quarter panel  C-pillar  B-pillar  A-pillar  fender

(note: strictly speaking, the pillars are the structures beneath the skin structures visible here)
Introduction

**"Conventional" Car**
- Roughly: 68% Ferrous Metal
  - 7% Nonferrous Metal
  - 7% Polymers
  - 8% Other Materials
- Weight: ~3000 pounds
- Internal Combustion Engine
  Roughly 20-27 miles per gallon

![Graph of US Average Vehicle Material Content from 1976 to 1990](chart.png)

---

"Super Cars" -- What Are They?

- Performance Associated With Exotic Vehicles
  - Low Weight - Below 2000 pounds
  - Specialized Powerplant
    (Note: power vs. economy is a standard automaker design tradeoff)
- Achievable Today With Specialized Materials and Production
  - Polymer Composite Vehicles
    e.g., Corvette, Ferrari, Lamborghini
  - Nonferrous Vehicles
    e.g., Acura NSX, Audi A8
  - Exotic Engines
    - Titanium Componentry - Race Cars & NSX
    - Polimotor - Race Cars
    Etc..........

- So, If It Can Be Done, What's All The Fuss About Improving Automobile Efficiency?
The Issue Is ... Cost!

- Vehicle Cost Is A Strong Function Of:
  - Material Choice, Which Influences...
  - Processing Options, Which Influence...
  - Manufacturing Methods, Which Are Driven By...
  - Market Strategies

- Underlying All This Is The Product Development Cycle
  - Car Making Is Not A Casual Endeavor
  - Product Development Costs Alone Can Be Hundreds Of Millions Of Dollars
  - Complexity Comparable To Aerospace Development
  - But Production Is Several Orders Of Magnitude Greater (i.e., 60,000 - 500,000/year vs. 60 to 250/year)

Advanced Materials & Automobile Development

Why Are Airplanes Made Of Aluminum & Composites, While Cars Are Mostly Steel?

- Design Processes Are Different
- Process Requirements Are Different
- Target Markets Are Different
Automobile Product Development Cycle

- Concept & Studio: Where The Car Starts
- Advance Engineering: Where The Car Takes Shape
- Product Engineering: Where The Details Are Filled In
- Production Engineering: Where The How Of Building The Car Is Worked Out
- Manufacturing: Where It All Comes Together

Vehicle Concept & Studio
Devise a Car Concept To Fit Within The Company's Overall Product Strategy

- Target Market - Families, First Car Buyers, Students, DINKs, Luxury, Sport Utility
- Vehicle Type - Sedan, Coupe, Van, Wagon, Truck, ...
- Vehicle Performance - Economy, Sport, ...

Fit Within Overall Strategy Important - Selling Too Many Cars Can Be As Bad As Selling Too Few

- Regulatory Issues - CAFE
- Economics
  — Expense Of Scaling Expected Low Production Design To High Volume Demand
CAFE

- Introduced To Compel Automakers To Reduce Gasoline Consumption
- Corporate Average Fuel Economy:
  \[
  \text{The Harmonic Average Of The Fuel Economy Of Vehicles Sold, or}
  \]

\[
\sum \frac{N_i}{\text{Fuel Economy of } i\text{-type vehicles}}
\]

- Interesting Consequences:
  - If Car A Gets 20 mpg and Car B Gets 40 mpg and the CAFE Target is 30 mpg, How Many Cars Of Type B Must Be Sold For Every Car A That Is Sold?

CAFE Over Time

CAFE Statistics
NHTSA Data

Graph showing CAFE statistics over time with lines for Average, New Domestics, and All New Cars.
Components of Domestic Automobile Sales
From MVMA Data Book

Advance Engineering

- Where Concept Gets Turned Into Engineering Drawings
- Normative, Rather Than Analytical, Design Process
- Based Upon Historical Designs
- Conservative Strategy To Limit:
  - Costs
  - Risks
  - Uncertainty

Highly Effective, Particularly In Mass Production Environments

- But, Difficult To Innovate In The Absence Of History Of Past Performance
- Particular Problem For Materials
Production/Manufacturing Technologies

Automobiles Are Mass-Production Products
What Does This Mean?

- Annual Production Volumes On The Order Of 100,000
- Production Rated On The Order Of 60-75 units/hour
- Have To Be Affordable To A Large Market

Contrast With Airplanes

- Annual Production Volumes Less Than 1000
- Production Rates On The Order Of 1/day
- Specialized Markets

These Differences Lead To Different Processing Requirements

---

Metal Processing Requirements

**Stamping**

- Suitable To Sheet Metal - Aluminum Or Steel
- High Speed Process - 1 Piece Every 10 Seconds
- Expensive Tooling - $10's Of Millions Per Part
- Expensive Equipment - $100's Of Millions Per Press Line

**Steel Stamping**

- Steel Makers Produce Stampable Alloys
- Automakers Can Just Form And Use

**Aluminum Stamping**

- Similar To Steel, But
  - Not As Deep A Draw (Not As Formable)
  - Heat Treatments May Be Required
Composite Materials Processing

Variety Of Processes (SRIM, RTM, TP Sheet, SMC)

Common Features
- Low Equipment Costs - On The Order Of $1 Million
- Moderate To Low Tooling Costs - $100,000 To Several Million $'s
- Slow Processing Times - 1 Piece Every Several Minutes

And, Of Course, RP/Cs Are More Expensive

- Steel Sheet Starts At Around $0.30 / lb
- Aluminum Sheet - Start At Around $1.80 / lb
- Composites - Start At $1.50 / lb For Low Performance, And The Sky's The Limit!

