined. The blades are then pressed into the shaft and inertia welded into place. The compressor blades are next press fit into the shaft. The shaft row with the compressor and impeller is threaded and then balanced using a stroboscopic light system. Finally, the shaft is placed into the housing and the housing parts are fastened together.

3.4.3 Size and Structure of the Industry

In 1978, turbochargers were introduced on American cars by Buick on its 3.8-litre, V-6 engine. During that year, total sale of Buick automobiles equipped with turbochargers was approximately 38,646. Garrett Air Research of Los Angeles was the only manufacturer of automobile turbochargers on a production basis. Garrett also supplied turbochargers for Mercedes and Saab, who sold about 6,400 turbocharged vehicles in the United States. The estimated dollar value of turbocharger sales for automobiles in the U.S. in 1978 is approximately 4.6 million dollars.

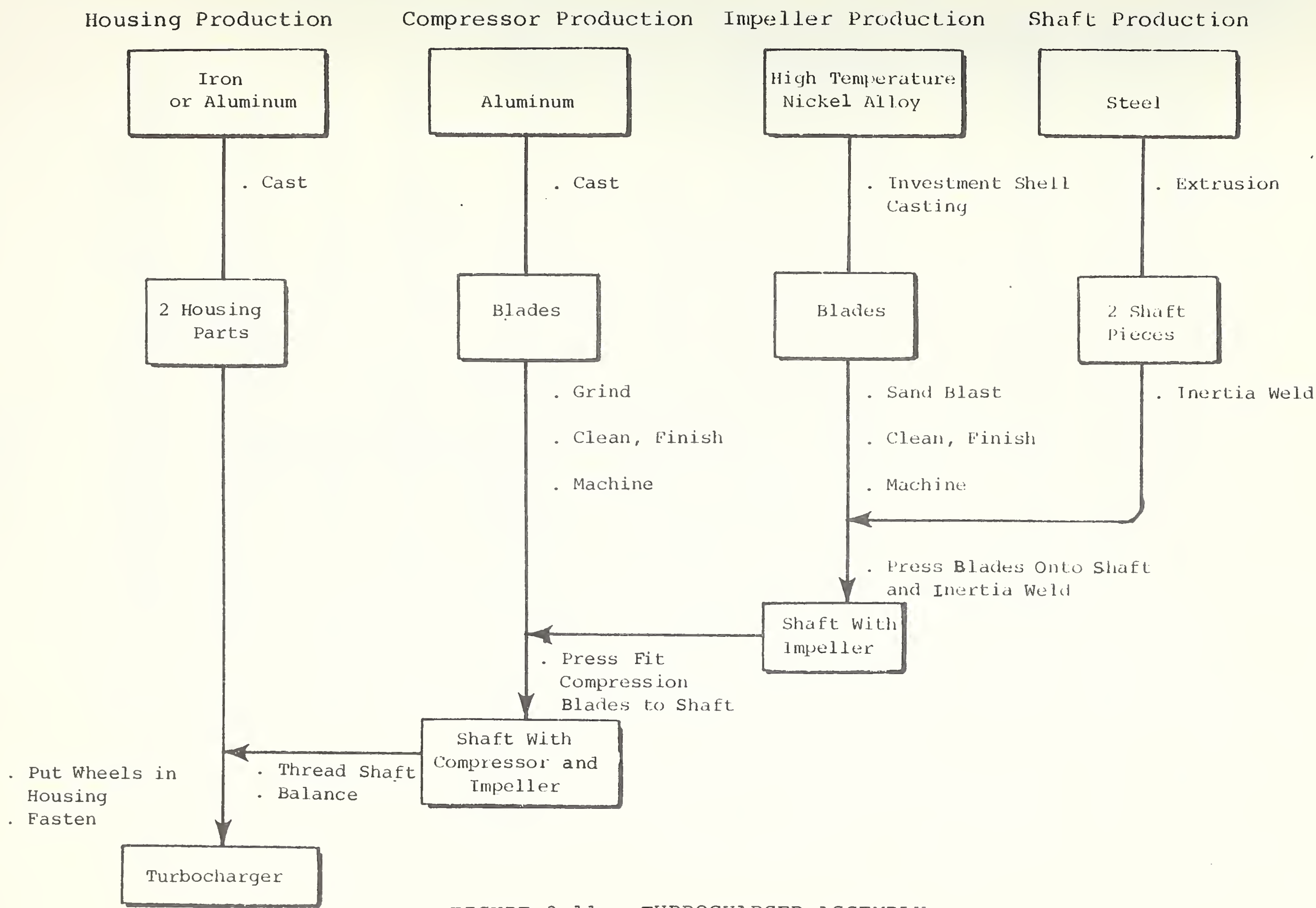


FIGURE 3-11. TURBOCHARGER ASSEMBLY

3.4.4 <u>Key Issues</u>

Two issues associated with the use of turbochargers are:

- Whether the cost of the unit is offset by the benefits of the supercharging

- The special design requirements for use of turbochargers with gasoline engines.

Each is described below.

Costs Versus Benefits of Turbocharging

In general, a turbocharged diesel engine will deliver, at the same performance level, greater fuel efficiency than a nonturbocharged engine. However, turbocharging involves a higher initial engine purchase price and possible higher long term maintenance expenses. The turbocharger essentially makes the engine work harder by processing more combustion air than normal. This causes greater wear and tear on individual engine components with earlier engine breakdowns and overhauls common among turbocharged vehicles. Thus, the basic concern is the increased maintenance costs of the turbocharged engine versus the improved performance.

Special Design Requirements for Turbocharging Gasoline Engines

Although turbochargers have been most commonly applied to diesel and aircraft gasoline engines, they may also be used with automotive gasoline engines with some modifications. Since the supercharged engine has to work harder, the following modifications are recommended:

- Engine bearings must be sized to withstand more heat and higher pressures than for an equivalent naturally aspirated engine.

- Individual components such as connecting rods have to be stronger.

- The carburetor and manifold should be designed to accommodate the increased airflows resulting from the pressurization of the air or air fuel mixtures.

Unless these and other modifications are made to a gasoline engine, use of a turbocharger will not be effective.

3.5 ELECTRONIC FUEL INJECTION

The concept of injecting fuel directly into the combustion chamber of an engine under high pressure is not new. It has been viable almost since the origin of the engine and in fact, mechanical fuel injection (MFI) systems have been, and still are, routinely applied to performance engines.

On the other hand, electronic fuel injection (EFI) systems are still in their infancy in terms of actual vehicle usage, even though EFI offers potential fuel economy, emissions and performance benefits. The reasons are very simple—cost and until recently, technology has stunted the growth (i.e., usage in vehicles) of EFI.

EFI is more than just the fuel injector, however. It is an assembly of sensors, actuators and an electronic control module, all of which are still in their infancy (i.e., a limited number of production cars presently have these devices) and are very expensive. Furthermore, fuel injector (see Figure 3-12) is a very precise mechanical assembly which requires precision machine tools. Until recently, these tools were not widely available.

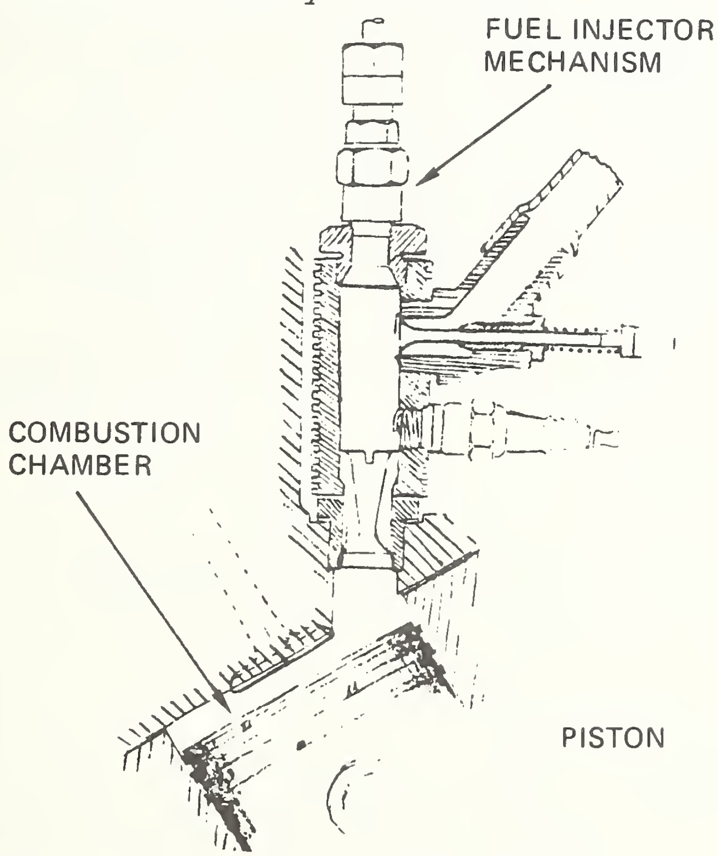


FIGURE 3-12. ILLUSTRATION OF FUEL INJECTOR

3.5.1 Basic Operation of Electronic Fuel Injection Systems

As described above, the basic function of EFI is to provide the engine cylinders precise quantities of fuel in the correct proportion with air to achieve the desired vehicle performance, the legal emissions levels, good fuel economy and pleasing driveability. This is accomplished by the fuel injector in combination with several other components including an electronic control unit pressure sensor, speed sensor, throttle position sensor and temperature sensor. The electronic control unit, using inputs from the sensors and a knowledge of engine physical and operating parameters, determines and directs the fuel injector to spray each cylinder with the exact quantity of fuel required for optimal performance, fuel economy and emissions.

An illustration of a typical EFI installation which shows the various components that comprise the EFI system is depicted in Figure 3-13.

