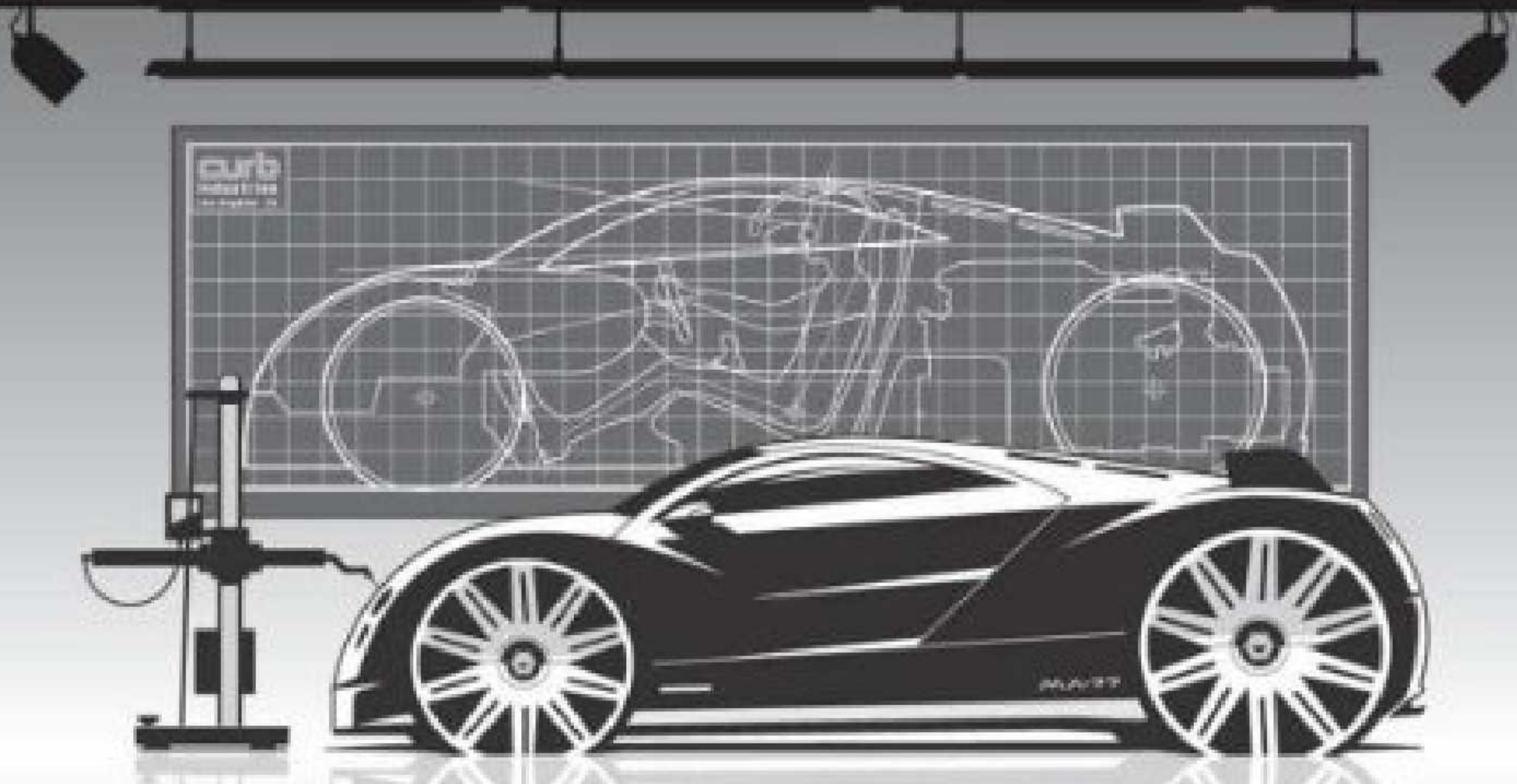
H-POINT

THE FUNDAMENTALS OF CAR DESIGN & PACKAGING



by Stuart Macey with Geoff Wardle
forewords by Ralph Gilles, Freeman Thomas & Prof. Gordon Murray

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"Fashion dates, but logic is timeless"

SIR ALEC ISSIGONIS – Vehicle architect and designer of the BMC Mini

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The Fundamentals of Car Design & Packaging

By Stuart Macey with Geoff Wardle

Art Center College of Design

designstudio PRESS

DEDICATION

This book is dedicated to Alf & Steve Macey.

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FOREWORD

The first time I met Stuart his legs were sticking out from under a prototype Minivan. He was literally underneath the van looking for a way to make the seats fold into the floor. Such is his curiosity and deep dedication to problem solving. Stu is the kind of packaging engineer that has an exceptional respect for design. Being an accomplished designer himself he has always recognized that the art of packaging is the great facilitator and ultimately, in the hands of the skilled designer, it is the great differentiator.

As a designer I am a firm believer that proportions are "everything." They are also deeply rooted in nature and our psyche. Much like how a child responds to a cute stuffed animal we respond to well sorted designs. Appealing designs are the direct bi-product of great proportions. Great proportions are the results of judicious packaging work. However, there is no such thing as the perfect car as every car is a compromise in some way. Great package work aims to minimize that compromise and allows the visionary designer and engineers as much freedom of design as possible. Each vehicle design has its mission, whether to maximize interior volume for occupants or to achieve exceptional on track performance or perhaps even to cheat the wind to achieve the best fuel economy possible. Artful packaging is the calculated rationing of these distinctive compromises. Great designers can manipulate this balance of compromises in their favor to create designs that provoke and titillate the senses, often creating an iconic product that punctuates the epoch in the process.

What enables these iconic designs is indeed the true mastery of packaging. As most vehicles are commercial products that must be relevant to the masses, great packaging can give a vehicle a much deeper well of greatness. A vehicle with thoughtful and practical solutions will always have greater staying power. It is up to the astute leadership of the firm and the design visionary to tune this balance of art, business and the forces of the practical consumer. Design can be a victim of flawed packaging as easily as it can be glorified by it. Needless to say, the art of automotive design has momentarily matured. Most packages are being regurgitated over multiple decades and the realities of physics and the wind tunnels are pushing design into a collective corner.
The savior comes within our times. We are on the brink of a brave new world of design where once again the components beneath the skin are changing in dramatic ways. With the fundamental change in system components comes the promise of new proportions enabled by creative packaging. New propulsion systems components will allow us newfound design freedom that will certainly have a profound effect on the style of

automobiles yet to be penned. We are an ever evolving species, yet our core needs and instincts remain somewhat constant in the end. As far as the business end of design is concerned, humans will always respond to provocative yet sensibly executed designs. This balance of the sensible and the provocative is what the art of packaging enables.

This book is a lifelong dream of Stu's and the direct byproduct of his passion for the automobile and the fascinating process of its creation. He manages to demystify the design process in a way that will allow aspiring designers to benefit immediately from what amounts to a career's worth of knowledge. Not only is the book artfully done, it is truly substantive and gives the student designer unprecedented access to the inner sanctum of vehicle design. This book is full of extremely helpful insights that help the aspiring designer grasp the fundamentals of good design.

This exceptional amount of information comes together to become an essential tool in the toolbox of an aspiring designer. In other words, it is the decisive bible of automobile packaging.

RALPH GILLES - Vice President of Design, Chrysler Motors

Vehicle design is not pragmatic, it is an art, a rebellious act that must also work and function. Stuart and Geoff have created "the guide" to help every designer and engineer find "the magic" that makes each vehicle design and architecture unique, and come alive in the studio. Certain vehicles have a stance, a look and proportions that tell an aspiring story that creates desirability and an identity. It's the "mojo" that no one seems to be able to explain! Read every word and every page of *H-POINT, The Fundamentals of Car Design & Packaging* and I guarantee it will give you the secrets to finding "the magic!"

FREEMAN THOMAS - Design Director, Ford Advanced Design

INTRODUCTION

In 2002, the Transportation Design Department at Art Center College of Design in Pasadena, California set out to re-focus their vehicle architecture education program. The goal was to help the undergraduate transportation-design students prepare for an automotive industry that was putting greater demands on their design studio teams in a global landscape that was becoming more competitive and complex.

The challenge to the faculty was to develop a syllabus which reflected the real world advanced concept development process and support the class with material that would be palatable to the students who were already in a very challenging educational program. After several years of development, these notes have been assembled to create *H-POINT*.

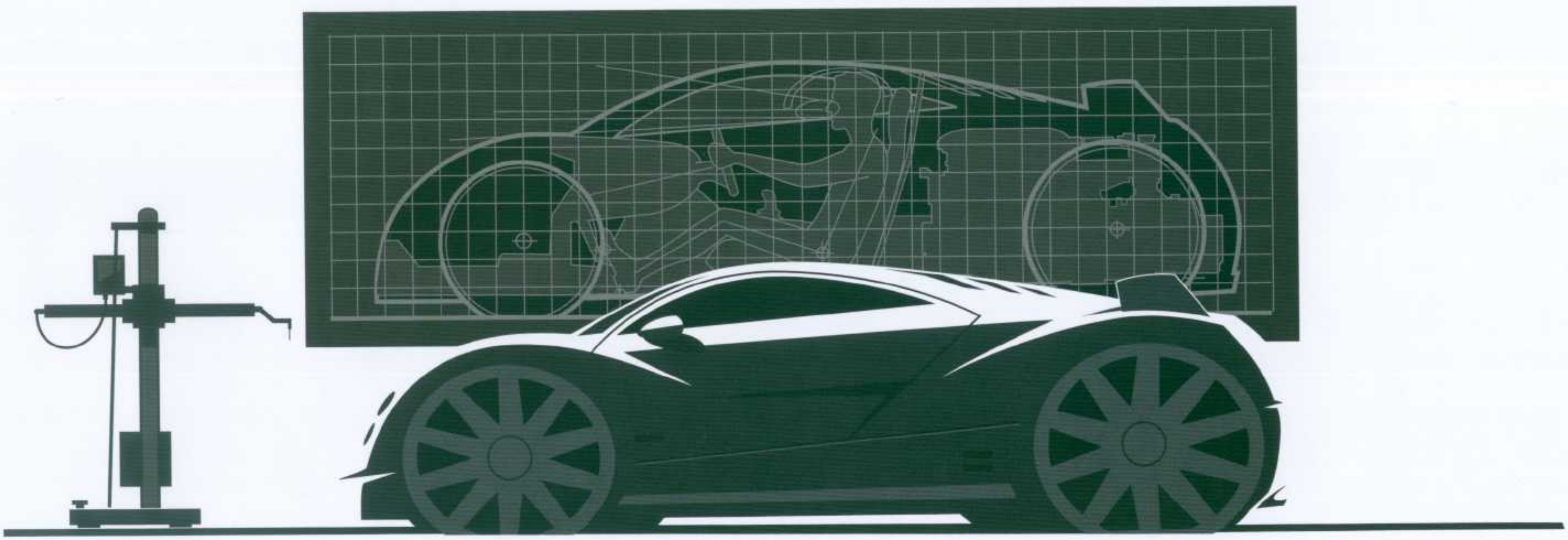
We have tried to pull together just the right amount of information and present it in a form that can be digested by even the most sleep deprived design student. Fortunately, much of a vehicle's exterior design can be established around a few of the major systems, so at the advanced stages of a project many components can be left out of the package to reduce its complexity. This has enabled us to boil the subject down, not having to describe every component in great detail, but rather to focus on only the key elements that influence the exterior and interior advanced design.

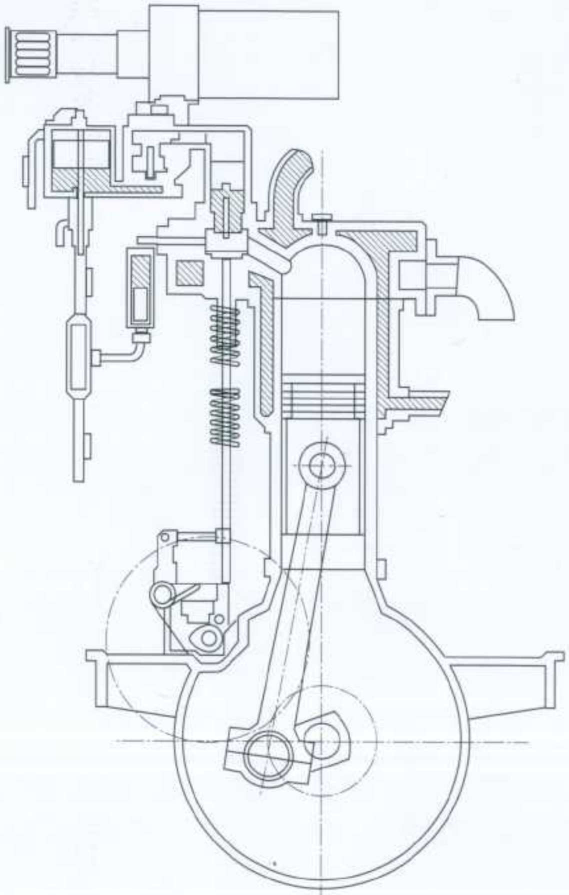
Car design can be a chicken-and-egg process, with the concept being driven by either design (emotion) or the package (logic). Ideally both are developed harmoniously to result in a pure and rational product. The processes used to develop concepts continually evolve as new tools emerge and the products become more and more complex, so the information contained in the following chapters is very generic and can be applied in any design studio environment.

Packaging, or setting up the vehicle architecture, has always been a fundamental element in the creation of a successful product, which is why the main objective here is to empower designers to be part of the package-development process from day one. History is full of examples of vehicles with groundbreaking designs which were driven by an innovative package. Cars like the Chrysler Airflow, VW Beetle, Jeep Wrangler, BMC Mini and the McLaren F1, for example, all pushed automotive design forward in their own way and still influence car design today.

Hopefully, this book will help you create the next historic icon.

The main objective for the advanced concept model is to develop form, proportion and architecture that pushes beyond current boundaries. To help the process flow, many important components are left out of the initial studies. Although this usually leads to a less than 100% production feasible package, the architecture should be close enough to the final solution that the concept's character is not lost after production engineering is complete.





A BRIEF HISTORY OF VEHICLE ARCHITECTURE

Probably the best way to understand the role of packaging in the design process is to look at how and why vehicle proportions have changed over time. The next few pages provide a concise overview of some of the key milestone vehicles from 140 years of automotive history and the events that influenced them. Note that many of the timeless cars and trucks shown were created entirely by their architects, but when styling or emotion became the driving factor for the concepts, their lifespan was often short.

Nicholas Otto is given credit for inventing the four-stroke internal combustion (I.C.) engine in 1876. This turned out to be one of the most significant inventions in the history of mankind. Its location, size, configuration and orientation have always had a major effect on a vehicle's exterior proportions.

Many of the early cars had simple two-cylinder engines, but as customers demanded more power the I.C. engine developed rapidly. The first six-cylinder appeared in 1902 followed by a V8 in 1903. Cadillac built a V12 in 1909 and started to mass produce a 70hp V8 in 1915. This became the benchmark motor in the USA for many years.

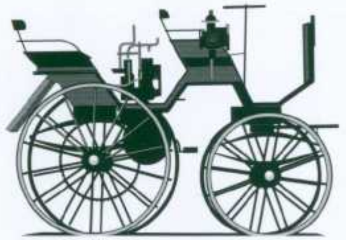
In 1912, Cadillac also introduced the starter motor made by Delco. This helped to give the internal combustion engine a clear advantage over steam and electric power plants, which had until then dominated early automobiles.

Major inventions, events & cultural changes that have affected vehicle architecture.

4000 BC The Wheel (Mesapotainia)	1776 Industrial Revolution (England)	1876 Four-Stroke Engine Niclaus Otto (Germany)	1888 Pneumatic Tire Dunlop (England)

THE FIRST MOTOR CAR

Gottleib Daimler is generally credited with creating the first vehicle powered by an internal combustion engine. Many early cars were adapted from horse-drawn carriages and had the same body and chassis architecture as well as a similar occupant package. Carl Benz's "Motor Car" was an exception and had a new package, from the ground up.

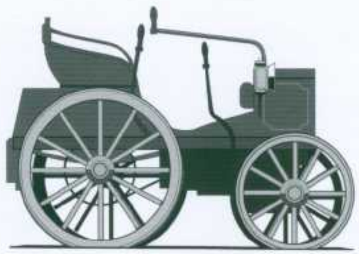


1886
DAIMLER MOTOR CARRIAGE
(GERMANY)

This is probably one of the first examples of an automotive designer stuck with the paradigms of the past. It was called the motor carriage and that's exactly how it was configured.

FRONT-ENGINE LAYOUT

Panhard-Levassor made some great strides in the early years of automobile design. They were the first to place the engine in the front of the car and link it to the rear wheels through a clutch and multispeed transmission. The Panhard-Levassor Company was one of the largest auto companies before WW I.



1891
PANHARD-LEVASSOR
(FRANCE)

At this time, many other cars added faux hoods to copy the style of the European Panhards. Significantly, millions of luxury cars and trucks today are built with this same basic component layout.

ALTERNATIVE PROPULSION

Electric and steam cars were in the majority in the US at the early part of the 20th century. Companies like Baker, Woods and Detroit Electric developed electric vehicles that were clean, reliable and easy to start. In Europe, Prof. Ferdinand Porsche was developing electric and hybrid vehicles for Lohne. Steam technology was mature at this time and cars made by Doble and Stanley were also quite successful.

1908
BAKER ELECTRIC
(USA)

The power, range and lower cost of I.C. engines soon made elecric cars uncompetitive. Ironically, the introduction of the electric starter motor in 1912 finished them off.

1893	1894	1899	1900	1903
Diesel Engine	Prop Shaft	Steering Wheel	Steel Frame	First Flight
Rudolf Diesel (Germany)	Renault (France)	Packard (USA)	Mercedes (Germany)	Wright Brothers (USA)

MASS PRODUCTION

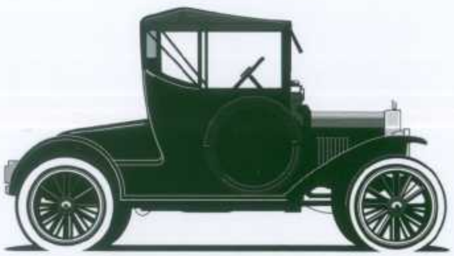
Henry Ford set out to democratize the automobile, by reducing the price of a car and raising wages through mass production. The Ford factory produced one Model T every three minutes. They were all painted black because that was the only color that would dry quickly enough to keep up with the production line.

UNIBODY CONSTRUCTION

This Lancia was a revolutionary car for the early 1920s, and the first car with a load-bearing unibody (monocoque). Other innovations included independent front suspension with coil springs and a narrow 13°, V4 aluminum engine with a single overhead cam.

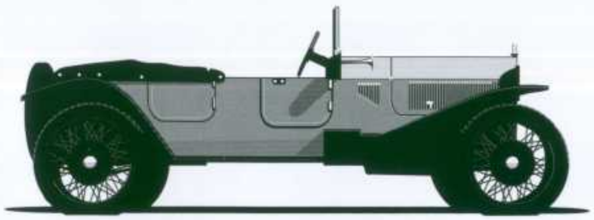
ART & SCIENCE

Ettore Bugatti was not only a great designer but also a brilliant vehicle architect who, along with his son Jean, were responsible for some of the most beautiful cars in history. Ettore had the unique ability to design structure empathically, without stress calculations. The Type 35 is still one of the most appealing and successful race cars of all time.



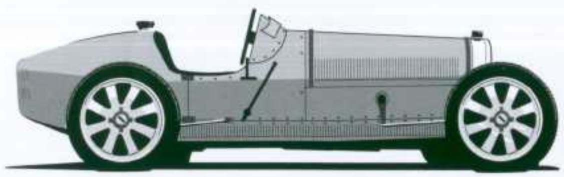
1912
MODEL T
(USA)

With annual vehicle sales today of over 60 million, it looks like Mr. Ford succeeded. The design of cars today is often influenced by the complexity and investment of high-volume mass production.



1922
LANCIA LAMBDA
(ITALY)

The vast majority of passenger cars and vans today are built with a frameless unibody structure and independent suspension.



1922
BUGATTI TYPE 35
(FRANCE)

Today, computer systems can aid designers to create organic structures which are fully optimized and often naturally beautiful.

1905
SAE Formed
(USA)

1912
Starter Motor Introduced
Delco (USA)

1914
Automatic Transmission
Mercedes (Germany)

1914 - 1918
World War I

1928
Synchromesh Gears
Cadillac (USA)

AERODYNAMICS & CAB FORWARD

Inspired by aerodynamic forms created by the Hungarian Paul Jaray, the revolutionary Airflow package pushed the occupants forward to the middle of the wheelbase. It was also one of the first US production cars to adopt unibody construction.

**1934
CHRYSLER AIRFLOW
(USA)**

The Airflow's advanced design was too radical for the market and was a disaster, almost bankrupting Chrysler. But after the initial design shock had passed, both Ford and GM adopted this form and architecture and were very successful with it.

THE PEOPLE'S CAR

Probably one of the best known cars of all time, it was originally designed before WW II, by Prof Ferdinand Porsche with sponsorship from Adolf Hitler. Much of its architecture was inspired by the Czechoslovakian Tatra T87. The rear engine (flat four) "people's car" was mass produced between 1938–2003, selling over 21 million units.

**1938 (45)
VW BEETLE
(GERMANY)**

Many other vehicles were built on its platform and although very successful in its own right, it is worth noting that the Beetle has had little influence on cars today. Its architecture was effectively a blind alley.

THE 4x4

Originally designed by Willys Overland in 1939 to carry four people—or two with a stretcher—over the rough terrain of war-torn Europe. The Citizen Jeep (CJ) was produced for civilian use after WW II. This was the first purpose-built 4x4 SUV. Updated versions with similar architecture are still manufactured today and it has become a design icon.

**1945
JEEP WILLIES (CJ)
(USA)**

The design, proportions and basic architecture are based on pure logic and have remained almost the same for over 65 years. The seven-slot grill and headlight layout also became the Jeep brand logo. The original Land Rovers were inspired by and designed from the early Jeeps.

1928 First Freeway Rome (Italy)	1929 Stock Market Crash Wall Street (USA)	1937 GM Styling Division Harley Earl (USA)	1939 First TV Broadcast (USA)	1939 - 1945 World War II

THE PICKUP TRUCK

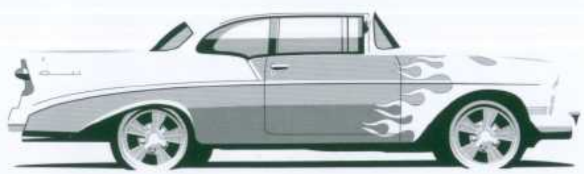
The DNA for pickup trucks can be traced back to the 19th century, but the Ford F150 has held the title of best-selling vehicle in the USA (and the world) for 20 years. Its architecture is still very similar to the original F1 with its body and bed mounted on a durable steel frame. The longitudinal front engine RWD/4WD powertrain and solid rear axle/leaf spring suspension layout also remain the same.

1948
FORD F1 TRUCK
(USA)

Truck architecture is another example of design based on logic. Today's trucks are becoming more luxurious and are used more as lifestyle vehicles. Crossover and derivative SUVs are often based on truck platforms.

DESIGN WITH PASSION

The '50s & '60s were glorious years for the US automobile industry. Fueled by cheap abundant gas, a strong economy, the baby boom and post war optimism, the cars of this era grew to be enormous, flamboyant and ideal for customizing. It is said that the difference between European and American cars in this era was "A foot of styling." What followed in the '70s was not pretty.



1956
CHEVROLET BEL AIR
(USA)

The US design studios simply could not react quickly enough to downsize their concepts during the oil crisis of the early 1970s. They lost a huge amount of market share to smaller, more efficient imports. Domestic market share has since dropped from 95% in the '70s to less than 50% today.

PASSENGER PRIORITY

Sir Alec Issigonis was asked to create a respectable small car to help Britain get through the Suez oil crisis. His answer was the Mini, which remained in production for 40 years, selling over 5 million cars. The transverse engine with FWD and 10-inch wheels created a "passenger priority" package which has been adopted by almost every high-volume car manufacturer in the world.

1959
BMC MINI
(ENGLAND)

Probably one of the most influential cars of all time, its innovative package layout can be seen in hundreds of millions of vehicles worldwide. Because of its relative complexity, the Mini made almost no profit for the manufacturer, but the advanced architecture allowed Issigonis to design an exterior which instantly dated BMC's other cars.

1945
Atomic Bomb Dropped
(Japan)

1948
State of Israel recognized
(Middle East)

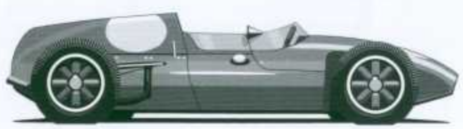
1956
Disneyland Opens
(California - USA)

1956
Highway Act
(USA)

1956
Suez Oil Crisis
(England)

MID-ENGINE LAYOUT

Charles & John Cooper entered their underpowered Formula 2 T45 in the 1958 Argentine F1 Grand Prix and won. This was the first car to win a GP with mid-rear engine layout which helped to create a more balanced and aerodynamic race car. The Cooper Climax T51 won the world championships in 1959 & 1960 and no front-engine cars have won an F1 race since then.



**1959
COOPER CLIMAX T51
(ENGLAND)**

The Benz & Auto Union race cars of the 1920s & '30s were the first mid-rear engine cars, but the Coopers were the first to win races because of their layout, rather than brute force. Today, the mid-engine layout is the signature for most European supercars.

THE BRITISH ROADSTER

Colin Chapman was a very innovative lightweight-sports-car architect who designed several classic icons. The Elan defined the small British roadster architecture. It weighed 590kg with a short 84" (2135mm) wheelbase. The small longitudinal front 1500cc engine drove the rear wheels and Chapman utilized the prop shaft tunnel as a "backbone" for the body structure.

**1962
LOTUS ELAN
(ENGLAND)**

Many of today's small roadsters are based on the Elan's philosophy but are usually larger to provide space for a more generous occupant package, a more powerful engine and a crashworthy body structure.

THE LUXURY SUV

The first fully off-road capable luxury SUV. The Wagoneer was the inspiration for the very successful Range Rover in 1970 and many other models that followed, including the 1984 Jeep Cherokee with a unibody. Initially, luxury SUVs represented only a small percentage of the market, but today they sell in very high volumes and earn large profits for their manufacturers. Their main drawback is fuel consumption.

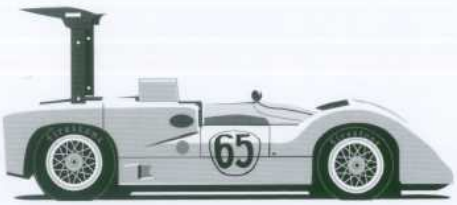
**1963
JEEP WAGONEER
(USA)**

To meet their original functional requirements, the architecture requires a very high floor and seating position. This provides owners with a sense of security and status. Most SUVs are sold for their image, not their functionality.

1960	1961	1961	1963	1965 - 1975
Beatles Formed (England)	Beach Boys Formed (California - US)	First Man in Space Yuri Gagarin (USSR)	SEMA founded (USA)	Vietnam War

DOWN FORCE

Designed by Jim Hall, the Chapparel was the first racing car to employ a large wing to create down force to increase traction without adding mass. Although much about aerodynamics and vehicle dynamics was known after WW II, it took at least 20 years to apply the knowledge.



1965
CHAPPAREL
(USA)

The lesson to be learned from this car is that some quite obvious solutions may take a while to become obvious to everyone. There are still plenty of inventions waiting to be realized.

THE HATCHBACK

The Golf was not the first hatchback. That honor goes to a version of the 1954 Citroën Traction Avant. It also owes much of its proportions to the 1971 Alfa Romeo Alfasud (also designed by Giugiaro). However, the Golf helped to define the formula for the perfect European family-sized hatchback. The GTI versions also helped to define the "Hot Hatch" market.

1975
VW GOLF
(GERMANY)

Hatchbacks are a staple of the European markets where many people can only afford one small car which has to serve many functions, including being easy to park.

THE MINIVAN

The thought of driving a minivan with imitation wood cladding sends a shudder down the spine of any young designer. However, the FWD, car-based architecture of the Chrysler Minivans was a stroke of genius, providing Americans with justification to once again drive large vehicles because these were efficient.

1985
CHRYSLER MINIVAN
(USA)

Ford and GM simply downsized their full-size vans with "on frame" body construction and RWD, which made them inefficient. Chrysler's passenger priority, unibody, and FWD architecture (like the Mini) changed the global minivan market forever, increasing sales by millions of units.

1969
First Moon Walk
(Neil Armstrong - USA)

1973
Oil Crisis
(OPEC)

1986 - 1988
FI Turbo Era
(Europe)

1989
Berlin Wall Falls
(Germany)

1990
Gulf War
(Middle East)

NEW MICRO CARS

The Smart car was designed specifically to offer safe, inexpensive, easy-to-park commuter transportation for two people. Its very short overall length is made possible by the 660cc engine that is packaged under the rear floor, a very strong "Tridion" body structure and a single row of seats. The ForTwo also fits into the Japanese "Kei" car segment which offers tax incentives to small, low-powered cars.

1990
SMART FORTWO
(GERMANY)

Ironically, perpendicular "nose first" parking is illegal in most European cities, so the Smart is unable to help solve chronic parking issues. This highlights the need for total transportation solutions. Significantly, the Smart is now sold in the USA.

X X LARGE

In the last year (2006) of the H1's production, it sold only a few hundred units. Although it was a specialist vehicle, it reset the bar for the size of large personal vehicles. Its original success in the US market was due to the role it played in the first Gulf war in 1990. With gas consumption around 10–12 mpg, it is not only great for helping to liberate oil-rich countries but also ideal for taking the kids to school in Detroit.

1992
HUMMER HI
(USA)

The average weight of vehicles is now much higher than it was in the '60s, mainly due to stricter crash requirements, improved performance and larger interior volumes. Many people also want to feel more secure while driving.

NEIGHBORHOOD ELECTRIC VEHICLES

US legislation allows certain types of vehicles to drive on public roads (35mph speed limit) without having to pass federal crash tests. This helps to reduce weight, cost and investment allowing NEVs to proliferate. The Gem seats 4 passengers, has a top speed of 25mph, a range of 30–40 miles and is very quiet. Most families own several different vehicles and the GEM helps to offset the cost and fuel consumption of larger cars.

1998
GEM E4
(USA)

Legislation and infrastructure play a big role in vehicle design. Today, many communities are growing up with provisions for neighborhood electric vehicles (NEVs) to help improve the quality of life for residents by reducing emissions, noise and anti-social driving habits.

1991
WorldWideWeb

1996
Google Founded
(USA)

2001
First iPod
(USA)

2001
9.11
(USA)

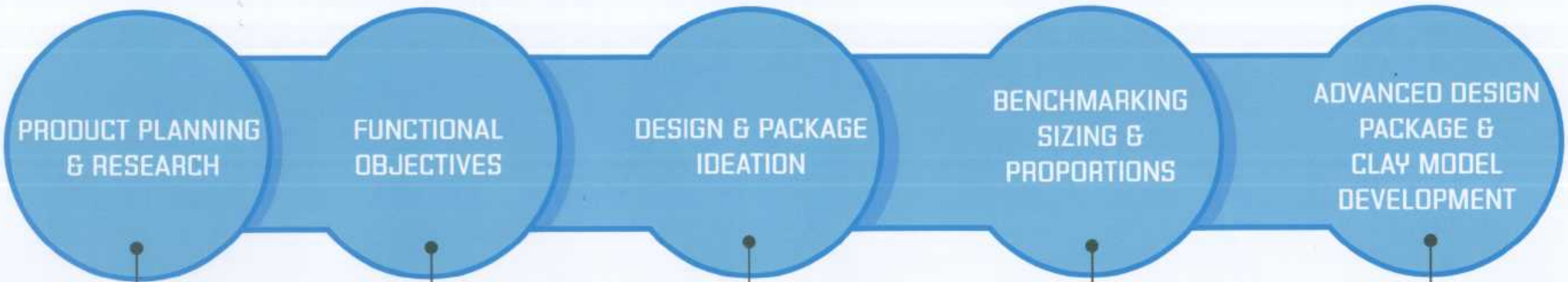
2003
War on Terror
(Middle East)

"Creating a concept from a blank sheet of paper can be very daunting for many designers. However, even though every project will vary, the basic principles and the key elements of the design process remain the same. Designing with a focused purpose and developing the architecture with a logical process ensures that every need is met."

GETTING STARTED | 01

THE ADVANCED CONCEPT DESIGN PROCESS

This stage usually takes 6 months to a year to complete. This mindset is different than the production phase, much looser and more progressive.



The process starts with researching the intended markets, customers and competition. Emerging technology and manufacturing strategies are also studied.

Primary goals for the project are set. These should be considered from both the customer and manufacturer's perspective.

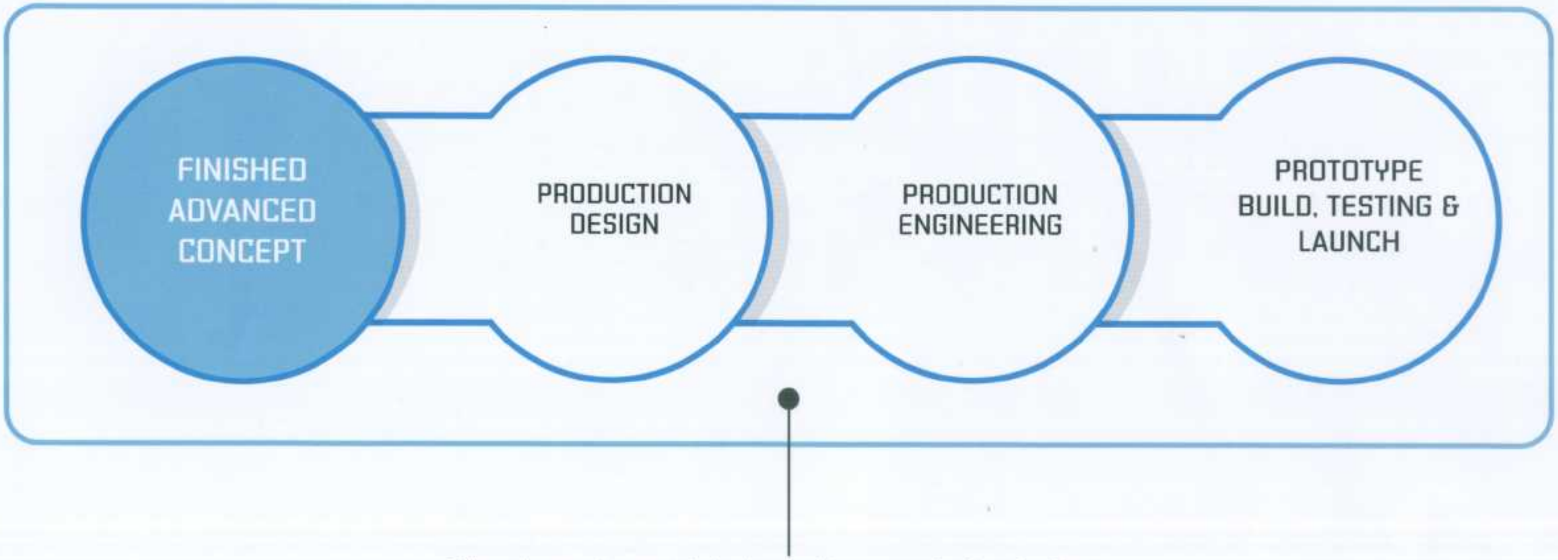
The basic layout of the major components and any innovative features are sketched loosely in various configurations.

Existing products with similar attributes are compared to validate the design direction. This process is used to establish the basic proportions.

Once the basic dimensions and hard points for the concept are formulated, the scale or full-size clay model is built and developed with the package.

THE PRODUCTION DESIGN PROCESS

This can be a three- or four-year timeline with usually one year in the studio. The final product must be 100% feasible, meeting all requirements for manufacturing and marketing.



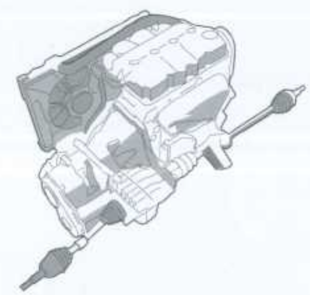
The advanced concept is handed to a production-design team. This group will develop the exterior and interior surfaces over a package that is 100% feasible for production and meets all of the cost targets, as well as the needs of the intended markets. After testing, a few minor design changes may be required.

SYSTEMS

Every package is comprised of the same group of systems (illustrated below). Each of these systems will vary greatly according to the functional objectives of the vehicle. Also, note that each of the components that make up the different systems is packaged within a spatial envelope, which allows for motion, manufacturing tolerances, clearances, heat insulation, maintenance and assembly.

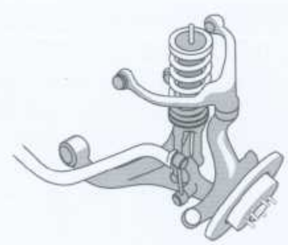
OCCUPANTS

INTERIORS & CARGO

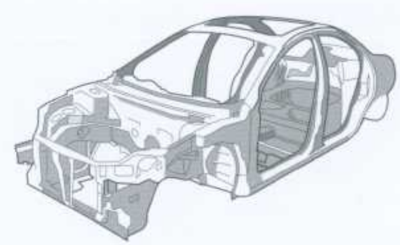


POWERTRAIN

WHEELS & TIRES



SUSPENSION & CHASSIS



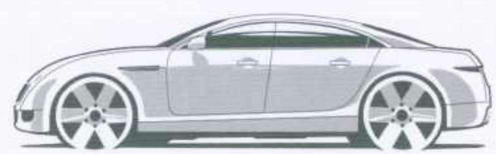
BODY

VEHICLE TYPES & MARKET SEGMENTS

At some point early in the design process, it should be decided which market segment the concept will be designed for. Quite frequently, a multi-functional concept is designed and will crossover to more than one segment. The market segment or vehicle type is often determined before the project is started, helping to focus the design team in a specific direction. For a "blue sky" project, the customer requirements may be the only consideration during the ideation phase and a market segment associated later. The latter approach can help to break paradigms associated with certain vehicle types.

MICRO CARS

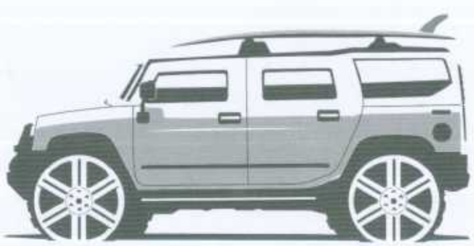
ECONOMY CARS



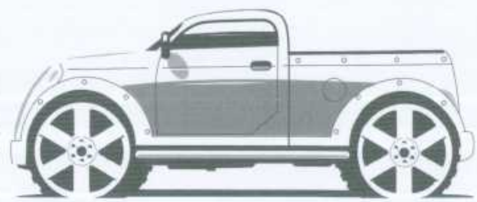
LUXURY CARS

SPECIALTY CARS

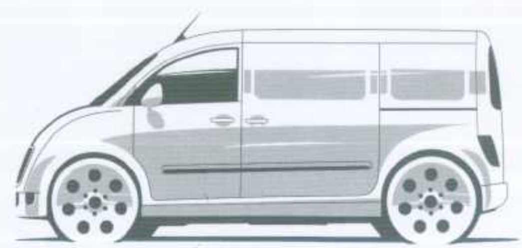
MINIVANS



SUVS



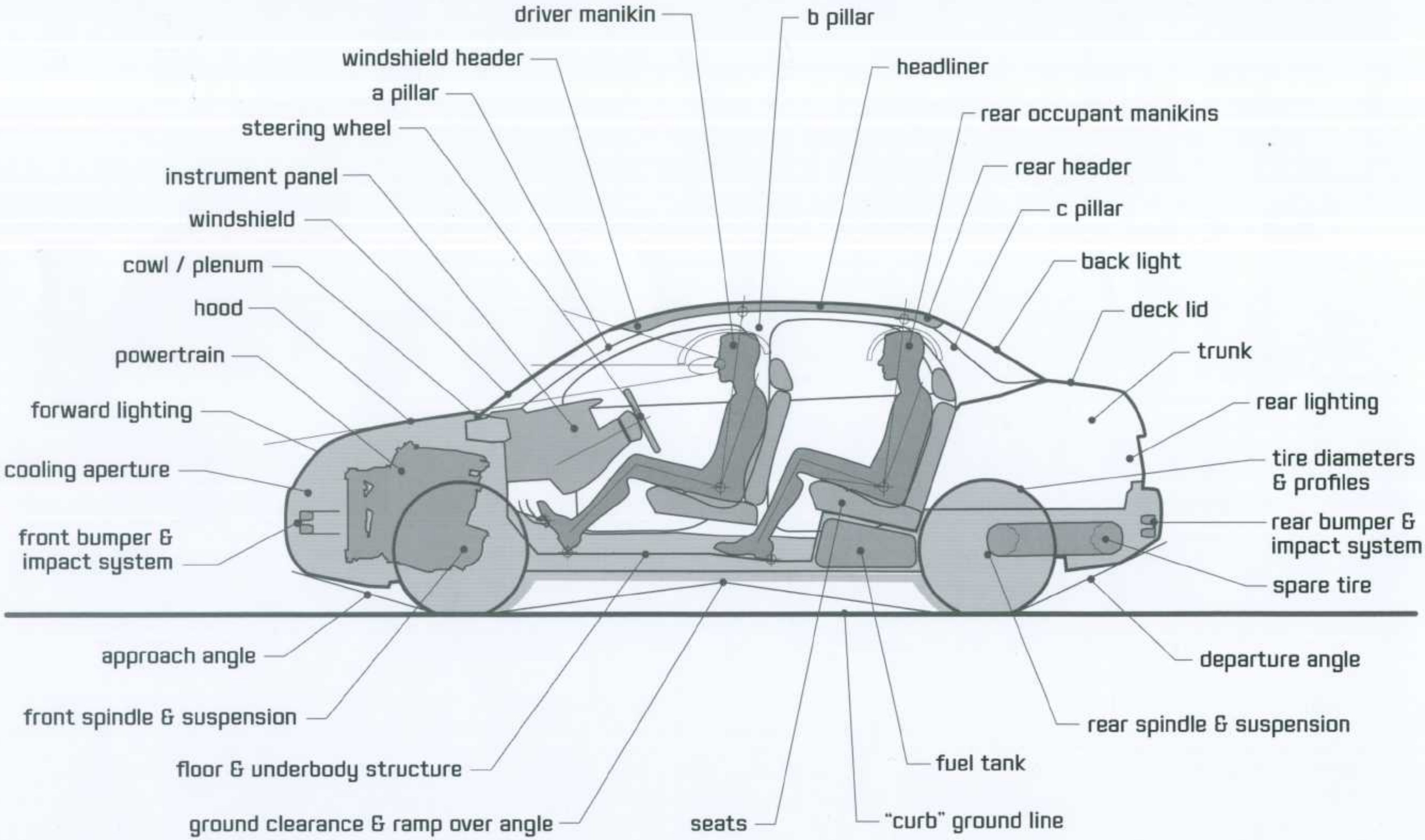
PICKUP TRUCKS

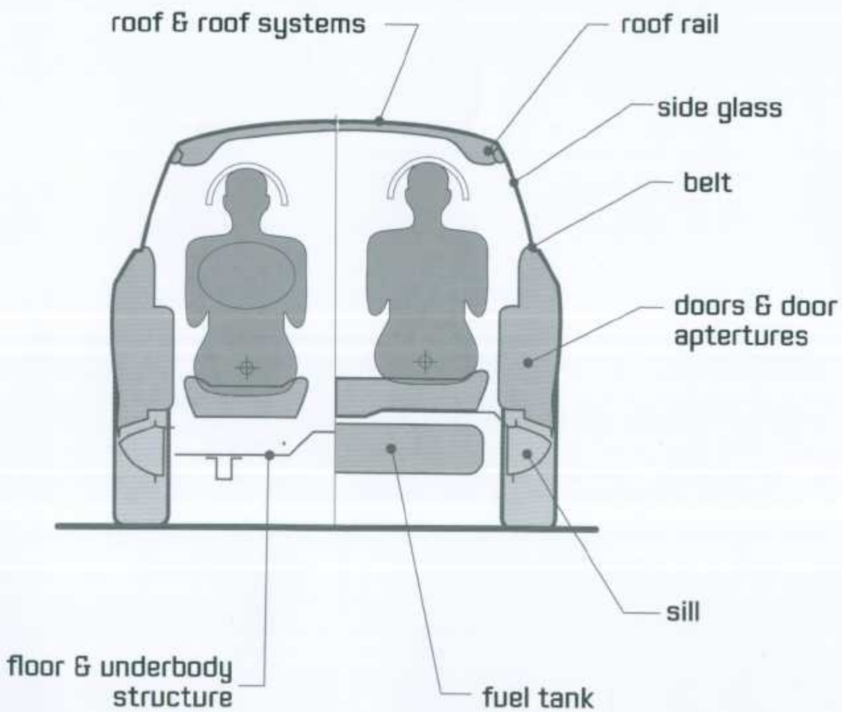


COMMERCIAL VANS

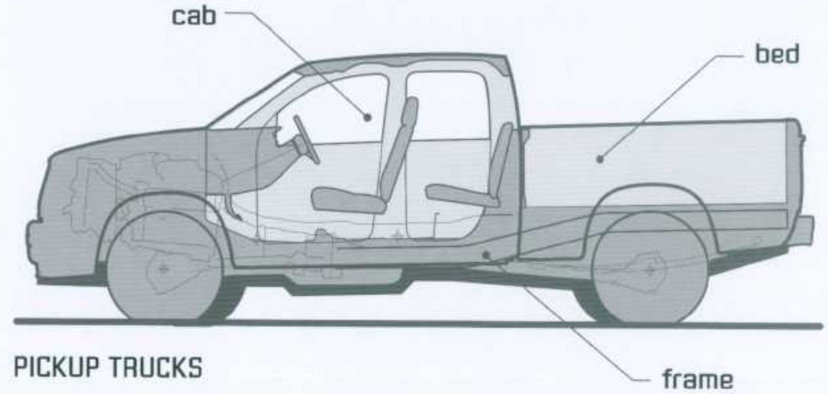
ANATOMY OF THE PASSENGER CAR PACKAGE

The elements in the package will vary from concept to concept, but the items shown in these illustrations feature in most vehicles. Each of these elements will need to be studied by the studio engineering team during the development of the project to provide a high level of confidence in the vehicle's design.