After Part-Making, There's Assembly

Current Assembly Plant Costs Start At About $800,000

- Body Line          Fabricates The Body-In-White
  Welding Processes - Spot and Arc
  Adhesive Bonding
  Mechanical Attachment

- Paint Line        Usually Accounts For Roughly 50% Of Plant Cost
  Washing & Drying
  Priming & Curing - E-Coat or ELPO
  Color & Clear Coats
  Final Bake

- Chassis & Powertrain Engines
  Suspension
  Transmission

- Final Trim      Interiors & Finishing
  Labor-Intensive Part Of The Process
Steel Again Has Advantages In Assembly

Body Line

- Spot Welding Preferred For Speed - Works Best With Steel
- Adhesive Technologies - Required For Composites, and Probably For Aluminum
- Compliance Between Different Materials A Problem

Paint Line

- Heat & Solvents Tough On Polymers
  - Aluminum Oxide Coatings

Trim Line

- Compliance Again A Problem - Can't "Bend To Fit" When Using Composites
- Aluminum Delicacy - Easy To Mar Surface

Strategies For Reduction Of Environmental Impact

- Design & Vehicle Lightweighting
  - Lightweighting Through Alternative Metals
    - Steel vs. Aluminum
    - Unibodies vs. Spaceframes
    - Changes In Emissions & Economics
  - Lightweighting & Recycling -- Polymer Substitution
    - Polymer Recovery Technologies
    - Effectiveness

- Manufacturing Technologies
  - Alternative Painting Technologies
    - Transition From Solvent-Based Paints
    - Cost vs. Airborne Emissions

- Alternative Fueled Vehicles
  - ZEV/Electric Vehicle & Alternatives
    - Cost & Effectiveness of Emission Reduction
US Passenger Car Fleet
Average Miles Per Vehicle Per Year

Passenger Cars
Light Trucks


Average Miles Per Year Thousands

US Passenger Vehicle Gasoline Consumption

Passenger Car Light Truck


Gallons of Gasoline Per Billions

Massachusetts Institute of Technology
Cambridge, Massachusetts

Materials Systems Laboratory
**US Automobile Fleet - Average Fuel Economy**

- **Passenger Cars**
- **Light Trucks**

Year:
- 1930
- 1940
- 1950
- 1960
- 1970
- 1980
- 1990
- 2000

Average Miles Per Gallon:
- 8
- 10
- 12
- 14
- 16
- 18
- 20
- 22

**US Vehicle Injuries and Fatalities**

- Roughly 0.6% of Vehicle Crashes Involve Fatalities
- Roughly 33% of Vehicle Crashes Involve Injuries
- Roughly 66% of Vehicle Crashes Involve Property Damage Only

Total Crashes Since 1988 Range between 6 and 6.8 million/year
### Injuries and Fatalities Normalized By VMTs

- Although the absolute numbers show uneven trends, normalized values show downward trends, although less so for Injuries
- Per 100,000 population:
  - Deaths: 26 -> 16
  - Injuries: 1400 -> 1300
- Per 100,000 Drivers:
  - Deaths: 51 -> 23
  - Injuries: 2000 -> 1950
- Per 100,000 Vehicles:
  - Deaths: 53 -> 21
  - Injuries: 1930 -> 1740

### Vehicle Safety Technologies: Estimated Lives Saved (NHTSA)

<table>
<thead>
<tr>
<th></th>
<th>Seat Belts</th>
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<th>Child Restraints</th>
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<td>10414</td>
<td>686</td>
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</tbody>
</table>

- Various Technologies Developed and Imposed
- Interesting To Contract Scale Of Effect
CAFE

- Introduced To Compel Automakers To Reduce Gasoline Consumption
- Corporate Average Fuel Economy:
  \[ \frac{\sum N_i}{\sum \left\{ \frac{N_i}{\text{Fuel Economy of } i\text{-type vehicles}} \right\}} \]

- Interesting Consequences:
  If Car A Gets 20 mpg and Car B Gets 40 mpg and the CAFE Target is 30 mpg, How Many Cars Of Type B Must Be Sold For Every Car A That Is Sold?

CAFE Statistics

[Graph showing CAFE statistics from 1978 to 1996 for different vehicle types and categories, including Domestic, Foreign, All New, PassCar Fleet, and LiteTruck Fleet.]
"First Principles" Mass/MPG Calculation

MPG = 8627.4 (Mass)

-0.74584

Rule of Thumb - 10-5 Rule

- A 10% Reduction In Mass...
- Yields A 5% Increase In Fuel Economy
- So, If A Baseline 3111 lb Vehicle Gets 21.6 mpg...

MPG = 895.24 (mass)

-0.463
Third Calculation - DeLuchi

- Some Scaling Modifications:

\[
\text{Mass} = 2 \cdot 2.015 \text{ FE} - 194.85 \text{ FE} + 6375.54
\]

### Current Vehicle Emission Standards (g/mi)

<table>
<thead>
<tr>
<th>Type</th>
<th>NMHC</th>
<th>CO</th>
<th>NOx</th>
<th>NMHC</th>
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<td>0.09</td>
<td>4.2</td>
<td>0.3</td>
</tr>
</tbody>
</table>

EPA Tier 1 (50K)  EPA Tier 2 (100K)  LEV Standards (100k/200k)

- LDV: All passenger cars
- LDT1: Gross Vehicle Weight Rating (GVWR) 0-6000 lb Loaded Vehicle Weight (LVW) 0-3750 lb
- LDT2: GVWR 0-6000 lb LVW 3751-5750 lb
- LDT3: GVWR 6001-8500 lb Adjusted Loaded Vehicle Weight (ALVW) 0-5750 lb
- LDT4: GVWR 6001-8500 lb ALVW 5751-8500 lb
CAFE Over Time

CAFE Statistics
NHTSA Data

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From MVMA Data Book
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