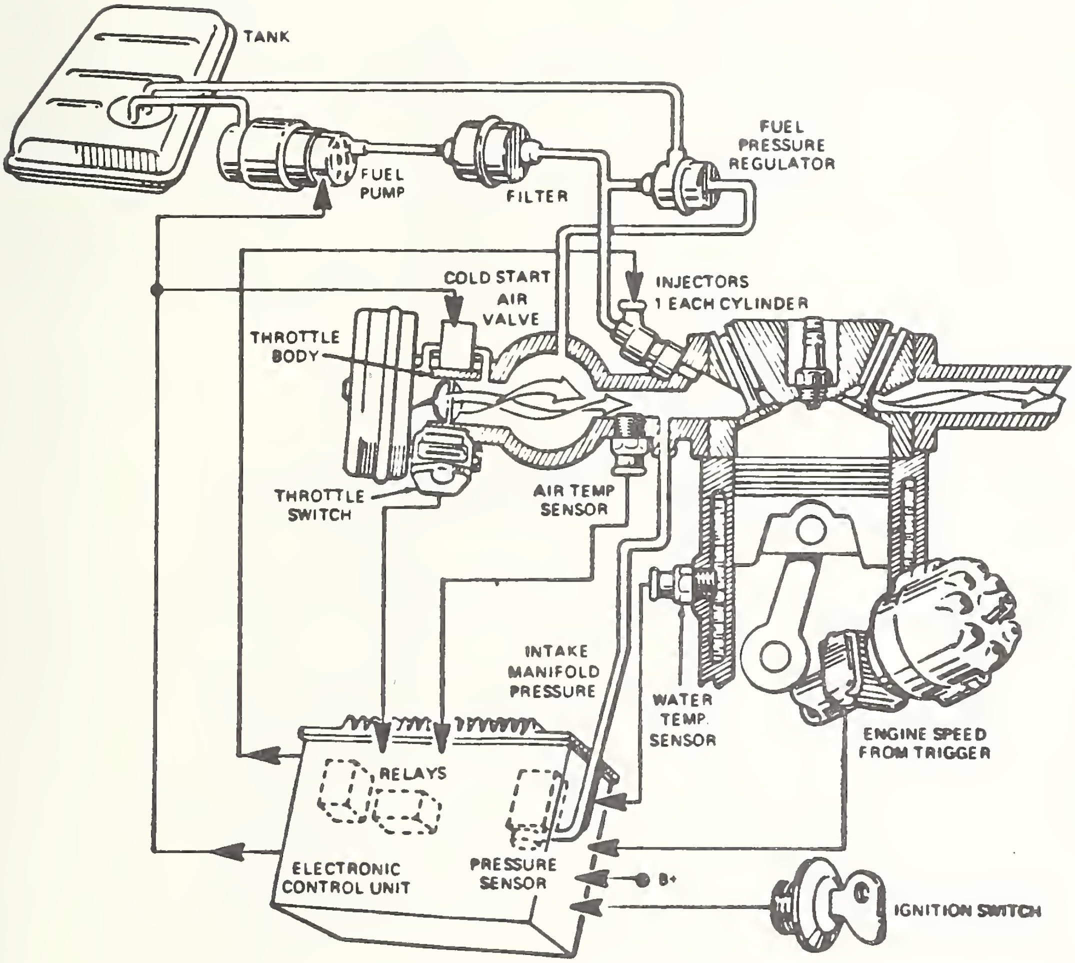
3.5.2 Manufacturing Processes

As shown in Figure 3-14, EFI includes many components found in other engine systems—filters, pumps, sensors, piping. The unique feature is the fuel injector. As described previously, the injector is a very precise mechanical assembly. In the General Motors systems, the EFI consists primarily of a solenoid together with 15 other components in a three and one-half inch long assembly. The key parts include the body, housing, electrical connector, orifice, needle and solenoid. These parts in general are:

- Made from steel tubing or steel rods—usually a high temperature, high tensile, machineable steel must be used.

- Machined to very precise tolerances

- Produced at a slow rate—many quality control checks/tests are required since repair is not possible once the parts are installed.



Source: Bendix, Inc.

FIGURE 3-13. TYPICAL EFI SYSTEM INSTALLATION

3.5.3 Size and Structure of the Industry

In 1978, electronic fuel injection was offered as standard on the Cadillac Seville. Total sales of cars with fuel injection for the year was 56,985. The Seville used a fuel injection system designed by Bendix with principal components supplied by Bendix, Bosch, and GM.

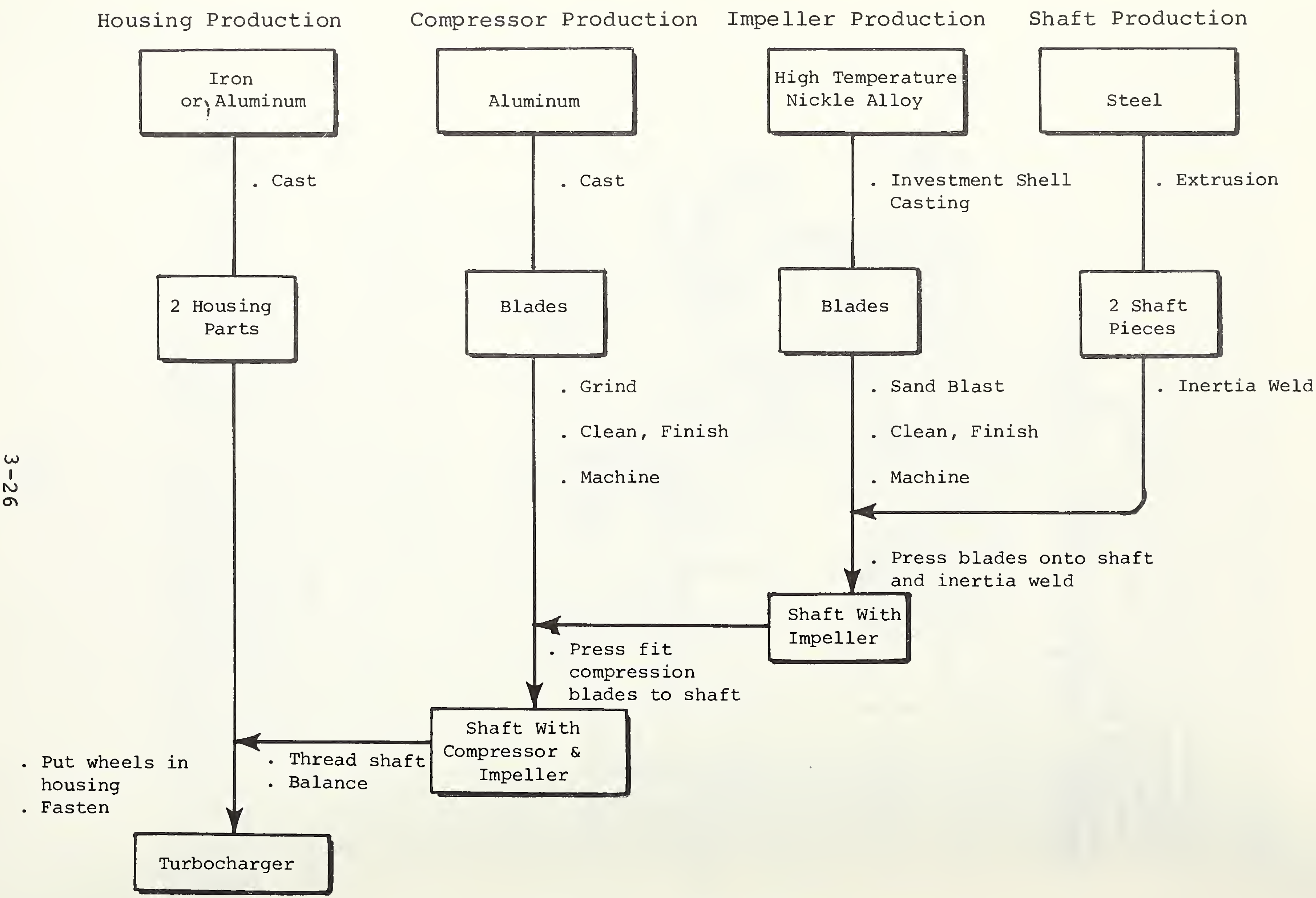


FIGURE 3-14. TURBOCHARGER ASSEMBLY

3.5.4 Key Issues

The primary issue facing the manufacturers of EFI systems is cost. Today's EFI systems are several times more expensive than carburetors. Thus, since the auto industry is very sensitive to cost, this type of cost differential at present can only be tolerated in luxury cars where the customer is willing to pay for superior performance or driveability or in performance vehicles were acceleration and power are valued by the customer. While it is likely that some increased cost will become more tolerable in the future as emissions and fuel economy standards become more stringent, the pace at which EFI enters the marketplace will still be a function of cost.

Some technical problems of fuel injection systems include:

- Lubricants in Engine Fuel. Pump gasoline for four-cycle engines does not lend itself well to high pressure injection because of its lack of lubricity compared to diesel fuels. Diesel fuel is inherently more "oily" so that some lubrication during the actual injection process is possible.

- Fuel Pump. A special high pressure pump is necessary to generate sufficient pressure to force the fuel through the nozzles and into the cylinder at the top of the compression stroke.

- Timing. A precise timing system is necessary to inject the fuel into the cylinder at the correct time in the engine cycle. This exact timing is a process that is rather complicated in that the fuel must be metered and distributed under very high pressure. The process is further complicated in multicylinder engines.

3.6 ELECTRONIC IGNITION

Electronic ignition uses a breakerless distributor with non-contacting components to send electronic pulses to the spark plugs, instead of the distributor with contact points found in conventional ignition systems. The rest of the electronic ignition is the same as on conventional systems and thus requires no change in manufacturing or materials.

Electronic ignition provides more precise firing control and results in longer spark plug life and improved driveability and fuel mileage than conventional ignition systems. Figure 3-15 contrasts the conventional and electronic ignition systems.

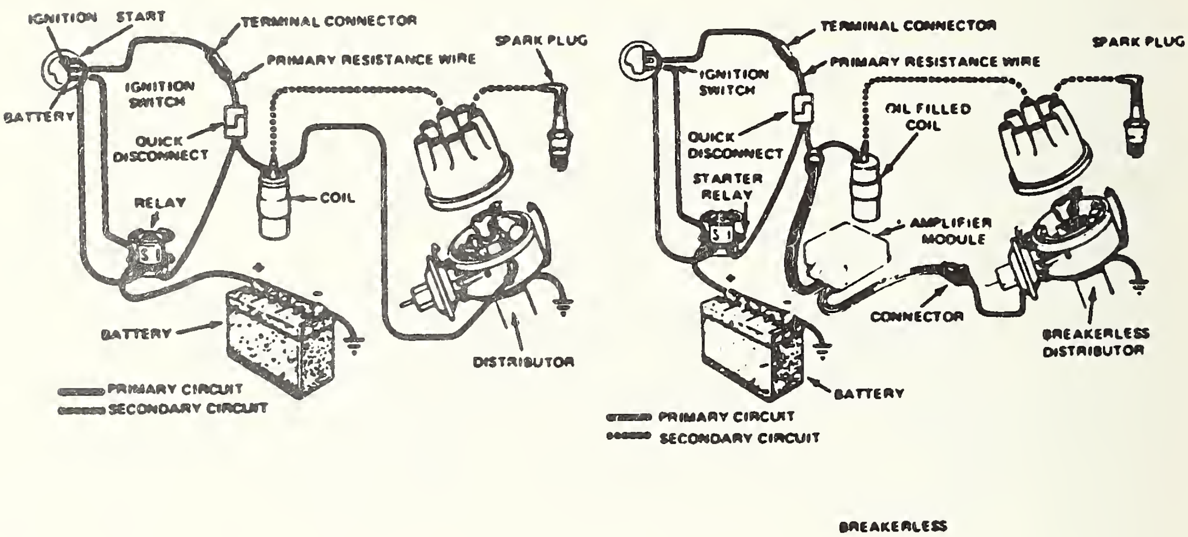


FIGURE 3-15. CONVENTIONAL AND ELECTRONIC IGNITION

3.6.1 Manufacturing Processes

The manufacturing processes and assembly involved in the electronic ignition distributor are virtually unchanged from those in the conventional distributor. The key common processes include blanking, stamping, and forming a weight-carrying plate, welding this to a steel shaft, adding a triggering shaft made from tubular steel, adding a molded plastic rotor, and placing the assembly in a casting housing.

In conventional ignition, a triggering mechanism and points are added. Electronic ignition replaces these with a trigger wheel and a sensor which is able to detect the wheel's motion. Also, with electronic ignition an amplifier is required to receive the signal from the sensor and trigger a much larger voltage to produce the spark. This amplifier is a small electronic circuit similar to, but less sophisticated than, the electronic control modules discussed earlier. The high temperatures inside the distributor put great demands on the design of the electronic circuit.

The sensor mechanism in the distributor typically consists of wire wound on a molded plastic bobbin and mounted next to a piece of riveted ferrite material.