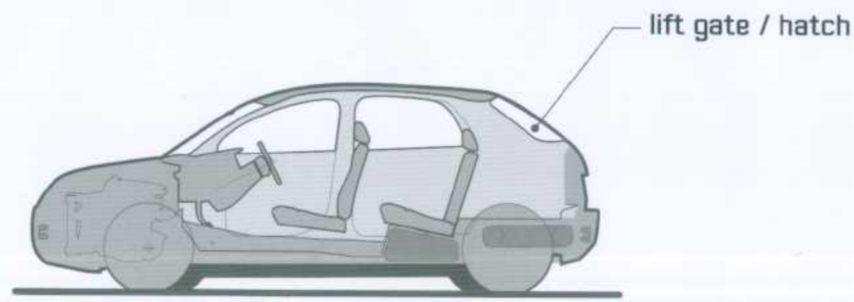




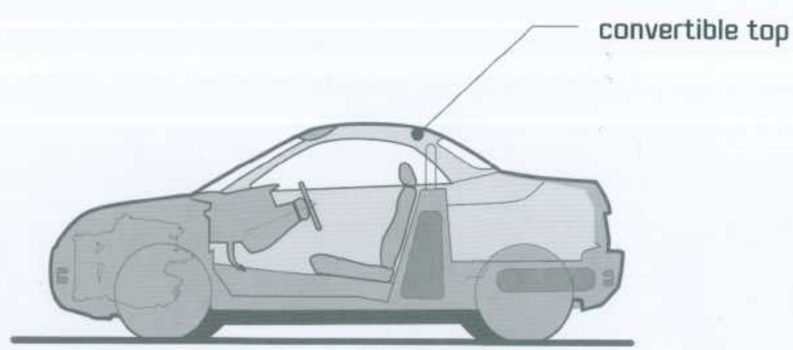
UNIQUE, VEHICLE-SPECIFIC FEATURES



PICKUP TRUCKS



HATCHBACKS



CONVERTIBLES

STEP-BY-STEP PROCESS

The initial package should be kept as simple as possible. Only a few elements are needed to set up the basic exterior hard points. Just like a design ideation sketch, do not try to include every detail or solve every problem. The main objective is to get started.

Fortunately, the bulk of a vehicle's proportions are established by only a few elements: the occupants, powertrain, tires, cargo storage, ground clearance and crash protection systems. These can be put together in a logical order, but expect to iterate the design continually. Try to think about which components will drive the package and which will be subordinate and why.

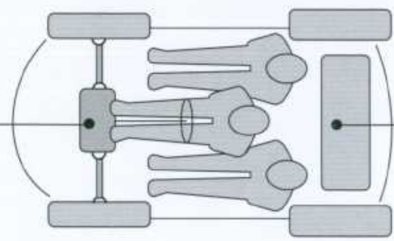
As each system is added, it is going to affect the elements already located in the package, so do not be afraid to start piecing the package together and making adjustments as the concept develops. Always be sure to reference the functional objectives that are driving the architecture. Usually, if you stick to sound logic, the package is quite simple to build and you will be able to defend the layout if it is ever challenged.

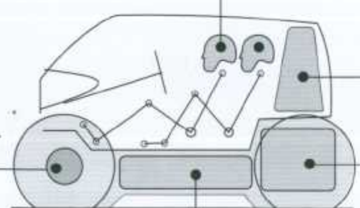
The examples, on the following nine pages, show how different types of vehicles can be approached with the same fundamental process even though they require totally different package solutions. Before creating the package geometry, loosely sketch out the package and arrange the major components based on the functional objectives.

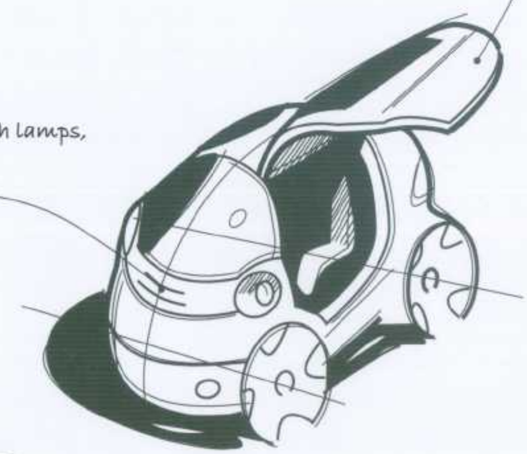
STEP 1

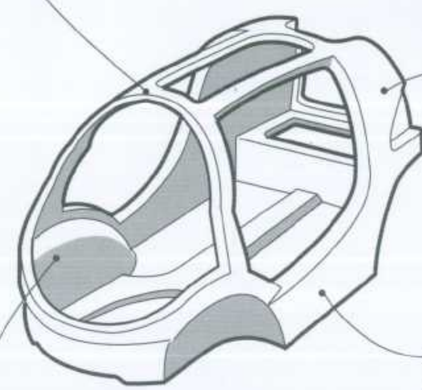
PACKAGE & DESIGN IDEATION

Loosely sketch out several package concepts based on the functional objectives. Include layouts of the occupants, cargo, powertrain, wheels and fuel. Also, think about the body structure and closures (doors) and any other special features that may influence the package.









STEP 2

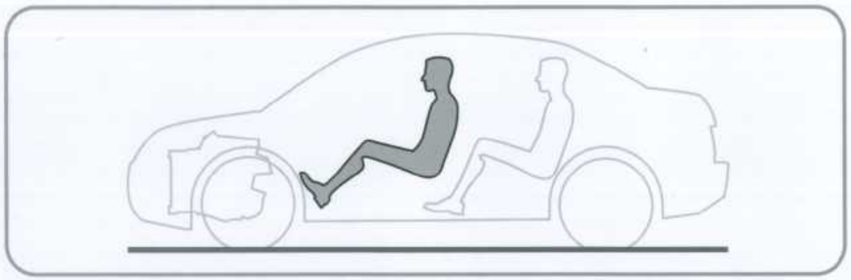
SET UP THE DRIVER'S HEIGHT & POSTURE

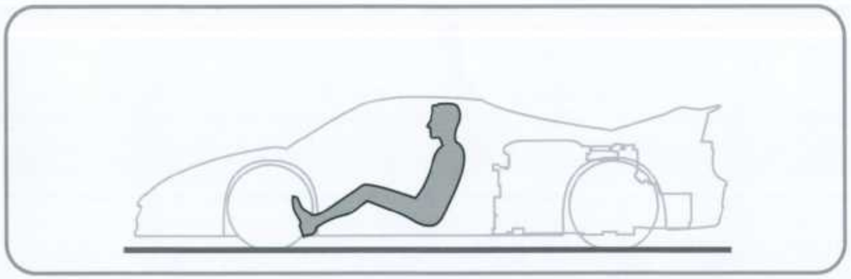
Start by positioning the driver using the SAE 95th percentile manikin. Establish the heel height from the ground and then the seating posture.

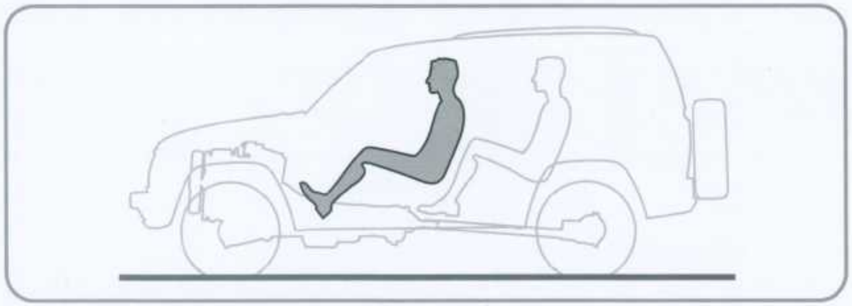
Consider the ground clearance and underbody structure when positioning the heel points. Before setting up the seating posture, think about the following: downward visibility, command-of-the-road seating (eye point from ground), center of gravity, ingress/egress and aerodynamics.

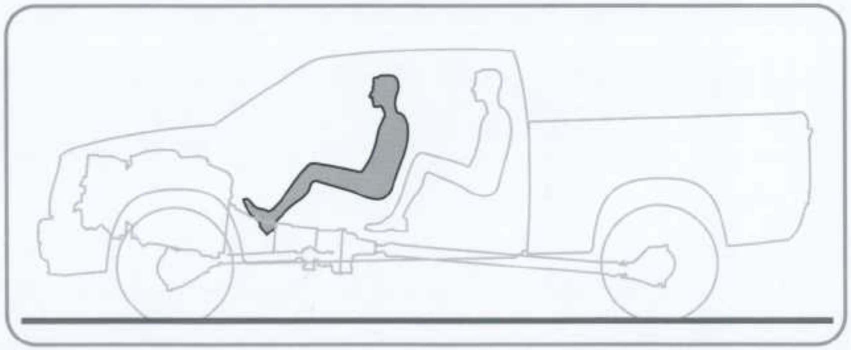
Probably the best way to get the driver location close is to look at existing vehicles with the same attributes and benchmark them.

See Chapter 4 for more information on benchmarking.









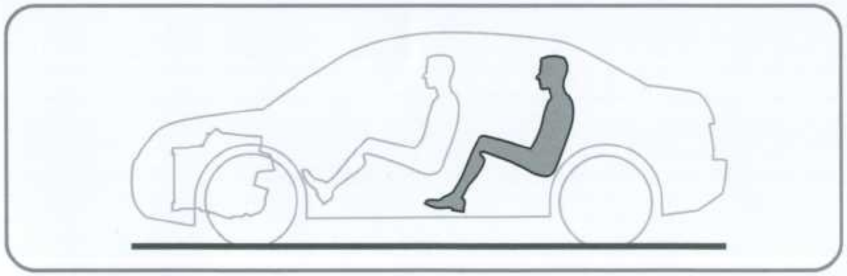
STEP 3

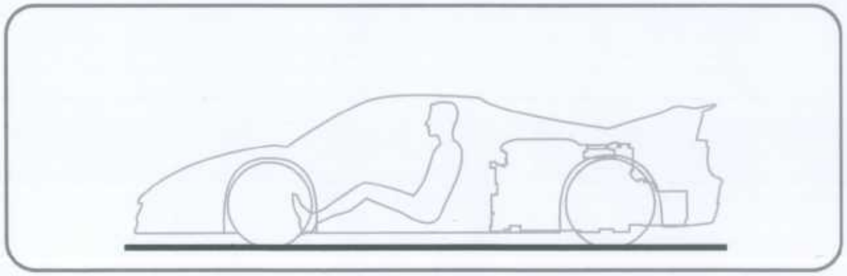
SET UP THE REAR OCCUPANTS

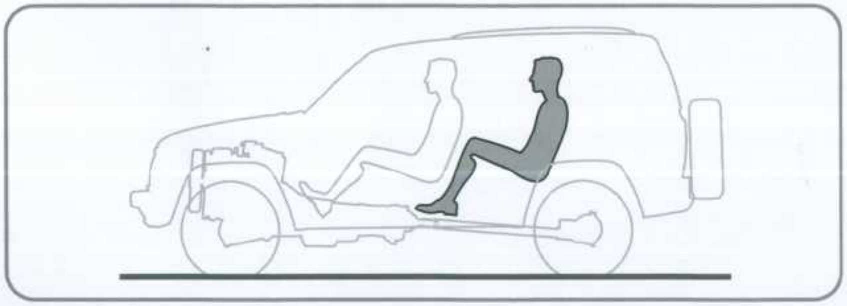
Add the rear occupants if there are any. Again, use a 95th percentile manikin with consideration for leg room and "theater" seating, if appropriate, to give the rear occupants better forward visibility.

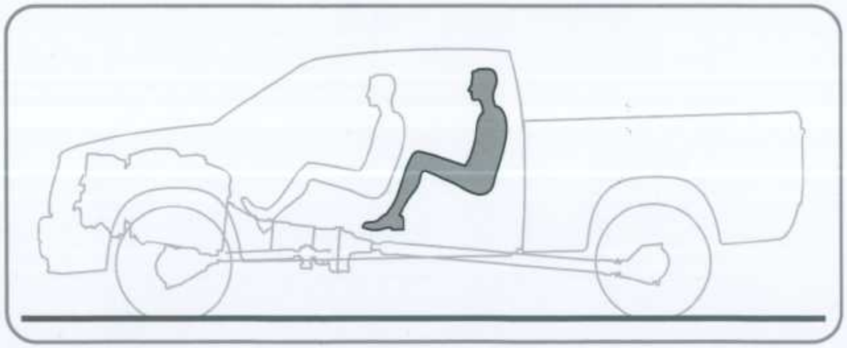
Note that some specialty cars, such as coupes or very small sedans will not fully accommodate a 95th percentile manikin in the rear.

With both manikins placed, establish a spacial envelope around them and develop visibility goals. Look at the effective headroom and shoulder room first, then look at the up and down angles through the windshield apertures. Any other important relationships to the occupants should be noted at this stage.







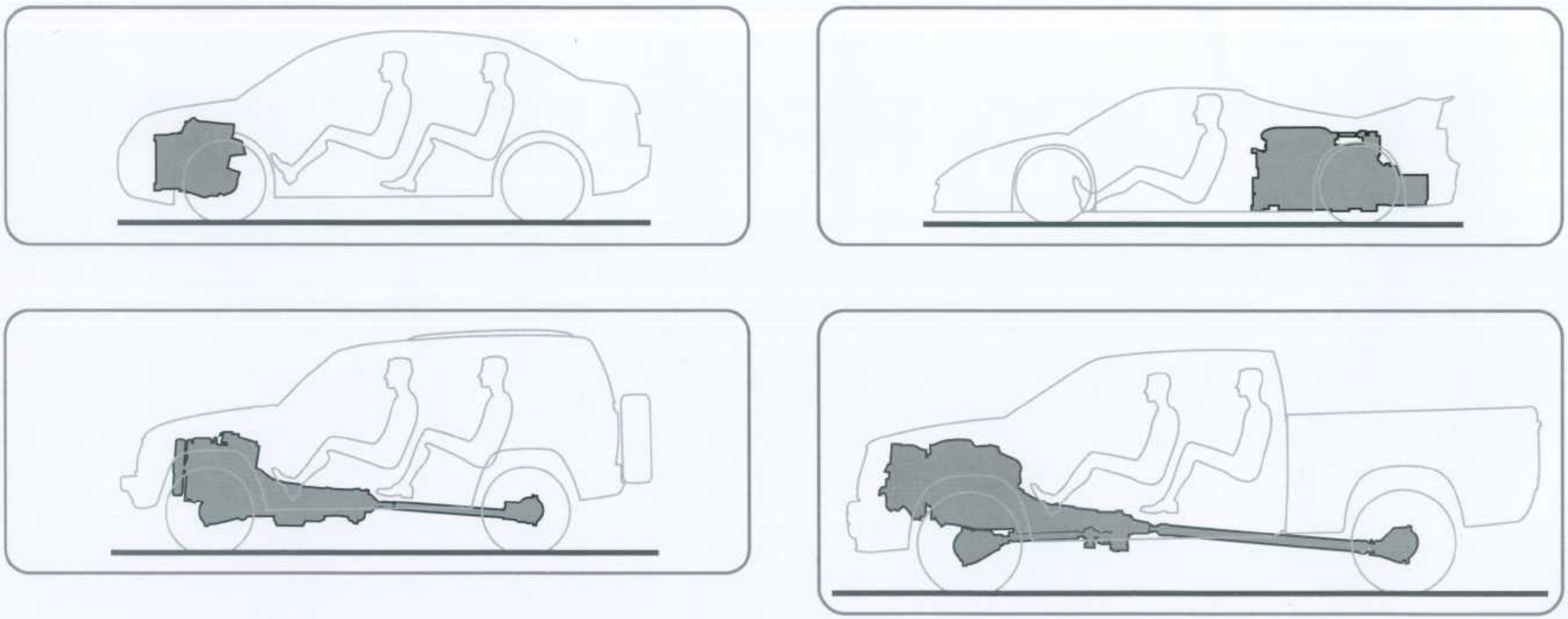


STEP 4

SELECT AND INSTALL THE POWERTRAIN

Select and position the powertrain (engine, transmission and final drive). The choice of system may have a dramatic effect on the proportions. Choose it based on the amount and type of power required and also think about which wheels will be used to feed the power to the ground.

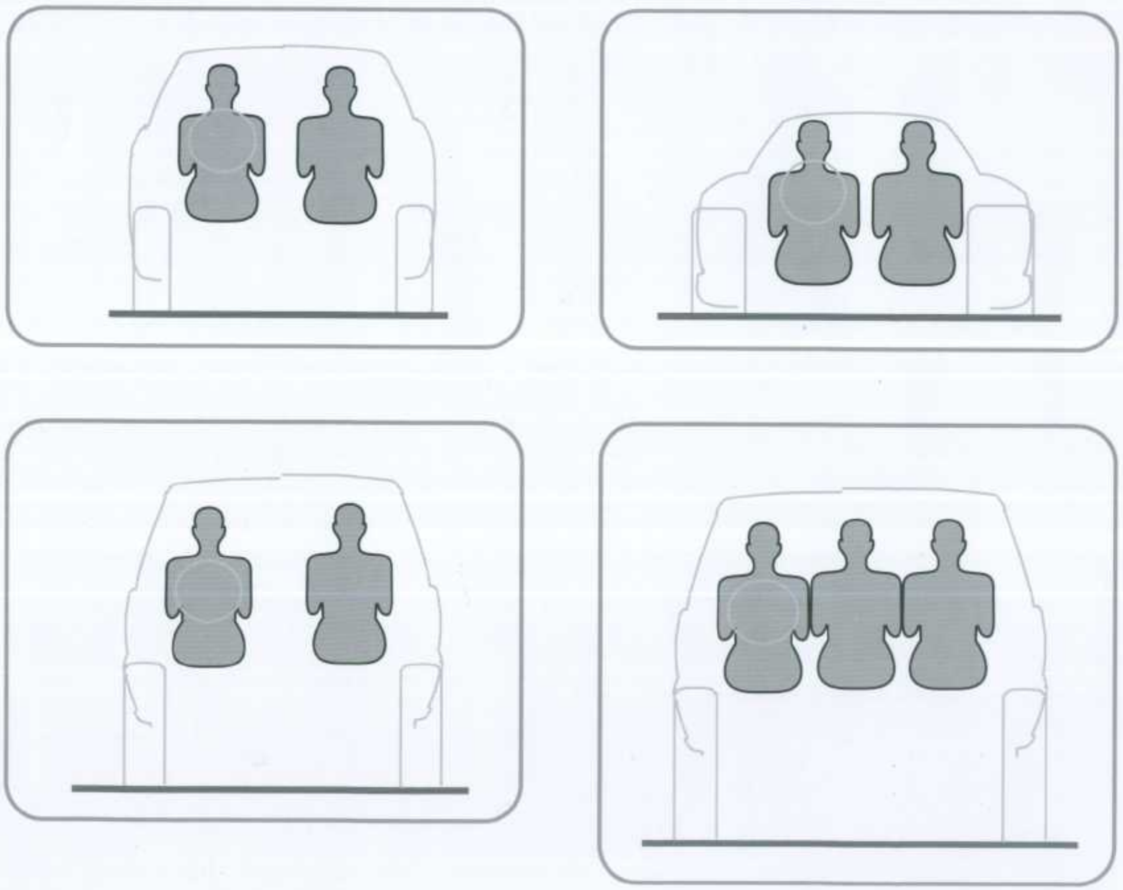
See Chapter 7 for more information on powertrain packaging.



STEP 5

SET UP THE OCCUPANTS' LATERAL LOCATION

After the powertrain is positioned, set up the lateral position of the occupants. Consider the overall width limitation and the interior environment expectations for the type of vehicle you are designing. The location of the manikins may also be affected by the powertrain, aerodynamics, passenger pass-through and three-across seating.

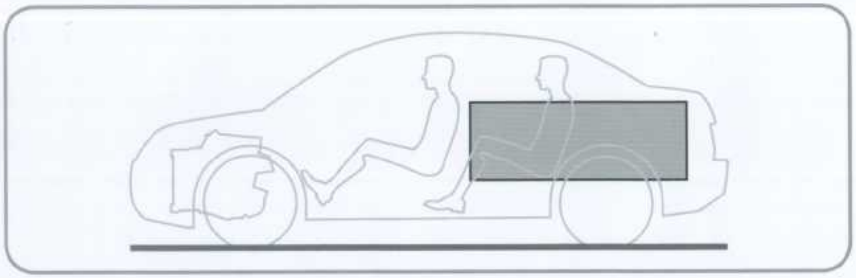


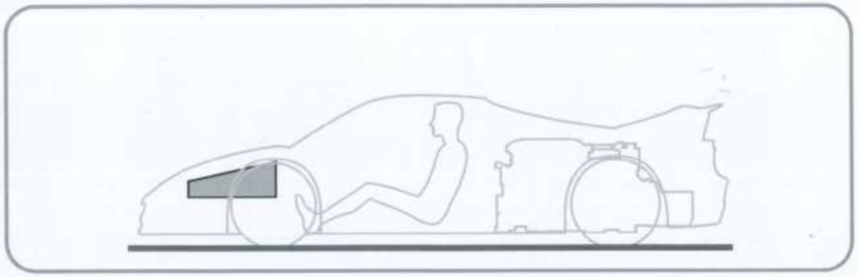
STEP 6

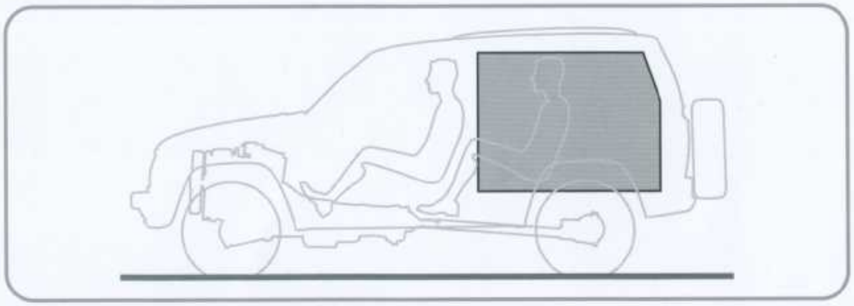
CREATE SPACE FOR THE CARGO

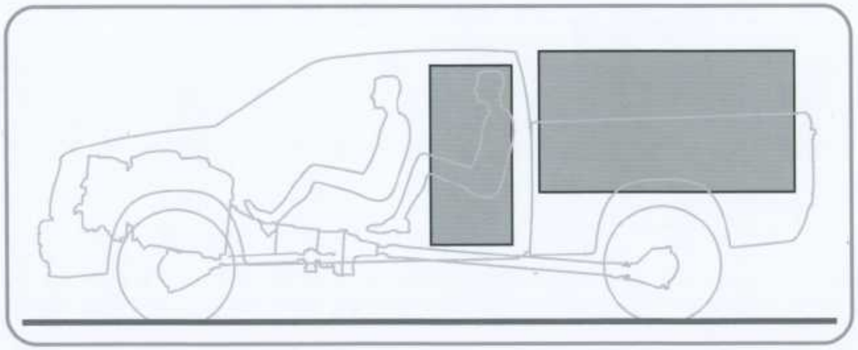
The cargo space may be designed around specific objects or a volume target. Look to create a flexible interior environment with folding seats and bulkheads. Weight will also be a consideration and this may affect the location and other elements in the architecture such as the body structure and suspension.

Refer to Chapter 6 for more information on cargo packaging.









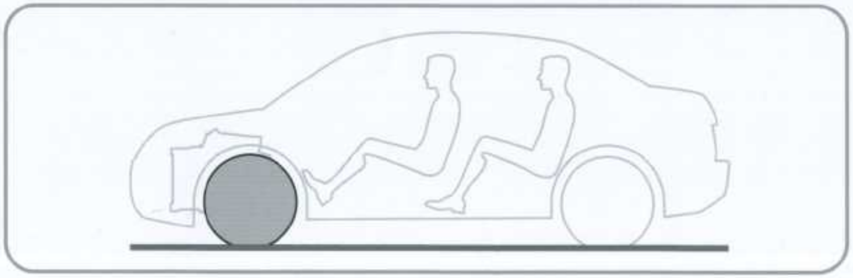
STEP 7

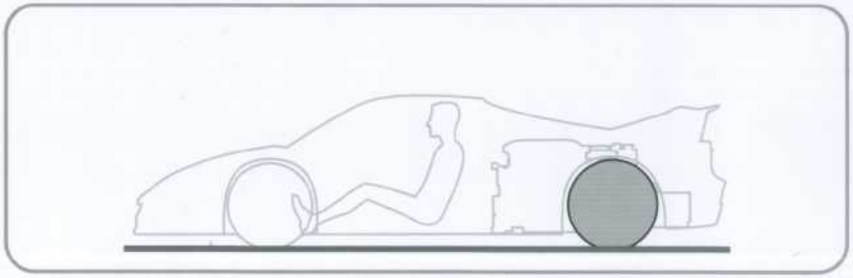
SIZE & POSITION THE (PRIMARY) DRIVEN WHEEL

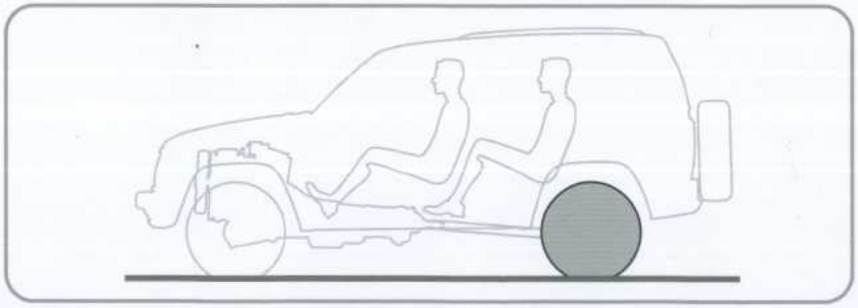
Determine the size of the wheel and tire package and locate the spindles of the driven wheels relative to the occupants and powertrain.

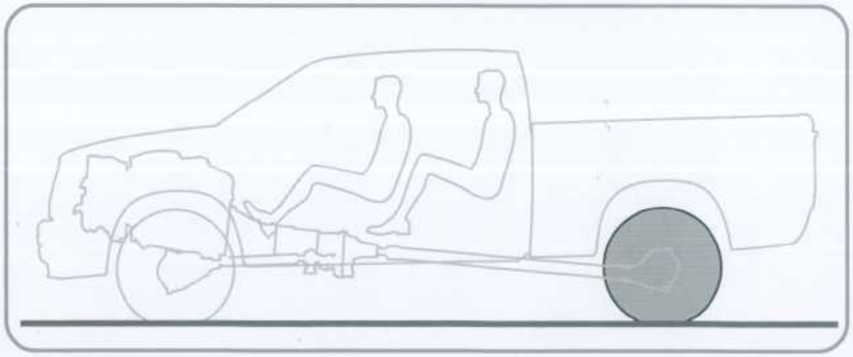
Study the packages below and note the relationship of these elements. They will differ greatly depending on the powertrain layout.

See Chapter 8 for information on wheel & tire choice and set up.







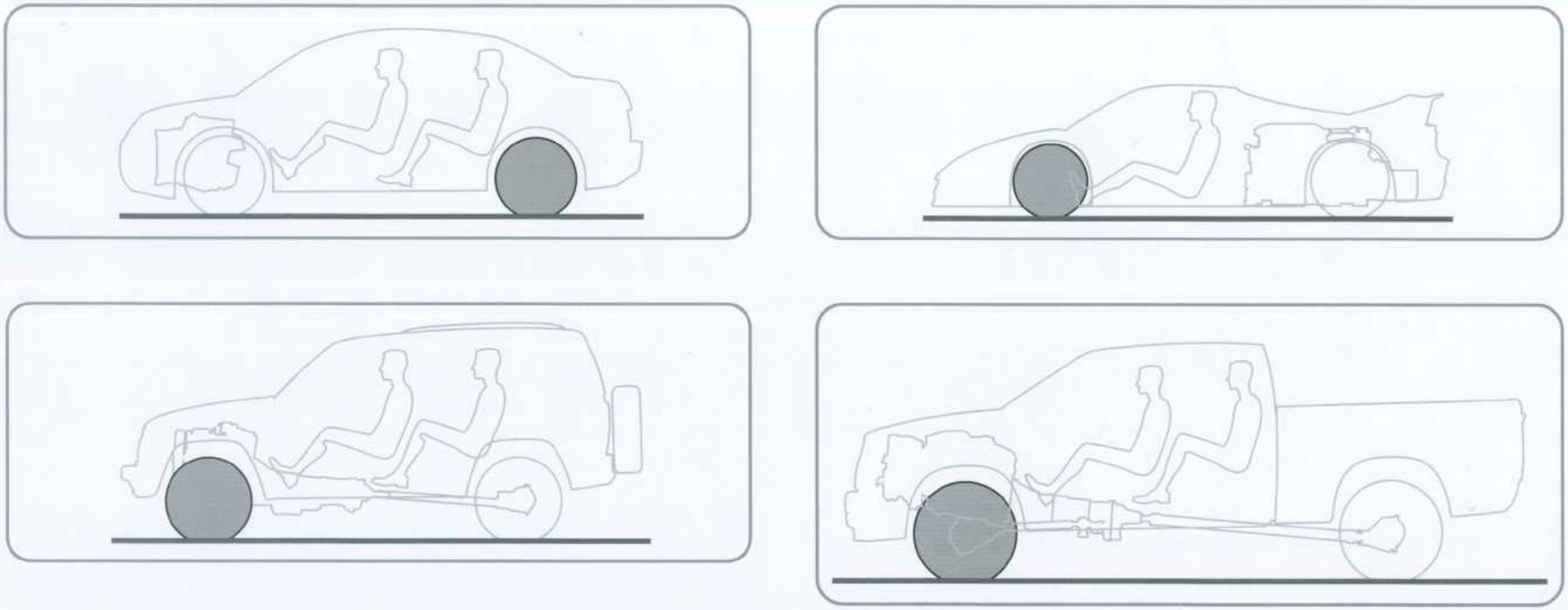


STEP 8

ESTABLISH THE WHEELBASE

The location of the other wheel/axle will depend on weight distribution or package efficiency. For smaller economy cars, the wheels will be as close to the occupants as possible. For high-performance or luxury cars, the wheelbase will be set up to improve handling or comfort. Trucks and commercial vehicles need to place the wheels under the cargo area, to limit the effects on the steering when the vehicle is loaded.

See Chapter 4 on size and proportion to help set up the wheelbase.

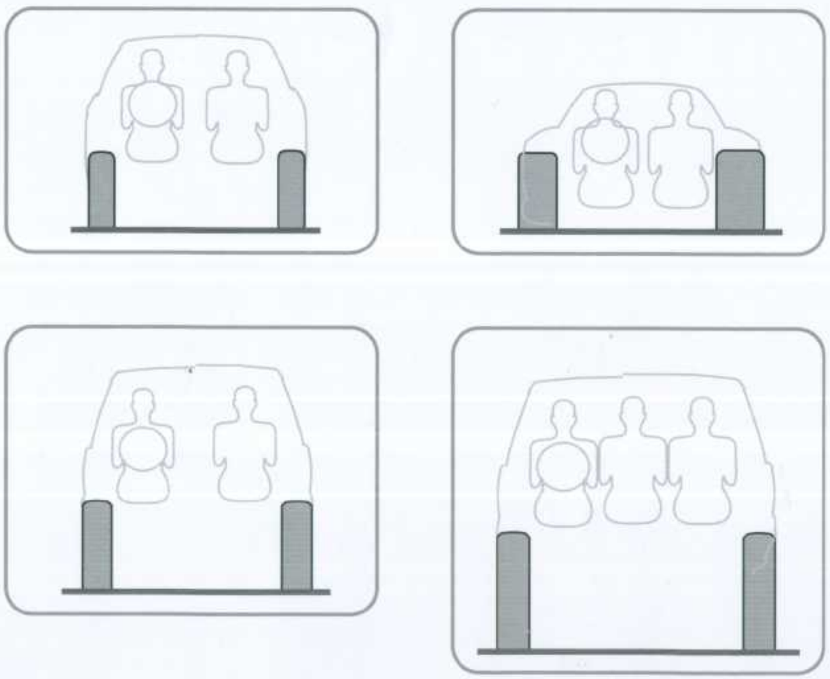


STEP 9

SET UP THE FRONT & REAR TRACKS

Although designers usually prefer the wheels to be as far outboard as possible, the track will be limited by the vehicle width target. The occupant package, cargo requirements or handling targets may also push the wheels outboard.

See Chapters 4, 6 & 9 to understand some of the factors that govern the track.

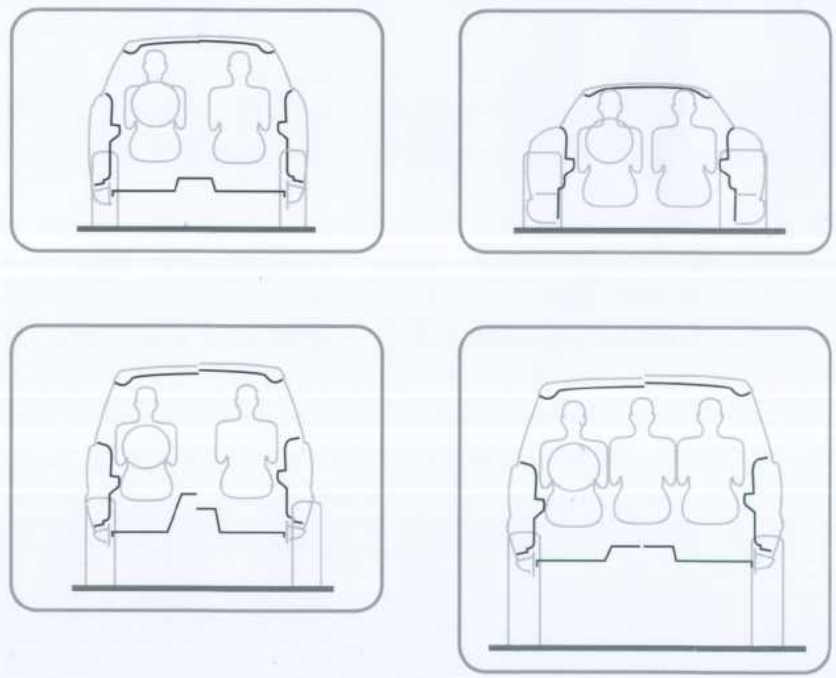


STEP 10

CREATE THE BODY AND INTERIOR TRIM SECTIONS

Develop the body and interior sections throughout the package. The body structure, door configurations and interior design will influence the exterior surface.

See Chapters 6 & 10 for more information on body architecture and interiors.



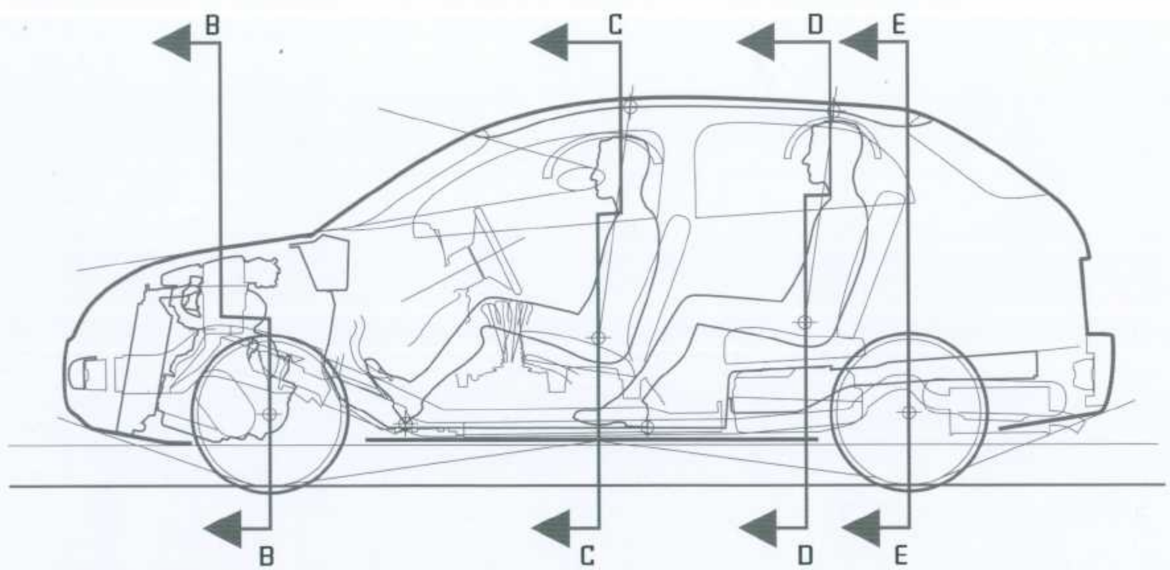
DESIGNING WITH SECTIONS

The bulk of the advanced package and the body is developed in five "Sectional Views" (multiple sections in one view) which are cut through the major elements of the package—i.e., the hip points (H-points), spindles, powertrain, fuel tank and the cargo compartment.

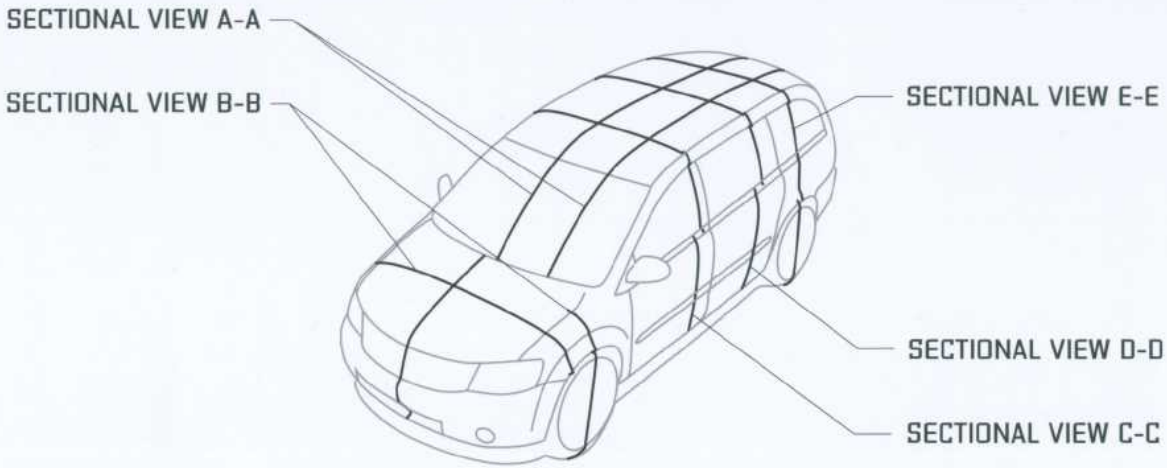
As the package progresses, more sections will be created around the vehicle, but to get the initial concept started, it is important to keep the studies as simple as possible.

The main objective here is to establish some of the main hard points, so that the exterior design can be modeled over the key elements of the package, developing the body structure as each section is constructed.

Every type of vehicle has special requirements and the location of the sections may vary. The engine may be in the rear or under the floor for some cars. For example, pickup trucks will need to be designed around the bed and the cab.



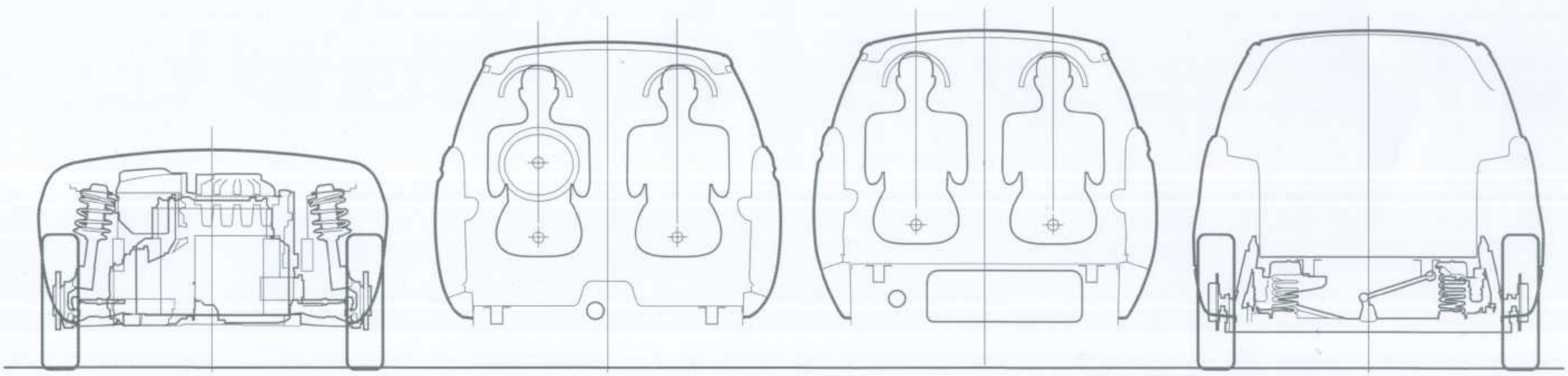
SECTIONAL VIEW A-A
This sectional side view is cut through the centerline of the body and the occupants. The other elements are shown to create a "picture" of the initial package layout.



The five main sectional views are cut through the major elements of the package. Because most vehicles have a lot of curvature in their surfaces, multiple sections are put in each view to form a simplified picture of each zone of the package.

For example, in the side-view section A-A, the vehicle outline is shown at the YO (Y-zero)* centerline. The occupants are also shown in this view with a section through the headliner at the occupant centerline. The headroom is cross-referenced and accurately illustrated in the rear-view sections.

*The Y-grid plane runs along the centerline of the car. Anything on-center is therefore located at YO.



SECTIONAL VIEW B-B

Cut through the front spindles and engine, this section is used to help prove out the front suspension and engine package under the hood and fenders.

SECTIONAL VIEW C-C

Cut through the front occupants' H-points and head contours, this key section is created to set up the door panels, side glass and roof-rail sections. Other elements like the roof over the head environment, sills, floor and underbody structure are also included here.

SECTIONAL VIEW D-D

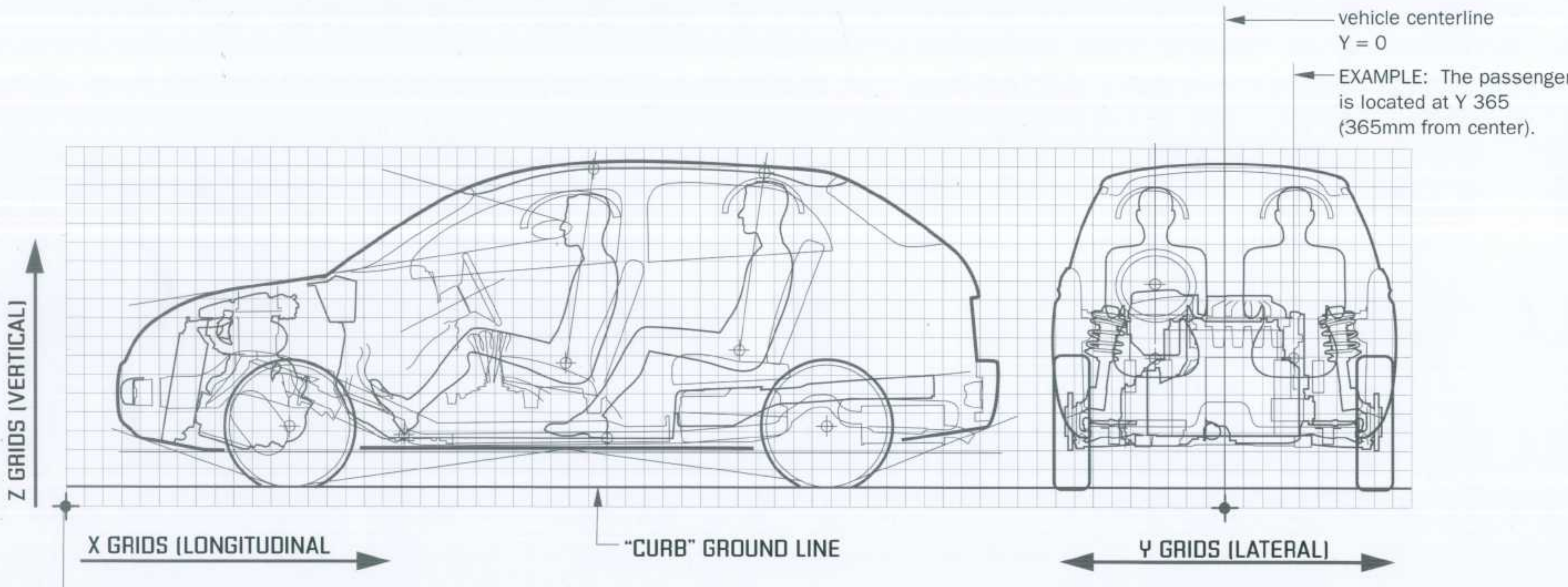
Cut through the rear occupants, this is similar to the section through the front occupants but here the fuel tank is often included under the rear seat.

SECTIONAL VIEW E-E

Cut through the rear spindles, this shows the cargo bay and the rear suspension system. Other items such as the exhaust system and spare tire may also be featured.

GRID PLANES (LINES) SAE J183

The package is built in a 100mm three-dimensional grid which becomes the master vehicle grid system throughout the project's life. This XYZ grid is created by the intersections of a series of horizontal, longitudinal and lateral planes. The grid reference system is used as a reference between the CAD (computer-aided design) models (or drawings) and the clay models. The location of the vehicle components and section cutting planes are also referenced to the grid.



GRID ORIGIN POINT

X = 0
Y = 0
Z = 0

The GRID ORIGIN POINT should be located out in front of the bumper and below the ground. Once created, it will always remain in the same place relative to the package. If the ground line is modified and pushed away from the body or the front fascia is moved forward, they will not move to a "minus" grid coordinate.

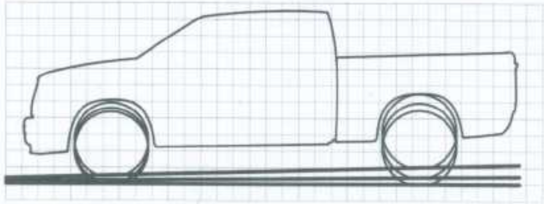
GROUND PLANES (LINES)

During the design process, the body, powertrain, occupants etc. maintain their location in the grid system. The ground line, however, is repositioned according to the location of the tire contact patch. (This is opposite to the real world where the vehicle moves up and down on a fixed road). Three different factors will cause a variation in the relationship of the vehicle to the ground line:

1. Loading (attitude)
2. Tire size variation
3. Ride height settings

These are illustrated below: Each require their own set of ground lines. There are several reasons to create a ground line for each condition. Maintaining the required ground clearance is one reason. Measuring the vehicle's overall height and step-in height is also a very important factor to consider.

Most vehicles are designed and modeled at "CURB" attitude.



VEHICLE ATTITUDES

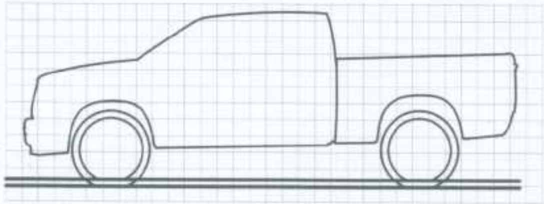
As the vehicle is loaded, the ground line will move closer to the body. The three ground lines or attitudes shown here are:

1. Curb — no passengers, full fluids.

2. Full rated — fully loaded to the gross vehicle weight (GVW).

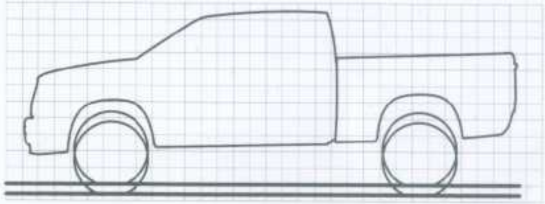
3. Full jounce — fully compressed suspension.

These are the three main attitudes used in the design process to check that the vehicle is meeting all the height and clearance requirements.



TIRE SIZE

Most vehicles are offered with several wheel and tire packages. This often results in several different tire diameters. If the suspension system is not adjusted to each tire, the vehicle's relationship to the ground will vary.

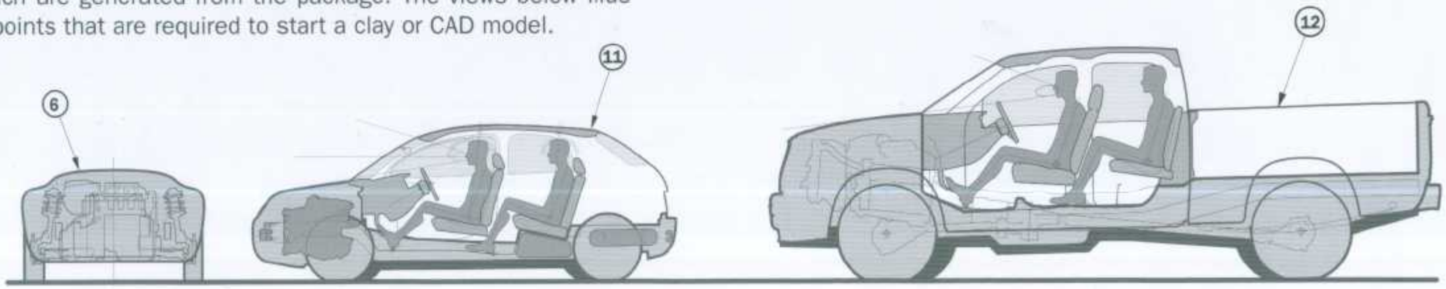


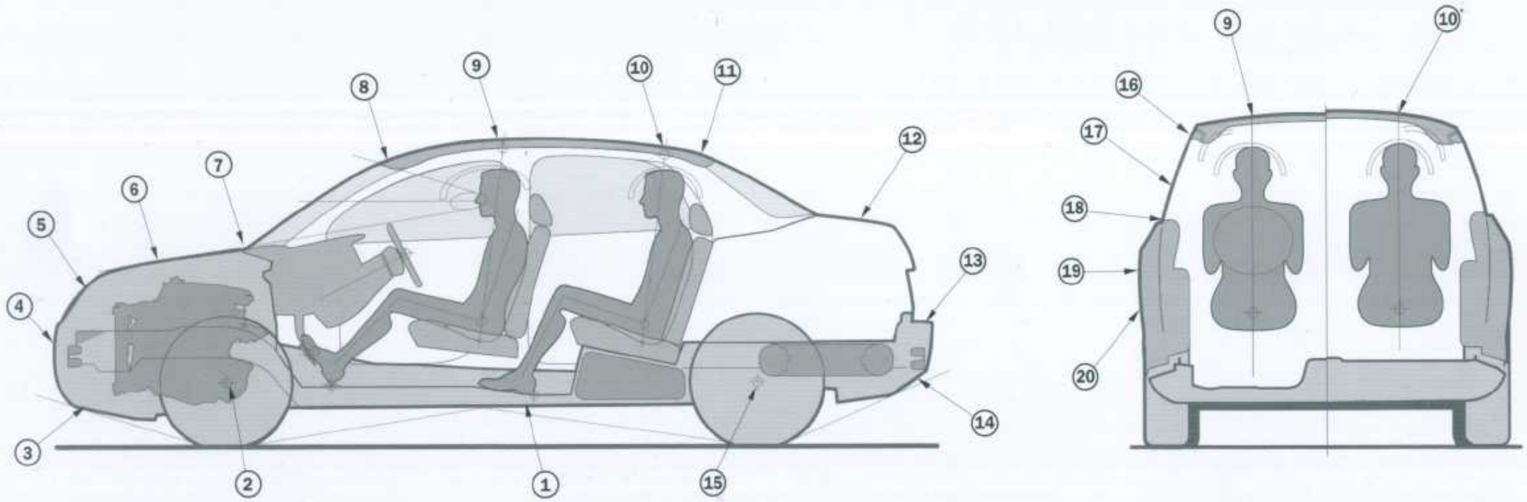
RIDE HEIGHT

Vehicles with on-road and off-road packages will usually have two or more suspension settings to improve the vehicle's performance in its intended environment.

KEY HARDPOINTS

A primary function of an automotive studio engineer is to feed the design team with hardpoints, which are generated from the package. The views below illustrate the main hardpoints that are required to start a clay or CAD model.





1. SILL & FLOOR HEIGHT Determined by the ground clearance, the ramp-over requirements of the vehicle and the underbody structure depth. The lowest point of the vehicle is often a chassis or powertrain component.

2. FRONT WHEEL AND TIRE The front spindle height is determined by the static load radius of the tire. Longitudinally, the jounce-and-turn tire envelope will establish the distance of the front spindle from the driver's foot. It may also be moved further forward to influence the weight distribution of the vehicle. Also, the output shaft location from the transmission will be a consideration for front-wheel-drive (FWD) vehicles. The track is determined by a combination of the distance between the front structure frame rails and the tire turn envelope. Tire size will be limited by body size, suspension components and the vehicle's turning circle.

3. CHIN HEIGHT The chin should clear a 162mm-high parking block. A 10° approach-angle line (when the vehicle is fully loaded) is recommended for passenger cars. Above 28° is required for off-road vehicles.

4. FRONT BUMPER LOCATION For passenger cars, the bumper system height must cover the "bumper band" which is generally mandated to be from 406mm to 508mm above the ground. The longitudinal location must provide enough crush space in front of the occupant's feet to meet high speed (40mph) frontal impact requirements. Any object which will not compress on impact—i.e., the engine, transmission, steering rack, etc.—is added to this dimension. The offset of the bumper impact surface to the body and lamps will depend on the collision requirements and the manufacturing cost limitations of the system. To meet low-speed impact requirements, bumpers with average cost and weight will require about 50–70mm of offset, but it is worth benchmarking vehicles with smaller offsets. For European cars, the front fascia profile should be shaped to meet pedestrian impact safety requirements for that continent.

5. LEADING EDGE Usually the cooling module affects the height and horizontal location of this point. Additional space is required for the hood latching structure.

6. HOOD PROFILE Influenced by the position of the engine induction system (manifolds, throttle body, etc). Recent European pedestrian head impact legislation has increased the required hood clearance to hard components. Toward the outboard edges, suspension towers often affect the hood height.

7. COWL / WINDSHIELD TOUCH DOWN The cowl height is limited by hardpoints generated from the engine clearance envelope and driver visibility. A downward vision angle of less than 6° may be a problem for shorter drivers. Longitudinal locations are controlled by engine maintenance access issues (forward) and proximity to controls (rearward) If the windshield is too far from the driver's eye point the A pillar may affect forward vision. An aggressive windshield installation angle may result in distorted vision (65° from the vertical is about the maximum, guaranteed to avoid distortion with current glass technology).

8. WINDSHIELD OPENING & HEADER Determined by the head to headliner relationship, header structure and head impact foam thickness. The upward vision angle will help to set up the header location. An upward vision angle less than 11° is considered a compromise.

9. FRONT ROOF Should provide appropriate room over the manikin's head form for head clearance, trim and a sunroof if required. The roof should be as low as possible to reduce weight, lower the center of gravity and minimize frontal area to reduce aerodynamic drag.

10. REAR ROOF A similar condition to the front headroom is desirable. Many vehicles however will compromise rear headroom to allow for a lower or faster roof line. This is common in sports coupes and in the third row of an SUV where occasional seating is provided.

11. REAR HEADER Similar to the front header. Hatchbacks will require additional structure in order to accommodate the mounting of the rear lift gate hinges.

12. REAR CARGO Most vehicles will have some cargo storage; for some it is a high priority. The height of the cargo area is governed by the size of the objects that are intended to be carried and the target storage volumes. Rearward visibility will also limit the deck and bed heights

13. REAR BUMPER LOCATION Similar height requirements to the front bumper but with additional consideration for load height variation which is greater at the rear. Rear impact requirements influence the rearward location of the bumper beam. The height of the fascia panel (bumper skin molding) will affect the lift over height for loading cargo.

14. BODY REAR LOWER (Departure angle). Can be less than the approach angle, (20° for off-road vehicles). Often the lowest parts of the car behind the rear wheels are the exhaust system and spare tire.

15. REAR SPINDLE The track and height are set up in a similar way to the front. The longitudinal location is normally as close to the rear occupant as the tire envelope will allow. In the case of a cargo truck or minivan, weight distribution will be a factor.

16. ROOF RAIL SECTION The outer skin of the roof rail is established by a stack up of several internally positioned components, while providing adequate clearance to the occupant head form. The section through the rail will comprise the body-in-white (BIW) structure, the door frame, head impact protection, and trim. Additionally, side curtain airbags may be packaged. The type of door construction used will affect the size and shape of the roof rail section.

17. SIDE GLASS Usually a radius, but occasionally flat. The upper location is set up by the roof rail design and location. The offset to the roof rail section depends on how it is constrained by the door system. The lower point at the belt line is positioned to provide adequate shoulder room and ensure that the glass will drop inside the door's outer profile.

18. BELT-LINE LOCATION The height and width can be driven by the exterior design, but the relationship to the occupant should be a consideration. The height relative to the occupants can be checked against benchmark vehicles to ensure that it is not too extreme. Adequate shoulder room should be provided to the door inner panel.

19. BODY SIDE PROFILE Must be designed to allow the glass surface to drop inside the door section, missing all of the hardware and obstructions within the door assembly.

20. WHEEL COVERAGE Most vehicles will be designed to meet European wheel coverage requirements. This standard requires that the body work covers the outboard edge of the tires in a zone between a line 30° (from vertical) forward of the spindle and 50° rearward.

PACKAGE DRAWING AND VISUAL COMMUNICATION

The initial package is developed accurately in a 3D CAD system, but as it progresses it should be clearly communicated to everyone involved in the project. This can be done effectively in a 2D graphic format.

The drawing on the opposite page is an example of a typical package logic board. It contains details about the package and the functional objectives that are driving it. Its goal is to describe the logic behind vehicle architecture so that the design team can make good decisions to steer the project.

The main views are graphic representations of the architecture with all of the major systems illustrated and described in detail. The vehicle dimensions are also included and benchmark comparisons to other vehicles are drawn to help put the concept into context. The benchmarks also prove out the feasibility of controversial proportions

A more detailed example of a package logic board is shown on pages 216–217. Benchmarking is covered on pages 82–85.

SAMPLE CONCEPT PACKAGE LOGIC DRAWING

A Brief Description of the Concept

BRAND LOGO

BENTLEY CONTINENTAL GT

Similar overall length and width

(lined up at ground and bumpers)

ASTON MARTIN DB9

Similar Height & driver seat height

(lined up at ground and driver H point)

MERCEDES CLS

Similar head environment

(lined up at drivers head)

PORSCHE BOXSTER

Similar powertrain layout and relationship to the occupant.
Similar occupant height from ground.

(lined up at H point or rear spindle)

INTERIOR

Draw the basic outlines for the main interior components such as the floor, I.P., steering wheel, seats, headliner and door trims. Show unique features such as folding seats, storage systems, etc.

BODY CONSTRUCTION

Describe the type of body construction and materials. Also state where each material is used.

BODY CLOSURES

Add information about the doors and other closures such as the hood and tailgate.

DRIVER

Use the SAE 95th percentile male driver manikin. Describe the driver seating position, lateral location and environment.

REAR OCCUPANT

Use the SAE 95th percentile male passenger manikin. Describe the seating position, lateral location and environment, note the relationship to the driver (couple).

POWERTRAIN

Describe the engine size, configuration and orientation. Also add information about power output, number of gears (speeds) and which wheels are driven.

ALTERNATIVE ARCHITECTURE

Show additional scaled down views to illustrate alternative solutions or different package configurations.

CARGO

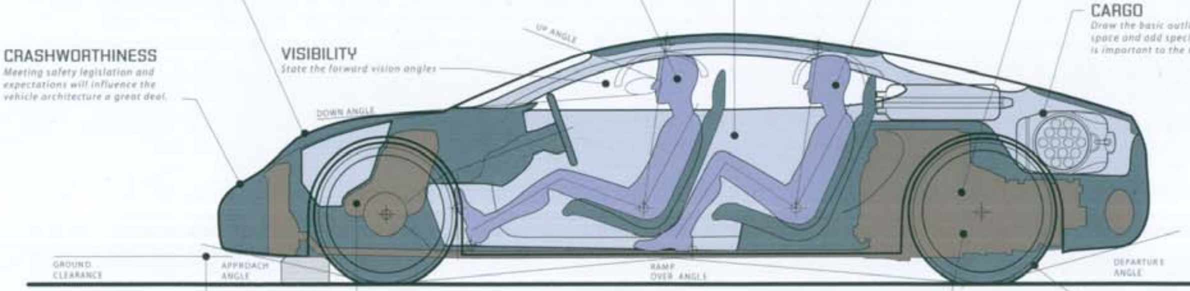
Draw the basic outline of the available cargo space and add specific items to be stored if it is important to the story of the package.

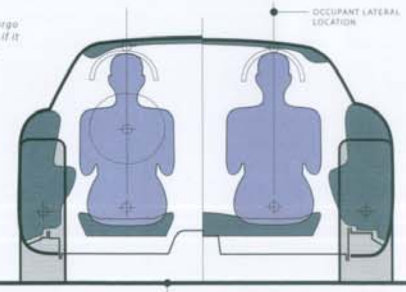
CRASHWORTHINESS

Meeting safety legislation and expectations will influence the vehicle architecture a great deal.

VISIBILITY

State the forward vision angles





GROUND CLEARANCE

The ground clearance dimension together with the approach, ramp over and departure angles should be added to the package.

FUEL STORAGE

Draw the basic outline of a realisticly sized fuel tank that matches the target range of the vehicle. For electric vehicles draw an outline of the battery pack or fuel-cell system.

FRONT AND REAR SUSPENSION SYSTEMS

Describe the suspension system. Include the name of the suspension and the spring type. For extreme off-road vehicles add jounce travel information also.

WHEELS & TIRES

Add the tire dimensions

CURB GROUND LINE

The initial package is developed at "curb" attitude

DESIGNER, NAME & DATE

Always add your name and date to your work

EXTERIOR DIMENSIONS

LENGTH	4820
WIDTH	1925
HEIGHT	1300
WHEELBASE	3070
FRONT TRACK	1635
REAR TRACK	1625

INTERIOR DIMENSIONS

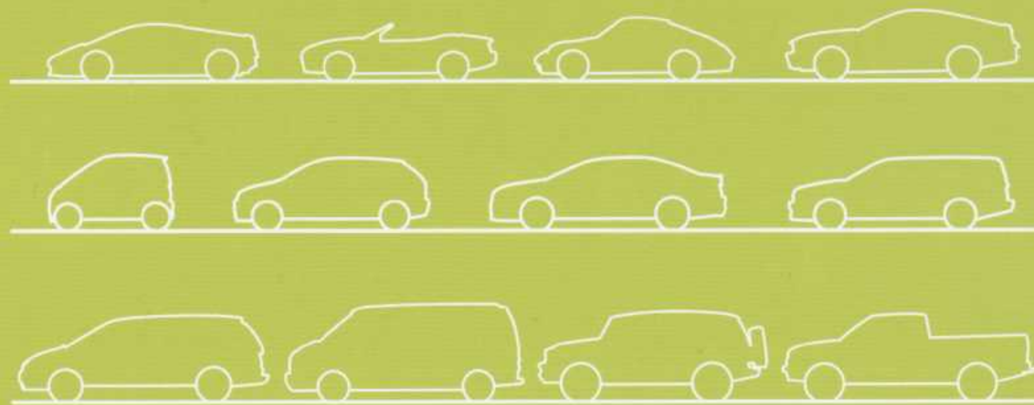
FRONT HEAD ROOM	950
FRONT SHOULDER ROOM	1430
COUPLE	815
REAR HEAD ROOM	930
REAR SHOULDER ROOM	1420
CARGO VOLUME (est.)	200 liters

TARGET SPECIFICATIONS

COST	$95,000
SPEED	175 mph
ACCELERATION	5.0 sec 0-60mph
WEIGHT	1800 kg
FUEL ECONOMY	25 city - 30 highway
SALES VOLUMES	25,000 per a year

FUNCTIONAL OBJECTIVES

Create some goals for your project. The information in the package drawing will relate directly back to these.
Describe the customer, market (country or continent), environment (city, mountain, farm, etc.), main uses and any other information that may affect the package. Set some appropriate target specifications for your vehicle, which will depend on the vehicle type. For a sports-car concept, speed and handling are important targets to set. For SUVs and trucks, load carrying capacity and ground clearance will be the focus.



"Every vehicle must serve a purpose, otherwise no one would buy it. Therefore, market segments are set up by function, and the vehicle architecture is created to meet the functional needs of the customers, manufacturers and the environment. The architectural proportions are set up by the systems' layout and the design follows."

FUNCTION & MARKET SEGMENTS | 02

INTRODUCTION TO FUNCTIONAL OBJECTIVES

A design team is only given one chance to start a project. One of the biggest mistakes they can make is not to consider the functional objectives of their concept in enough depth early enough in the life of the project.

Every product must serve a purpose for its customer and manufacturer. These need to be thought through really well before the first line is drawn on the package or design. At first it may feel that focusing on this aspect of the process will grind a project to a halt, but the truth is the functional objectives are going to make each team member stop and think about what they are doing and approach the design with a fresh perspective.

The best approach is to start with all the right questions and not necessarily the answers. Every so often the auto industry goes through a revolution, often brought about by advances in technology, economic pressure, ecology or political issues.

Three main areas (shown opposite) need to be considered when setting out the objectives for the project: the customer, the manufacturer, and the market or environment. These will drive the basic architecture of the project, and technology will make it work.

The customer will usually have special needs that the vehicle should meet. These may be physical or emotional. The customer demographics and lifestyle should be examined very carefully. It will be difficult to understand why some elements in the architecture are desirable to a certain customer. Classic examples of this are people who drive off-road vehicles but never go off-road, or buy a pickup truck but never carry a load in the bed. There is obviously something else about the architecture that attracts these buyers.

The environment or market the customer lives in will have a great effect on the design, which may be influenced by the climate, terrain, infrastructure, economy, or legislation. This is significant because any given customer will need a different vehicle depending on their geographical location.

Ideally, the manufacturer's limiting parameters should remain unnoticed by the customer. The overwhelming fact remains that automobiles are very complicated to build and require a massive investment of capital, so taking care of business will be a primary consideration for any successful designer. This often involves working within a budget and timeline, developing a concept that is feasible for manufacture and that fits into a long range strategy.

The considerations described on the opposite page represent the factors that will influence the design of a car or truck. Not all of these apply to every vehicle but they should be thought about before crossing them off the list.

Most specialist cars, by nature, perform well in one aspect at the expense of another. Some functional objectives can be polarizing leading to tension within the design team, making it even more important to be very clear about prioritizing them. If each team member clearly understands the functional objectives, difficult decisions will be easier to rationalize.

Interpreting this information is largely the responsibility of the studio engineers. Their job is to understand the physical and emotional needs of the customer, and convert them into architecture using the most appropriate technology. They also have to understand the limitations of the intended markets and the business model of the manufacturer. Finally, they have to be able to communicate this clearly to the rest of the design team.

FACTORS THAT DRIVE THE FUNCTIONAL OBJECTIVES

The lists below contains the key factors that should be considered before the functional objectives are set up.

CUSTOMER FOCUSED ATTRIBUTES

cost • image • size • interior space • cargo volume • number of passengers • economy • weight • handling • speed • flexibility • comfort • durability • off-road capability • trim level• security • colors • noise/vibration/harshshness (NVH) • emissions • towing capacity • customizing potential • loading capacity • aftermarket component availability • command-of-the-road seating • easy ingress/egress • maneuverability • range • sound • power • safety/crashworthiness • brand identity

MANUFACTURER'S CONSIDERATIONS

manufacturing capability • manufacturing costs • product lineup • platform sharing strategy • derivatives • production volumes • dealer network • marketing strategy • manpower • paint • available components & systems • warranty • RHD/LHD

MARKET FORCES

infrastructure • population density • parking • economy • taxation • insurance • ecology • culture • legislation • security • climate • consumer advocate groups • sales volumes • discrimination • infotainment

APPLYING OBJECTIVES TO THE ARCHITECTURE

As the key factors are analyzed, specifications and solutions should be listed to help build the package. The package illustrations show how a few of the major elements are established around the functional objectives.

HALF TON / THREE-QUARTER TON
1900MM - 2450MM BEDS
INTERIOR VOLUME 4.0 CU METERS

FULL-SIZE TRUCK
SIMILAR TO F 150

- STRONG MUSCULAR APPEARANCE
- TALL GRILL
- LARGE BUMPERS
- BIG WHEELS & TIRES
- HIGH BELT LINE
- TALL OCCUPANT PACKAGE

- 400MM GROUND CLEARANCE
- 4 X 4 OPTIONAL
- LONG SUSPENSION ARTICULATION
- HIGH-STRENGTH STEEL FRAME

CUSTOMER FOCUSED ATTRIBUTES

cost • image • size • interior space • cargo volume • number of passengers • economy • weight • handling • speed • off-road capability flexibility • durability • comfort • trim level • security • colors • noise/vibration/harshshness (NVH) • emissions • towing capacity customizing potential • loading capacity • aftermarket component availability • brand identity • command-of-the-road seating • easy ingress/egress • maneuverability • range • sound • power • safety /crashworthiness

NORMAL OFF-ROAD TRUCK
DURABILITY CYCLES

LARGE POWERFUL ENGINE
350 BHP MINIMUM
350 LB.-FT TORQUE
V8 - V10

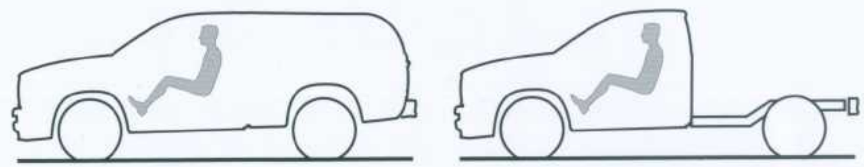
4200KG
TOWING CAPACITY

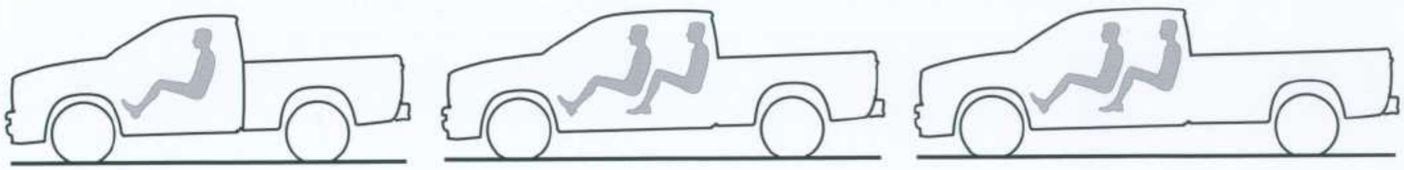
MANUFACTURER'S CONSIDERATIONS

manufacture • manufacturing costs • product lineup • platform sharing • derivatives • production volumes • dealer network • marketing strategy • manpower • paint • available components & systems • warranty

• FULL-SIZE LIGHT & HEAVY TRUCKS
1500, 2500, 3500
• STANDARD AND QUAD CAB
• 6-FT. & 8-FT. BEDS

CHASSIS CAB & SUV DERIVATIVES





LENGTH SHOULD FIT IN A GARAGE
(WITH 2450MM BED)

• USA REGULATIONS ONLY
• TRUCK BUMPERS
• WIDTH UNDER 2030MM

MARKET FORCES

infrastructure • population density • parking • economy • taxation • insurance • ecology • culture • legislation • security • climate • consumer advocate groups • sales volumes • discrimination

500,000
ANNUAL SALES

• MUST BE A "REAL
TRUCK"
• AMERICAN BUILT

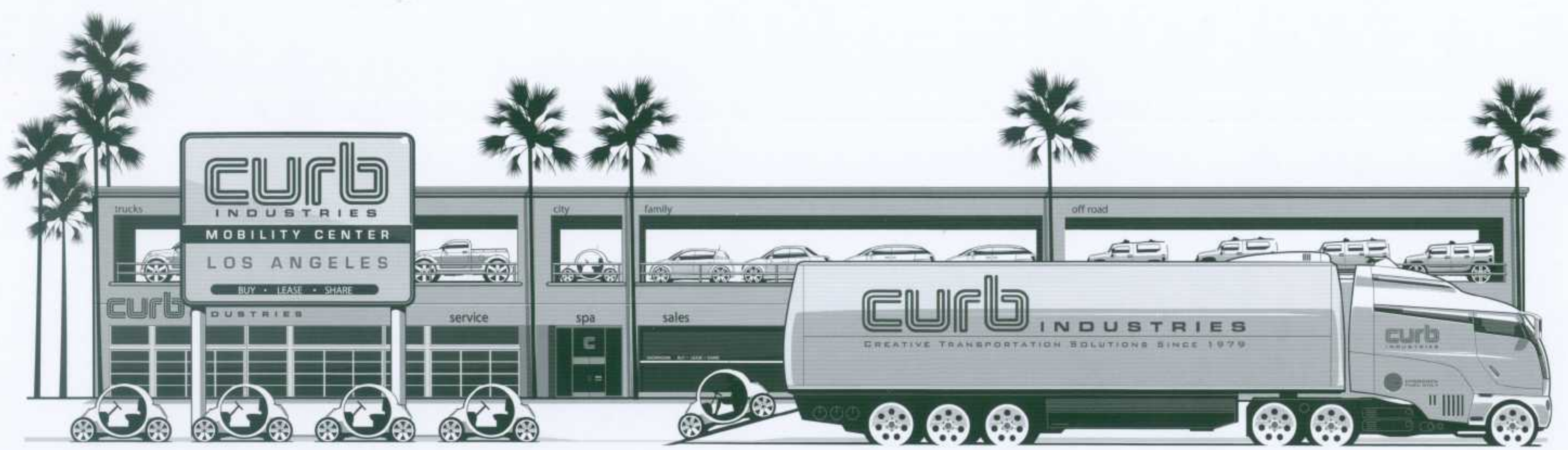
POSITIONING THE CONCEPT

No vehicle is ever designed in isolation, so it is important to look at other vehicles that it will compete against, or alongside which it will be sold.

The market positioning graphic on the opposite page can provide a clear illustration of how the new concept stacks up against other products. It also shows where holes in the market exist.

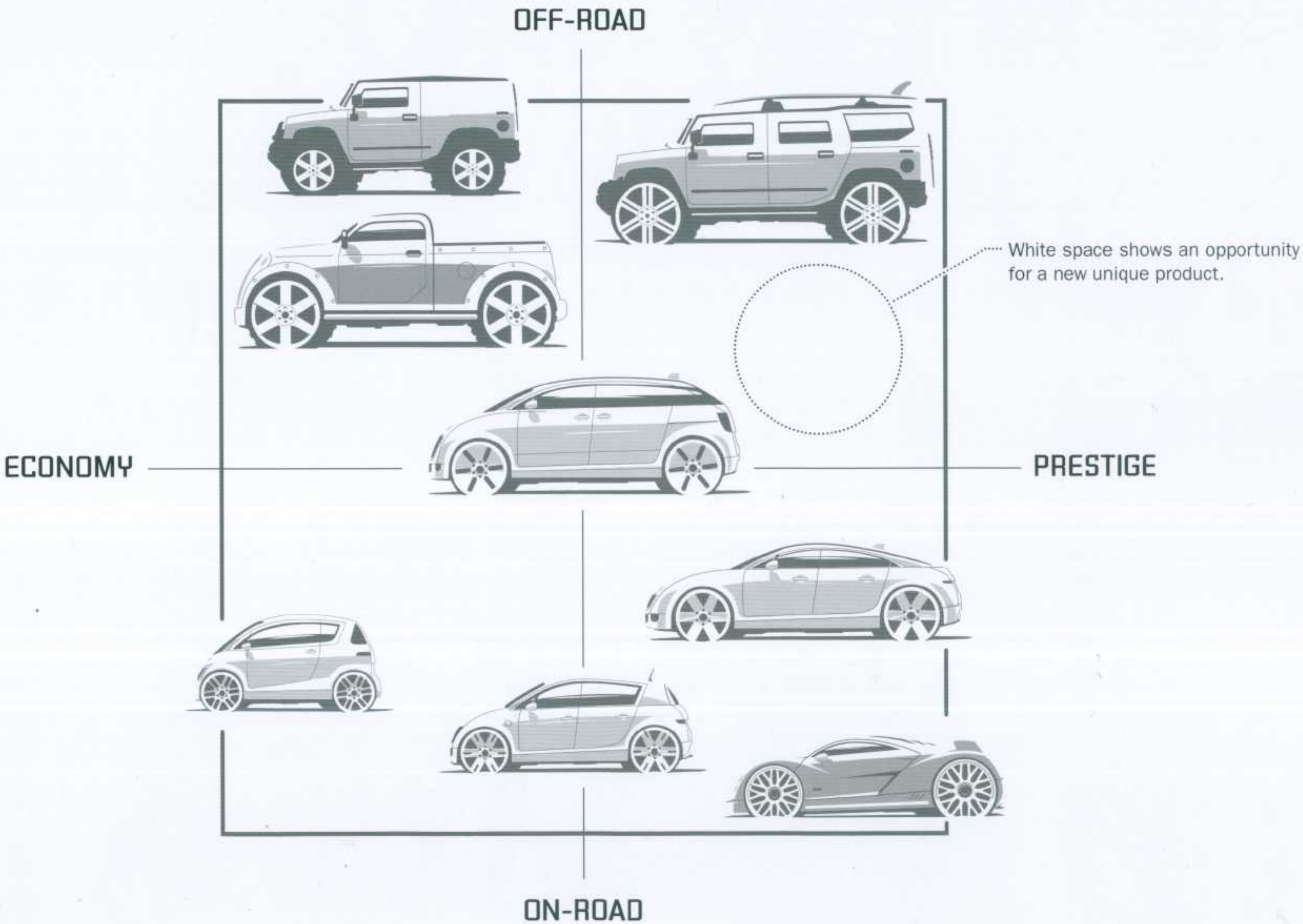
Each chart or graph can be set up with polarizing attributes on each side. The example shows on-road versus off-road vehicles. The cars and SUVs are positioned from one extreme to another from top to bottom. From left to right is economy vs. prestige, so the vehicle can slide across the page according to its cost.

Other subjects can be pulled from the list of factors on p. 49 to make up several charts, ensuring that the concept does not clash with other products in the brand portfolio.



VEHICLE POSITIONING GRAPHIC

This graphic helps to visualize where the concept falls within the manufacturer's showroom. It can also be used to position the concept against the competition and highlight areas of opportunity.



INTRODUCTION TO VEHICLE SEGMENTS

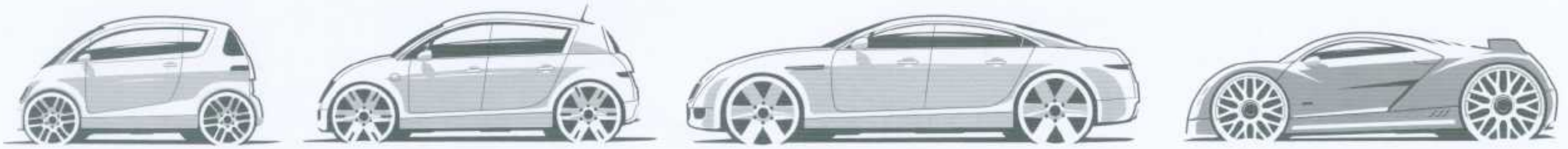
At some point early in the design process, the concept will need to be classified as a particular category of vehicle, for instance a car or a light truck or a commercial vehicle. This is because most countries have specific legislation for each vehicle category, which can affect design decisions. This legislation might range from specific design criteria and taxation policies to use limitations and emissions standards. For a variety of reasons, most governments want to control the types of vehicles that use their nation's infrastructure.

In addition, there are many other organizations that have vested interests in classifying vehicles. Consumer groups need to test and compare cars and trucks and organize their data. Insurance companies need to assess the risk for different types of products. Local authorities may apply operating limits on certain types of vehicles. The vehicle design can be affected by factors that range from crash requirements and overall dimensional limitations, to the number of wheels and lighting specifications. Taxation classes are often determined by engine size and power output but may also be affected by overall size, value and the number of wheels.

Use regulations are usually set up to permit vehicles with specific functions to excel in their duties. A good example is the off-road vehicle, which USA regulations allow to be designed without the same bumper regulations that apply to cars. This enables them to achieve good approach and departure angles in extreme off-road conditions.

Neighborhood electric vehicles are allowed to drive on the main roads without passing 40mph crash regulations. This helps to reduce their size, weight and cost, effectively reducing their fuel consumption and emissions.

CARS



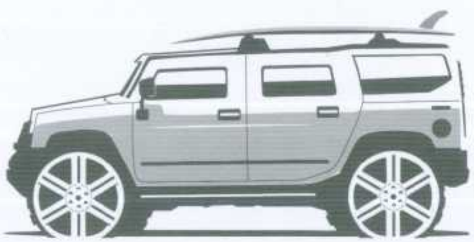
MICRO CARS | ECONOMY CARS | LUXURY CARS | SPECIALTY CARS

Each country, and often region, sets out classifications to either promote or inhibit certain types of transportation. In markets with high population density or limited natural resources, the government usually tries to encourage the driving of smaller vehicles by taxing larger cars and the fuel that they run on. In some cases tax refunds are given for vehicles that are clean and ecologically friendly. If space is limited, then there might be incentives for driving vehicles under a certain size.

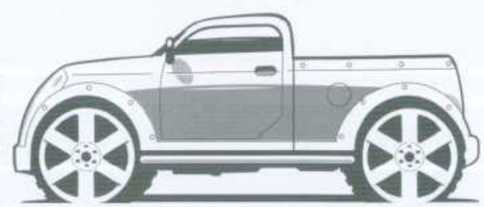
The segmentation in this chapter is divided by architecture. For example, economy cars come in many sizes but they all share a common philosophy, so their architecture is usually quite similar. Luxury cars also come in a variety of sizes. For example, a midsize luxury car will usually have a different architecture than a midsize economy car. Therefore, the eight segments shown on the following pages are divided by clear architectural differences.

TRUCKS

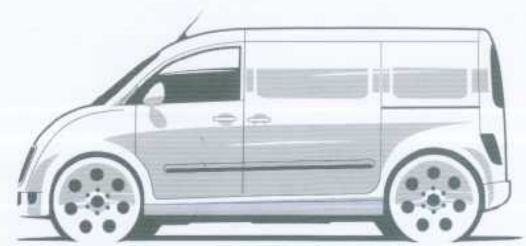
MINIVANS



SUVS

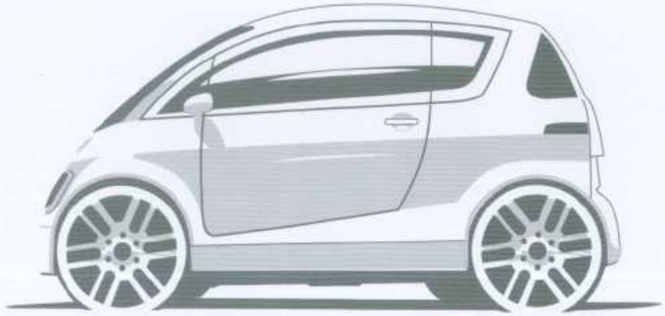


PICKUP TRUCKS



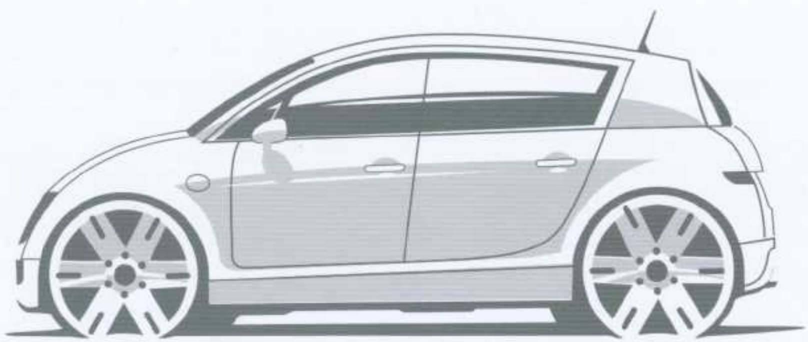
COMMERCIAL VANS

MICRO CARS



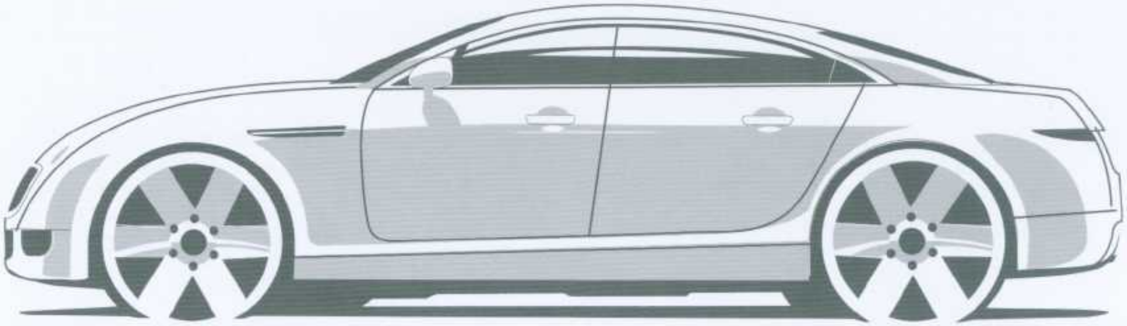
This is the smallest type of passenger car allowed to drive on all roads. Micro cars are usually designed to meet specific dimensional and performance targets which allow them to fit a certain type of vehicle classification. They are often designed for only two occupants and with a minimum amount of cargo space. A small (unorthodox) powertrain package and small tire envelopes also help to minimize the vehicle's size and weight. The body is designed for light-weight, low-cost, and high-volume production but must still meet all local government impact regulations. They are usually configured with two conventionally hinged doors and a liftgate.