3.6.2 Size and Structure of the Industry

As described in the section on electronic engine contorls, in 1978 the total automotive electronics market was approximately 282 million dollars. Of this amount the sale of electronic ignition systems accounted for approximately 41 percent or 115 million dollars. Estimates are that the 1982 automotive electronics market will be over one billion dollars. Thus, conservatively the sale of electronic ignition systems should total at least 410 million dollars.

Major suppliers include Motorola, Intel, Texas Instruments, RCA, Fairchild, National Semiconductor and Sprague.

4. PASSIVE RESTRAINT SYSTEMS

4.1 GENERAL

Recent Federal motor vehicle safety standards have been emphasizing occupant crash protection. The U.S. Department of Transportation has mandated that passive restraints on full-size passenger cars must be phased-in beginning with the 1982 model year. Intermediate and compact cars will have to be equipped with passive restraint systems by the 1983 model year. By 1984, all passenger cars will be required to have automatic protection systems.

This requirement for automatic protection systems in the cars of the future has major ramifications for automotive manufacturers. Introduction of these systems involves the design, production and assembly of entirely new components, as well as provision of warranties, service and parts.

Passive belt systems and air bag systems constitute the two main types of technology for automatically deployed occupant restraints. This chapter discusses both these systems, as follows:

- The major components of the system
- The processes used to manufacture the system
- The size and structure of the industry which manufactures the system
- The key issues presently facing this industry.

4.2 AIR BAG SYSTEMS

An air bag is a device which inflates automatically in head-on accidents to cushion the front-seat auto passengers from injury. When a car is involved in a frontal crash, the impact causes a sensor to activate a gas generator. This generator then inflates the air bag which protects the passenger. Thus, upon impact the vehicle occupant moves forward into the bag, while the lower body is restrained by a combination of air bag and knee restraint. Figure 4-1 shows an air bag restraint system fully deployed.

4.2.1 Major Components of Air Bag Systems

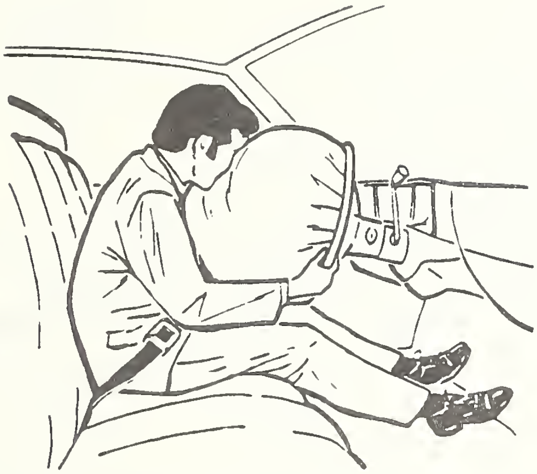
Although variations exist in propellant charge and air bag configurations among different manufacturers' designs, there are essentially only two types of air bags:

- Driver position air bag
- Passenger position air bag.

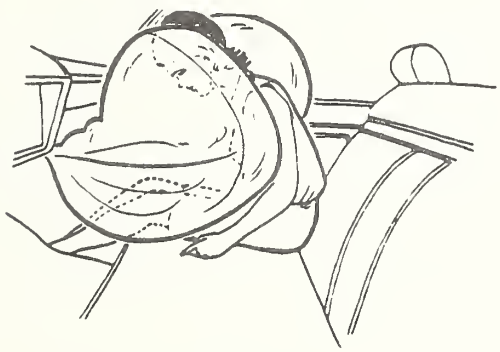
The driver's bag must be deployed from the steering wheel, while the passenger's bag is contained in the instrument panel.

The two designs are similar in major components. As shown in Figure 4-2, the air cushion restraint system, or air bag system, is composed of the following parts:

- Cushion and Inflator Assembly. This assembly consists of the air bag, gas generator (inflator), bag/generator housing, and trim cover. This assembly is the major subassembly of the overall air bag system since it contains the lifesaving device. Separate assemblies are required for the driver and passenger sides. The driver side assembly is contained in the hub of the steering wheel. The passenger side assembly is hidden in the right side of the dashboard.



DRIVER SIDE
(Air bag in Steering Wheel—
Steering Column Absorbs Energy)



PASSENGER SIDE
(Torso and Knee Air Bags
Absorb Energy)

FIGURE 4-1. AIR BAG PASSIVE
RESTRAINT SYSTEM

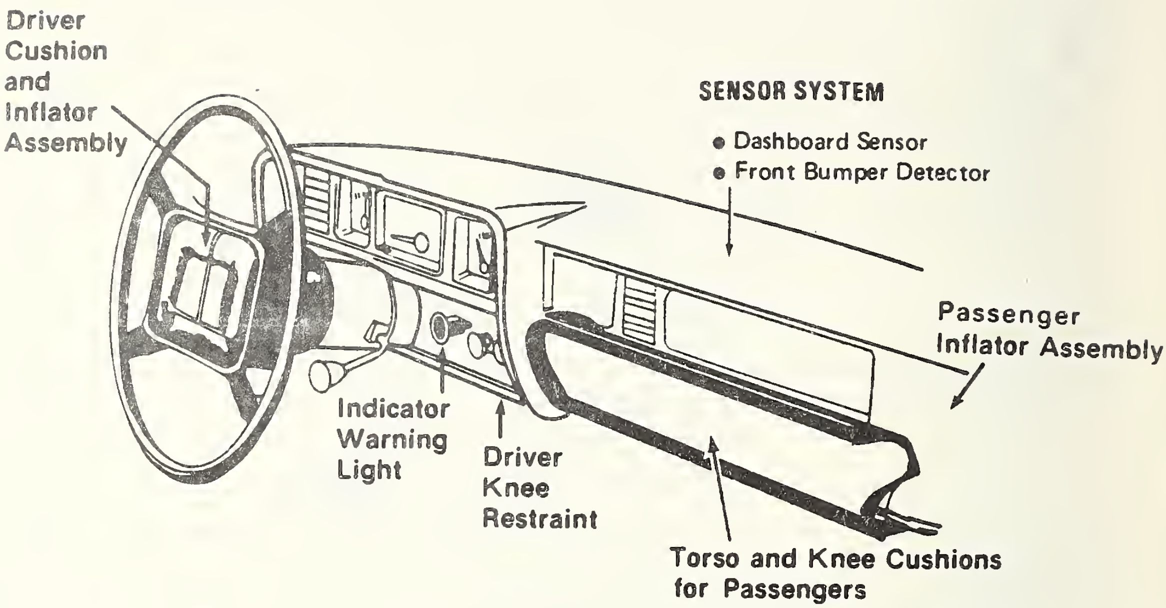


FIGURE 4-2. MAJOR SUBASSEMBLIES/COMPONENTS OF AN AIR BAG SYSTEM

- Sensor System. The sensor system is used to actuate the air bag system. It is designed to detect severe impacts rapidly and to provide the necessary triggering signals to deploy the bags. The sensor system usually consists of two sensors—a dashboard sensor and a front bumper detector. Both are used to detect severe impacts and the deployment criteria of both must be satisfied for the bags to deploy.

- Readiness Monitor and Indicator Assembly. The readiness monitor and indicator assembly provides a diagnostic check of the electronic integrity of the air bag. This assembly is extremely important due to the length of time which may elapse before the system is required to function.

Driver and passenger knee restraints can also be included with air bags for added occupant protection. On the passenger's side this knee restraint is typically part of the cushion and inflator assembly. On the driver's side, it is a separate interior trim item.

4.2.2 Overview of Manufacturing Processes for Air Bags

Air bag systems are made using traditional manufacturing techniques. At the present time, no specialized or sophisticated machinery is required, although special automated equipment may be needed in the future as increased volumes of air bags are required. The current low volumes of air bags are produced with inexpensive machinery in a labor intensive fashion.

Each major component of the air bag system is manufactured at a separate plant. The manufacture of the air bag system can be discussed in terms of several separate processes. These include the manufacture of the cushion and inflator assembly, the electronic sensors, the readiness monitor, and the knee restraints. Each of these is discussed below.

The manufacture of the cushion and inflator assembly can be discussed in terms of the gas generator cartridge, the inflator assembly, and the air bag. An overview of this process is presented in Figure 4-3.

- Manufacture of the Gas Generator. The basic process for manufacturing the gas generator involves combining two chemicals with the appropriate supporting structures to form a propellant cartridge. The techniques used include grinding, sifting, weighing and blending of the chemicals into pressed pellets which are then packed into the cartridge. The cartridge itself is formed from sheet metal stock using blanking, stamping, welding and deburring processes.

- Manufacture of the the Inflator Assembly. The inflator assembly forms a sealed housing for the propellant, a diffuser for gases generated and an attachment point for the bags. The basic processes involved in the manufacture of the inflator assembly include weaving steel wire into screens, cutting and inserting filter materials into the housing, and cutting, deburring, and finishing steel tubing to form the propellant housing. Once all of this is inserted into the cartridge, further processes involve sealing and crimping the ends on a press, inserting the initiator squib, and sealing the inflator assembly.

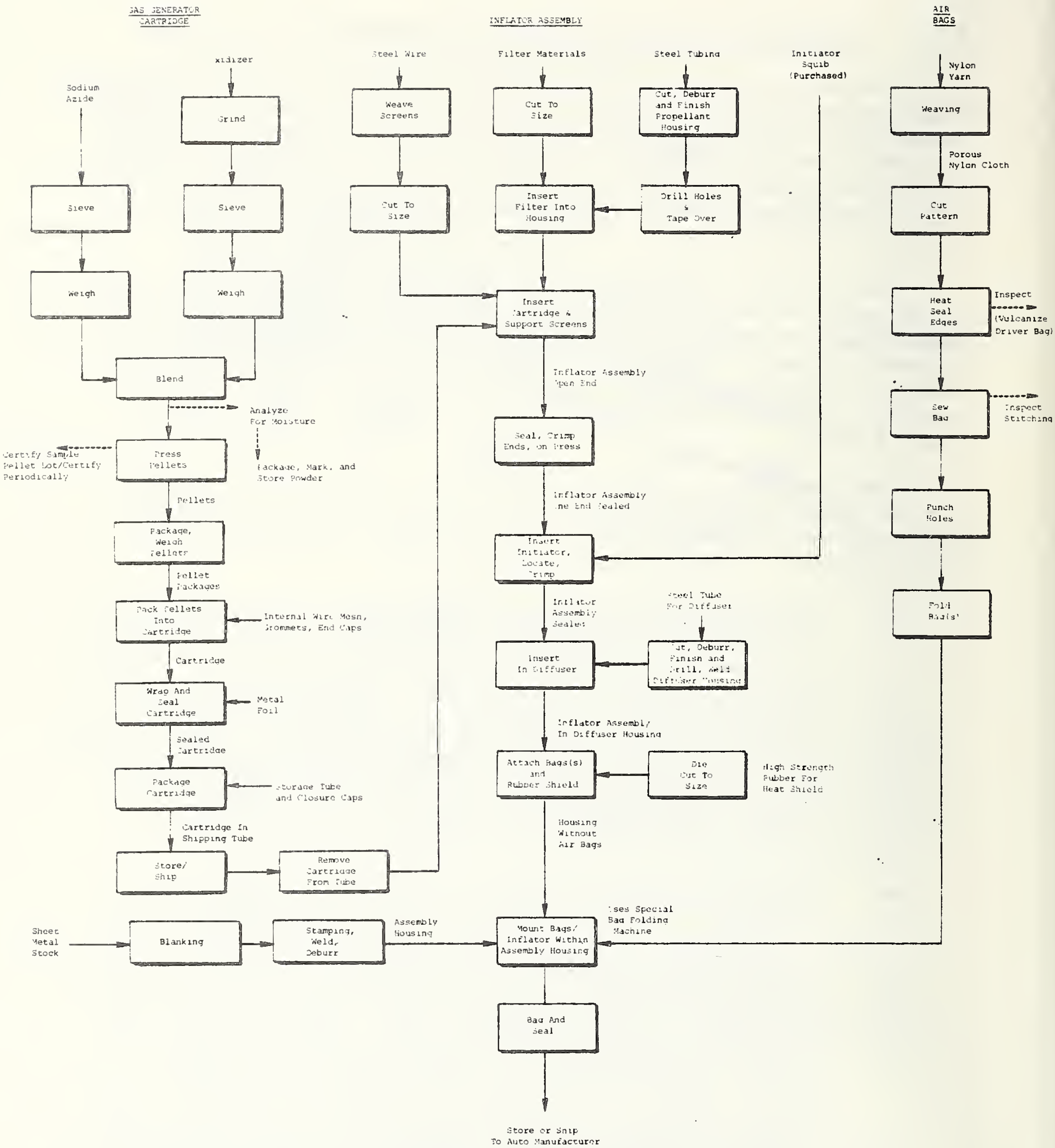


FIGURE 4-3. OVERVIEW OF THE PROCESSES INVOLVED IN THE MANUFACTURE OF THE CUSHION AND INFLATOR ASSEMBLY* (PASSENGER SIDE)

* At this time no plant exists for the volume production of cushion and inflator assemblies. Therefore, this diagram represents a description of the processes that are likely to be employed during the next few years when air bag systems begin to be produced in quantity.