ECONOMY CARS



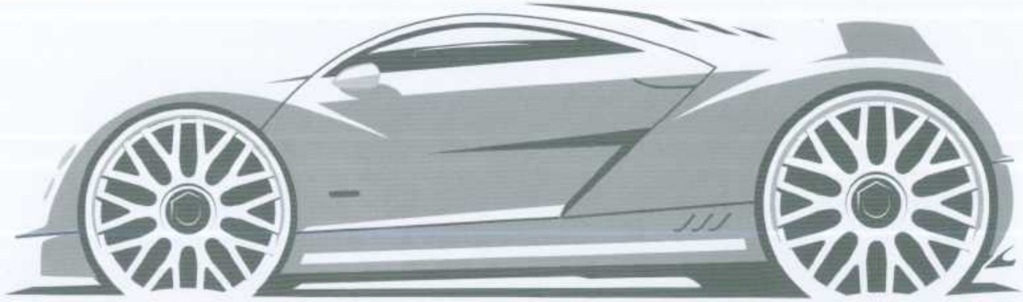
This group represents the largest share of the global passenger car market and is often referred to as the B, C and D segment of vehicles. The objective is to provide inexpensive 5-passenger-plus-cargo transportation, so the packaging needs to be very efficient. Designers look to achieve the largest interior space within the smallest exterior box dimensions to minimize cost, weight and aerodynamic drag. The powertrain and suspension systems are optimized for space efficiency, rather than performance. The body structures are designed to meet very high production volumes and low-cost targets.

LUXURY CARS



This segment is often referred to as the executive or E class. Interior space, refinement, speed, handling and a prestigious appearance are high priorities. The powertrain, occupant package and tire envelopes are usually generous which result in large overall dimensions. The body is designed for high-quality and often high-volume production, with attention to noise reduction through optimized aerodynamics and structural stiffness. The suspension systems are uncompromised to ensure the handling and ride comfort are also fully optimized.

SPORTS & SPECIALTY CARS

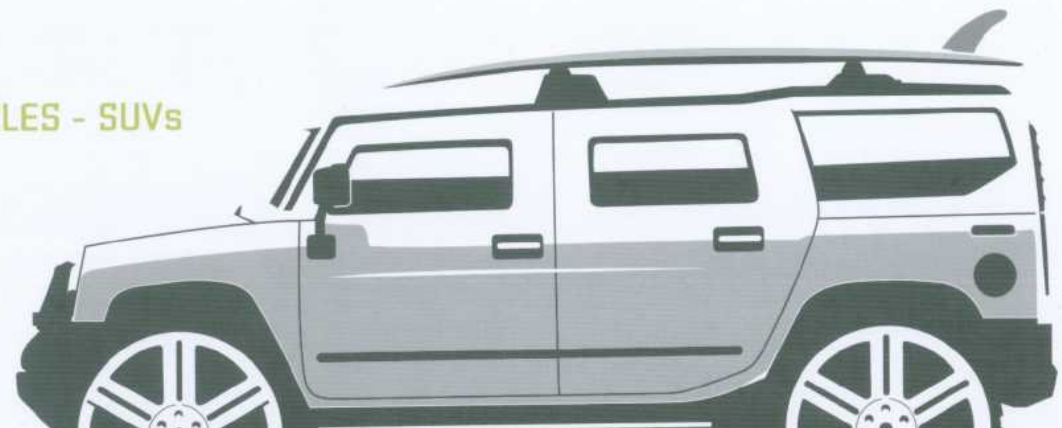


The main objectives for this segment are high performance and exotic design. Uncompromised powertrains, body structures, suspension, tires, aerodynamics and a low center of gravity are priorities. The occupant environment is minimized and cargo space is generally compromised. Customers of extreme, high-performance sports-cars are usually affluent enthusiasts, so high purchase price is not usually an issue. This allows these cars to be built by hand in low volumes.

MINIVANS

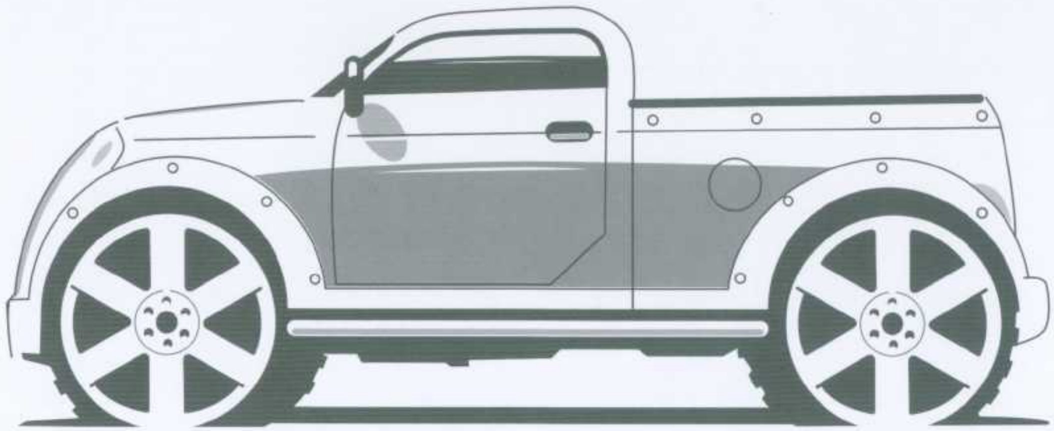
This is a relatively young segment, defined by a passenger-oriented package, usually for seven or eight. They are designated as trucks in the US market due to their cargo-carrying capability. Powertrains need to be large enough to pull the vehicles when fully loaded but packaged to have a minimum impact on the occupant environment. The unibody construction is designed for very high production and closures usually include sliding rear doors. Suspension systems should be economical and efficiently packaged with the rear suspension designed for load carrying and ride-height variance. Typically, the interior will have a flat floor with the capability to reconfigure and stow the seats. Additionally, the occupants will sit high for security and a commanding view of the road.

SPORT UTILITY VEHICLES - SUVs



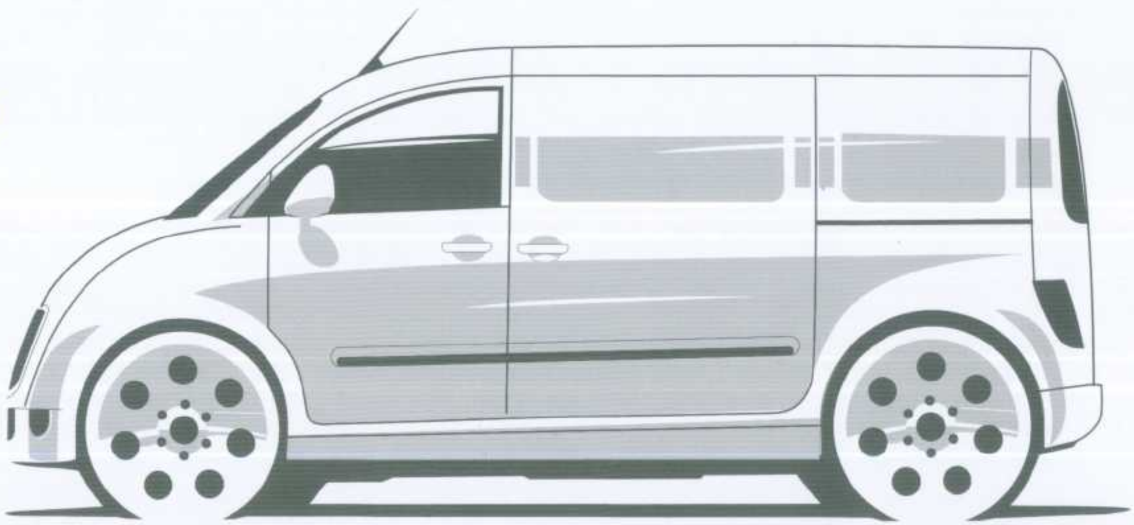
The sport-utility segment has grown rapidly in recent years, offering the feeling of security, a strong image and flexibility, while being able to accommodate 4 to 8 passengers. The majority of SUVs have longitudinal powertrains with 4WD and high ground clearance for off-road and bad weather driving. This is complemented by suspension systems with long travel, good articulation and aggressive tires. The body construction may be of "body-on-frame" type for large SUVs which are usually derived from pickup trucks designed for serious off-road duties. Some SUVs are designed for road and light trail use only, which is reflected in their passenger-car-like systems and typically unibody construction.

TRUCKS

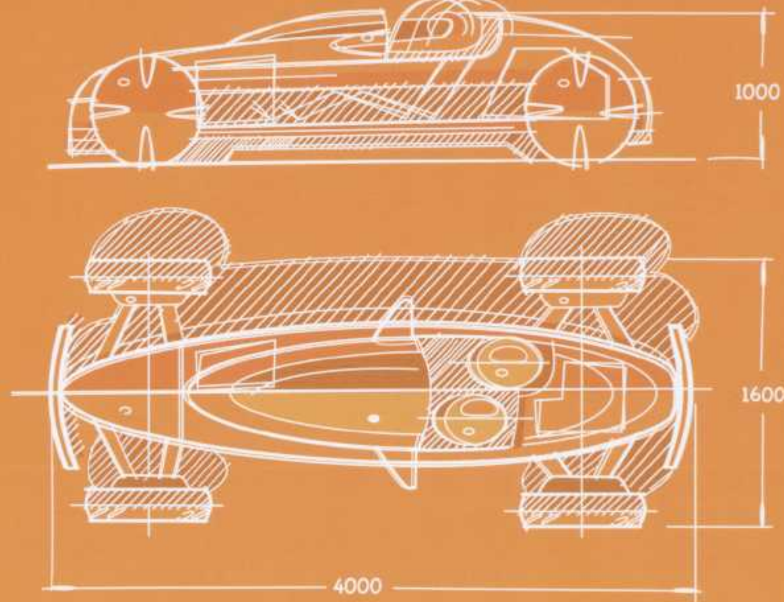


Pickup trucks are used for both commercial and personal applications. Their durable construction, powerful, high-torque engines and 4WD are designed to carry and tow heavy loads in all types of environments. Suspension systems must be able to support a wide range of loading conditions and offer various ride-height options. The body construction is traditionally body-on-frame and often is the basis for an SUV derivative. Trucks come in numerous length configurations depending on cab and bed-size requirements.

COMMERCIAL VANS



Principally designed to provide economical cargo transportation for businesses, the architecture of these vehicles needs to be very flexible to create a wide variety of derivatives. Usually, a unibody construction that can be adapted to include a strong framework for open-bed versions and a platform for coach builders. The body design should also facilitate dimensional variants with closures that are sized for loading standard-sized objects. Powertrains and suspension systems are designed for heavy load carrying with minimum intrusion into the cargo space. The footprint of the vehicle should be kept as small as possible to improve maneuverability in urban environments.



"You only get one chance to start a project, so make sure to explore every possibility right away. Never start a project with the answers – just questions."

PACKAGE IDEATION | 03

INTRODUCTION TO PACKAGE IDEATION

The main objective for package ideation is to study as many system configurations as possible in a short period of time. The process is similar to design ideation where each concept is sketched out loosely on paper and evaluated as a cluster of ideas.

After setting the functional objectives, there is a small window of opportunity in the product development process to be innovative with the vehicle architecture. This window often closes quickly due to project time constraints, so ideas need to be free-flowing and clearly communicated.

It is easy to jump to conclusions and rely on paradigms that have been applied on previous projects and walk backwards into the future. So make good use of this phase of the project and don't hold back, once you're deeper into a program there may not be an opportunity to return to this phase. Don't worry if some of the ideas are bad; what appears to be a dumb idea during brainstorming can often lead to the development of a really good one later.

First look at the basic proportions (as shown on the opposite page) and think about what may drive them.

Next, configure some of the key elements—i.e., the occupants, cargo, tires and powertrain—and look for opportunities. Look at the big chunks and see how they can be reconfigured to work more effectively. The powertrain, for example, often provides great opportunity for innovation and will greatly affect the proportions. The occupant package and cargo storage is also an area where there is great potential for fresh thinking because they take up more space than the other elements.

Although this phase requires a broad focus, do not totally overlook small details. Often a minor innovation may be the key to a successful package.

Look closely at the functional objectives to select and place each element. Next look at the body structure, closures (doors, gates, hood & trunk) and breathing apertures to see how these may affect the overall proportions and design. Also look at the interior design possibilities. Seating and telematic concepts may have a great impact on the overall architecture.

The example project on the following pages illustrate how you may go about this process. The word picture created for this example is "An Aspirational Commuter Car." This statement communicates both the physical and emotional aspects of the theme. It sums up the vehicle and customer in just a few words, but also creates an open brief.

From this heading, specific objectives or targets for the concept need to be developed. Look at the subjects on p. 49. Think about the three entities involved in the product development: the customer, the manufacturer and the market environment. Choose several of these to help steer the design. Some of these are simple, like top speed, fuel consumption, and the number of passengers. Other factors like manufacturing strategies and international legislation will be more complex subjects, but should be given consideration. Try to think about how each objective may affect the basic architecture. Requirements for passengers, ground clearance, a large engine, heavy cargo, and doors will have an impact even on a loose ideation sketch. Other less influential features like lighting, instruments and trim may be ignored at this time unless there is a specific focus on these systems.

As a commuter vehicle it will probably be small, inexpensive to buy and drive, easy to park, carry only one, two or three people, and have limited cargo capacity. It may be sold all over the world and therefore be manufactured in very high volumes. To be aspirational, the styling will be important and performance may need to be stepped up.

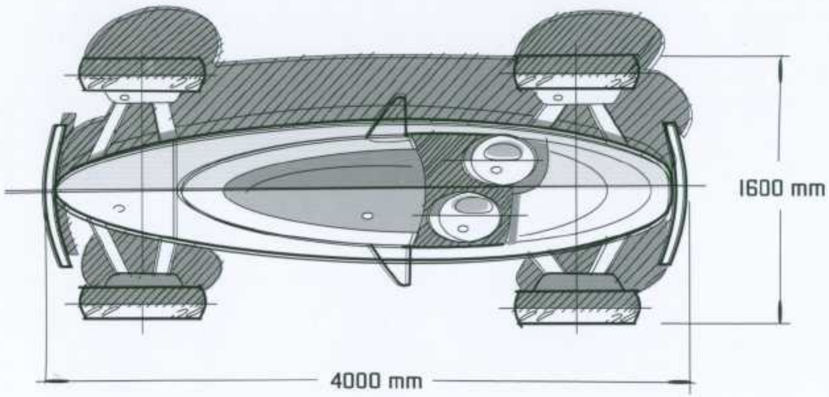
LOOSE EXTERIOR PROPORTION SKETCHES

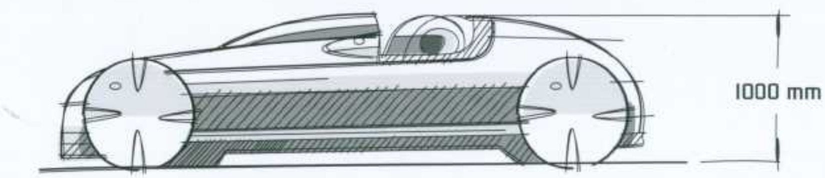
Keep the sketches very simple; at this stage they are just to look at basic proportions. These three options look at various ways to approach the Aspirational Commuter Car.

The low car will probably be performance oriented to make it aspirational. The short vehicle will be more practical and easier to park and maneuver. The narrow concept will be able to cut through traffic and be very easy to park.

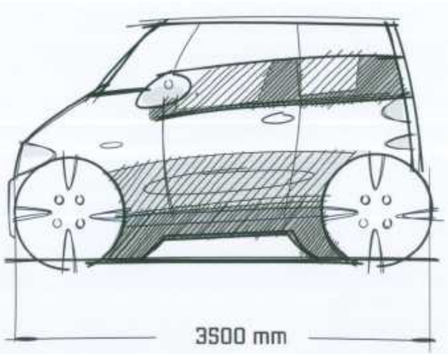
At this stage set some size limitations based on the known environmental requirements. For example, to park sideways, the length of the short car will need to be similar to the width of a large truck. To cut through traffic, the ultra-narrow concept will need to be the width of a large motorcycle.

OPEN WHEEL - LOW, LONG

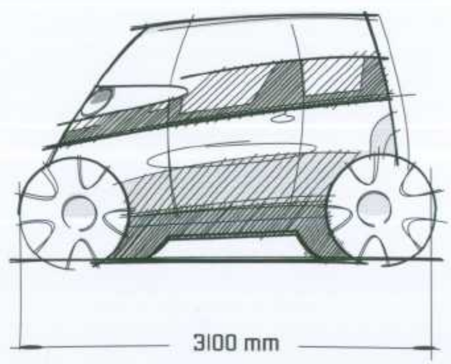




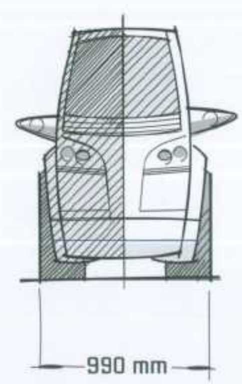
TWO BOX - TALL, SHORT



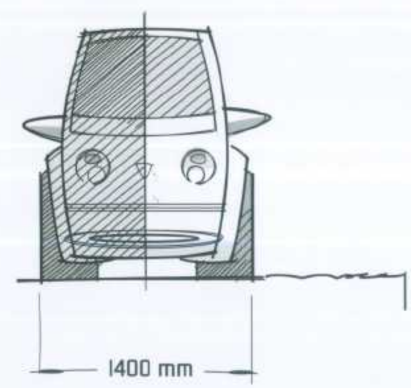
ONE BOX - TALL, SHORT



ULTRA-NARROW



NARROW



PACKAGE IDEATION PROCESS

Sketch several layouts with the occupants, cargo, tires and powertrain. At this stage, don't include other elements in the package unless the design brief specifically requires a focus on other areas. Also, do not worry too much about scale. Accuracy is not important here. This will be addressed at the next phase of the process.

The main objective is to get as many ideas down on paper, quickly, so that you can think about how the exterior proportions will be influenced by the major elements. For example, when thinking about the powertrain, just look at whether it is large or small, at the front or the back, longitudinal or transverse, electric or internal combustion, FWD or RWD.

Configure the package in as many different ways as possible and exhaust all of the possibilities. Try to make sure all of the ideas meet the functional objectives and target specifications. Each sketch should only take 5 to 10 minutes to draw, so it should be possible to create many ideas in a short time period.

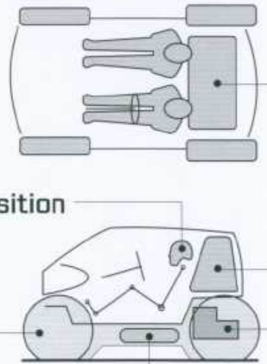
Looking at the example concept sketches, the brief for this project didn't specify how many passengers need to be carried, so the ideation work looks at layouts with one, two and three occupants. The study also looks at the different types of passengers. Knowing that a commuter car will need to be small and inexpensive the powertrain options are limited and only very efficient package configurations are given consideration.

Don't underestimate the magic that comes from drawing out your ideas. In the same way that a new design may develop as it is rendered, sketching out the architecture will often foster new concepts that would never have been conceived had they not been part of the ideation process. This is a problem for many engineers who simply never sketch their ideas on paper.

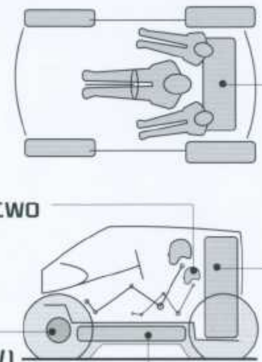
TARGET SPECIFICATIONS

Top Speed	75 mph
0-60mph	7 Seconds
Cost	$9,000 - $12,000
Fuel Consumption	60mpg or Equiv.
Range	40 - 60 miles
Safety	5 Star Crash (IIHS & NCAP)

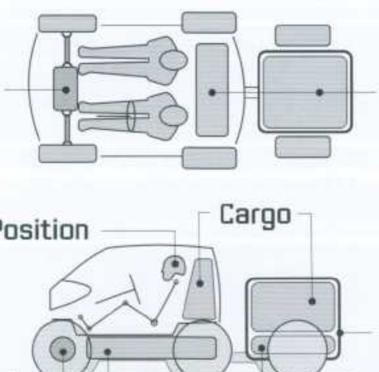
TWO PASSENGERS



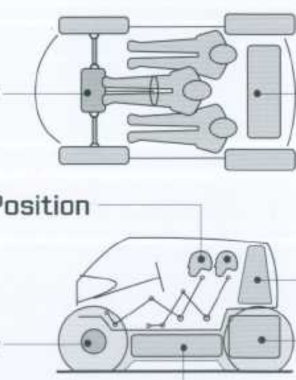
THREE PASSENGERS (1 ADULT + 2 KIDS)



TWO PASSENGERS + CARGO TRAILER



THREE PASSENGERS



As you work through this process, continue research into the major elements of the package.

Consider the seating position for the occupants. Think about the number of passengers, how they will relate to each other, their orientation and approximate location. Also, set up their height from the ground and posture. Make notes on the drawing as you go.

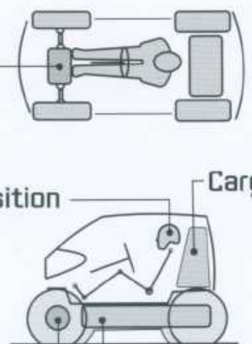
The powertrain specification should be estimated from the target performance goals and approximate weight of the car. Also look at which wheels will drive.

The cargo requirements should be set out in the functional objectives. If specific items need to be carried, get the measurements and include these in the sketches.

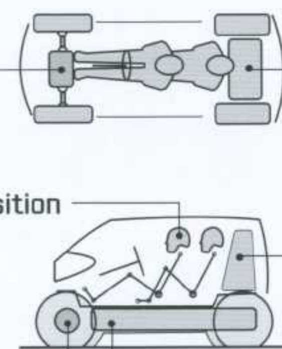
If the wheel size or locations are important, add information about diameters, wheelbase, track, etc.

Loosely sketch a body profile over each package to look at the proportional difference between each study.

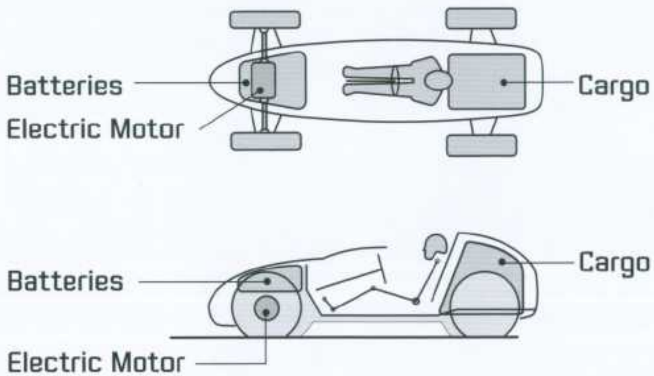
ONE PASSENGER



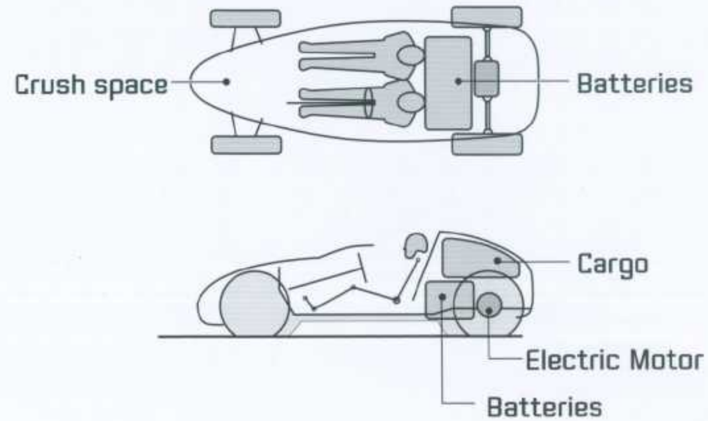
TWO PASSENGERS (TANDEM)



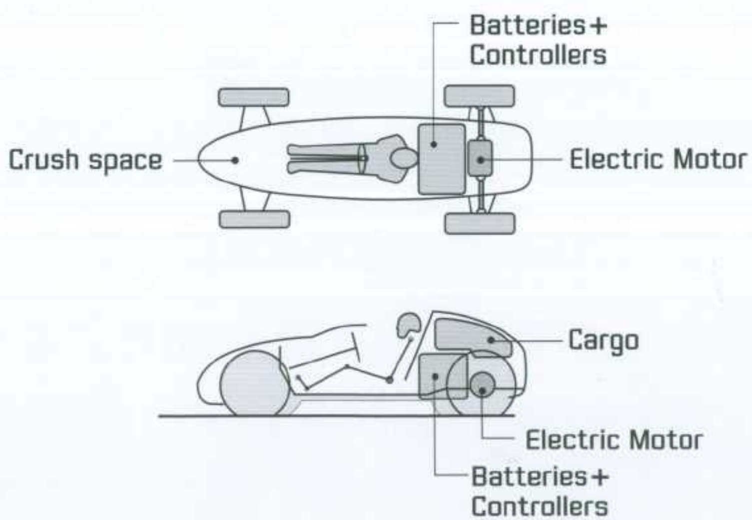
ONE PASSENGER FWD



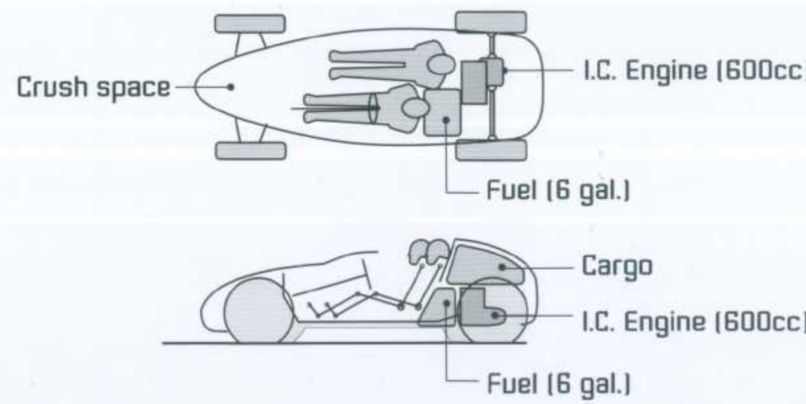
TWO PASSENGERS



ONE PASSENGER RWD

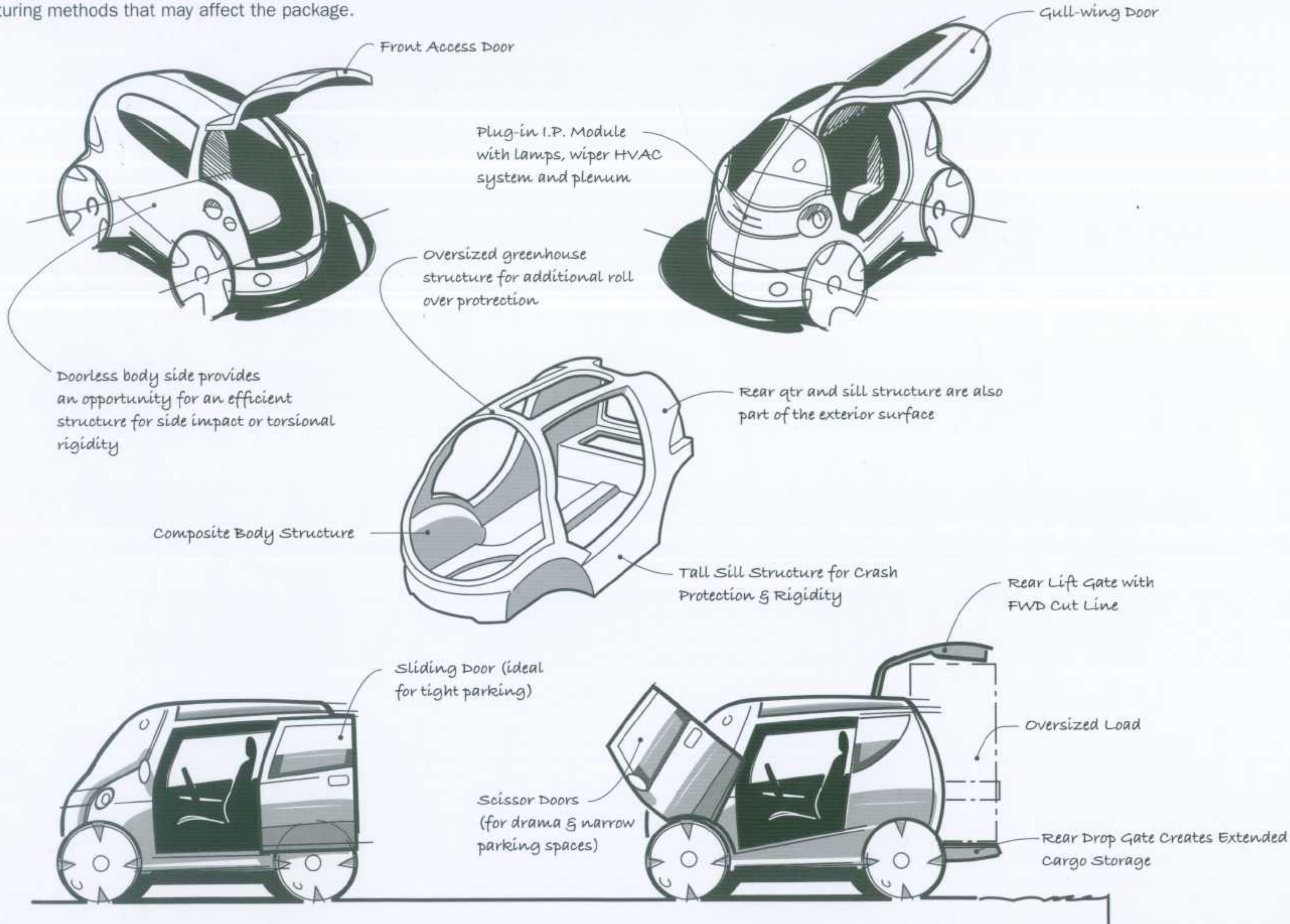


TWO PASSENGERS (STAGGERED)



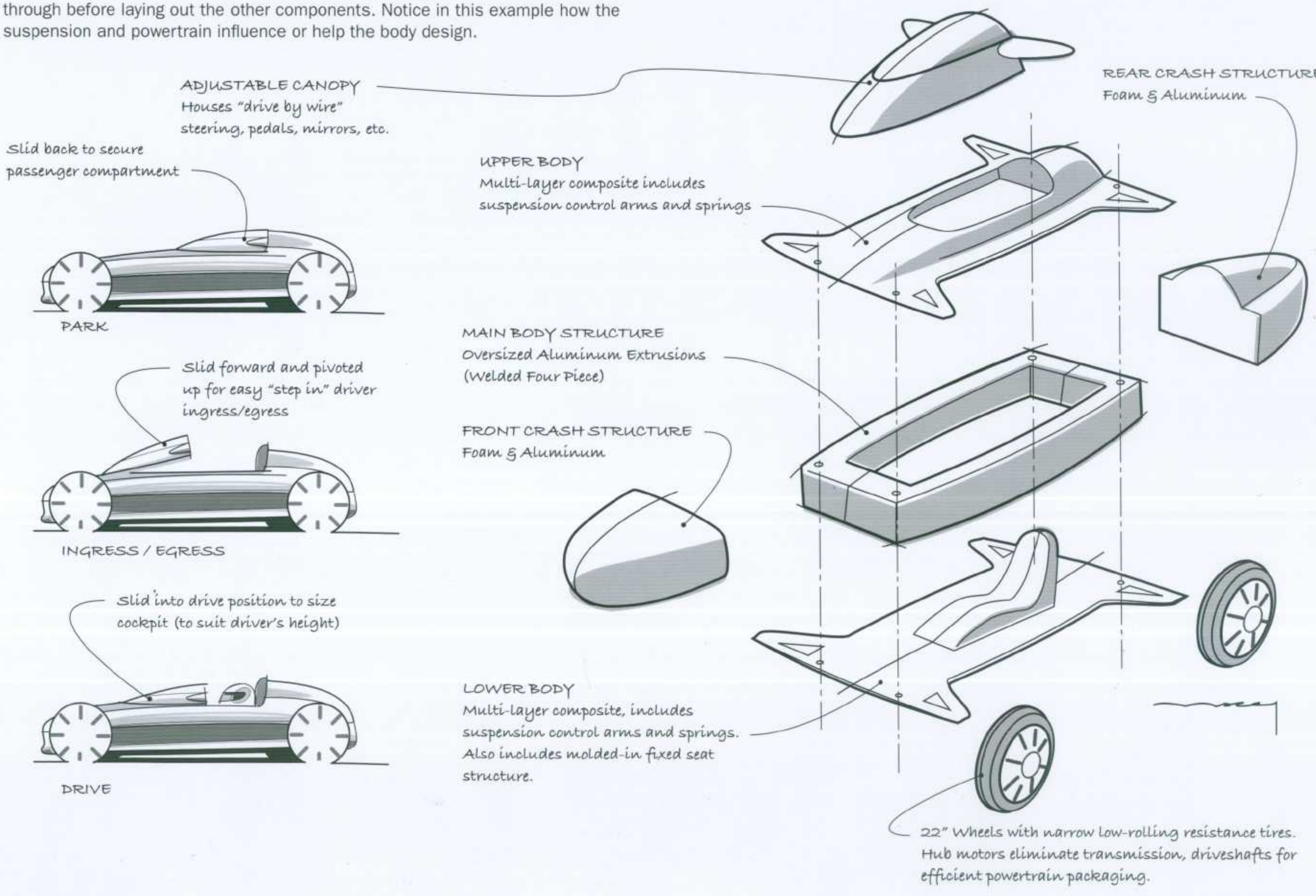
COMPOSITE MICRO-BODY CONCEPT

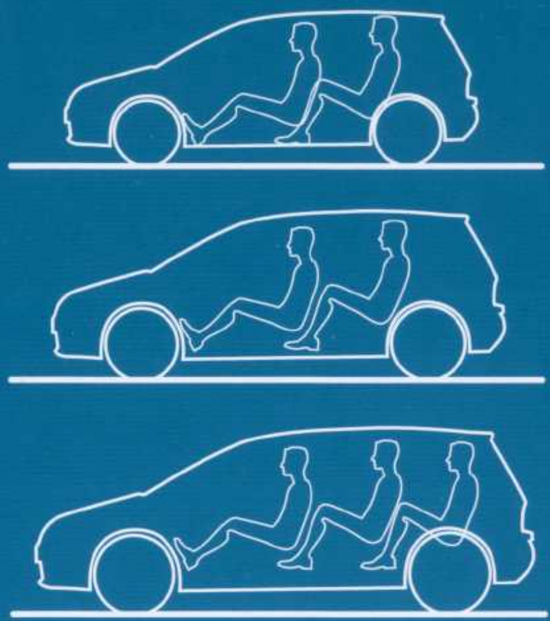
Sketch the body structure, apertures and closures. Look at various ways to open the doors and configure the body. Think about how the main load bearing structural elements may be configured. Consider the materials and possible manufacturing methods that may affect the package.



FIVE-PIECE ULTRALIGHT BODY CONCEPT

This is a great time to look at unorthodox body structures and manufacturing processes. These will have a dramatic effect on the package and need to be thought through before laying out the other components. Notice in this example how the suspension and powertrain influence or help the body design.





"After the ideation process is complete, the overall dimensions and proportions of the concept should be established. Getting the size right is critical to ensure that the vehicle is as efficient as possible and makes the right statement about its purpose."

SIZE & PROPORTION | 04

INTRODUCTION TO SIZING & PROPORTIONS

Setting up the size and proportion of a vehicle can be approached in several ways.

The first approach may be purely emotional. You may have already decided that the concept will be large or small, high or low, have a short or a long hood. You will be working with a mindset that the vehicle needs to be designed to look a certain way for the customer to accept it. If this is the case, the package can often be designed under the skin, because there will be nothing revolutionary about it. It is taking what we already know today and simply refining it. This is a case of the package being lead by the design.

Another approach may be driven by a specific requirement to meet dimensional legislation or market segmentation. This combined with a challenging set of functional objectives may require some innovative packaging to fit everything into a limited envelope.

The final methodology is to start only with the functional objectives. This involves research into advanced technology to develop innovative solutions before building the package around the occupants and new kinds of componentry. The exterior proportions can define the forms around this fresh architecture.

If some of the functional objectives for the vehicle are to fit into a small footprint and be fuel efficient, then a fully optimized package will develop. If the customer requirements call for a much larger vehicle with an emphasis on making a statement with its size, then the package can be relaxed in some areas.

The vehicle function & segments chapter gave an insight into some of the factors that set up the proportions. As always, the occupant package will have a major influence on the vehicle's size but the powertrain and cargo are often the elements that define the proportions of the main "boxes." If a car is of the three-box layout with a long hood, or long dash-to-axle relationship (front wheel set well forward of the A pillar), there is a good chance that it is a luxury car with a large engine.

There may not be a great deal of emphasis on larger cargo space, but room for suitcases and golf clubs might be an important requirement.

A smaller, two-box hatchback will be a more efficient and versatile design with a smaller engine, but larger cargo environment for carrying bulkier objects.

So, proportions are always going to relate to the function of the vehicle. This may be an obvious statement but every time a new project is kicked off, the design team should fully investigate what opportunity there is for the architecture of the vehicle to make an exciting statement about its intended function. Similarly, the designers can consider how new technology could be applied and how that might lead to a redistribution of the masses.

New advanced propulsion systems, for example, are very different in their size, proportion and arrangement to conventional internal combustion engines. So a concept that employs an electric powertrain should not look the same as one with a conventional internal combustion engine.

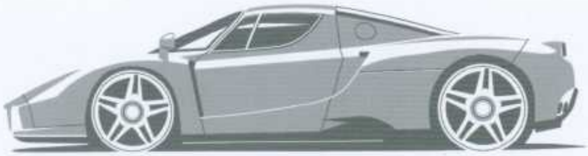
The three sports cars shown below may have similar objectives but look totally different because their engines are in different locations. Performance cars vary a great deal in appearance for this reason.

The left car has a large mid-front engine which creates a long hood, pushing the driver towards the rear of the wheelbase.

The middle car is a mid-rear engine layout with the transaxle behind the engine. This package creates a longer rear end, pushing the rear wheel away from the driver.

The right car has a rear-mounted engine which requires a lot of mass behind the rear wheels but does allow a small amount of room for rear passengers.

MID-FRONT ENGINE

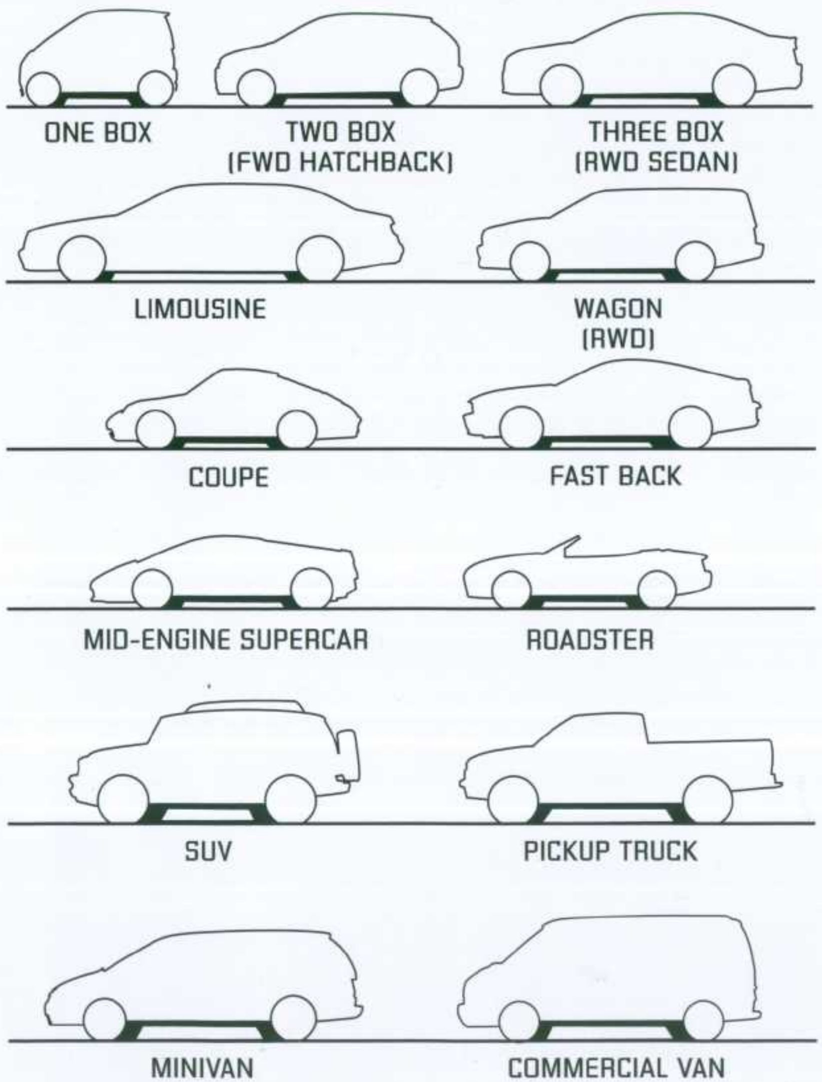


MID-REAR ENGINE

REAR ENGINE

PROPORTIONS & BODY TYPES

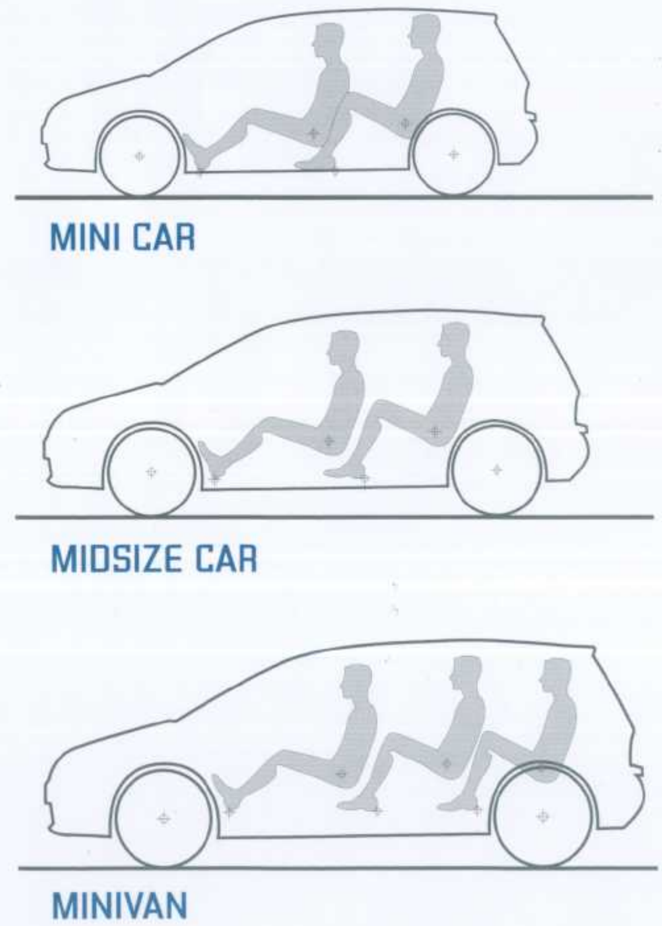
The side-view proportions of the body are influenced by the occupants, cargo and powertrain packages. Additionally, the ground clearance, crash systems and aerodynamics will affect the profile. All of these, in turn, are driven by the functional objectives. Below are some typical examples of various body types and proportions.