- <u>Manufacture of the Air Bag</u>. Manufacture of the air bags involves processes somewhat unique to automotive applications. These include weaving nylon yarn, cutting patterns, and heat sealing edges, in addition to the sewing, punching and folding operations.

- <u>Manufacture of the Sensor System</u>. Manufacture of the electronic sensors involves the basic manufacturing processes of stamping/forming, casting, extruding, and/or joining/assembly. Depending on the type of sensor, the processes of electroplating, electromagnetizing, and cutting may also be used. The only special manufacturing area would be the mounting brackets for the sensor, which would be tailored to specific vehicle applications. An overview of this process for dashboard sensors is presented in Figure 4-4.

- <u>Manufacture of the Readiness Monitor and Indicator Assembly</u>. The readiness monitor and indicator assembly consists of a plastic housing (lens/flange), bulb, receptacle, and cable. Except for the bulb, all parts are made from injection molded plastic. The bulbs are mass-produced in great volume from thin gauge tin and molten glass in highly specialized machinery.

- <u>Manufacture of Driver Knee Restraints</u>. The manufacture of the driver knee restraints involves the injection molding of plastic on traditional machinery.

Installation of the cushion and inflator assembly, sensor system, readiness monitor, and knee restraints are performed at the automobile manufacturer's assembly plants. The integration of the major components into the final installed vehicle system is displayed in Figure 4-5. There are typically three separate portions of the system that would be purchased from the following suppliers by the automobile manufacturer:

- Cushion and inflator assembly supplier
- Specialist sensor (decelerometer) supplier
- Readiness monitor vendor.

The vehicle manufacturer in performing final integration and installation must provide the trim cover, wiring, fasteners and some electronics in most cases.

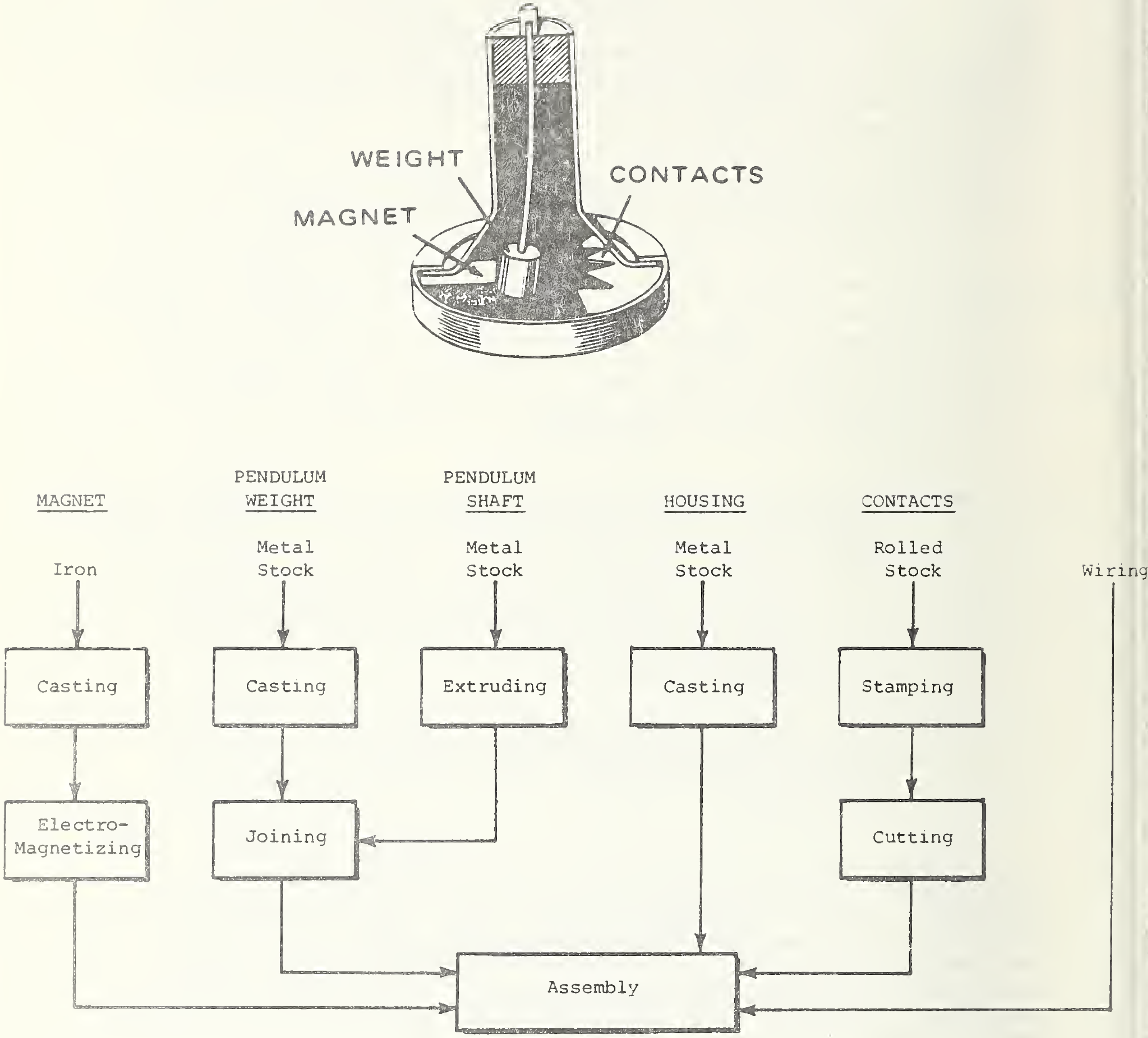


FIGURE 4-4. MANUFACTURING PROCESS
FOR DASHBOARD SENSOR

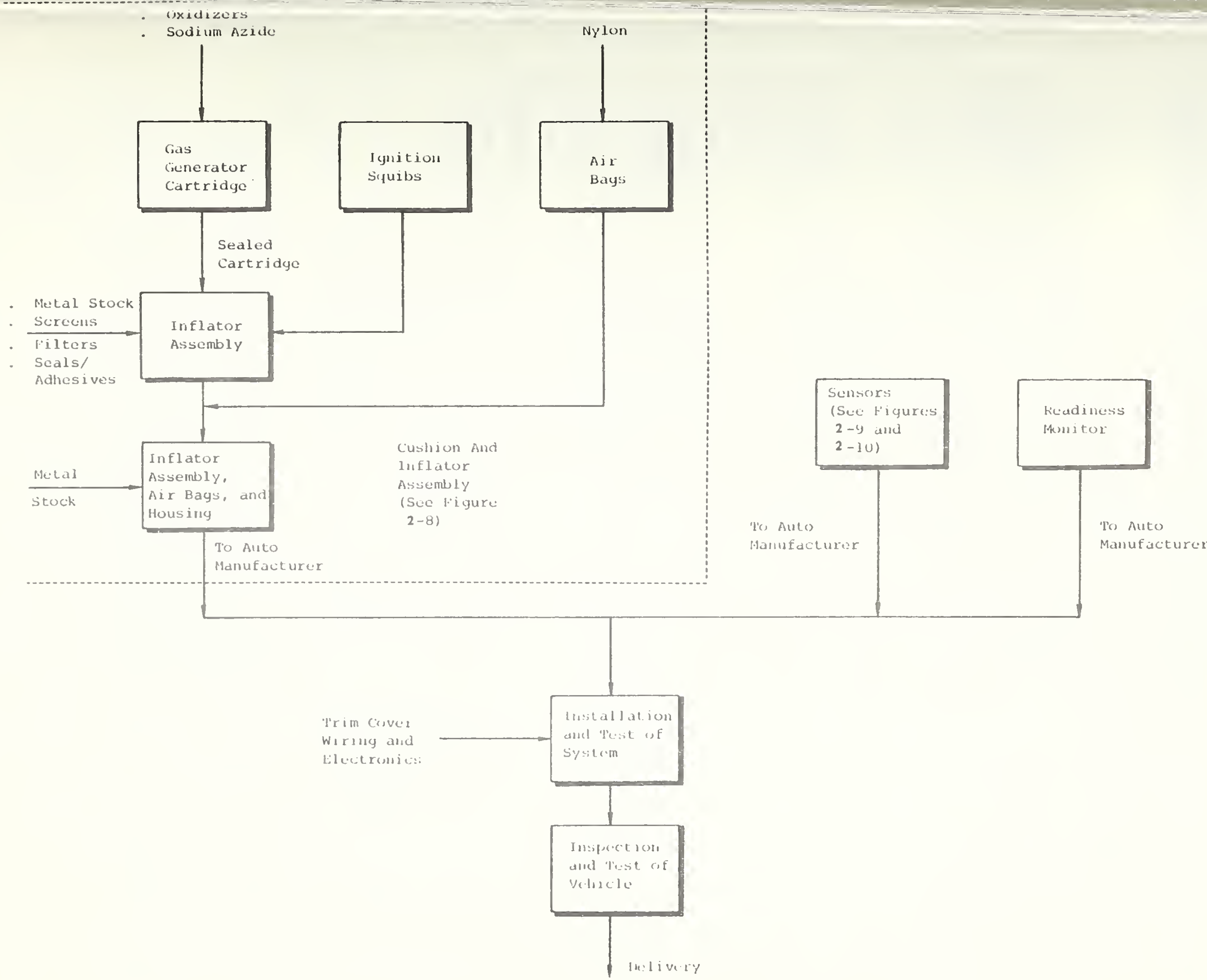


FIGURE 4-5. PROCESS FOR OVERALL MANUFACTURE AND INTEGRATION OF AIR BAG SYSTEM IN A VEHICLE

Several changes in interior vehicle design would also be required to accomodate the introduction of air bag systems. Additional engineering and manufacturing changeovers would be necessary considerations.