SIZING THE CONCEPT

After the initial ideation phase, the next step is to determine the size of the vehicle. The one consistent component in each package is the scale of the occupants, so the scale of the concept can be set up around the driver and passengers. Benchmarking existing known vehicles will help perform this task.

Notice the exterior shape has not changed but the vehicles are different sizes. Using the occupants as the basis for scaling, the size can be adjusted to fit comfortably around them.



VEHICLE CLASSIFICATION BY SIZE

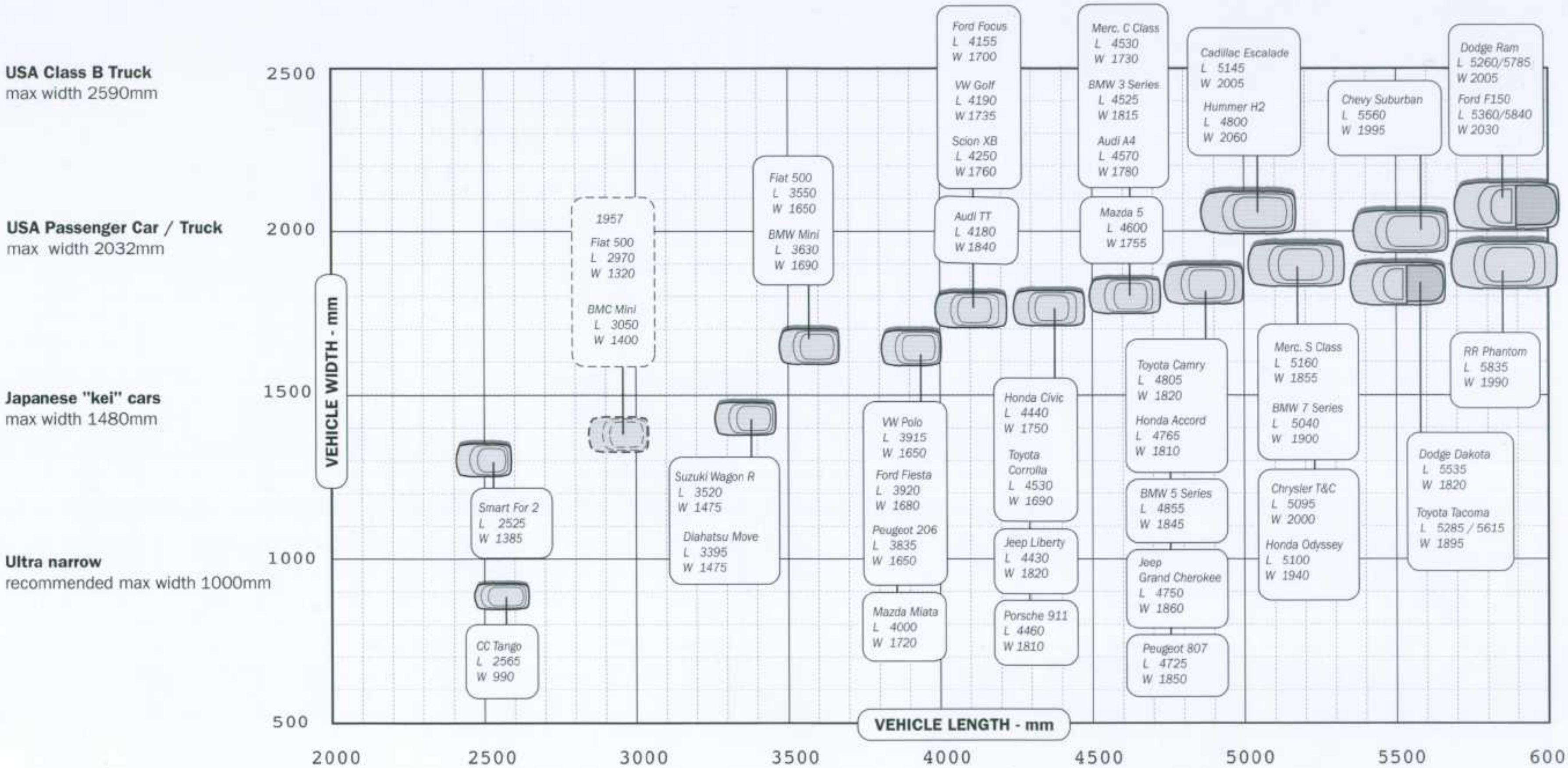
Often the size of a vehicle will put it into a category or market segment. Unfortunately, there is a lot of ambiguity in this area. This can be seen in the matrix on the opposite page, which may appear somewhat confusing.

Size is relative, so if you are working on a small car in Europe or Japan it will be much smaller than a small car in the USA. The type of vehicle will also make a difference. A small truck, for example, will be much longer than a small car, van or SUV. The market's view of size is constantly changing. Notice (on the opposite page) the size of the original Mini & Fiat 500 is much smaller than the current models. Cars have grown considerably in recent years in both size and weight.

In some markets, legislation will set a mixture of dimensional, functional, weight or power-output division lines. These are usually there to help reduce vehicle size in regions with a dense population or for economical and environmental reasons. Because some vehicles need to be configured a certain way to perform their intended function, they will be exempt from some limitations. Some divisions are mandated and strictly enforced, others are encouraged with tax incentives or penalties. Countries with poor economies, limited oil resources and/or high population densities, will have stricter limitations.

In the USA, personal vehicles have a gross vehicle weight (GVW) of less than 8,500 lbs. Commercial (class A or B) trucks require special licenses to drive them. The main division for non-commercial vehicles is between passenger cars and light trucks. Passenger cars have to meet stricter fuel consumption limits and their bumper design is governed by low-speed impact requirements. To be classified as a truck, the vehicle has to be either primarily designed to carry cargo, carry 9 or more people behind the driver, have an open bed or be designed for off-road use. Much of this criteria is open to interpretation, allowing some vehicles to be classified in either category.

So before starting the project, try to understand the objectives from the customer, brand and environmental perspective. Look at the size of competitive vehicles and the cars and trucks in the showroom of the brand. Check all local legislation and think about how the environment and climate may affect the vehicle's architecture and classification.



Euro NCAP	Cars	Super Mini · Small Family Car · Large Family Car · Executive Car (4.8m +)
	Minivans	Small MPV · MPV
	SUVs	Small Off Roader 4x4 · Large Off Roader 4x4
European Segments	Cars	Micro · A Class · B Class · C Class · D Class · E Class · F Class
	SUVs	C Class · D Class · E Class
	Vans	B Class · C Class · D Class
US EPA Classification (Cars by interior volume) (Trucks by GVWR)	Cars	Mini Compact (-85 cu ft) · Sub Compact (85 - 100 cu ft) · Compact (100-110 cu ft) · Midsize (100-120 cu ft) · Large (120 + cu ft)
	Wagons	Small Wagon (-130 cu ft) · Midsize Wagon (130-160 cu ft) · Large Wagon (160+ cu ft)
	Trucks	Small (under 4500 lb) · Standard (4500-8500 lb)
Consumer Groups (MSN. Autos)	Cars / Wagons	Small · Midsize · Large
	Luxury Cars	Entry Luxury Cars · Luxury Cars · Ultra Luxury Cars($100k+)
	Sports Cars	Sports Cars · Exotic Sports Cars ($70k+)
	Vans	Passenger Vans / Cargo Vans
	SUVs	Small SUVs · Midsize SUVs · Large SUVs · Luxury SUVs
	Trucks	Small Pickups · Large & Heavy Duty Pickups

EXTERIOR LONGITUDINAL PROPORTIONS

Front Impact Structure & Powertrain

The size and orientation of the engine will significantly affect the proportion of the front end. Free crush space for frontal impact is required around the powertrain and chassis components to help meet frontal impact requirements.

Driver Package

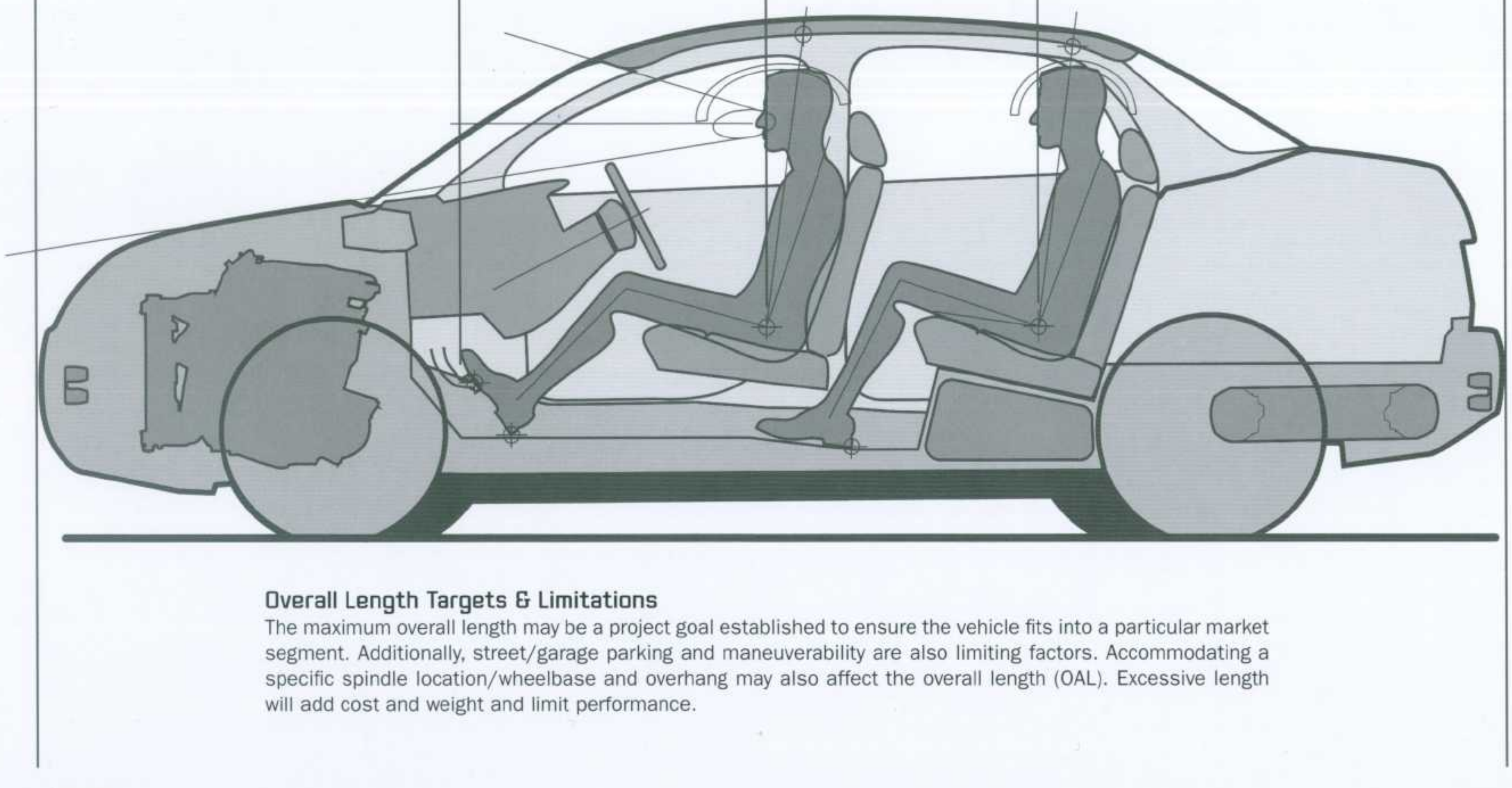
The space occupied by the driver's lower limbs is determined by the chair height. An increase of chair height will shorten the horizontal length between the feet and the hips.

Rear Occupant Package

The distance between the front and rear occupants (couple) will directly affect the vehicle length, which is why the rear passengers suffer the most in smaller cars.

Rear Impact Structure & Cargo Space

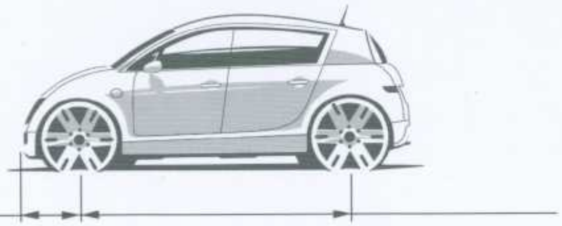
This space is mainly used to accommodate cargo, the spare tire and fuel tank. Protecting the rear occupants and fuel from rear impact will also influence this dimension.



Overall Length Targets & Limitations

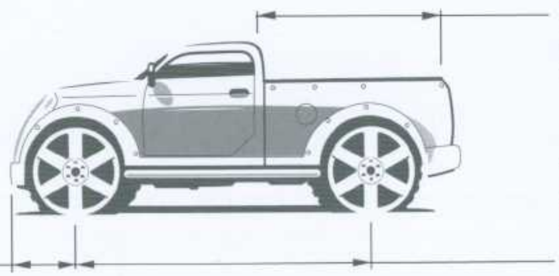
The maximum overall length may be a project goal established to ensure the vehicle fits into a particular market segment. Additionally, street/garage parking and maneuverability are also limiting factors. Accommodating a specific spindle location/wheelbase and overhang may also affect the overall length (OAL). Excessive length will add cost and weight and limit performance.

FWD
The front overhang and spindle is set up by the driveshaft location.



The wheelbase is set up efficiently around the passenger location.

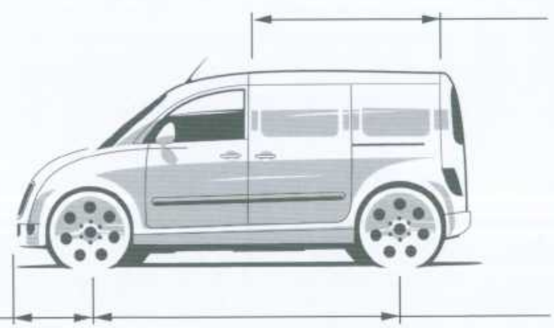
RWD
The front wheel is set forward to improve approach angle and minimize the effects of a heavy load on the steering.



Bed length is determined by function. They range from 850 to 2500mm.

The rear wheel location is set close to the middle of the bed for ideal load distribution and ramp over.

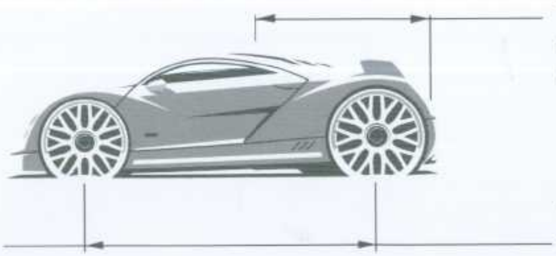
RWD / FWD
The front wheel is set forward to allow the driver to be located in a forward location.



Rear cargo bay length is determined by functional requirements.

The rear wheel location is set behind the side load door which is designed to allow specific items to pass through, which are usually over 1000mm.

RWD
The front wheel is positioned to establish perfect weight distribution.



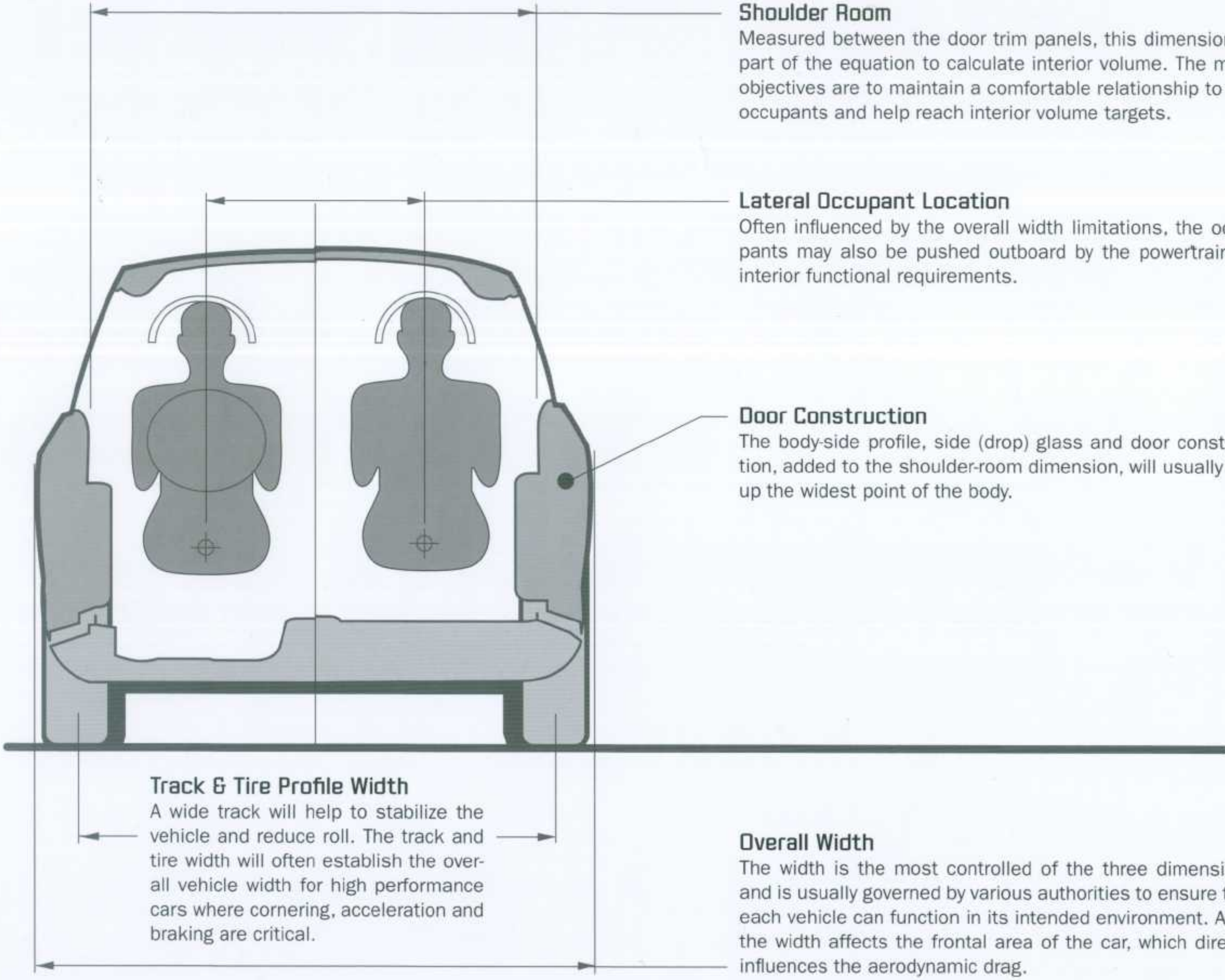
The engine transmission fuel tank and crush space are all located behind the driver.

The rear wheel is lined up with the driveshaft location.

The three-box passenger car with a front engine (on p. 76) is quite straightforward in its break up. Other vehicles will have a similar set of requirements governing the length of each chunk of the package, but may end up with different proportions because they have different functions.

Spindle locations are set by several different factors. Often the wheel center is slaved to a driveshaft location, so the driven wheel is usually placed first. The other spindle or axle may be located by the need for an efficient, short package or for optimum weight distribution.

EXTERIOR LATERAL PROPORTIONS



Shoulder Room

Measured between the door trim panels, this dimension is part of the equation to calculate interior volume. The main objectives are to maintain a comfortable relationship to the occupants and help reach interior volume targets.

Lateral Occupant Location

Often influenced by the overall width limitations, the occupants may also be pushed outboard by the powertrain or interior functional requirements.

Door Construction

The body-side profile, side (drop) glass and door construction, added to the shoulder-room dimension, will usually set up the widest point of the body.

Track & Tire Profile Width

A wide track will help to stabilize the vehicle and reduce roll. The track and tire width will often establish the overall vehicle width for high performance cars where cornering, acceleration and braking are critical.

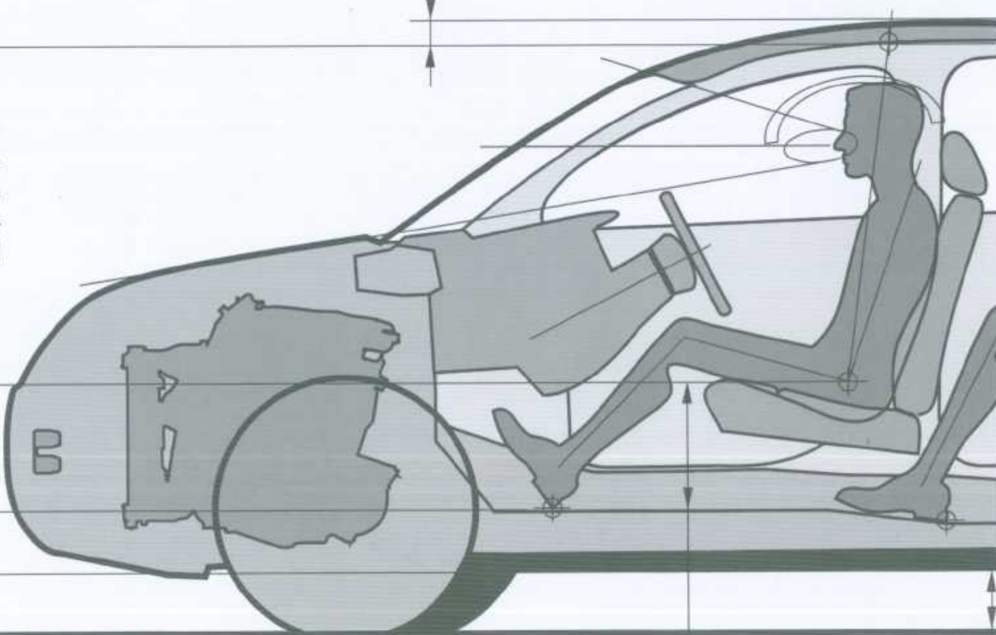
Overall Width

The width is the most controlled of the three dimensions and is usually governed by various authorities to ensure that each vehicle can function in its intended environment. Also, the width affects the frontal area of the car, which directly influences the aerodynamic drag.

EXTERIOR VERTICAL PROPORTIONS

HEADLINER & ROOF SYSTEMS
Space is required to accommodate trim and various roof systems such as sunroofs and roof racks.

EFFECTIVE HEADROOM
The distance between the seat and the headliner is determined by head clearance requirements and spatial expectations.



OVERALL HEIGHT
The vehicle's handling, aerodynamics, ground-clearance needs and occupant comfort all have to be considered when determining the overall height. Garage and underground parking access can limit the maximum height for vehicles such as SUVs and minivans.

UNDERBODY STRUCTURE
Provides space for an appropriate structure. Heavy-duty vehicles may require a separate frame system. Most unibody cars will require an integrated rail system under the driver's feet.

CHAIR HEIGHT
Lowering the chair height will help to lower the center of gravity and minimize the frontal area to reduce drag. Minivans & SUVs utilize a higher seating posture to provide command-of-the-road seating positions.

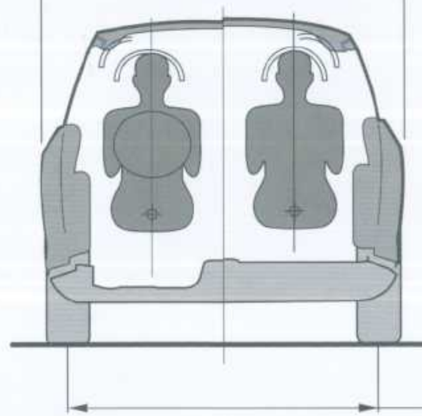
GROUND CLEARANCE
Off-road vehicles require high ground and "ramp over" clearances to avoid bottoming out on rough terrain. Sports cars will have minimal ground clearance to lower their center of gravity and improve aerodynamic performance.

KEY DIMENSIONS

These key dimensions are used to set up and communicate the size and attributes of the package. Developing concepts are under continuous scrutiny and these measurements help to keep the design team informed. Additional dimensions may need to be added depending on the type of vehicle and its functional objectives. An off-road truck, for example, may need to record ground clearance and bed length.

WIDTH

The maximum width of the body (excluding mirrors) often measured at the B pillar.



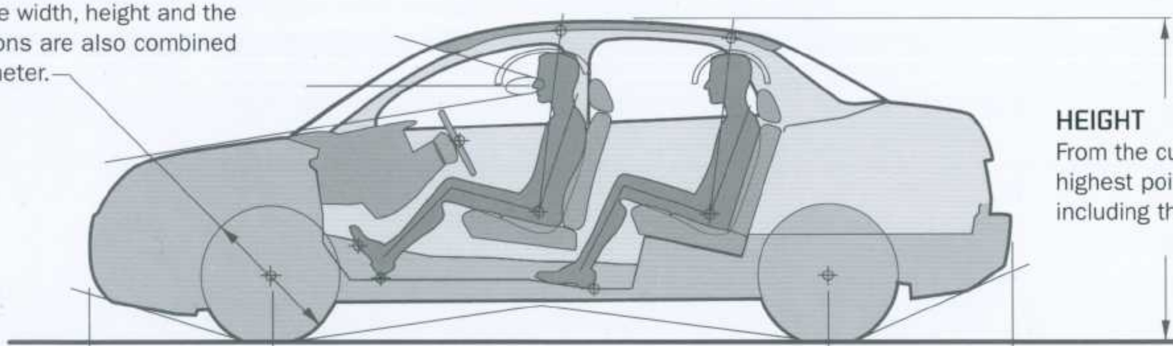
- Length
- Width
- Height
- Wheelbase
- Front Track
- Rear Track
- Front Overhang
- Rear Overhang
- Tire Size
- Tire O.D.

FRONT & REAR TRACK

The distance between the tire profile centers at the ground line.

TIRE SIZE & TIRE OUTSIDE DIAMETER (O.D.)

Tires are specified by their profile width, height and the wheel diameter. These dimensions are also combined to produce the tire outside diameter.



HEIGHT

From the curb ground to the highest point of the vehicle including the roof rack.

FRONT OVERHANG

Measured from the front spindle to the most forward surface of the body.

WHEELBASE

The distance between the front & rear spindles.

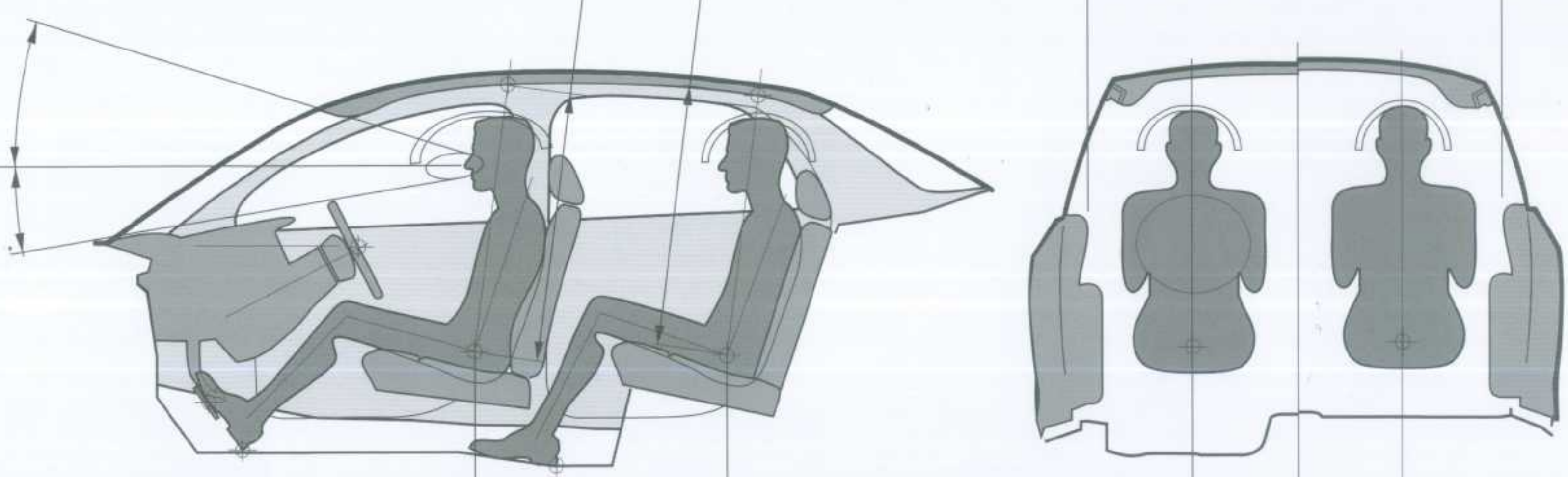
REAR OVERHANG

Measured from the rear spindle to the most rearward surface of the body.

OVERALL LENGTH

From bumper to bumper, (the sum of the wheelbase & overhangs).

- Front Headroom
- Front Shoulder Room
- Driver Lateral Location
- Forward Up Angle
- Forward Down Angle
- Couple
- Rear Headroom
- Rear Shoulder Room



BENCHMARKING

Benchmarking is the most empowering packaging tool a designer can use. It provides the key building blocks to set up the proportions quickly and with confidence.

After the functional objectives have been established, start to research existing vehicles with similar attributes. If the intended market segment is mature, this should be a straightforward process. If the concept is reaching into new and unknown areas, benchmarking will require more thought and creativity.

The illustrations on pages 84–85 show a simple benchmarking study, where several products have been selected for comparison and are superimposed with the basic package of the new concept. Although this looks quite primitive, a great deal can be learned from this simple study. Because an existing car or truck is the result of a huge amount of research and development, benchmarking serves to provide a sound foundation to launch a new concept study, as long as the design team doesn't just follow the same paradigms.

Before starting the study, it is a good idea to examine a comparison vehicle and understand its design philosophy. Get to know the vehicle as intimately as possible by reading various consumer reports and test driving if possible. After this, elements of the package can be dissected and used where they make sense.

Break up each package according to the information on pages 76–79. Giving separate consideration to key elements that make up the overall dimensions.

Ultimately, you will need several benchmark studies to prove the new concept.

The overall dimensions, the occupant package, the powertrain package, crashworthiness, cargo storage and any other innovative features incorporated into the design can be validated by demonstrating their similarity to other vehicles.

Line up each comparison according to the story it tells. For example, if headroom is the focus, line up the occupant's heads to each comparison vehicle. If it is the H-point to ground dimension, line up the ground lines of the vehicles.

Add the relevant dimensions to each study to add a higher level of accuracy to the comparison.

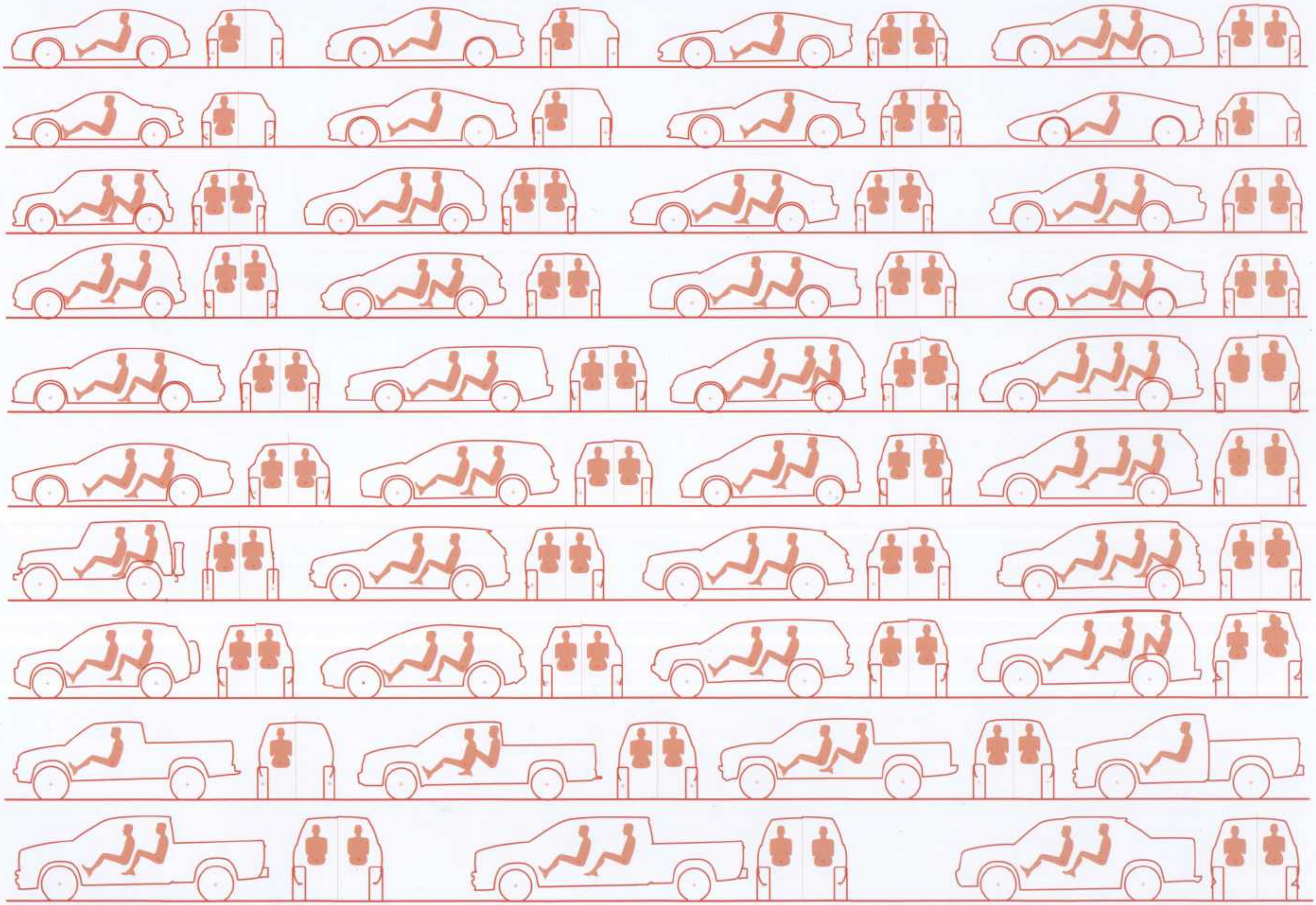
It is always advantageous to have access to a database of packages. Most companies will either buy these from organizations who specialize in vehicle measurement or they measure competitive vehicles and maintain their own database of package drawings.

For basic benchmark studies, each package should contain the vehicle outline, tire O.D. (outside diameter), spindles, occupants, h-points and heel location. These should be drawn in side and front views. A full set of dimensions is also very helpful.

There are many online resources which provide valuable information. The manufacturers' websites have all their vehicle specifications and measurements. Websites like www.autos.msn.com have tons of information and can create dimensional comparisons quickly. This information can be cross-referenced with vehicle-safety information from www.euroncap.com, www.safercar.gov or www.safecarguide.com.

A GRAPHIC PACKAGE DATABASE

The database should contain packages which contain the outlines, tires, and occupants drawn in side views and rear views.



BENCHMARK STUDIES

The example shown here is an off-road sports truck concept with a V12 engine. The five comparisons shown below demonstrate how elements of several different vehicles can be used to build and communicate the new concept.

To set up the basic package for a concept, several comparisons are usually necessary. Each comparison will help the design team understand the various features and attributes of the architecture. The comparisons below show the following:

1. Ground clearance, wheelbase and driver heel height.
2. Driver posture, head environment and windshield location.
3. Engine/Transmission envelope.
4. Cargo storage.
5. Overall dimensions.

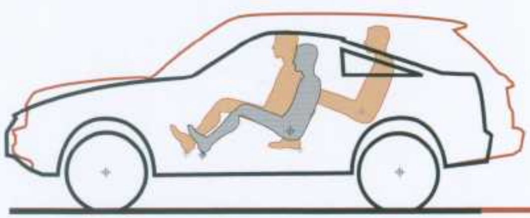
After developing the concept to this level, start to consider other large elements in the package, such as the fuel tank, spare tire, and stowing seats. Do not get too hung up on these components but respect the space they will occupy. As the project moves forward, an engineering team will become more involved and adjust the package accordingly. The main goal is to translate the emotion of the sketch into a rational model.

V12 OFF-ROAD SPORTS TRUCK - IDEATION SKETCH

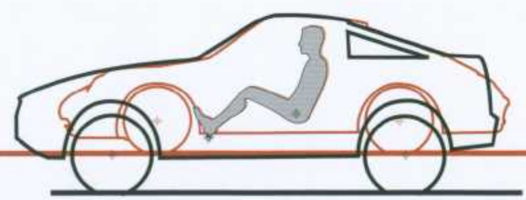
1. The concept has the same wheelbase and ground clearance as the Range Rover so it should have a similar off-road capability. The driver's heel is also a similar height, providing room for a strong and durable underbody structure suitable for off-road use.

2. The occupant has a similar posture and relationship to the 911 interior environment—i.e., the roof and windshield. Note: The packages are lined up at the driver H-Point.

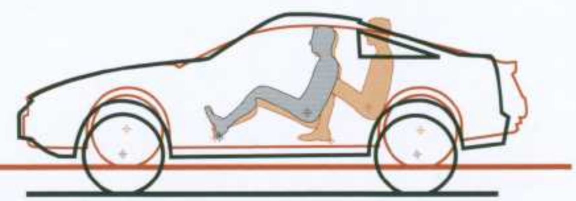
3. The DB9 has a similar V12 engine. This front end comparison shows a similar hood profile and front end to driver's foot relationship, proving the engine should fit. Note: The packages are lined up at the driver's ball of foot.



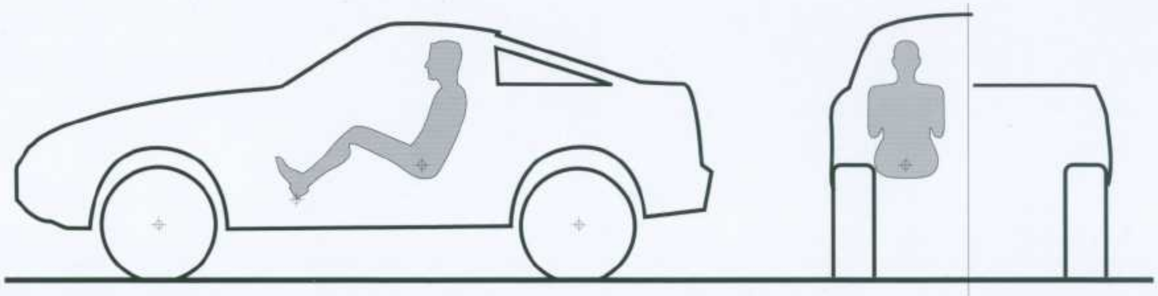
RANGE ROVER SPORT
(Similar wheelbase & ground clearance)



PORSCHE 911
(Similar head environment & driver posture)



ASTON MARTIN DB9
(Similar engine size & location)

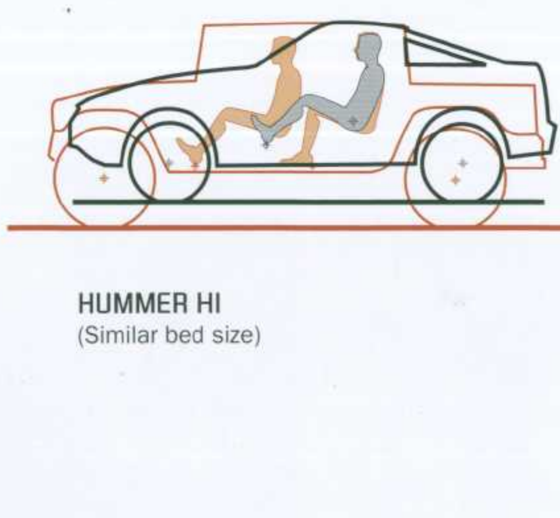


BASIC PACKAGE ORTHOGRAPHIC DRAWING

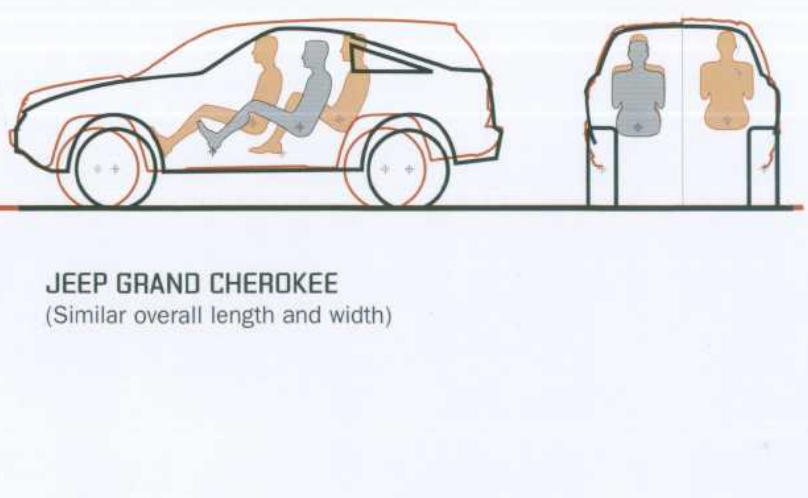
This initial package may look primitive but it is enough to start a scale model with confidence. Most of the main slab surfaces—i.e., the side glass, body side, hood, roof and windshield—can be blocked in from these side- and end-view profiles. The package will become more complex as the model develops, but should be kept very simple at the start.

4. The concept will have a similar bed size as the Hummer H1. Note: the packages are lined up at the occupant's shoulder.

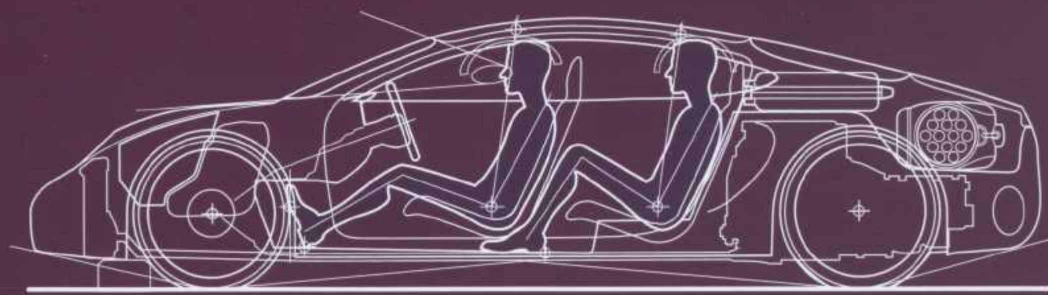
5. Although the new concept is a different type of vehicle than the Jeep, the overall dimensions are similar, helping to communicate the size. The occupants' lateral location (the transmission will pass between them) and the tracks are also similar. Note: the packages are lined up at the ground and bumpers.