4.2.3 Size and Structure of the Industry

Almost every component of the air bag system is new to the automobile. The suppliers have developed designs and indicated their willingness to produce air bags, but have not committed funds to develop the necessary production capability. The air bag manufacturing industry is small at this time primarily because of the amount of investment needed and the uncertainty surrounding the potential market.

The capital investment required for a plant to manufacture air cushion restraint systems is estimated at $10 million. Rather than investing in advanced technology production equipment, the current industries are more labor intensive.

Several factors are essential in estimating the potential size of the air bag industry. For example, styling, comfort, performance, cost, and public acceptance must all be considered. Based on discussions with a major auto supplier of inflator modules, it is estimated that by 1984, 1.5 million vehicles will need air bag systems to meet the Federal mandate.

To meet the demand for air bags, two supplier industries are critical—the materials suppliers and the component manufacturers. Figure 4-6 shows the anticipated principal suppliers for both materials and components. The materials used in the manufacture of air bags are all conventional materials, none of which are in short supply. The component manufacturers, however, need more assurance of the size of the market before they equip themselves with a production capability.

The air cushion and inflator assembly, the major air bag system component, will be manufactured by Hamill Manufacturing Company and Talley Industries. Hamill will make the passenger-side system and Talley will make the driver-side system. These companies will make the bag, the housing, and associated parts, and assemble them with the gas generator to form the cushion and inflator assembly.

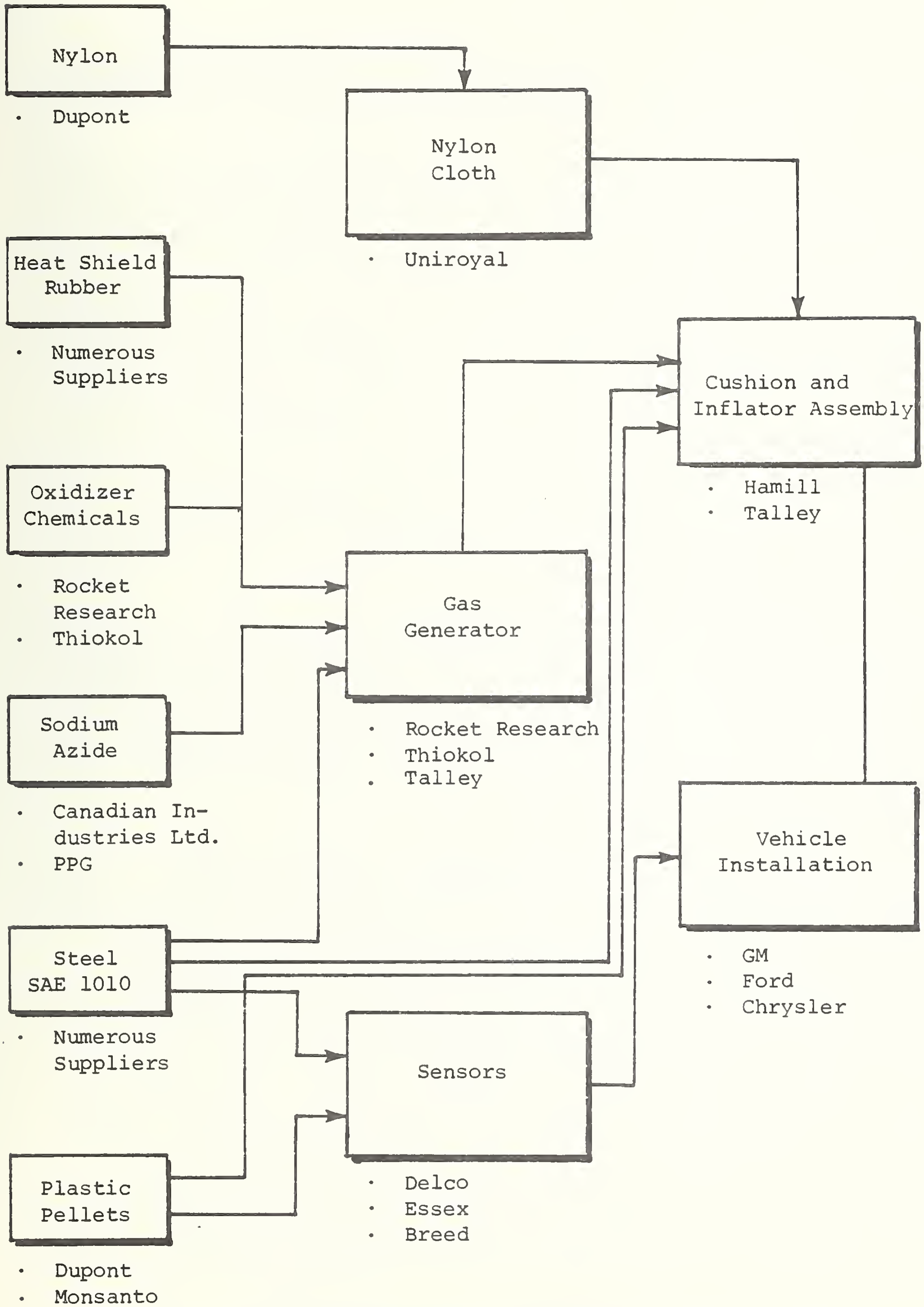


FIGURE 4-6 ANTICIPATED PRINCIPAL SUPPLIERS FOR AIR BAG MATERIALS AND COMPONENTS

The gas generator will probably be made by Thiokol Chemical Corporation and Rocket Research, Inc. The sodium azide propellant will be produced by Canadian Industries, Ltd., and PPG Industries, Inc.

Uniroyal will be the major supplier of the nylon cloth used for the air bags, and Dupont will supply the nylon yarn. The various other materials needed will be supplied by Monsanto, Dupont, Rocket Research, and Thiokol.

Eaton Corporation, one of the early innovators in air bag technology and a major supplier to Ford and Volvo, announced in 1977 that it was discontinuing the production of air bags. The firm made clear that the move was a business decision based on the amount of investment needed to continue as a supplier and on a survey of the potential market. Another firm, Controlled Laser, which previously marketed a driver-only, add-on air bag system, dropped production and sales on the grounds of product liability problems.

4.2.4 Key Issues

With passive restraint systems planned for introduction beginning in model year 1982, the auto manufacturers and their suppliers are moving toward fulfilling the FMVSS No. 208 mandate. General Motors, Ford, and Chrysler have publicly announced plans to voluntarily install air bags in at least one car line in the 1981 model year, one year ahead of the required date.

Although it appears that progress is being made toward full implementation of the standard, questions and concerns still remain. One concern is the capability of the supplier industry to meet the demands of the auto manufacturers within the timetable established. Other issues include such items as the effectiveness/reliability of air bag systems, the safety of the chemical sodium azide, public acceptance, cost, maintenance and product liability. Each of these issues is discussed below.

Capability of the Supplier Industry

While no difficulty is anticipated in supplying the materials needed to manufacture air bags, the troubling fact is that no air bag mass production facility is yet in place.*

* Plans are,however, underway to build such plants.

Since the available lead time before the manufacturer must begin full-scale production of air bags is waning, the absence of this capability is of some concern.

Market uncertainty both in terms of size and timing has caused much skepticism on the part of the suppliers. At present, investment in new plants and equipment is also restrained by product liability issues, lack of firm orders from the automobile manufacturers, and the relatively large business risk for a market that might be substantially delayed and/or smaller than predicted. High start-up costs associated with manufacturing a completely new product may also hinder the potential air bag manufacturers from supplying the market needs.

Effectiveness/Reliability

As air bags are designed to deploy only in frontal impacts, there is not any protection for side impacts, rear collisions, and rollovers. Another concern is that air bags are not currently crashworthy at speeds above 30 mph.

Critics of air bag systems are also concerned that the bags will not function as designed. That is, they will deploy inadvertently, or they will not deploy upon impact. Tests have shown the unlikelihood of this occurring. However, very strict quality control inspection and tests will be required by automobile manufacturers of the air bag system component suppliers.

Toxicity of Sodium Azide

The safety of the chemical sodium azide is a subject of controversy. Proponents of air bags argue that the chemical is stable in its pure form and converts to harmless nitrogen gas when ignited by a spark. Opponents point out that the chemical may cause gene mutations, premature aging, cancer, and birth defects. Information on the minimum safe level of exposure has not yet been developed. However, officials of the EPA and OSHA have determined that sodium azide, as used in the air bag inflators, does not appear to present a significant environmental or occupational hazard. Concerns still remain regarding the disposal of air bag systems when automobiles are ultimately scrapped.

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* U.S. DOT, NHTSA Occupant Protection Program Progress Report No. 2, April 1979.

Public Acceptance

Since it is the public who must ultimately buy the vehicles, acceptance of the air bag system as a viable alternative or complement to the seatbelt system is essential. Manufacturers must therefore select the passive restraint option with the least number of impacts as far as cost, styling and comfort are concerned.

It is likely that air bags would be used on the makes/models which had bench seats rather than bucket seats. This is logical since only air bags would restrain the middle occupant of the front seat.

Cost

The high costs associated with air bags are another major concern to both manufacturers and consumers. Air bags have been estimated at a price to the consumer between $131 (NHTSA) and $650 (GM).* Because of the higher cost associated with air bags, it is likely that the manufacturers will first introduce air bags on full-size cars where the percentage impact (i.e., increase) on cost is least. Air bags on intermediate and smaller size cars are expected to be offered as options.

Replacement costs to the consumer have been estimated to be as high as 2.5 times the initial sale price due to accessibility issues. Thus, air bags may pose a significant inflationary threat to auto damage claims and costs.**

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* Cost differences are due to design details, assumed production volumes, contractual arrangements with suppliers and other factors. These price estimates were presented in the following documents:

- (NHTSA): Occupant Protection Program Progress Report No. 2, April 1979
- (Allstate): Automotive Occupant Protective Safety Air Cushion Expenditure/Benefit Study for the Allstate Insurance Company by the John Z. Delorean Corporation.
- (DOT): Analysis of Cost, Leadtime and Production Capabilities for Implementation of Passive Restraint Systems in Automobiles

** As stated by Mr. James Wasylik, Director of Research for Vale Laboratory.

Maintenance

Maintenance and replacement of passive restraint systems is a serious problem facing the repair industry and a critical issue in the government's mandate for the systems. The greatest concern is whether or not a mechanic will be able to effectively replace the air bag system. At present, the location of the sensors and passenger air bag will not be easily accessible to the mechanic. In addition, so few cars will be equipped with air bags that mechanics will have little incentive to become skilled in this repair.

The principal maintenance problem associated with the air bag is related to the electronic diagnostic system. If a problem is indicated, there is a question as to whether the system should be repaired or replaced. This factor, coupled with the potential liability of the repair garage, combine to make repair of the system unattractive to most repair businesses.

Product Liability

Current product liability law holds a manufacturer liable for injuries caused by defective products. Manufacturers and component suppliers are concerned that they will be held liable for injuries even if the air bag operates as designed. Persons suffering injuries may charge that the system did not serve the intended purpose to prevent injury during an impact. Thus, the problem of manufacturers' liability is a serious issue facing the government.

4.3 PASSIVE BELT SYSTEMS

In most of the belt concepts which have been developed, automatic donning and doffing of the belts with minimum occupant participation is the primary concern. Passive belts are designed to move into place as each front seat occupant enters the vehicle and closes the door. Most passive belt systems have a single diagonal belt which fits across the chest, plus a padded knee bolster below the dashboard which prevents the occupant from submarining or sliding out from under the belt in a crash. Figure 4-7 shows the passive belt system used by Volkswagen.