HUMMER HI
(Similar bed size)



JEEP GRAND CHEROKEE
(Similar overall length and width)



"Without question, the most critical elements in every vehicle package are the occupants. If you get the occupant positions and postures wrong, the entire architecture may need to be redesigned. Because the manikin geometries are constant and represent the customers, the vehicle bodies are scaled around them."

OCCUPANT PACKAGING | 05

OCCUPANT MANIKIN INTRODUCTION

It cannot be overemphasized how critical the driver and passenger packaging is to the overall architecture. The occupants directly or indirectly influence every aspect of the vehicle's design.

It is often said that cars and trucks should be designed from the inside out. This refers more to the occupant package than the interior systems.

The main objective is to set up the driver and passengers to be comfortable and safe, then create an envelope around them and use key reference data within their geometries to set up the rest of the vehicle package.

The most important reference point in the package is the driver's hip (H) point. This is also referred to as the Seating Reference Point (SgRP). Almost every element of the package will be influenced by its location and if modified, the effects may be seen throughout the vehicle.

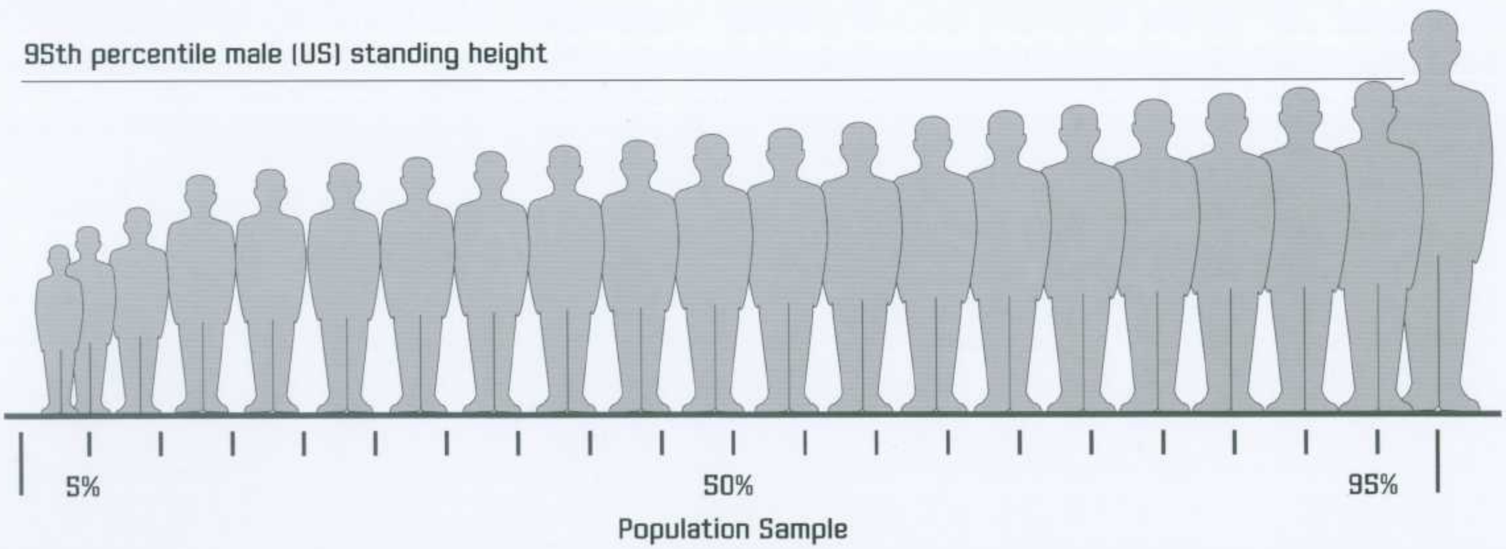
Each car company will use several manikins that suit their purpose. One of the most popular occupant packaging tools is the SAE 95th percentile male manikin, which is ideal for setting up the initial interior space, ensuring that the vast majority of the global population will fit into the package envelope.

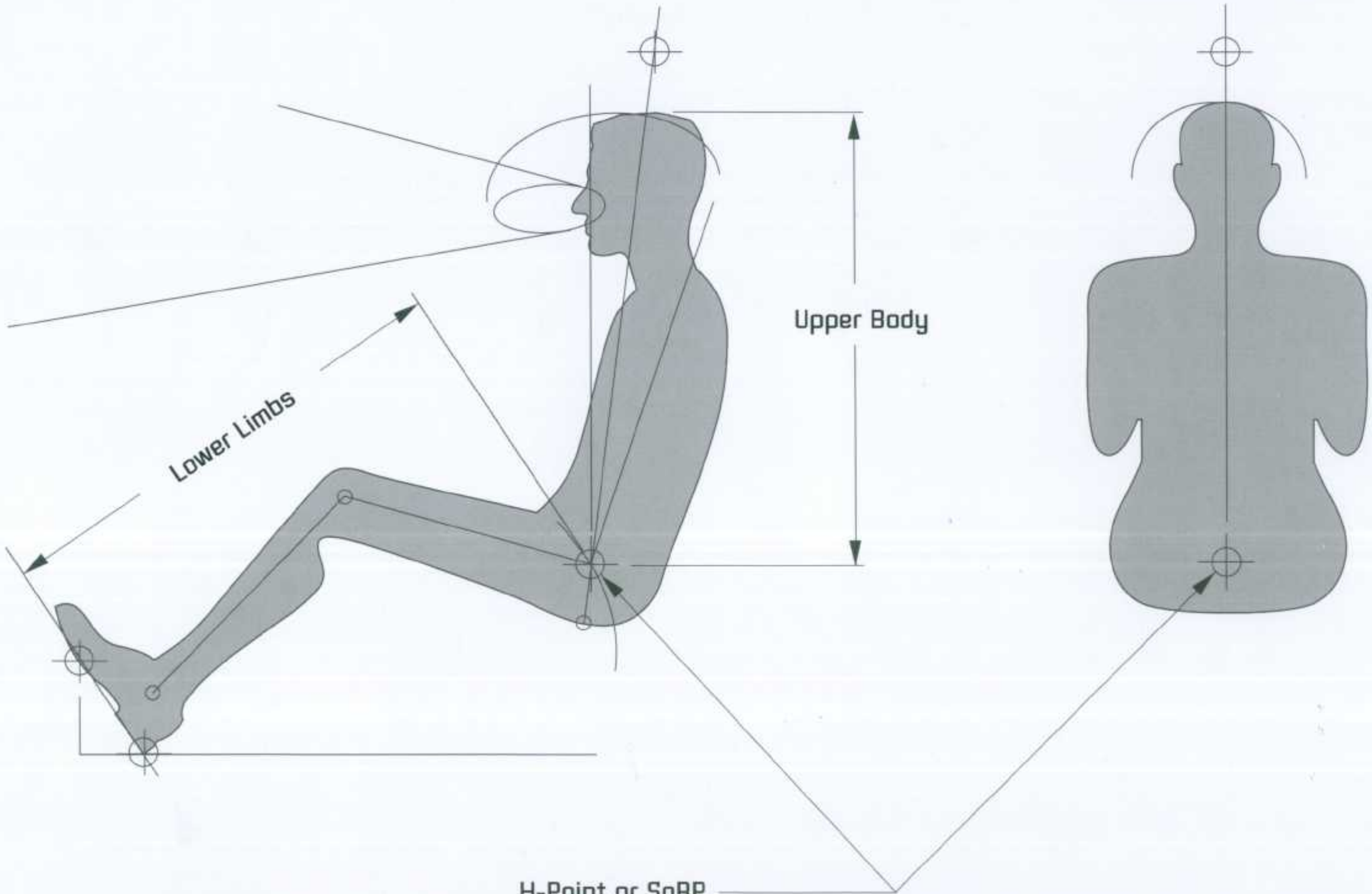
The SAE has worked with various groups to establish anthropomorphic (size, proportion and movement) data which represent the volumes occupied by drivers and passengers as they sit and operate vehicles. The results of this data have been converted into sets of geometry that represents the stature of a 95th percentile US male (97.5% of the total US population, including females) sitting in a car seat.

This geometry can be used to set up the interior systems, locate controls, complete vision studies, position the powertrain, establish the wheel/tire package and even place the bumper beams.

The limbs, torso and head of the population sample are meaşured individually to create a manikin that is built from 95th percentile male parts. The sitting manikin can be utilized in two halves, from the H-point to the feet (to establish leg room) and from the H-point to the head (to set up the head environment).

After the initial package has been built, other smaller manikins (5th percentile female and 50th male) are used to ensure that smaller people will be able to drive in comfort and safety.





H-Point or SgRP
(Hip Point or Seating Reference Point)
The most important reference datum in the package.

THE ANATOMY OF THE SAE (J826) 95th PERCENTILE MALE DRIVER MANIKIN

H-POINT (HIP POINT) or SgRP (SEATING REFERENCE POINT)
The main reference point for the occupants and one of the major datum points for the vehicle package. Often referred to as the "Seating Reference Point" (SgRP or R-point in Europe), it is always located on the comfort (accommodation) curve.

ACCOMMODATION CURVE (SAE J1516–1517)
This curve maintains the correct relationship between the H-point and foot to ensure a comfortable posture for the driver's legs while operating the foot pedals.

ACCELERATOR HEEL POINT
The heel-point location is often referenced to define the floor and step-in height.

BALL OF FOOT POINT
Located on the accelerator plane. A main reference point for frontal impact crush space measurement.

ACCELERATOR FOOT PLANE
This plane rotates about the ankle pivot and is usually locked at 87° to the shin centerline.

TORSO LINE
Defines the back angle inclination.

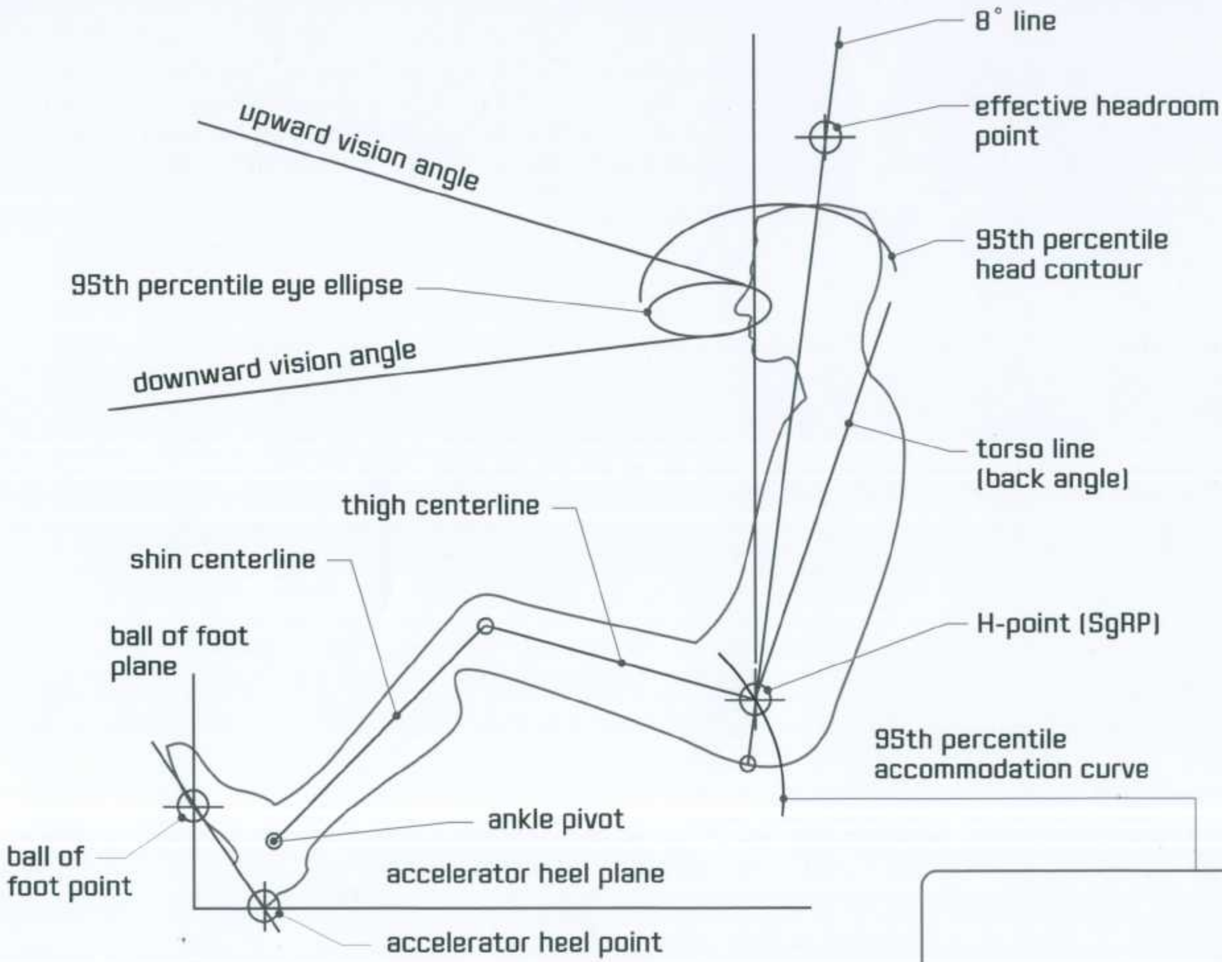
95th EYE ELLIPSE (J941)
The 95th eye ellipsoid represents a three-dimensional volume within which 95 percent of driver's eyes will be contained. Its location remains constant to the head contour.

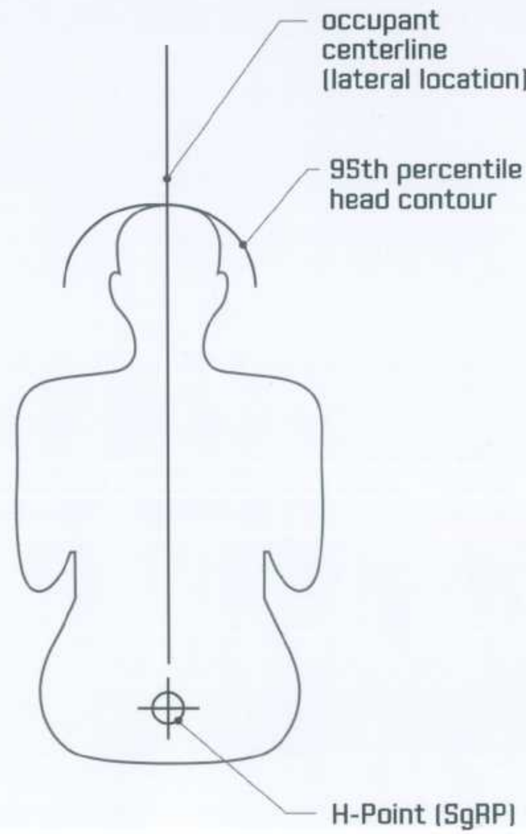
95th PERCENTILE HEAD CONTOURS (SAE 1052)
The head contours are defined by three-dimensional surfaces and represent the areas within which the 95th percentile occupant heads are contained. They incorporate seat-track travel and head movement. The position of the head contour is determined by the H-point and back angle.

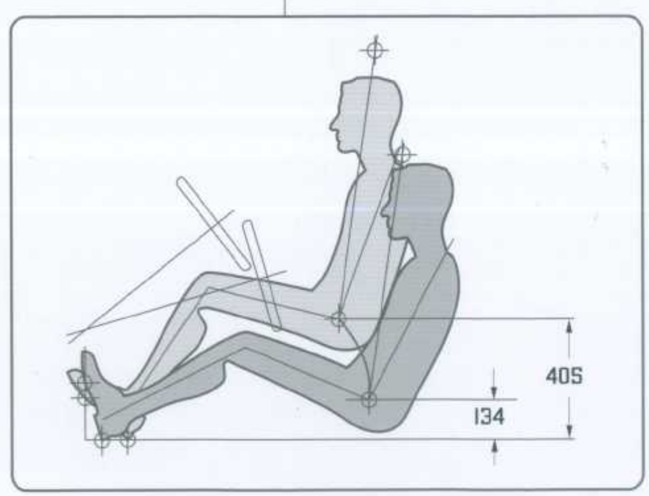
VISION ANGLES
The upper and lower vision angle lines are constructed tangentially to the 95th percentile eye ellipse and touch the first elements in front of the driver which obscure upward and downward vision. These are instrumental in the set up of the windshield aperture.

EFFECTIVE HEADROOM POINT (SAE J1100)
The intersection of the headliner trim and a line 8° from vertical, through the H-point. These are used to set up hard points on the roof surface above the headliner trim or sunroof.

LOWER LIMBS
The leg geometry consists of the shin and thigh centerlines, which are constrained by the ankle pivot and the H-point. Their configuration is automatically updated as the H-point to heel relationship is changed. The thigh centerline is used to set up the steering wheel location and the shin determines the knee-blocker surface on the instrument panel.







The height variation limited by the accommodation curve only applies to passenger cars and light trucks. Other vehicles such as golf carts, NEVs, and delivery trucks, which are designed for easy ingress/egress and short-distance driving, may require a taller seating posture. In these cases the H-point-to-heel vertical dimension may be as high as 530mm. This also often applies to Class B vehicles (heavy trucks) which usually have 150mm of vertical seat travel to accommodate shorter drivers. Seat adjustment in passenger cars is mostly horizontal.

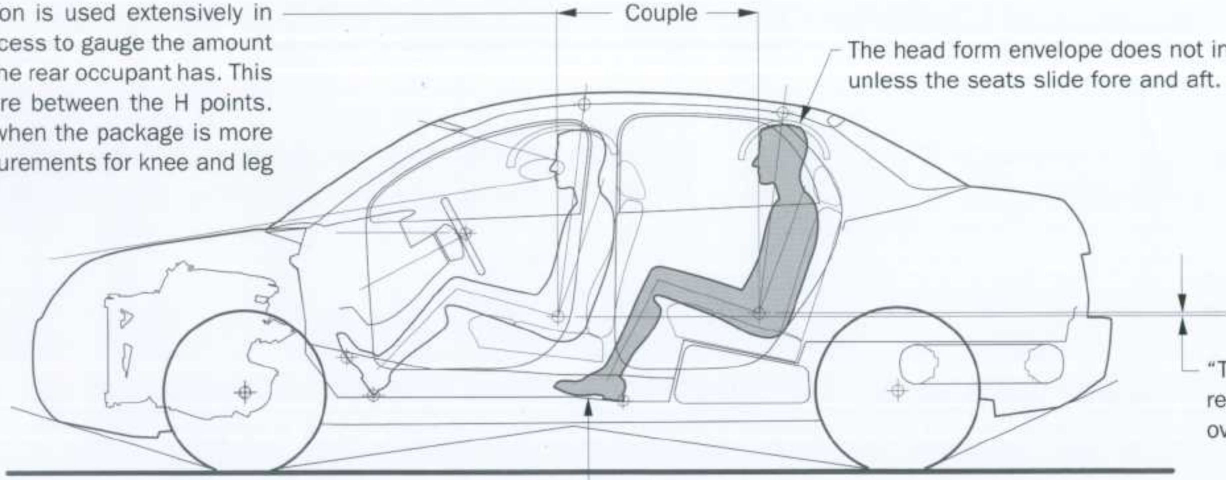
SETTING UP THE DRIVER HEIGHT & POSTURE

The driver's height and posture are governed by several factors, namely: center of gravity, aerodynamics, ingress/egress, comfort and visibility. The vehicle height should be established by a combination of these factors. The graphic on the following page shows how the driver height and posture varies with the functionality of each vehicle type. The dimensions provide an approximate range to help set up the driver in a traditional package.

For crossover vehicles, think about combining the attributes. For example a sporty off-road vehicle may have a high heel point for ground clearance and structure, but may need a low chair height to keep the roof height as low as possible. If the engine is in the rear, forward visibility over the hood won't be a problem.

SETTING UP THE REAR OCCUPANTS

The "couple" dimension is used extensively in the initial package process to gauge the amount of leg and knee room the rear occupant has. This is a horizontal measure between the H points. Later in the process, when the package is more mature, specific measurements for knee and leg room are recorded.

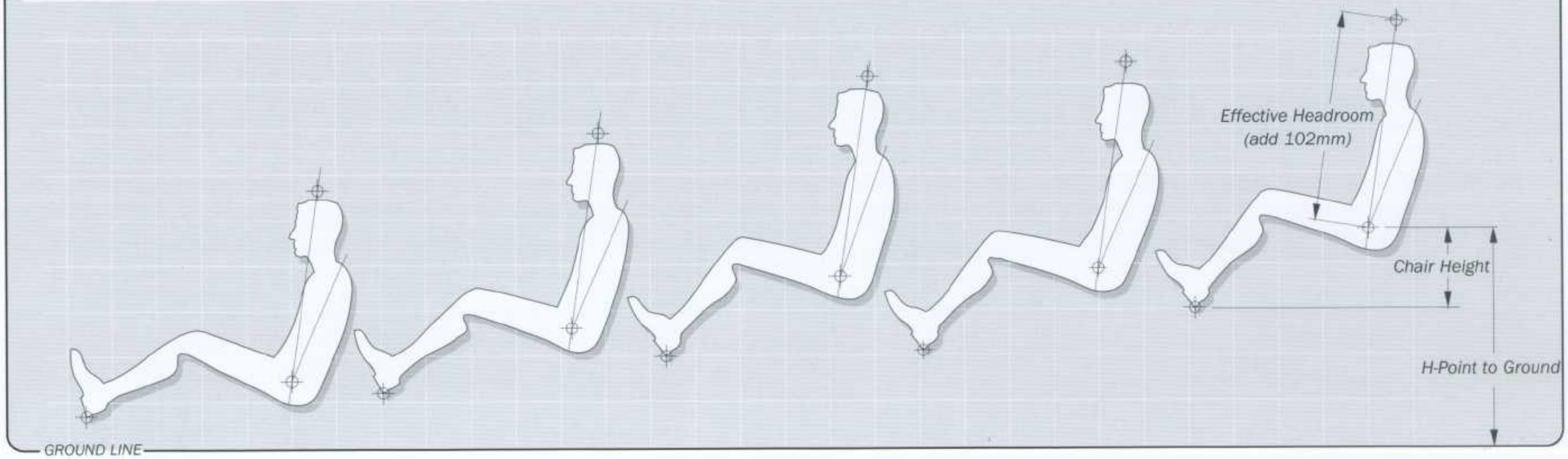


Because the rear occupants do not control the vehicle, their leg posture is not controlled by the accommodation curve. Notice how the knee angle is quite different to the driver and their feet are flat on the floor. Second, the demographics for the rear occupants may be different to the front occupants. They may be children or people who are shorter in stature to the driver, so headroom, for example, may be less.

Lastly, the function of the rear compartment will often be quite different to the front, so space may be needed for reclining passengers, swiveling or stowing seats, video monitor viewing, etc. These will all affect the spacial requirements and H point location. Other factors to consider are: roof height fuel tank size, rear cargo, three across seating, rear suspension and rear tire requirements.

VARIOUS DRIVER HEIGHTS FROM GROUND AND POSTURES

H-Point to Ground	300 - 350*	400 - 500	700 - 750	700 - 800	700 - 950
Chair Height	135 - 180	200 - 250	300 - 350	300 - 350	300 - 350
Effective Headroom	950 - 960	970 - 1000	990 - 1010	1010 - 1020	1010 - 1020
Back Angle	28° - 30°	22° - 25°	22° - 24°	22° - 24°	22° - 24°



SPORTS CARS
The driver height is kept as low as possible to lower the center of gravity and reduce drag. Getting in and out of the car may be difficult but that is a compromise sports car owners will accept.

PASSENGER CARS
Most passenger car H-points are set up for a combination of easy ingress/egress and low center of gravity. Although not as extreme as most sports cars, they are relatively low.

MINIVANS
Usually set up quite high to provide a sense of security and good visibility. The tall chair height also helps to create an efficient package and provides excellent ingress and egress.

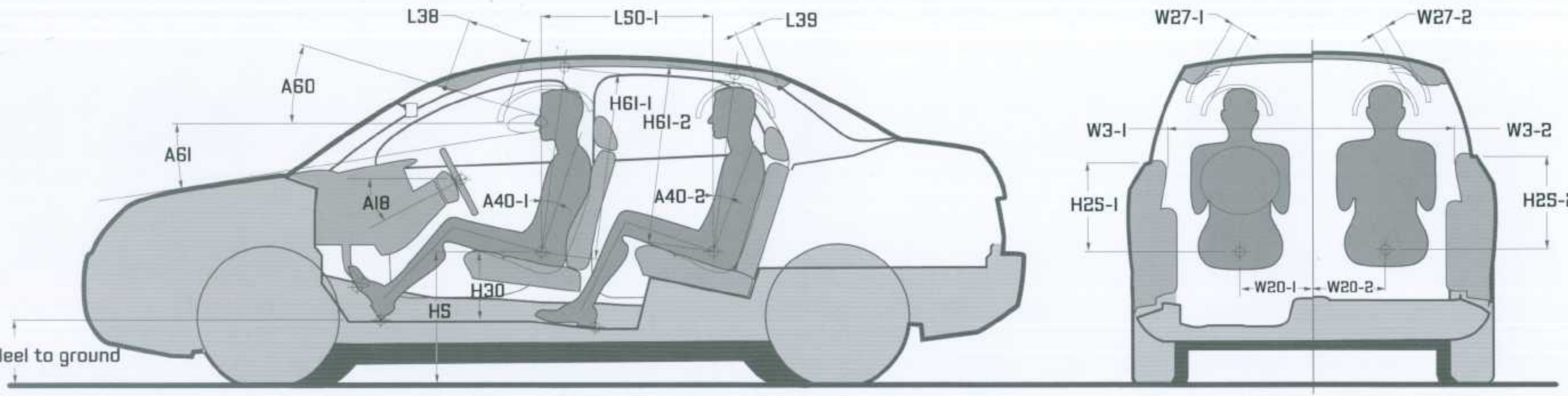
SUVs
A combination of high ground clearance and a durable underbody structure push the heel height up. The chair height is also tall to help the driver see over the engine, which is usually mounted high above the front axle.

LARGE OFF-ROAD TRUCKS
Similar to SUVs, the occupants often sit very high because of the ground clearance and the separate frame that the body sits on. Because the engines are usually very large and mounted high, the driver's eye point may end up in a very high position.

*All measurements in millimeters unless otherwise noted.

OCCUPANT ENVIRONMENT DIMENSIONS

Below is an illustration of the major dimensions that set up the interior environment around the occupant package. These are part of the SAE J1100 measurement index. Using the same measurement system for every project ensures that there is no confusion and the package database remains consistent.



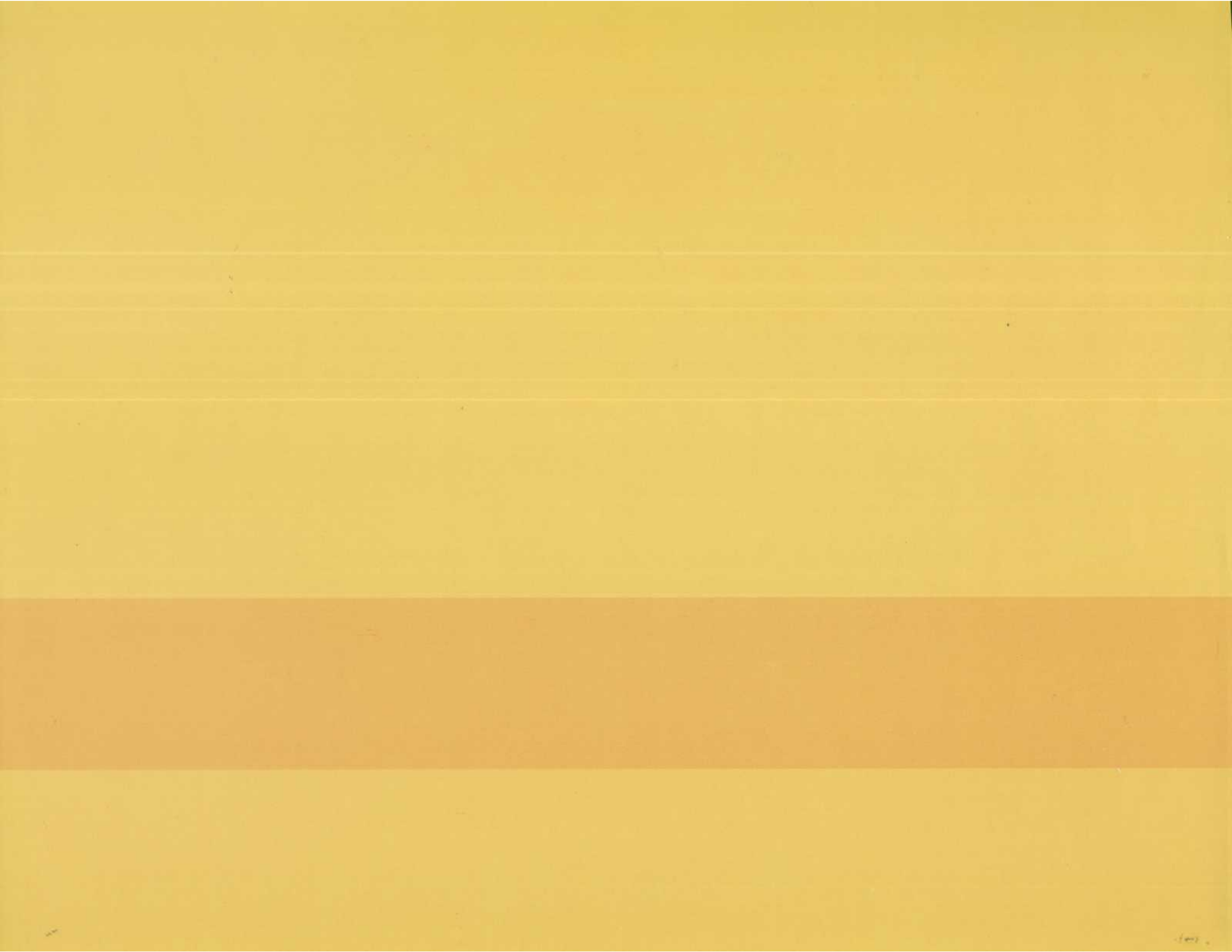
For steering wheel set up, see p. 102.

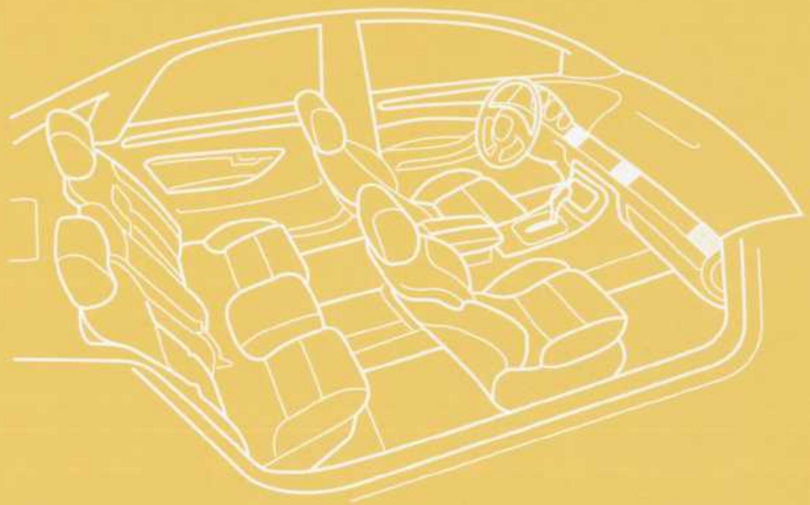
APPROXIMATE REFERENCE DIMENSIONS

The table below contains some examples of dimensions taken from current production cars. Use these to set up an initial package, assuming that the criteria that has driven these numbers is similar to your concept. As the design develops and key elements in the package evolve, these may change.

As you work through the process, develop an understanding of the factors that govern these interior environment dimensions.

		DRIVER & FRONT PASSENGER										REAR OCCUPANTS						
		Heel to Ground (Ref)	Chair Height H30	H point to ground H5	Back Angle A40	Effective Head Room H61	Upward Vision Angle A60	Downw'd Vision Angle A61	Shoulder Room W3	Hip Room W5	Lateral Location W20	Couple L50	Chair Height H30-2	Back Angle A40-2	Effective Head Room H61-2	Shoulder Room W3-2	Hip Room W5-2	Lateral Location W20-2
CARS	**NEV**	325	400	725	15.0	1075	11.0	10.0	-	-	275	-	-	-	-	-	-	-
CARS	**SPORTS CAR**	175	150	325	28.0	950	8.0	5.0	1350	1275	325/400	-	-	-	-	-	-	-
CARS	**MICRO CAR**	350	275	625	21.0	1000	14.0	11.0	1200	1150	300	-	-	-	-	-	-	-
CARS	**SMALL ELECTRIC CAR**	450	250	700	24.0	975	15.0	9.0	1325	1325	350	750	275	26.0	950	1325	1325	325
CARS	**SMALL CAR**	225	250	475	24.0	975	15.0	7.0	1350	1325	350	750	275	27.0	950	1350	1325	325
CARS	**MEDIUM CAR**	250	250	500	24.0	975	14.0	7.0	1475	1400	350	850	275	27.0	950	1475	1400	325
CARS	**MEDIUM COUPE**	250	175	425	24.0	950	13.0	5.0	1375	1325	350	750	200	27.0	875	1375	1325	325
CARS	**LARGE CAR**	275	250	525	24.0	975	14.0	6.0	1500	1450	375	900	275	27.0	975	1500	1450	400
CARS	**LARGE LUXURY CAR**	275	275	550	22.0	975	15.0	7.0	1550	1500	400	975	300	28.0	975	1550	1450	375
TRUCKS	**MINIVAN**	425	350	775	20.0	1010	19.0	11.0	1575	1525	425	850	375	22.0	1000	1575	1525	400
TRUCKS	**SMALL SUV**	400	350	750	22.0	1010	15.0	9.0	1425	1400	400	800	375	24.0	1000	1425	1375	375
TRUCKS	**MEDIUM SUV**	450	300	750	22.0	1010	14.0	6.0	1500	1450	400	825	325	24.0	1000	1500	1450	425
TRUCKS	**LARGE SUV**	450	325	775	22.0	1025	14.0	7.0	1650	1600	375	875	350	24.0	1025	1650	1600	375
TRUCKS	**SMALL TRUCK**	400	300	700	22.0	1010	14.0	7.0	1475	1450	375	625	325	18.0	950	1475	1425	400
TRUCKS	**LARGE 4x4 TRUCK**	600	350	950	22.0	1025	15.0	8.0	1700	1650	475	950	375	18.0	1025	1700	1650	475
TRUCKS	**COMMERCIAL VAN**	725	350	1075	22.0	1010	10.0	10.0	1675	1625	525	900	425	19.0	1000	1675	1625	500





"Ideally, the package starts from the inside and works its way out. If the architecture is driven by cargo, innovative seating or telematics, the concept will be heavily influenced by the interior design."

INTERIORS | 06

INTRODUCTION TO INTERIORS

The interior components can be divided into about seven systems, shown on the opposite page. These are typically developed and manufactured by various suppliers who work with the major auto companies from the beginning of the design process. They will often be delivered to the assembly line complete and ready to install.

The interior design on most projects will follow the exterior. There are exceptions, particularly if the vehicle interior has special features which will affect the overall package, such as rotating or stowing seat systems or special cargo needs. These will drive the initial package together with the occupants, creating hard points to work around.

An important concept to understand is that *the interior must be safe*, so each component is designed to reduce injury to the occupants during a collision.

Some parts contain the active and passive safety systems, such as the air bags, seat belts and knee blockers. They can be attached directly to the vehicle structure to aid their function.

Other items, such as the headrests and roof linings are designed to prevent head and neck injuries as well as trauma, in the event of severe impacts.

Trim

The trim features extensively in early package studies because it is designed to reduce head trauma if the occupants strike the upper body structure during an impact or rollover. As the roof rail, pillar and header sections are developed, they always include the trim. The door trims are set up relative to the occupant's H-point to establish the armrest height, the location of door release levers and various switches for power windows and locks.

Controls, Instruments & Switches

The steering wheel, shifter, hand brake and turn-signal stalks all have to be located where the driver can use them effectively and also allow easy ingress/egress. Some of these primary controls may be set up with the initial package if they influence other key systems. The instrument cluster is usually seen through the steering wheel, so accurate vision studies are crucial. The illuminated screen should also be shrouded from reflecting in the windshield by the cluster brow. Other switches and controls will need to be located within reach of the driver and front passenger.

The Instrument Panel (I.P.) & Consoles

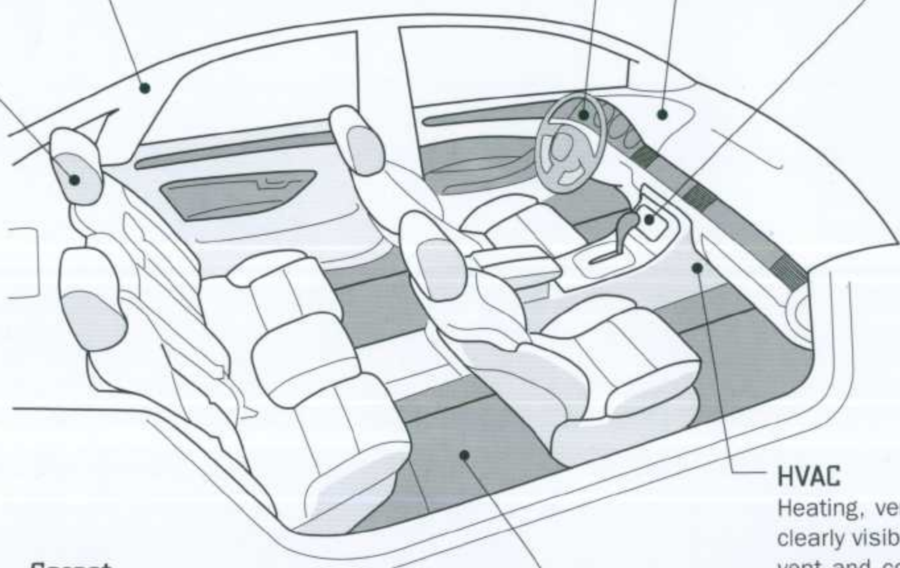
Generally, the I.P. will not influence the exterior proportions of the car, so its design can follow the exterior. However, many of the key components are directly related to the driver location and posture to provide reach, visibility and safety. If the occupant package changes, it will tear up the I.P. and console design. This is one reason why the interior design is not started until the exterior development is quite advanced. Overhead consoles will help redistribute some components and free up "real estate" on the I.P. but their size is often limited by the sunroof.

Telematics

The telematics may have a dramatic effect on the layout of the vehicle package. For some cars it may just be a navigation screen and an mp3 dock, but others may have a 50" flat screen TV with a full home theater system. This was not possible a few years ago, so new technology may redefine what a vehicle represents to the mass market.

Seats & Seat Belts

The seats are designed around the occupants' package location and posture. They occupy a large volume and adjustment ranges have to be factored into the location of adjacent components. Special seat systems that rotate or stow will require studies at the initial stage. The front seat belts will normally be attached to the B pillar. In some vehicles there is no B pillar and the belts are attached directly to the lower body structure and/or the seat structure. Attaching belt anchors to seats adds considerable stress loads to the seat structure.



Carpet

The carpet does not influence the package too much other than raising the heel points. Luxury cars may have a lot of sound insulation which can stack up to become significant to the packaging of the heel point.

HVAC

Heating, ventilation and air conditioning systems are clearly visible in all cars because of the air distribution vent and controls. What are hidden are the modules that heat and cool the air and pump it through the cabin. These units can be quite large and are usually located between the foot wells, behind the center stack.

INSTRUMENT PANEL & CONSOLES

The instrument panel (I.P.) is one of the most complex assemblies in the car. On most conventional interiors the area around the instrument cluster is very crowded, with the steering column, instruments, I.P. structure and HVAC ducting all competing for the volume. The center stack layout also needs to be carefully prioritized and organized so that vent outlets, HVAC controls, telematics (navigation, radio, CD, etc.), cup holders, switches and storage trays all fit and are ergonomically positioned.

Additional consideration must be given to safety because much of the instrument panel is within the head impact zone. This means that the contours, radii and hardness of all surfaces have to be designed to pass all interior safety legislation and testing procedures. Also, during a high-speed frontal impact the occupants rely on the knee blockers and air bags to restrict their forward travel and cushion the impact. For this reason the relationship of the I.P. and controls to the driver and front passengers is critical, with everything set up for reach, vision and safety.

Special consideration should be given to vehicles in global markets where both left- and right-hand drive configurations are required.

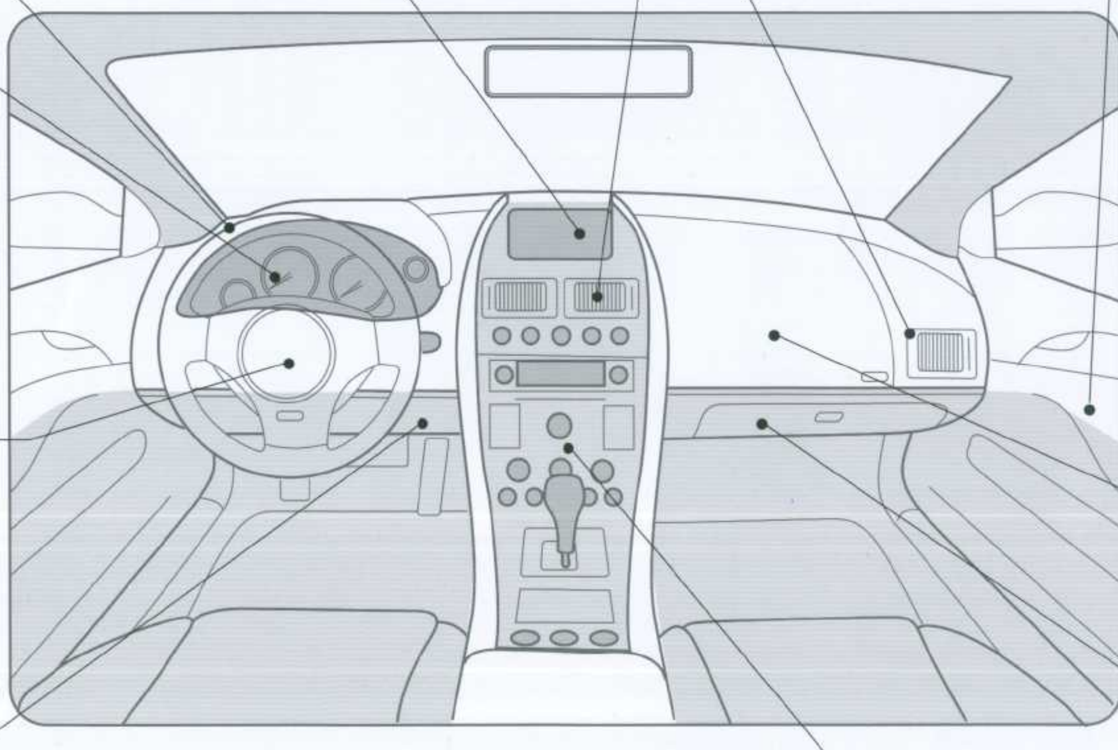
STEERING WHEEL
Mounted on the steering column which is usually adjustable and attaches to the main I.P. structure.