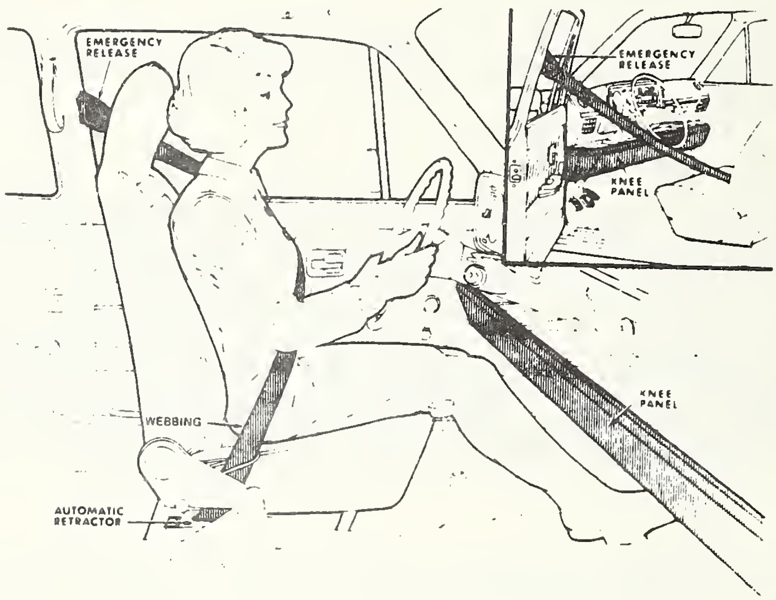


FIGURE 4-7. PASSIVE BELT SYSTEM EMPLOYED BY VOLKSWAGEN

Some systems also have an active lap belt (not shown in Figure 4-7) which the occupant can choose to buckle to increase the level of protection in other than frontal crashes, such as rollovers. There is also an emergency release for the diagonal belt, to facilitate post crash escape.

4.3.1 Types of Passive Belt Systems

Passive belt systems can be classified into two-, three-, or four-point connection systems. The two-point systems have been used in the Volkswagen Rabbit, as shown in Figure 4-7, and the General Motors Chevette. The two-point system consists of a single automatic upper torso belt, connected to the floor and the retractor on the door, as shown in Figure 4-8. Alternatively, the belt can be connected to the door and the retractor on the floor (see Figure 4-7).

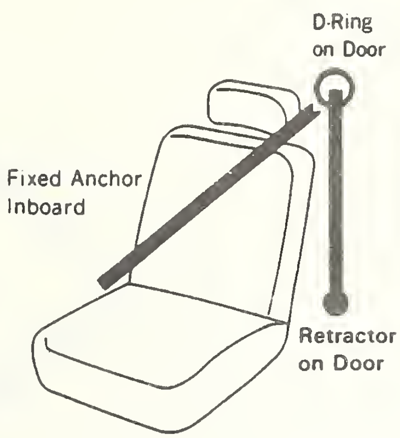


FIGURE 4-8. TWO-POINT PASSIVE BELT DESIGN WITH RETRACTOR AND D-RING ON DOOR

The three-point system consists of a combined automatic torso belt and lap belt. In most cases, the two automatic belts are permanently attached at some point so that the belts move together. This system is connected at the door, roof rail, and floor pan. Various alternative combinations of retractors and their locations have been considered for the three-point systems. The sketches in Figure 4-9 show some of these designs. One of the more successful combinations features a double retractor with a fixed webbing juncture (see Figure 4-9(d)). This system improves the fit and the pressure on the occupant, as long as the D-ring is properly designed.

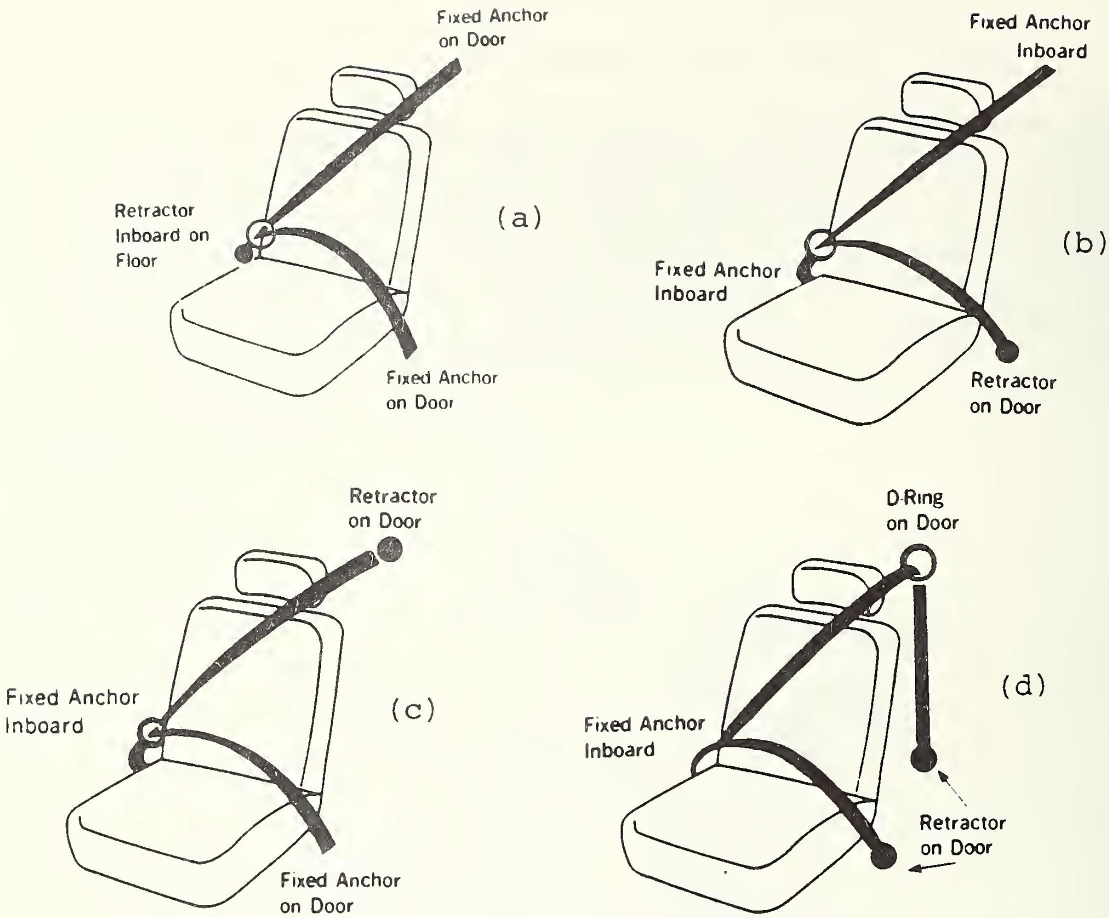


FIGURE 4-9. THREE-POINT SYSTEM
ALTERNATIVE COMBINATIONS

Other designs now in the prototype stage include the four-point connection systems. These systems provide upper torso and lap belt restraints utilizing three retractors. In addition to connection points on the floor and door, there is also a connection point on the steering wheel or column.

As shown in Figure 4-10, the inboard lap belt and shoulder belt retractors are located on the floor, and the outboard lap belt retractor is connected to the door. The third connecting point, the outboard shoulder belt anchor, is also connected to the door.

The fourth point of connection is on the steering wheel or column. Once the occupant has been seated, the clips are detached and fastened temporarily by using a magnet, stow ring, or stow clip. When detached, the excess webbing is retracted into the two housings and the occupant is restrained.

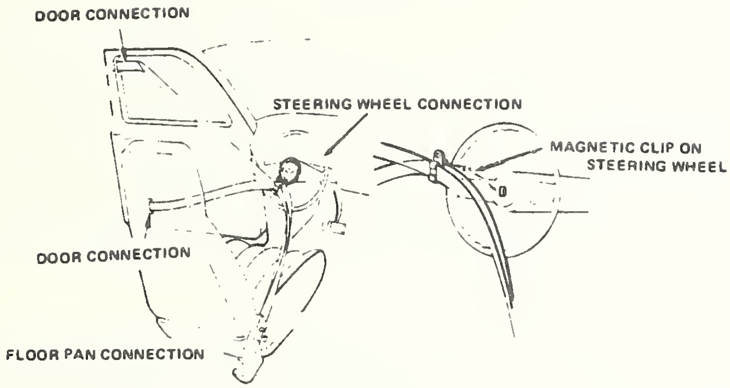


FIGURE 4-10. FOUR-POINT, THREE-RETRACTOR PASSIVE LAP/SHOULDER BELTS

4.3.2 Major Components of Passive Belts

Existing passive belt systems have three major components: Belt webbing, belt retractors, and buckles or emergency releases. Each is described below.

- Belt Webbing. The belt webbing is the part of the system which acts as a harness. It directly touches and restrains the motorist's body upon impact.

- Belt Retractor. The belt retractor is a small, spring-powered device which reels the webbing in and out as the motorist enters the car. It also locks the webbing into position when sudden force is applied. The retractor is made up of the spool, ratchet wheels, springs, pendulum and pawl, and housing.

- Buckle (Emergency Release). The buckle or emergency release joins the two ends of the webbing together while providing a point of voluntary exit for the motorist. After the webbing, the buckle is the most standardized component of the passive belt system. The buckle consists of two parts, the clasp and the prong.

In addition to these components, advanced design passive belt systems feature components to improve belt tightness during a crash. These systems include the following:

- Belt grabber. The belt grabber is a device built into the retractor which senses spool-out and clamps the belt, not the spool.

- Pretensioner. The pretensioner is a more complex device which automatically tightens the belt system around the occupant very shortly after an accident begins.

Pretensioners are not presently manufactured for passive belts, although they have been included in some prototypes. The major components include the gas propulsion unit, tube, and Pelton wheel.

4.3.3 Overview of Manufacturing Processes for Passive Belts

This section describes briefly the processes which are used in the manufacture of the following basic passive belt components:

- Webbing
- Retractor
- Buckling mechanism
- Pretensioner (may not be required).

In final assembly, these components are joined, assembled and permanently attached to the car. The first component, webbing, is the simplest and most standardized of the belt components. The next simplest component is the buckling mechanism. The retractor and pretensioner vary considerably in design and manufacture among different suppliers. There are also subtle variations between make/model applications from the same supplier to fit the specific needs as specified by automotive manufacturers. This "tailoring" of seat belt systems to specific makes/models makes it difficult for seat belt manufacturers to achieve significant economies of scale in mass production manufacturing of seatbelt. Manufacturing processes for each of these components are discussed below.