TELEMATICS SCREEN
Primarily for navigation, providing TV & video in the I.P. is illegal in most countries.

AIR DISTRIBUTION VENTS
Positioned to blow conditioned air at the occupant's face and torso.

DOOR TRIMS
The door trims are usually designed to flow into the I.P., so these are often modeled and sketched at the same time. These also relate closely to the occupants and set up the "shoulder room" and "hip room" dimensions. The armrests, release levers and switches should be set up appropriately to the occupant. The door trims are also designed to help minimize injury during a side impact.

INSTRUMENT CLUSTER
Usually housed behind the steering wheel, occasionally in the center stack, the instruments usually include the speedometer, tachometer, fuel gauge, engine temperature, battery charge, and warning lights.



DRIVER'S SIDE AIR BAG
Packaged in the center of the steering wheel it works more effectively if the steering wheel is angled toward the driver's face.

PASSENGER SIDE AIR BAG
Can be mounted in the top pad or on the front of the instrument panel.

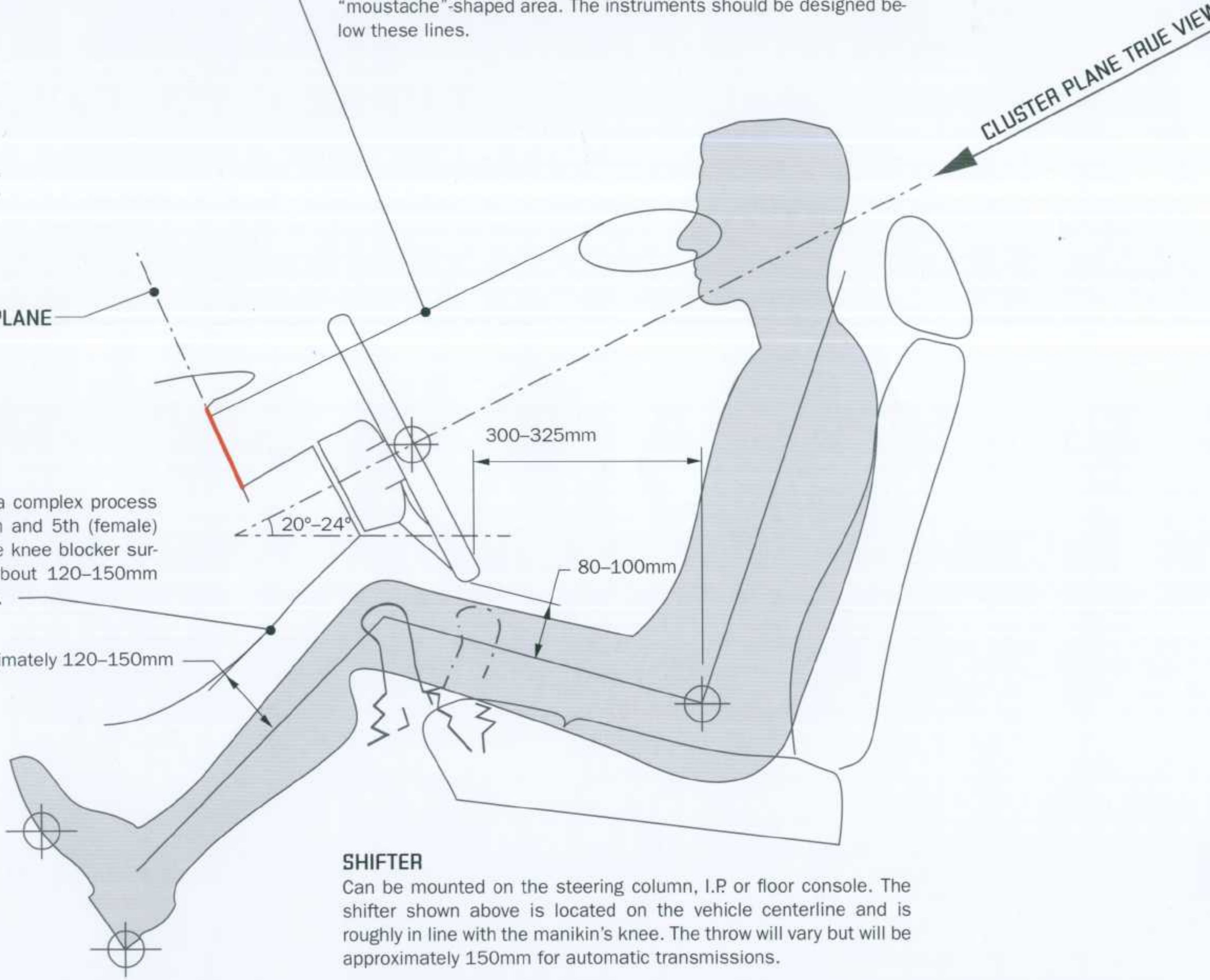
KNEE BLOCKER (GLOVE-BOX DOOR)
Working in a similar fashion to the driver's knee blocker, it utilizes the glove-box door to provide a solid pad to prevent forward travel off the seat.

KNEE BLOCKER
Working in conjunction with the air bag, it is a component of the active safety restraint system (SRS). Its relative location to the occupant is critical to prevent an unbelted occupant from "submarining" during a frontal impact. It is connected directly to the main I.P. structure to provide a solid pad.

CENTER STACK & CENTER CONSOLE
The shifter, telematics, HVAC controls, vents, radio, cup holders and banks of switches may be housed in the center stack and should be within easy reach of the driver and passenger. The SAE J287 recommended reach zones should be utilized to place these items.

CLUSTER VISIBILITY

The instrument cluster visibility is set up through the steering wheel using the 95th percentile left and right eye ellipses which project binocular vision lines onto the cluster plane resulting in a "moustache"-shaped area. The instruments should be designed below these lines.



KNEE BLOCKER

The location set up by a complex process involving the 95th, 50th and 5th (female) percentile manikins. The knee blocker surface usually ends up about 120–150mm from the shin centerline.

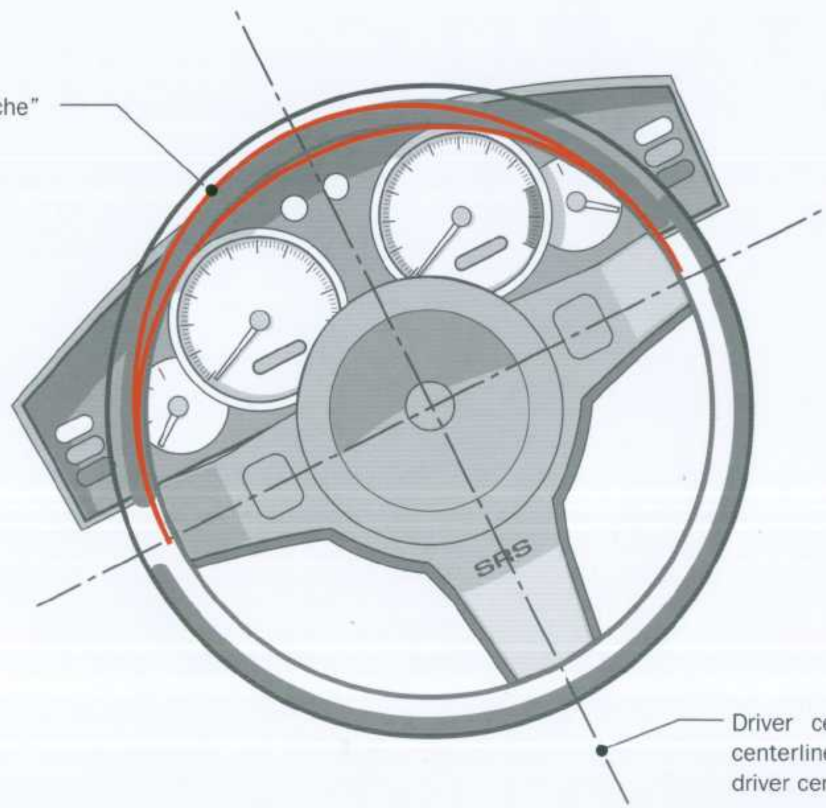
SHIFTER

Can be mounted on the steering column, I.P. or floor console. The shifter shown above is located on the vehicle centerline and is roughly in line with the manikin's knee. The throw will vary but will be approximately 150mm for automatic transmissions.

STEERING WHEEL SET UP & INSTRUMENT CLUSTER VISIBILITY

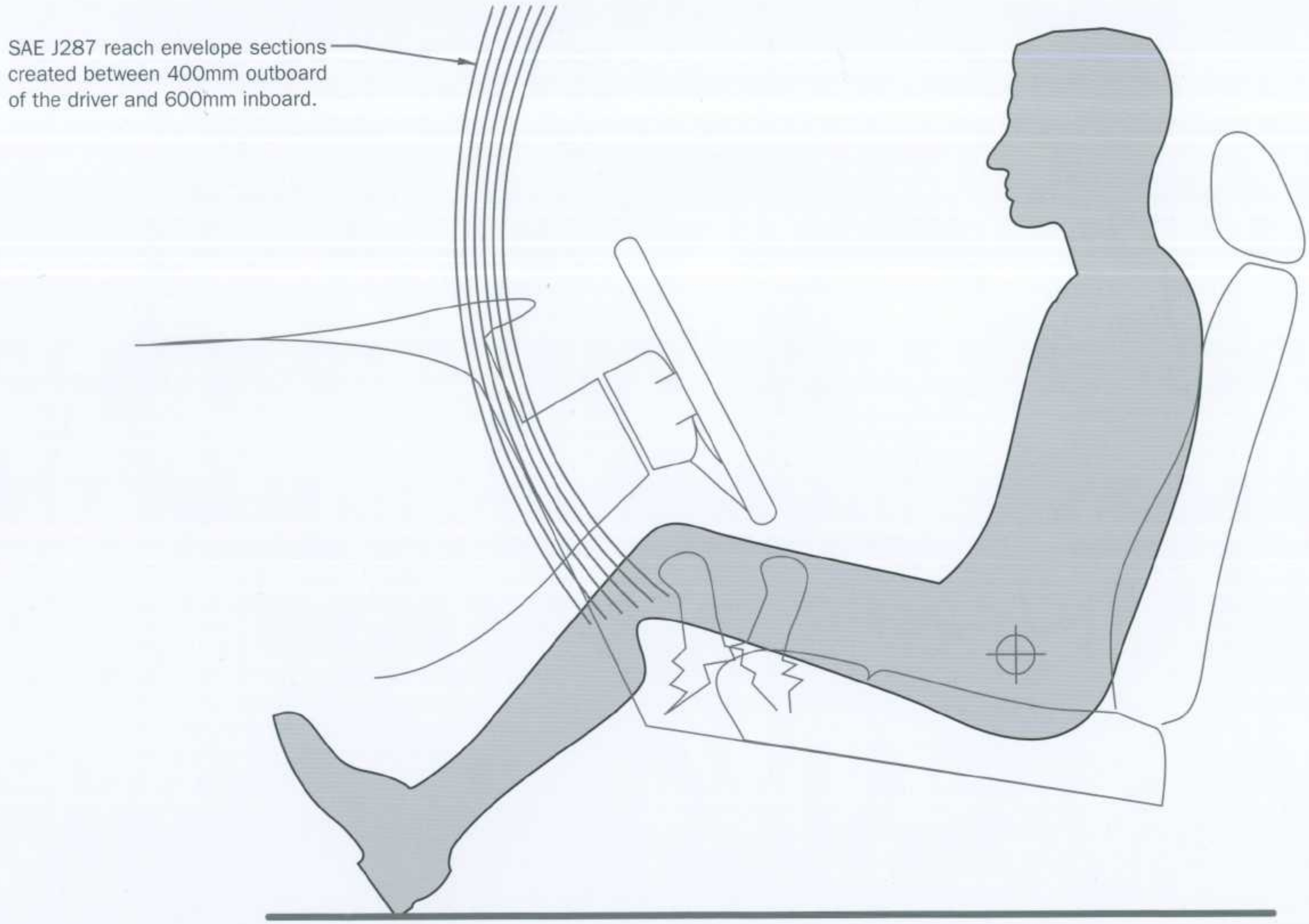
The steering wheel center is mounted on or close (within about 10mm) to the driver centerline and usually has a diameter of about 380–400mm. In side view it is set up to the occupant relative to the thigh and H-point. The angle of the steering wheel is roughly 90° to the column which is itself normally between 20°–24° from the horizontal.

The bottom of the steering wheel to the thigh centerline is usually between 80–100mm. The distance between the base of the steering wheel to the H-point is usually between 300–325mm horizontally.



REACH ENVELOPES

The objective of the reach envelopes is to provide recommended zones to locate each control lever or knob that the driver may need to adjust while driving with a seat belt fastened. The geometry for these envelopes is given in SAE J287. The envelopes are represented by a series of sections cut every hundred millimeters, from 400mm outboard of the driver centerline to 600mm inboard. These sections relate to the H-point location in x, y and z directions.



SEAT CONTOUR & CONSTRUCTION

Most car seats are made from cloth or leather-covered foam, supported by a sprung steel frame mounted to adjustable tracks which sit either on the floor or on risers as shown opposite.

Establishing a relationship between the H-point and the seat is important but difficult to control. The seat cushion foam and occupant flesh combined will compress about 50mm, so the seat should be drawn intruding into the occupant. After the seat has been manufactured, the 3D H-point machine (SAE J826, 76kg) can be placed to check the accuracy of the final H-point location.

The headrest is designed to prevent whiplash injuries during a rear impact and is required to be at least 730mm above the H-point and 315mm behind, with the torso back angle set to a nominal 22°.

SEAT PACKAGING

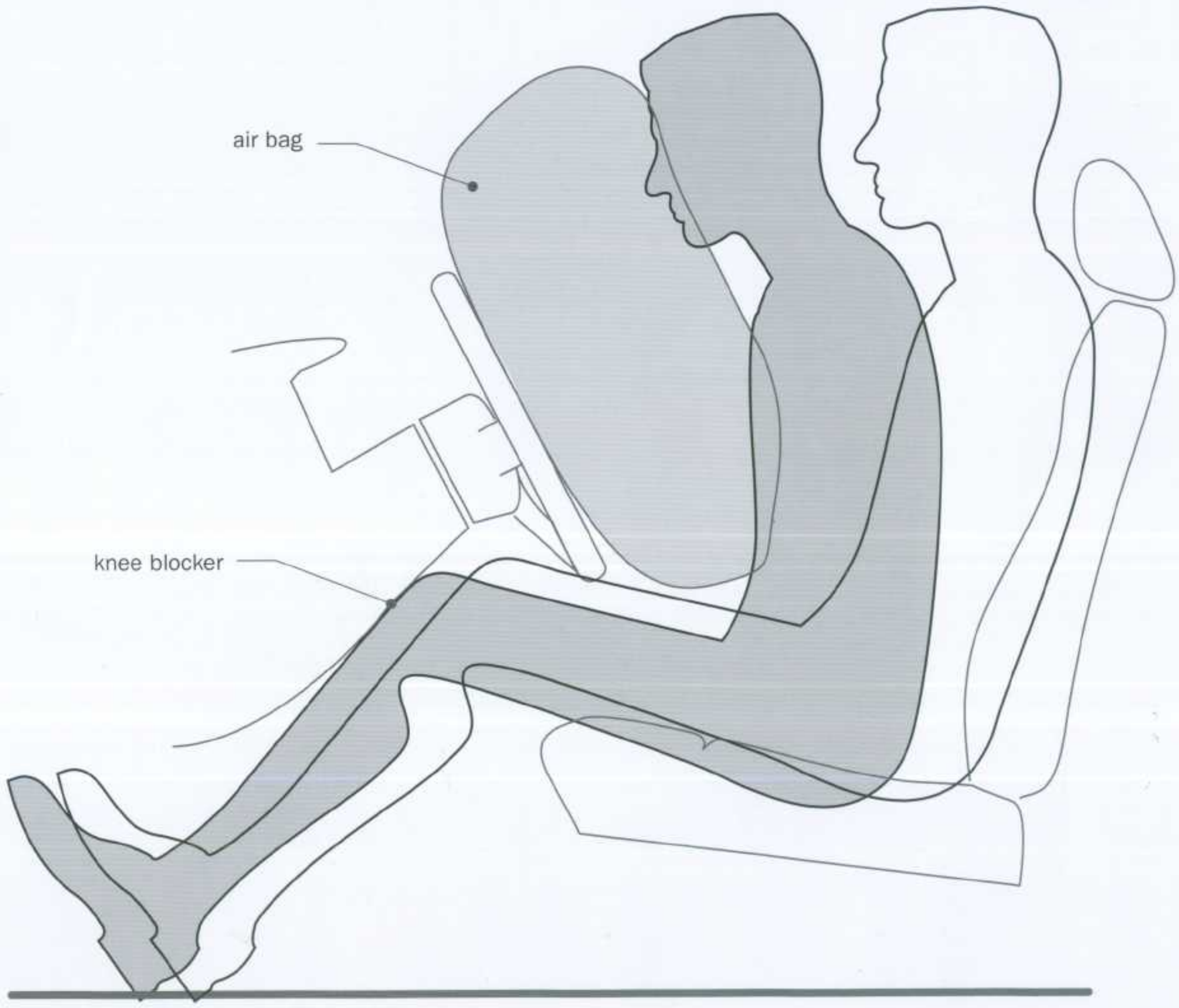
Seats take up a large portion of the interior volume, especially when their full range of adjustment is taken into consideration.

Always ensure that adequate clearance (15mm) is designed between the movable seat components and the adjacent systems—i.e., door trims and center console.

Note: On vehicles with very low chair heights, the seat tracks may be mounted vertically on the sill and console to help make the seat height compact.

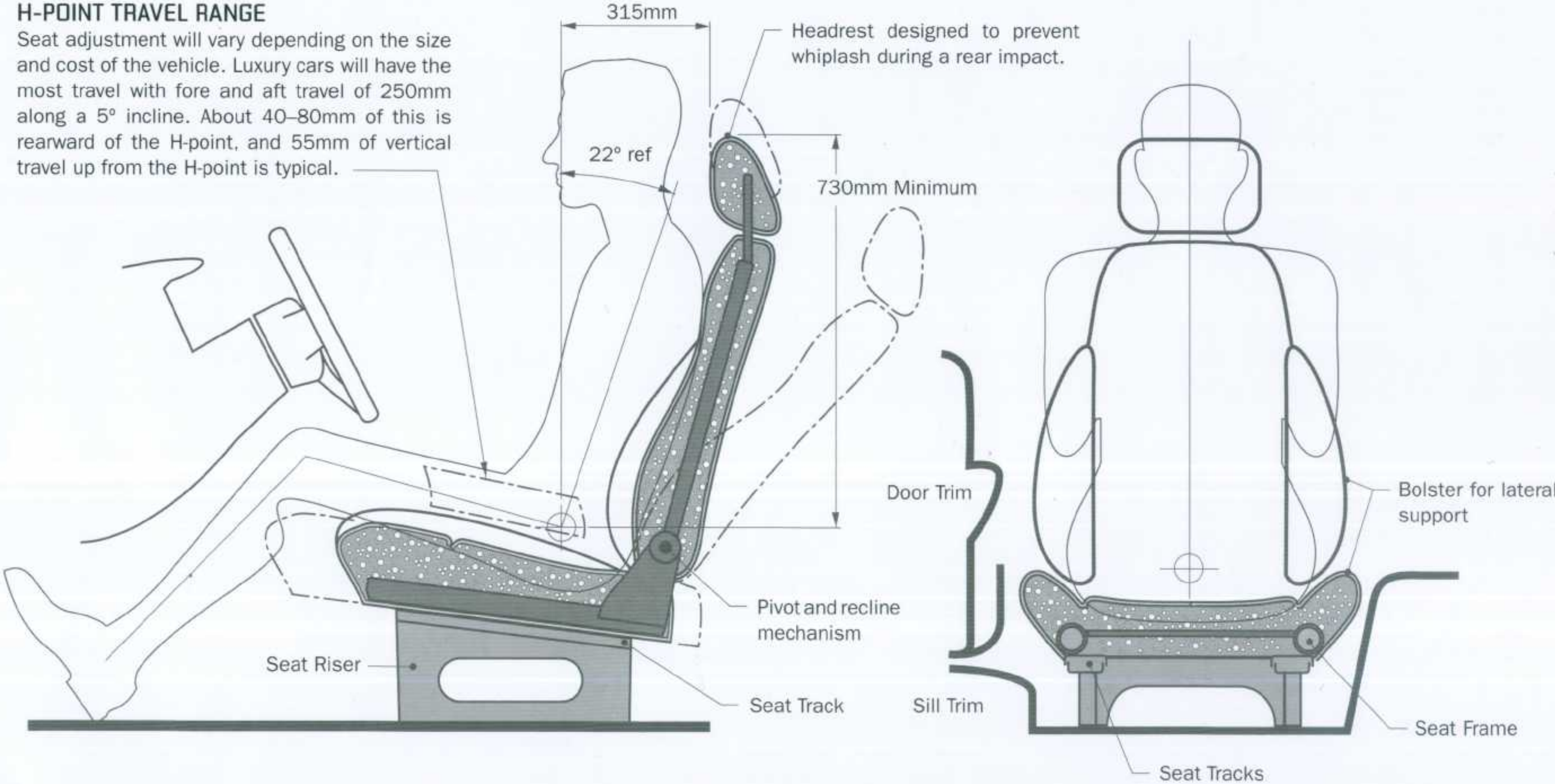
AIR BAG DEPLOYMENT

The active restraint systems are designed to protect the front occupants in a high-speed frontal impact, even if they are not wearing seat belts. Notice that the momentum of the driver causes the manikin to slide forward until the knees hit the knee blocker on the instrument panel. The air bag deploys in a split second to cushion the impact and protect the driver from hitting the steering wheel. The passenger side air bag deploys from either the top or rear of the instrument panel in a similar fashion. Side curtain and seat bolster air bags also deploy from the side rail and seat cushions to protect the driver's head and torso in side impacts.



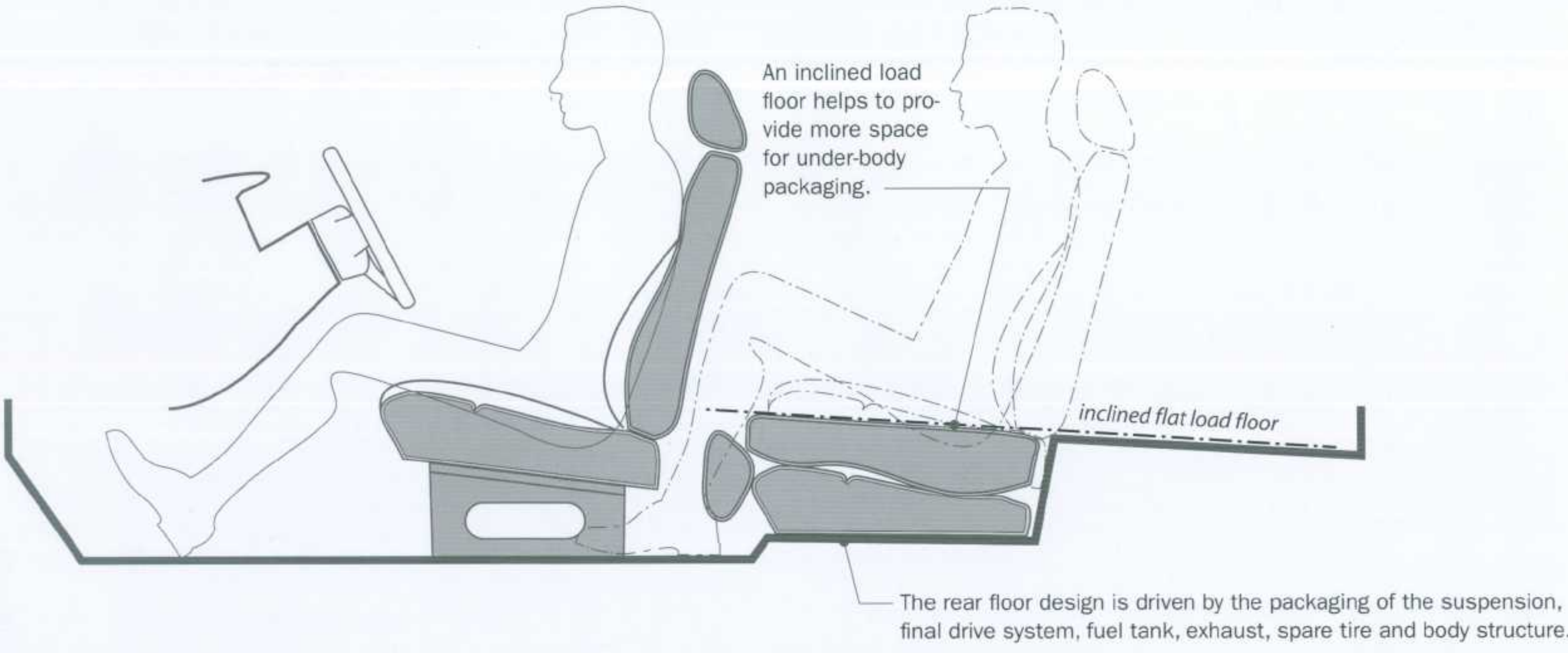
H-POINT TRAVEL RANGE

Seat adjustment will vary depending on the size and cost of the vehicle. Luxury cars will have the most travel with fore and aft travel of 250mm along a 5° incline. About 40–80mm of this is rearward of the H-point, and 55mm of vertical travel up from the H-point is typical.



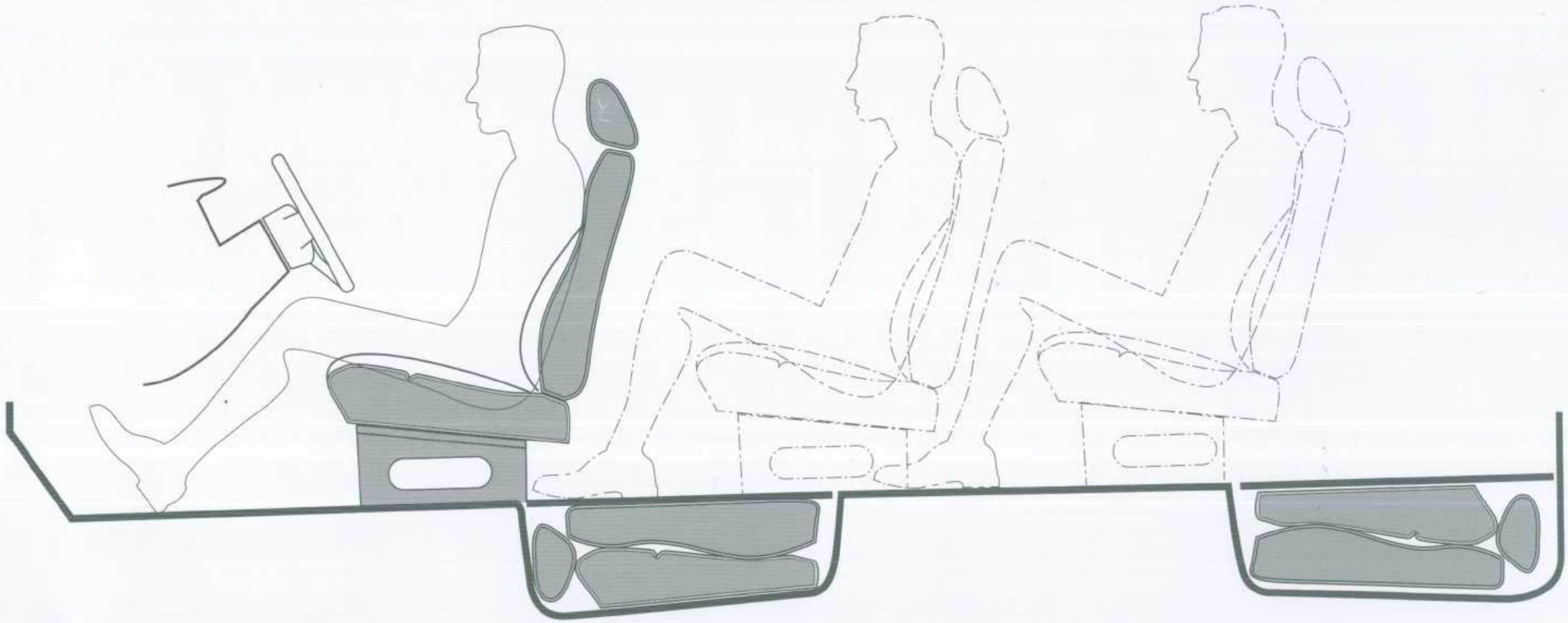
TYPICAL HATCHBACK & SUV FOLDING REAR SEAT

Ideally, the seat should be designed to provide comfortable seating in the upright position and also to stow efficiently in the foot well (with the headrest in place) to provide a flat load floor. Achieving this will depend on the under-floor packaging of the suspension, final drive system, fuel tank, exhaust, spare tire and body structure. An inclined rear floor will help to create a flat load floor with the seat in a higher position.



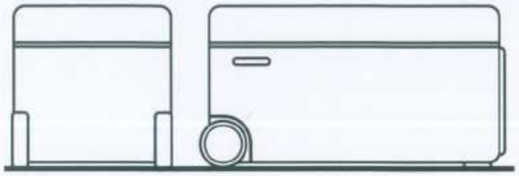
TYPICAL MINIVAN STOWING SEATS

Minivan floors are usually flat and quite high so stowing seats flat into the floor is possible with some creative under-floor packaging. Because the chair height is often high, the seat risers can be used to articulate the seats into their stowed position. When the seats are in their normal, upright position the vacant under-floor storage is an additional bonus for hiding valuables. A feature of this magnitude will have to be considered at the initial package ideation stage.



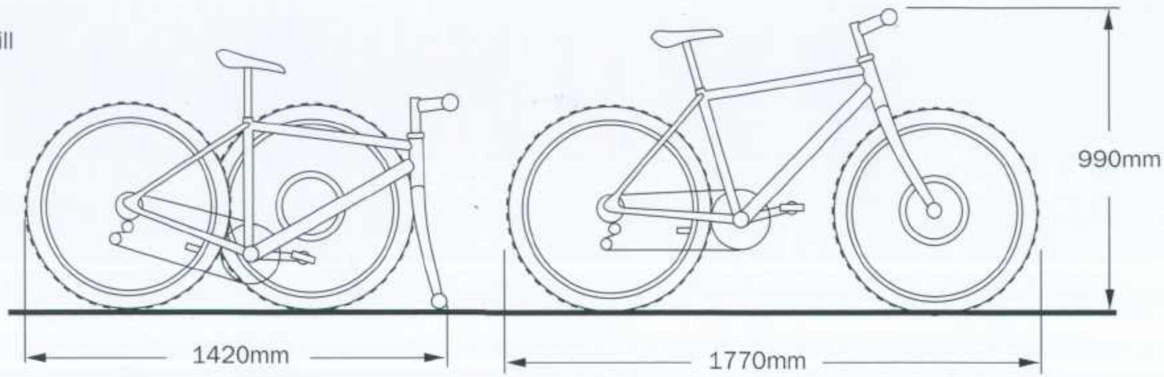
CARGO STORAGE

The customer's lifestyle will dictate the type of cargo he or she will carry. Here are some examples and approximate dimensions.



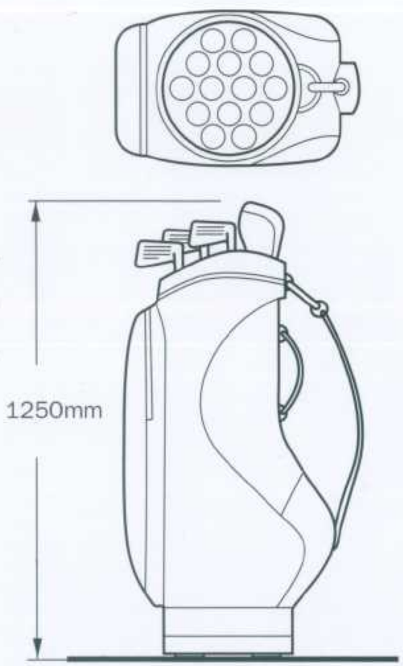
ICE CHEST / COOLER

These are sold in various sizes, the larger ones are between 50–100 liters.
50 liter = 700mm x 380mm x 440mm
100 liter = 930mm x 400mm x 440mm



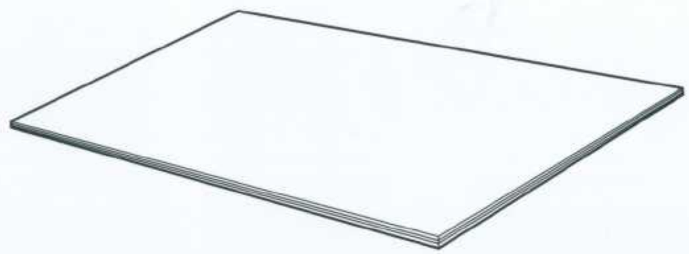
ADULT MOUNTAIN BIKES

Most bikes have quick-release wheels and saddles which makes them easier to store in a vehicle. The wheel diameters are usually 660mm.



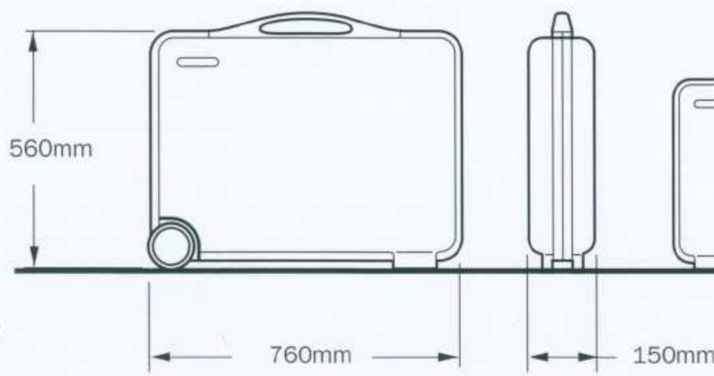
GOLF BAG

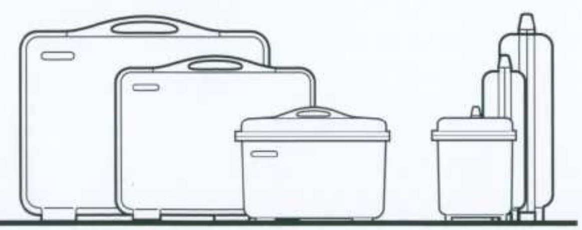
These vary quite a bit in plan-view size but are usually about 1250mm high, with the clubs.



PLYWOOD SHEETS

Building materials are sold in standard sizes. Large plywood sheets are 1220mm x 2440mm (4 ft. x 8 ft.).





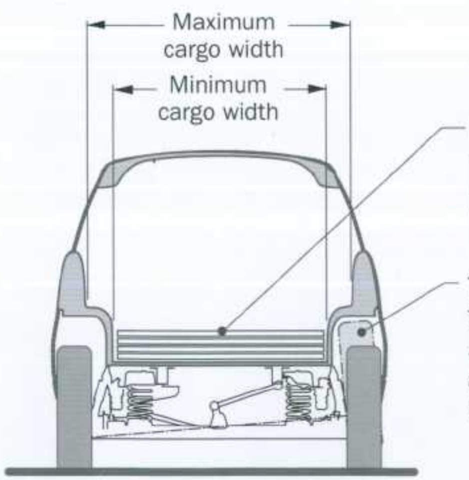
LUGGAGE

Suitcases come in all shapes and sizes. A typical large suitcase's dimensions are illustrated at left.

DESIGNING FOR CARGO

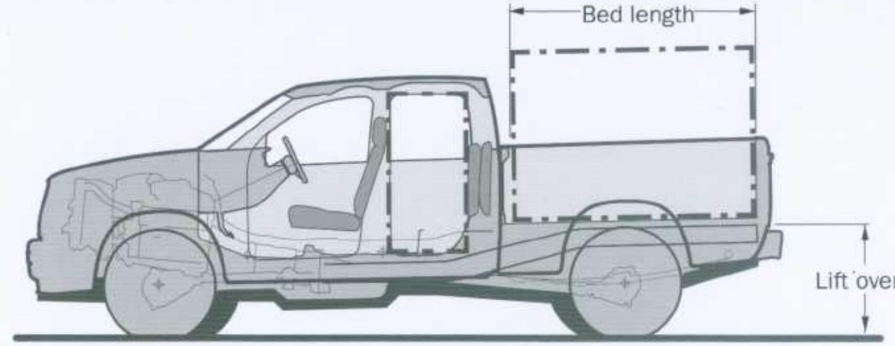
Cargo can take up as much space, or more, than the occupants, so it is worth thinking about from the start. Several factors should be investigated to determine the architecture adjacent to the cargo storage area.

1) Overall dimensions are usually designed around specific items to be carried. This often relates to the customer's lifestyle.
2) Interior volume is a big selling point in passenger cars (see p. 113). If several smaller items are carried, the volume measurement helps to determine how one car compares to another.
3) Aperture size should be as big as possible to allow large items to be fed into the cargo bay.
4) Lift-over height and floor height should be as low as possible. For most vehicles this will be just above the bumper height (530mm). For trucks the load floor may be quite high to allow for the frame rails and suspension travel.
5) Suspension design may need to be compact to help lower the load floor, or very strong to carry heavy loads.
6) Load floors should be flat to make organizing and moving heavy objects easier.
7) Underbody and seat design should be set up for maximum space flexibility.
8) Tumblehome & backlight attitude should be as vertical as possible.
9) Rear wheel placement should be set up for optimal weight distribution.



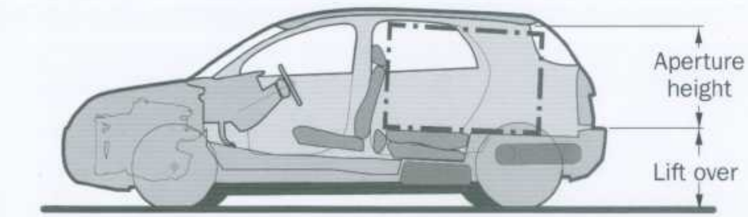
PLYWOOD
4' x 8' plywood sheets stacked between the wheel house trim.

TIRE IN JOUNCE
The rear track and suspension geometry is designed around the cargo width and load-floor height.



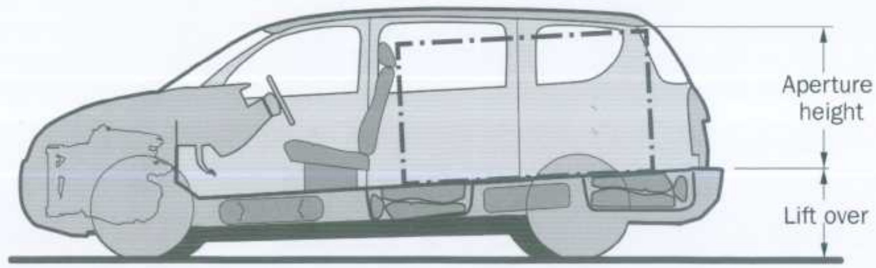
PICKUPS AND COMMERCIAL VEHICLES

These types of vehicles are designed around their capacity to carry cargo. The bed length or cargo bay varies between 1700mm to 2450mm for most commercial trucks. Personal trucks may have beds as short as 850mm.



HATCHBACKS & WAGONS

Designed for multifunction between carrying cargo or rear passengers. Exterior body shapes may compromise cargo-size potential. The seats will usually fold down over the fuel tank.



MINIVANS

The angled floor provides a low step in height for the driver and a lift over at the rear bumper height. Loads are easier to move around if the floor is flat. The underbody components are designed around stowing the seats.

INTERIOR VOLUME MEASUREMENT

The interior volume index is used primarily to determine how much usable space is available for the occupants and cargo. The volume is reported in cubic feet or cubic meters and is the sum of the key interior measurement, shown right.

Target volumes are often set out in the functional objectives. Creating a competitive space becomes an important marketing tool, so these numbers are often used by consumer groups to describe how efficient a package is and how it stacks up against a competitive vehicle.

In the US, the Environmental Protection Agency (EPA) uses the interior volume to determine vehicle-size classifications.

EPA INTERIOR VOLUME INDEX

Class	Mini Compact Car	Subcompact Car	Compact Car	Midsize Car	Large Car	Small Wagon	Midsize Wagon	Large Wagon
Cubic Feet	under 85	85 - 99.9	100 - 109.9	110 - 119.9	over 120	under 130	130 - 160	over 160

EPA INTERIOR VOLUME INDEX

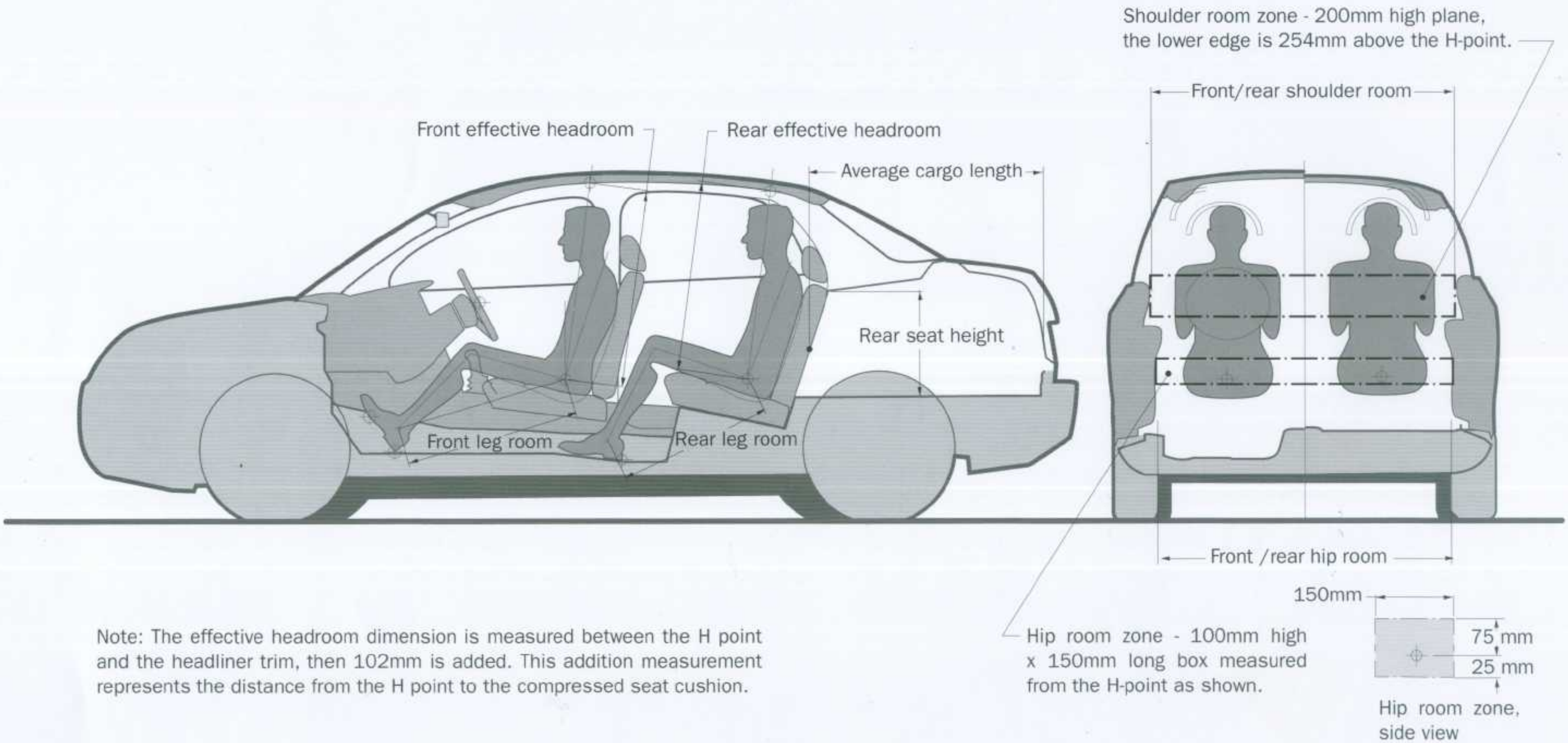
Front Interior volume + Rear Interior Volume + Cargo Volume

FRONT & REAR (PASSENGER) INTERIOR VOLUMES

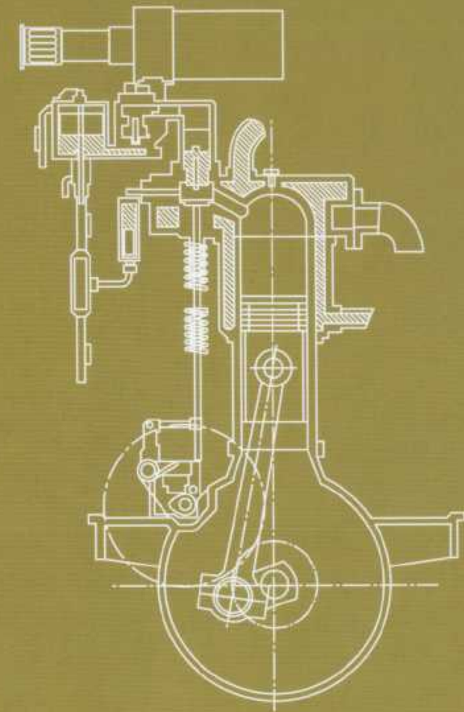
Head room x Leg room x Shoulder room (Use hip room if it's larger than shoulder room)

CARGO VOLUMES

Rear Seat Height x Average Trunk length x Rear Shoulder room



Note: The effective headroom dimension is measured between the H point and the headliner trim, then 102mm is added. This addition measurement represents the distance from the H point to the compressed seat cushion.