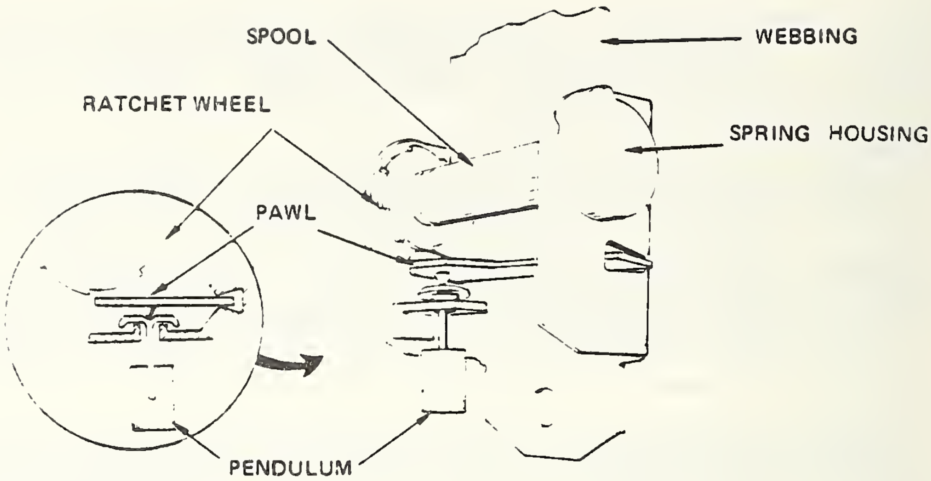
- Manufacture of the Belt Webbing. Manufacture of the belt webbing begins with a nylon compound which is extruded through a die with a small aperture to form nylon fiber. The fiber is then stretched to give it the necessary high tensile strength. The stretched fibers are woven into long webbed nylon strips, and finally cut into separate webbed belt lengths. The cut ends are then heat sealed.

- <u>Manufacture of the Retractor</u>. The passive belt retractor has four principal components: spool, ratchets, pendulum, and housing. These are manufactured from steel, lead, and plastic. The primary processes used include blanking, stamping, die casting and blow molding. An overview of this process is shown in Figure 4-11.

- <u>Manufacture of the Buckling Mechanism</u>. The two components of the passive restraint buckle, the clasp and the prong, are both manufactured from steel using the processes of stamping, joining, and finishing. The clasp is covered by a plastic grip, and both the clasp and the prong are attached to the belt webbing. An overview of this process is shown in Figure 4-12.

- <u>Manufacture of the Pretensioners</u>. The pretensioner is the most complex passive belt component. The basic concept of the pretensioner is to add an active device to the belt retractor so that the belt webbing is automatically pulled taut over the motorist upon detection of an impact. The electrical sensor system which senses the impact and triggers the pretensioner is similar to sensors used in air bag technology. The belt retractor used with the pretensioner is the same type of retracter discussed above. The gas propulsion unit is extruded or forged, machined, finished, and joined. The tube is made from steel using the processes of extruding, cutting, machining and forming. The Pelton wheel is die cast from zinc and press fit with a shaft which is also fit to the retractor spool. Figure 4-13 summarizes a possible set of manufacturing processes for the pretensioner.

The belt assembly process is semi-automated. A conveyor belt system is used for a portion of the assembly operations, while others require that the unit be removed from the conveyor belt to perform several minor operations. The joining and assembly processes are labor-intensive but utilize some automated procedures such as air-powered riveting.



RETRACTOR

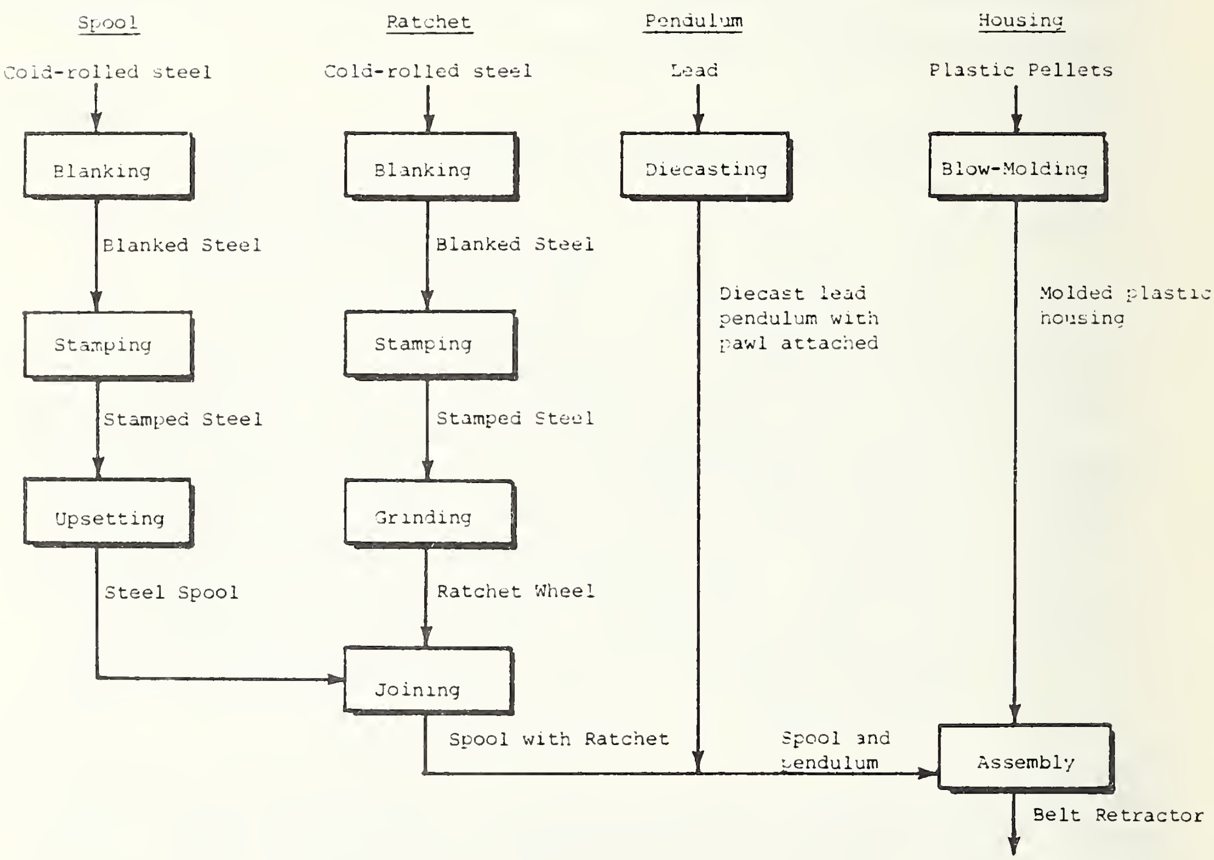
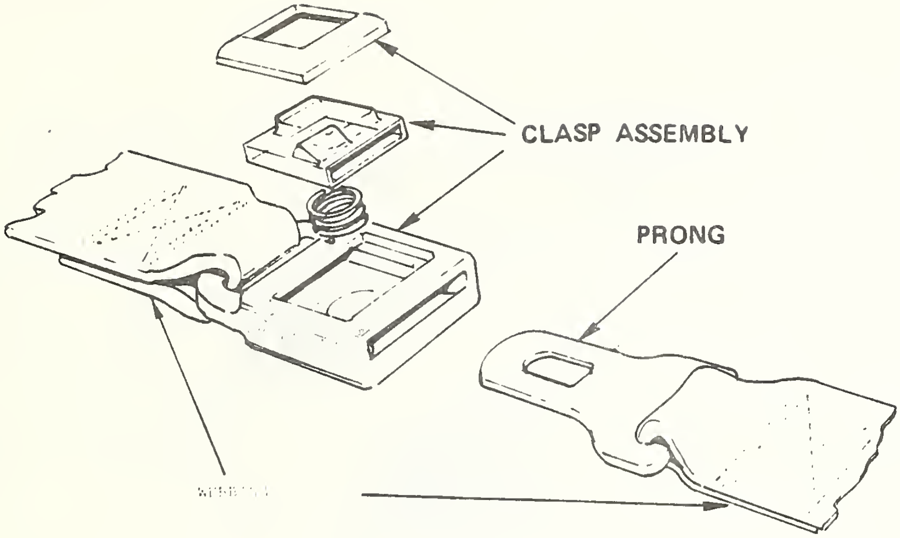


FIGURE 4-11. OVERVIEW OF THE PASSIVE BELT RETRACTOR MANUFACTURING PROCESSES



Buckling Mechanism

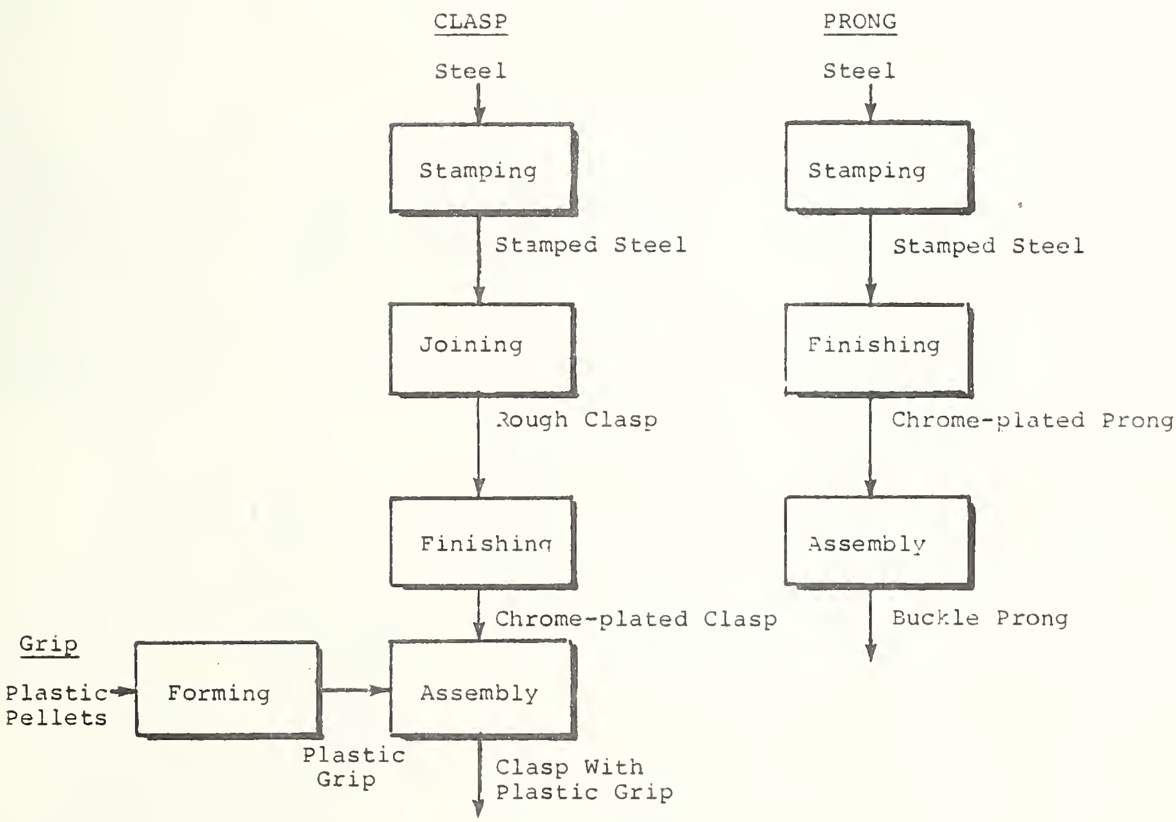
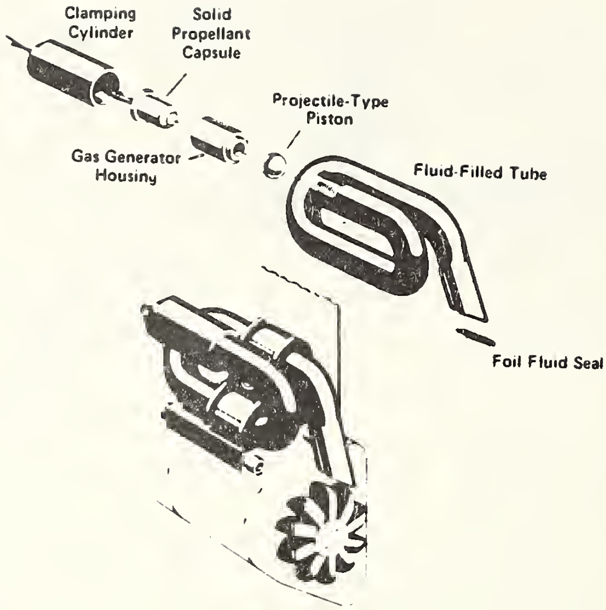


FIGURE 4-12. OVERVIEW OF BUCKLE MANUFACTURING PROCESSES



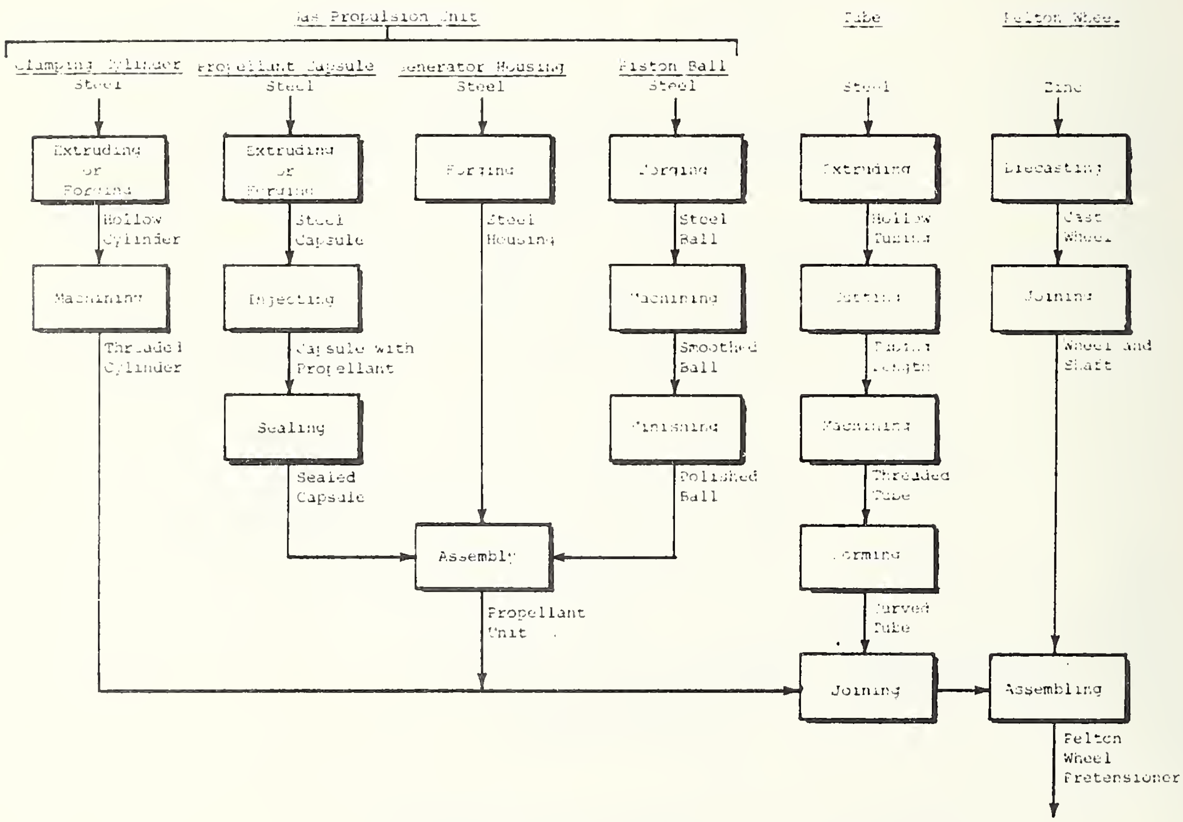


FIGURE 4-13. MANUFACTURING PROCESSES FOR A PELTON WHEEL PRETENSIONER

4.3.4 Size and Structure of the Industry

Companies which supply conventional seatbelt systems also manufacture the passive belts today. Passive belts of a simple design are currently in production, although design improvements continue to be developed to improve both comfort and performance. At present, no configuration of a passive belt system using a pretensioner has been marketed. Current seatbelt suppliers have indicated complex devices would not be required to meet the Federal standards for the foreseeable future.

The estimated demand for vehicles with passive belts by model year 1984 is 9.7 million. Since little special tooling or other preparation is required on the part of the suppliers, the passive belt industry will be able to develop from the existing active seatbelt base. If more complex passive belt systems are to be manufactured, such as those including pretensioners, a production capability will have to be developed.

The current major suppliers of seatbelt systems are Hamill, American Safety Equipment, Irvin and Pontineer. These companies as shown in Figure 4-14 are expected to be the principal suppliers of passive belt systems. The only subcomponent is the webbing, which is made largely by Southern Weaving. Other basic materials will be supplied by companies such as Dupont and Monsanto. Given the expected requirements for passive restraints, it is questionable whether these firms will be able to meet future production needs.

4.3.5 Key Issues

This section discusses the factors which affect the outlook for passive seatbelts. The principal issues include the capability of the supplier industry to meet the demand, effectiveness, reliability, maintenance and product liability of the system.

Capability of the Supplier Industries

The capability of the supplier industry to meet the demands within the timetable established by the Federal standards is an important issue for the near-term future. Because of the similarities between the manufacturing of active and passive belts, seatbelt suppliers should be able to substitute the passive belt systems for their existing products. This process will take some time and it is questionable whether the demands for passive belt systems will be met.

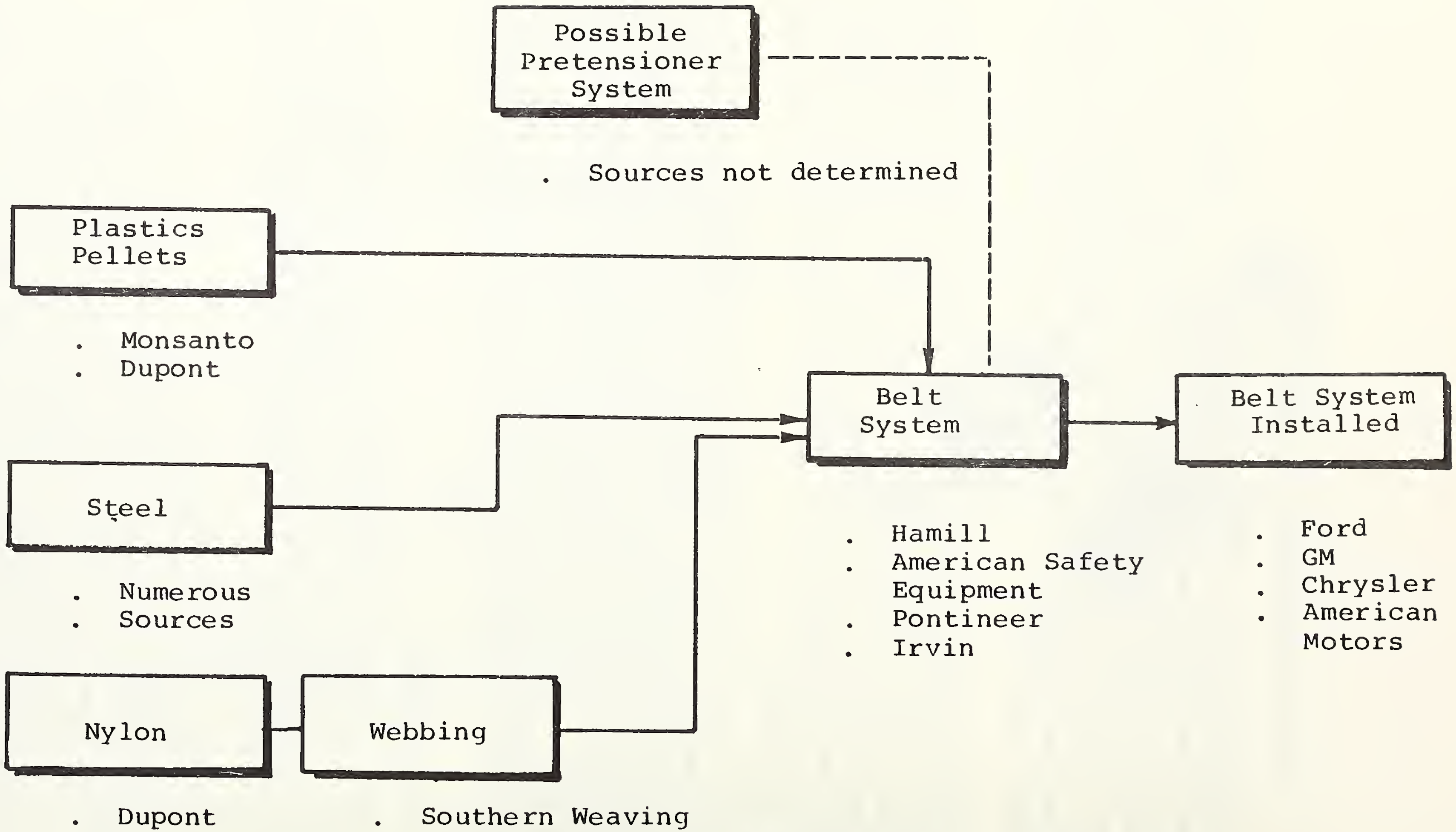


FIGURE 4-14. ANTICIPATED PRINCIPAL SUPPLIERS FOR PASSIVE BELT MATERIALS AND COMPONENTS

If more complex passive belt systems are manufactured in the future, modification to the doorframe and mid-door post of the affected automobiles may be necessary. These changes, however, will be the responsibility of the auto manufacturers and will doubtless be combined with other considerations relating to comfort, cost, and interior styling. If pretensioner-powered passive belt systems are needed to meet performance standards, a production capability for this component will have to be developed.

Effectiveness

The passive belt is superior to the air bag system in that it will hold the driver securely in the car under all conditions of impact—side, rear, front, or rollover. There is some possibility, however, that the driver's head will slip forward onto the steering wheel, or his face will be cut with glass, depending upon the severity of the accident. Another danger facing the user of a passive belt system is that he will be forcibly contained within the seat during a direct impact to the area where he is sitting. If the emergency release can be activated in time, the motorist may be released, although there is often not sufficient time for this. A compensating factor is that comparatively few accidents involve impacts of this type.

Reliability

Passive belts are designed to always be in position to protect the passenger in case of an accident. Passive belt systems are, however, subject to tangled webbing, malfunctioning retractors, or other hardware breakdowns which now contribute to non-usage of belts. More complex systems would cause the reliability problems to increase.

Maintenance

Passive belt systems do not present a major problem in the aftermarket at present. The status of passive belt operability is easily determined. Mechanics can readily inspect most passive belt components and may be able to correct minor mechanical problems. Failure of the retractor, however, will necessitate replacement.

Replacements costs for the current Chevette passive belt system are $9.00 for parts for each front side, and $50 for labor.

Future Pelton wheel pretensioner belt systems may be considered unserviceable. Once the propellant is expelled from the propellant capsule, and the Pelton wheel has been activated, the unit will require complete replacement.

Product Liability

The problem of manufacturers' product liability is a serious issue as discussed previously in the air bag section. The manufacturers and component suppliers are concerned that they will be held liable for injuries even if the passive restraints operate as designed.

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