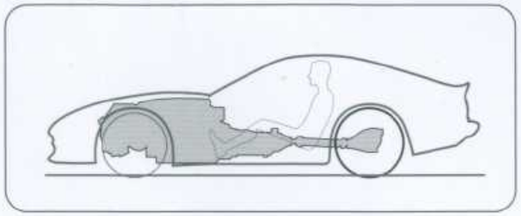


"The powertrain is one of the most influential systems on the architecture, due to its size and weight. Battery electric, hybrid and revolutionary powertrains create opportunities to reinvent architectures for more efficiently packaged vehicles."

POWERTRAINS | 07

POWERTRAIN ANATOMY

THE BASIC ANATOMY OF THE INTERNAL COMBUSTION ENGINE (I.C.E.) POWERTRAIN



The simplified graphic below shows a side view of a conventional, longitudinal, front-engine, rear-wheel-drive layout. Other internal combustion engine configurations can look completely different but contain the same basic elements.

THE ENGINE

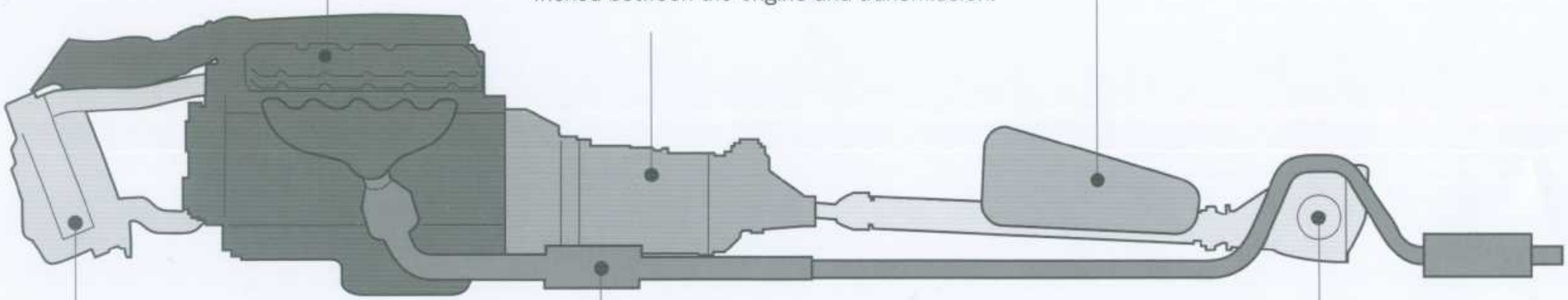
These come in many different sizes and configurations but they are made up from similar components: the cylinder block, cylinder head, oil pan (sump), pistons, crankshaft, flywheel, induction system, exhaust manifold, starter motor, accessory drives and several other auxiliary components. Due to its size, weight and relationship to the wheels it is one of the most influential components in the package.

FUEL TANK

The volume will depend on the size and range of the vehicle. The main factor to consider for fuel-tank packaging is its protection during a high-speed impact.

TRANSMISSION

Manual or automatic transmissions are usually attached to the end of the engine to feed the power at various speeds to the final drive. The clutch (manual) or torque converter (automatic) is sandwiched between the engine and transmission.



COOLING

The cooling module is usually packaged at the front of the vehicle where fast-moving cool air is easy to access. Cooling modules are sized according to the engine power and loading capacity. Often other coolers for oil, air conditioning, transmissions and intercoolers are packaged together with the engine cooler, creating quite a large volume that needs to be placed where there is airflow.

EXHAUST

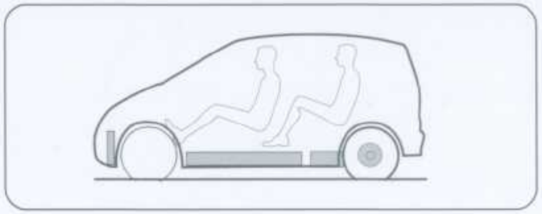
Exhaust packaging is not usually the focus of early package studies, but large components in the system such as catalytic converters and silencers should be given some thought.

FINAL DRIVE

This comprises the drive shafts, differentials and transfer case (for 4WD). Their motion, linked to suspension travel, should be considered during the initial package study.

THE BASIC ANATOMY OF AN ELECTRIC POWERTRAIN

Packaging an electric system requires a different attitude to a conventional powertrain. Here the motors are relatively small but the energy or fuel-storage systems are quite large in comparison to those of internal combustion systems. The main thing to take advantage of is the low-profile potential for these components. If the system can be packaged under the floor, for instance, it allows the designer the opportunity to reduce the overall length of the vehicle and change the exterior proportions.

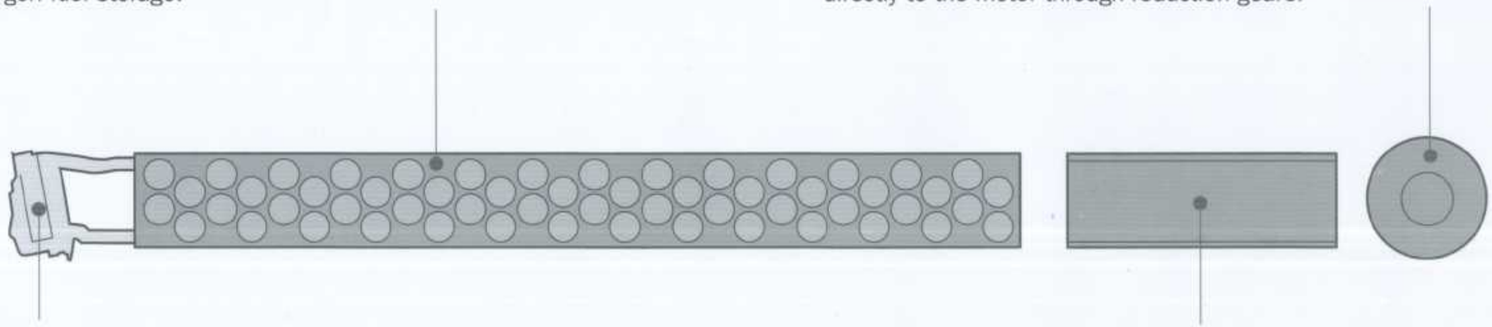


BATTERIES / FUEL CELL

The electric power can be stored in batteries or created by a fuel cell. The batteries can be made from various materials based on cost versus power density requirements. The fuel-cell system consists of several components including the fuel stack, compressor and hydrogen fuel storage.

THE MOTOR & FINAL DRIVE

Electric motors are very powerful for their size and develop a lot of torque at low revs. This allows them to be packaged easily on the axle or at each wheel and also eliminates the need for a conventional transmission. The final drive (shafts) and differential can be attached directly to the motor through reduction gears.



COOLING

Although electric systems are far more efficient than internal combustion engines, they still generate heat which needs to be dissipated.

ELECTRONIC CONTROLLERS

The energy from the power source (batteries, fuel cell or generator) must be processed and fed into the electric motors. The control systems that do this can be surprisingly bulky but they can be put somewhere conveniently out of the way.

SELECTING A POWERTRAIN

The powertrain is the system that provides and transmits power to the wheels. Historically, the vast majority of cars have used an internal combustion engine (I.C.E.) and some kind of mechanical system of gears and shafts that connect the engine to the driven wheels. In the future we may see a greater variety of powertains available such as electric motors with batteries or hydrogen fuel cells or combinations of systems (hybrids).

Choosing a powertrain is often a complex task, so look closely at the functional objectives before laying out the engine, transmission, and final drive system. Give the following criteria close consideration:

What "type" of power is required to meet the functional objectives?
Some vehicles will require a lot of power, others only a little. High amounts of torque will be needed to tow or carry heavy loads, favoring large gasoline engines or diesels. Brake-horse-power (BHP) will be a priority for performance cars, sometimes requiring higher revving ability and efficiency rather than outright engine size. Luxury cars focus on quiet, smooth powertrains with good acceleration, while environmental concerns encourage powertrains that are clean and fuel-efficient.

What powertrains are available?
Developing internal combustion engines and transmissions takes a long time and is expensive, so each manufacturer generally already has their own limited but strategic range from which to choose. Sometimes a manufacturer will develop an engine with a competitor to save costs. As the industry moves away from internal combustion engines, it is likely that the manufacturers will source powertrains from their suppliers rather than develop them themselves.

What is the main priority for the package?
The functional objectives will influence the priorities of the package. For some cars, power and performance are a high priority so the powertrain may dominate the architecture. For others the passengers and cargo may be the most important consideration so the engine and transmission layout will be driven by package efficiency (see the opposite page).

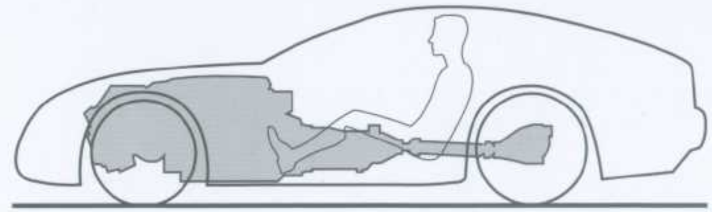
What are the constraints of the package?
Powertrains take up a lot of space, particularly conventional internal combustion engines and mechanical transmissions, so finding room for them can be challenging. Some packages can be designed around large components but often dimensional constraints will limit the size of the engine and limit the final drive options.

What are the traction requirements?
The final drive system distributes the power to the wheels, so this part of the powertrain will be influenced by traction requirements. Front-wheel-drive cars gain an advantage because the weight of the engine is directly over the wheels. Rear-wheel-drive cars work well when loaded or under acceleration but usually require the transmission to pass along the center of the vehicle, through the passenger compartment. Driving all four wheels is ideal but a more expensive and heavier solution. Vehicles designed for off-road use or for operation in hostile climates may require special all-wheel-drive (AWD or 4WD) configurations, which usually intrude into the occupant package more than a 2WD layout.

POWERTRAIN PRIORITIES

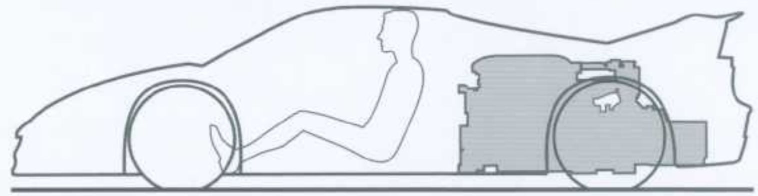
POWER

High-performance cars often use their engine to make a bold statement. In this package the power train dominates the side view and has a dramatic effect on the proportions, exterior design and occupant package.



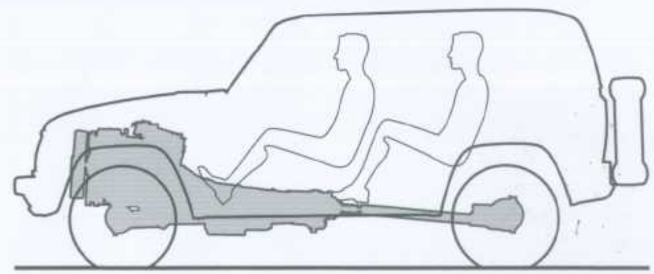
WEIGHT DISTRIBUTION & AERODYNAMICS

A mid-rear engine package works well when very high speeds and handling are critical. This layout allows the designer to distribute the weight of the major components closer to the middle of the wheelbase. This reduces the polar moment of inertia, allowing the car to change directions more quickly. Because there is no engine up front, the hood can be lowered for better air penetration and forward visibility.



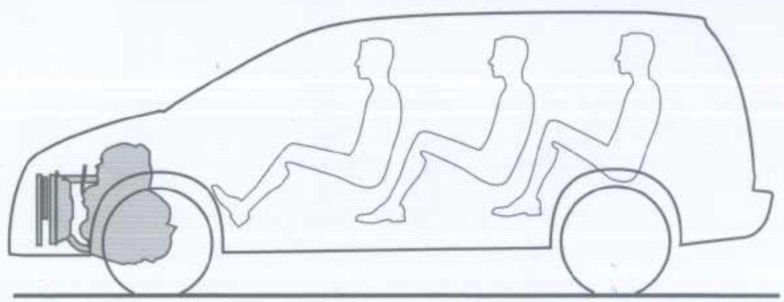
TRACTION & TORQUE

For serious off-road vehicles, traction takes a high priority, so durable 4WD systems coupled to motors with low speed/high torque characteristics are a requirement. This usually results in a tall powertrain with a large center tunnel between the front occupants.



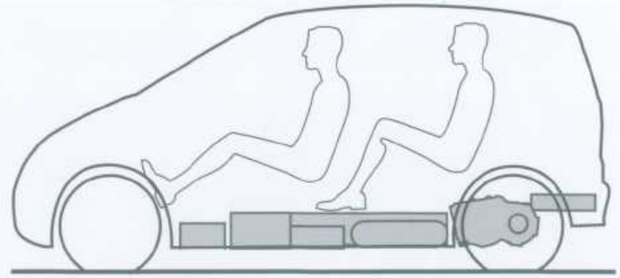
OCCUPANTS & CARGO

Minivans require a very efficient package and put great emphasis on the occupants. The transverse engine and transmission occupy only a small portion of the architecture. Because all of the powertrain components are in front of the occupants' feet, the entire floor can be designed flat.



ENVIRONMENT

Alternative propulsion systems are being developed to help reduce harmful emissions, but their size and proportion also create new packaging opportunities. Generally, the motor and transmission are a fraction of the size of conventional internal combustion engine powertrains, but the fuel systems (batteries and fuel cells) are considerably larger compared with gasoline fuel tanks. Because no one component is large in all directions, the entire powertrain can usually be packaged under the floor.



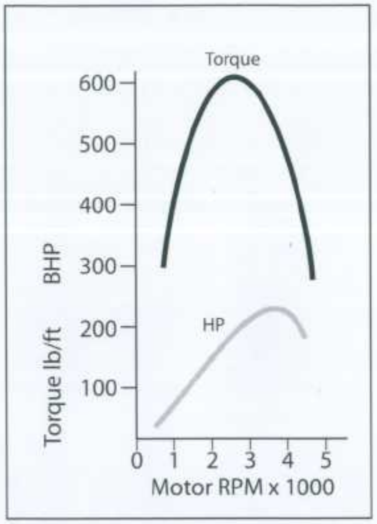
POWER CHARACTERISTICS

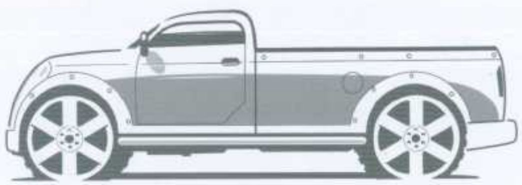
Before specifying the engine and transmission, the power requirements should be studied. The type of power will depend of the type of functions the vehicle has to perform.

Engine power or torque is measured at the (rotating) crankshaft in pound/foot (lb/ft) or Newton meters (Nm). This is multiplied by the engine speed (revolutions per minute or RPM) to give the total power output which is measured in Horse-power (HP) or Kilowatts (kW).

The curve graphs (below) illustrate the different power output characteristics of various motors. For a large vehicle to have smooth acceleration or carry heavy loads uphill, it needs an engine with high torque. To maintain a high speed, a higher revving engine is required with more brake horsepower (BHP).

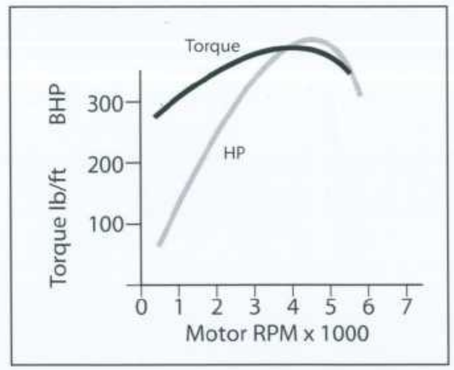
Brake horsepower is the power as measured at the end of the crankshaft, at the engine; unlike horsepower which is the power measured at the wheels...or, historically, at the back end of a horse.





TYPICAL HEAVY-DUTY TRUCK ENGINE

Engine Size	7.0 liters - In-line 6
Max HP	250 @ 3500rpm
Max Torque	600 @ 2500rpm
Vehicle weight	6000kg
Towing capacity	8000kg
Acceleration 0–60mph	12 sec.



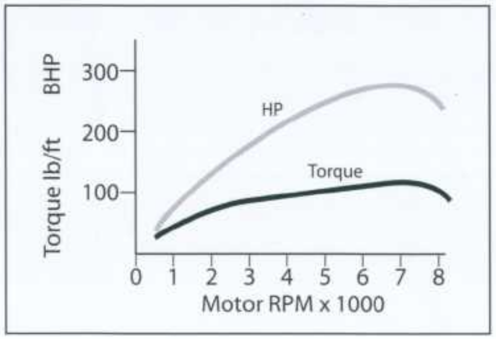
TYPICAL SUV / LARGE CAR ENGINE

Engine Size	5.0 liters - V8
Max HP	375 @ 5000rpm
Max Torque	350 @ 4000rpm
Vehicle weight	3500kg
Towing capacity	5000kg
Acceleration 0–60mph	8.0 /6.0 sec.

It is quite simple to choose an engine based on the vehicle function. A few other factors may also affect the engine choice such as package space, cost, fuel consumption, emissions, sound and smoothness.

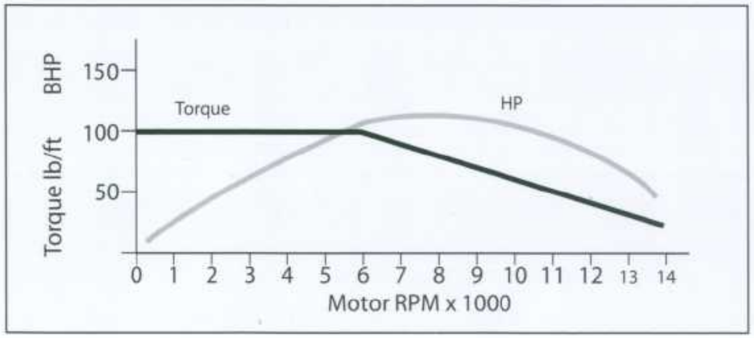
The far-left graph illustrates a typical heavy-duty truck engine. It may be expected to carry and tow very heavy loads so it needs very high torque at low revs. The other graphs show how the relationship between torque and HP changes as the weight of the vehicle reduces and speed and handling become more important.

The graph on the far right shows the dramatic difference between internal combustion engines and electric motors. They provide good smooth acceleration without the resulting high top speed. Because electric motors are so much smaller than I.C. engines producing the same torque, they create some interesting packaging opportunities.



TYPICAL SMALL PERFORMANCE CAR ENGINE

Engine Size	2.0 liters - In-line 4
Max HP	250 @ 5000rpm
Max Torque	120 @ 4000rpm
Vehicle weigh	1200 kg
Towing capacity	n/a
Acceleration 0–60mph	6.0 sec.



TYPICAL ELECTRIC MOTOR

Engine Size	110 kW (peak)
Max HP	220 @ 8000rpm
Max Torque	200 @ 0–6000rpm
Vehicle weight	1200kg
Towing capacity	n/a
Acceleration 0–60mph	4.0 sec.

I.C. ENGINE CONFIGURATIONS

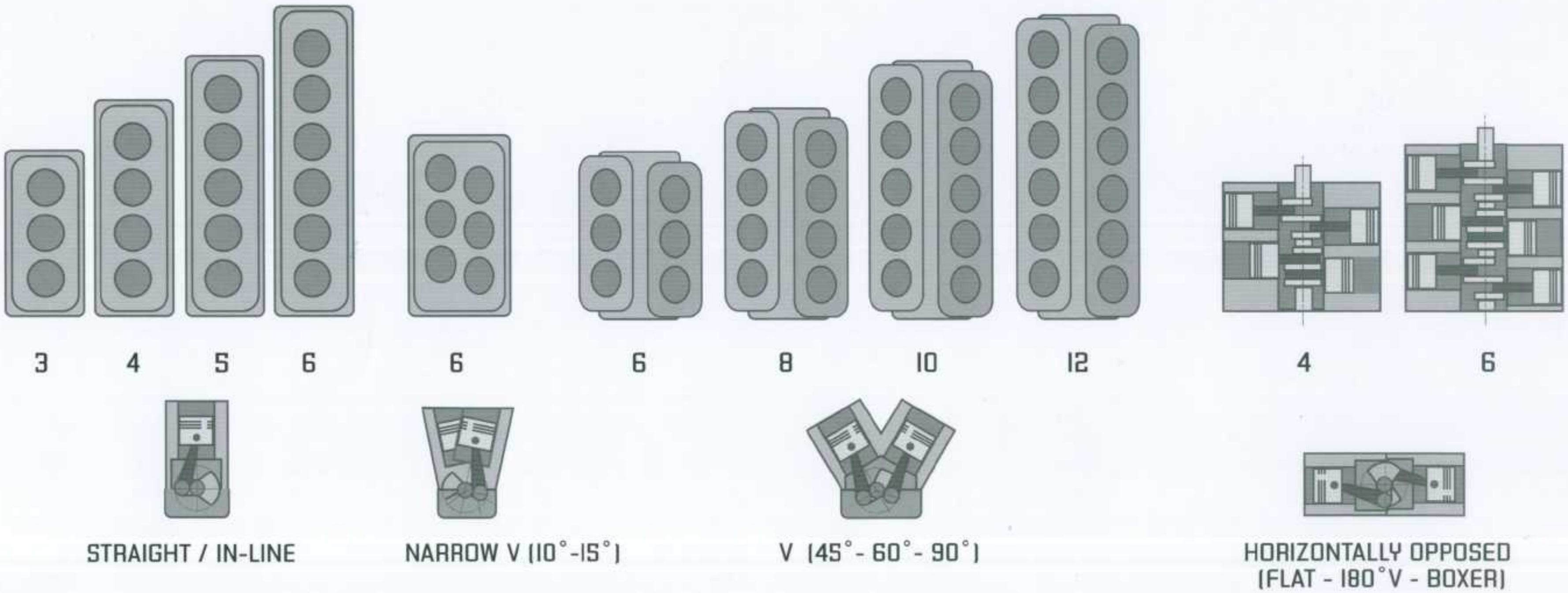
The number of cylinders and their configuration will depend on several factors. Cost, power, package space, weight distribution and vibration are the main considerations behind each selection.

Smaller engines tend to have fewer cylinders, which are usually arranged in straight-line configurations (in-line). As engines get larger to produce more power, the number of cylinders increases, keeping the piston size to a minimum. With an increase in cylinders the configuration may change from in-line to a "V" formation to minimize the engine length. Some engines flatten the V out to become "horizontally opposed" or "boxer" engines. This not only shortens the engine but decreases its height which is very useful to help lower the center of gravity and hood or deck height.

Short engines (in-line fours and V sixes) are often used in transverse applications (mounted across the car) where the designer is trying to keep the vehicle length short. The longer engines (straight sixes and V eights) usually need to be placed in a longitudinal orientation generally requiring them to drive the rear wheels.

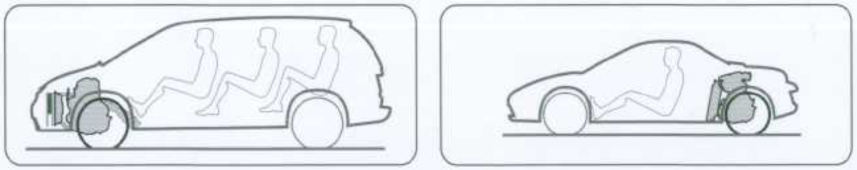
CYLINDER & BLOCK CONFIGURATIONS

The blocks are configured to help the vehicle meet its functional objectives by either improving the package, performance or comfort. Larger engines have more cylinders to minimize the size and reciprocating mass of the pistons.



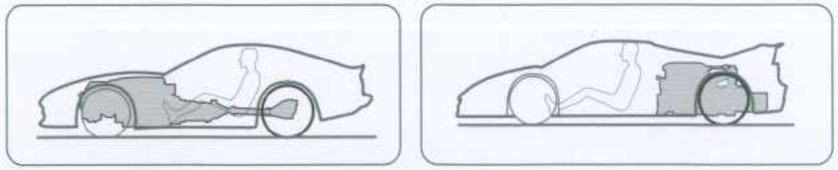
PROPORTIONS INFLUENCED BY ENGINE LENGTH

Below are four examples illustrating how the number of cylinders and engine length may influence the overall size and proportions.



TYPICAL SHORT ENGINE APPLICATIONS

In-line four or V-six engines are often used on vehicles where package efficiency or minimizing overall size is a priority.

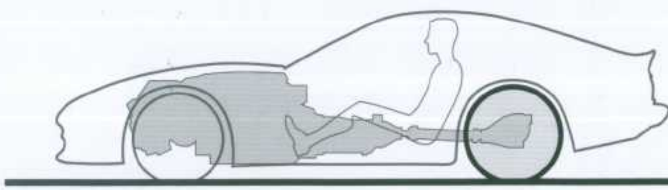


TYPICAL LONGER ENGINE APPLICATIONS

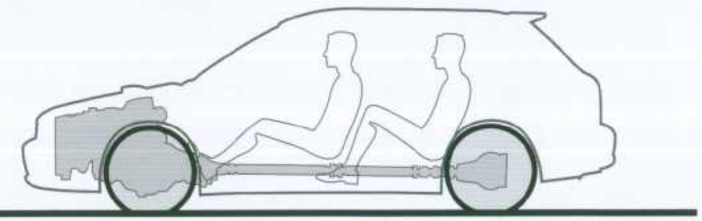
Larger engines are used when power is a priority. The vehicle proportions are quite different to the cars with smaller engines.

POWERTRAIN LOCATIONS AND ORIENTATION

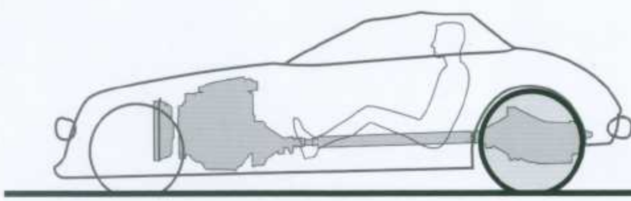
The internal combustion engine has been used in just about every possible location and orientation. Each configuration has its strengths and weaknesses being chosen to meet specific functional objectives like power, package efficiency, traction or weight distribution. Here are some examples of typical production-vehicle solutions.



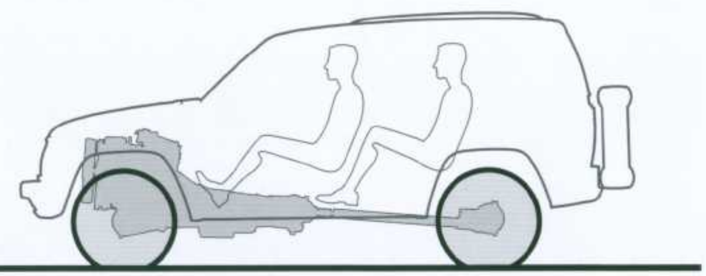
Mid-Front Longitudinal Engine - RWD



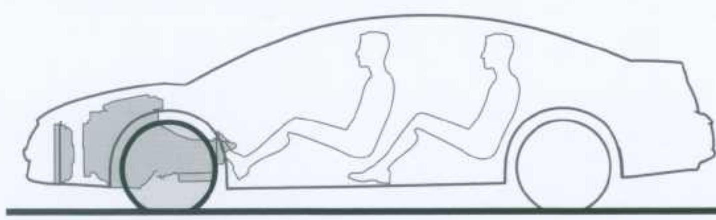
Front Longitudinal Engine - AWD



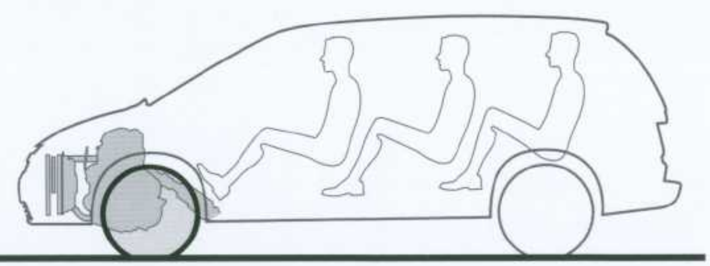
Mid-Front Longitudinal Engine - RWD (Rear Transmission)



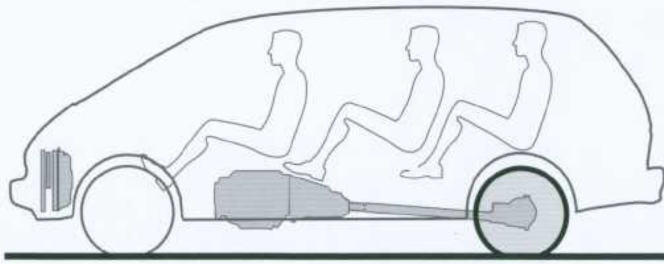
Front Longitudinal Engine - 4WD



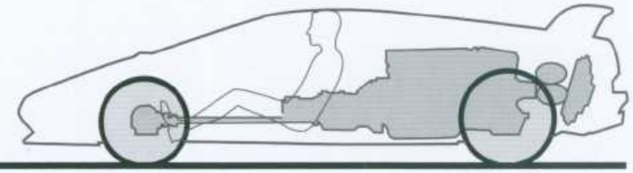
Front Longitudinal Engine - FWD



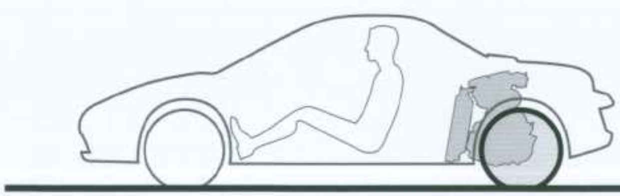
Front Transverse Engine - FWD



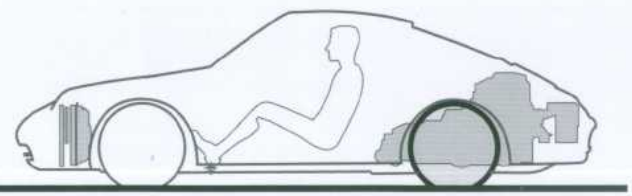
Under Floor Longitudinal Engine - RWD



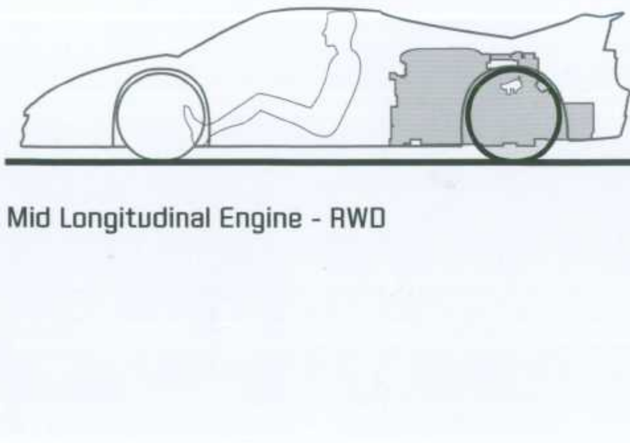
Mid Longitudinal Engine - AWD



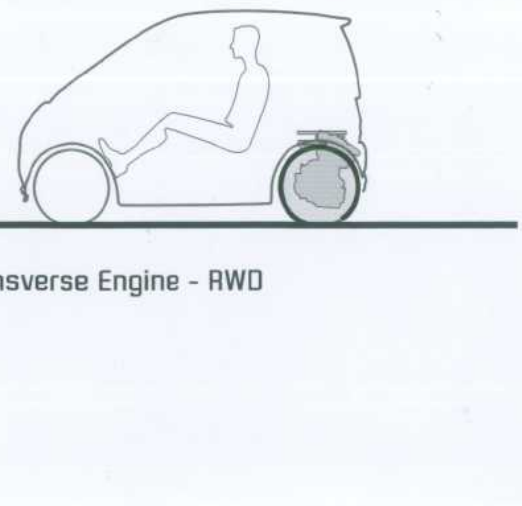
Mid Transverse Engine - RWD



Rear Longitudinal Engine - RWD

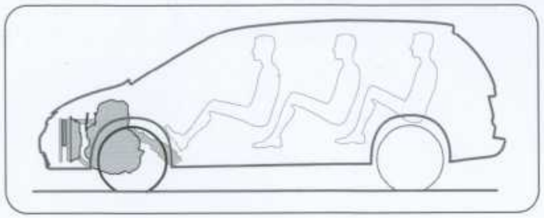


Mid Longitudinal Engine - RWD



Rear Transverse Engine - RWD

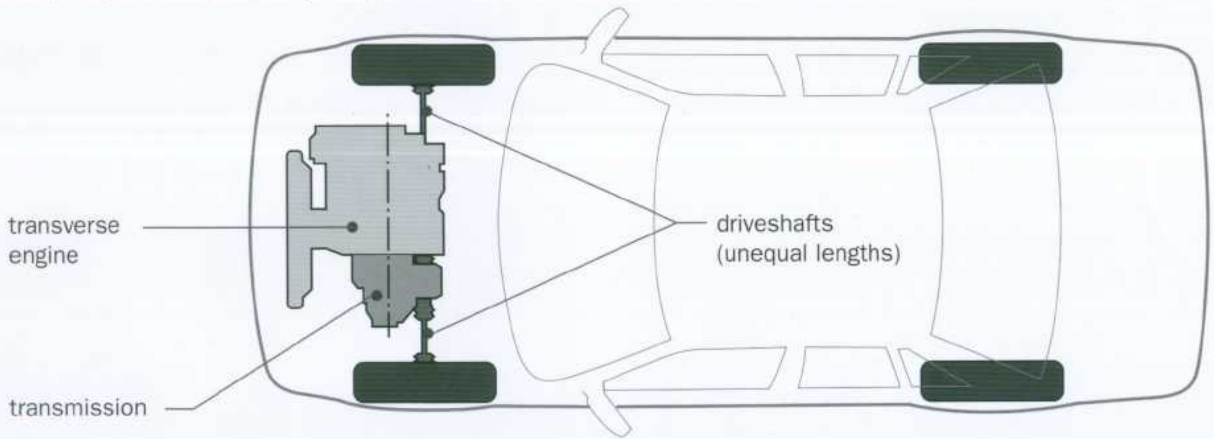
FRONT TRANSVERSE ENGINE - FRONT-WHEEL DRIVE

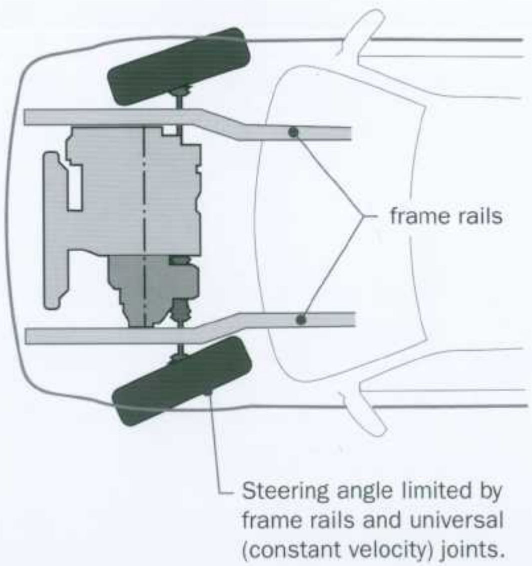


One of the most popular configurations for passenger cars over the last 25 years. This is a very space-efficient layout, which can be mounted to the body with the powertrain and suspension pre-assembled. It is ideal for small economy cars or large minivans where passenger space is a priority. This layout is also used on most standard midsize cars.

The width between the front frame rails can limit the length of the engine, making this layout unsuitable for luxury cars. The offset transmission also causes the driveshaft length to be shortened on one side, limiting suspension travel. The shorter driveshaft also requires the spindle location to be close to the transmission output shaft in side view so the engine location is governed by the front wheel center.

This configuration is easily adapted to a parallel hybrid system with little overall size change.

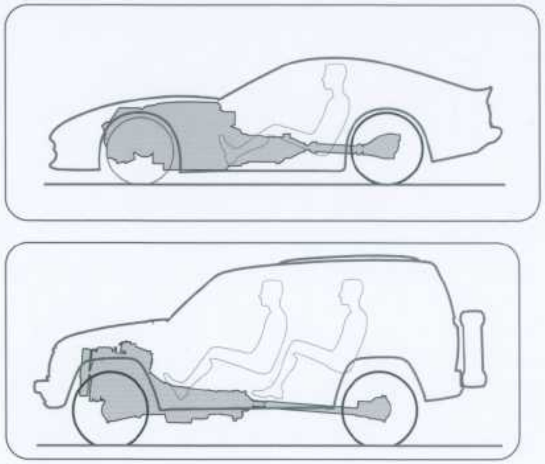


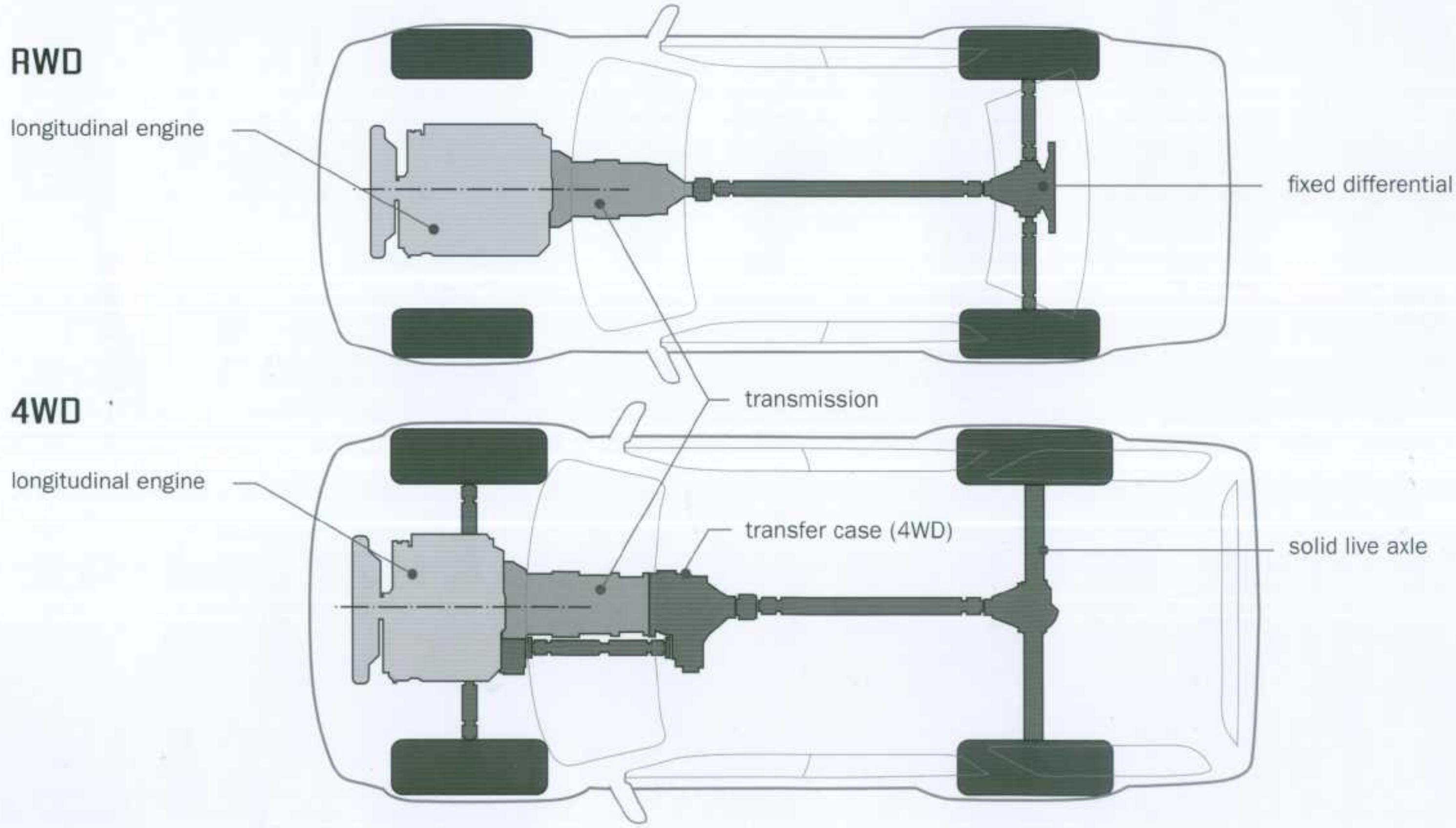


FRONT LONGITUDINAL ENGINE - REAR-WHEEL DRIVE & 4WD

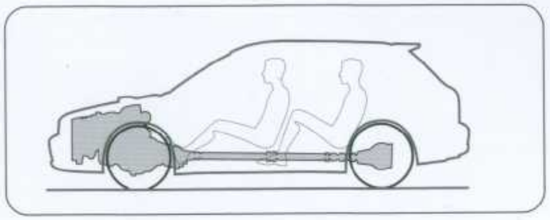
This traditional layout was introduced in the late 1800s and is still used on the vast majority of pickup trucks, luxury passenger cars and sports cars. The longitudinal orientation allows for larger (longer) engines to be installed between the frame rails without restricting the steering angles, helping to reduce turn circles on vehicles with longer wheelbases. Because the engine is not linked directly to the driven wheels it can be positioned for optimum weight distribution. The manual gear shift can also be directly linked to the transmission for crisp gear changes.

Final drive can be through a fixed differential or articulating solid axle. Four-wheel drive is achieved through a transfer case and additional driveshaft to the front axle. The longer driveshafts also allow for greater suspension articulation for off-road vehicles.



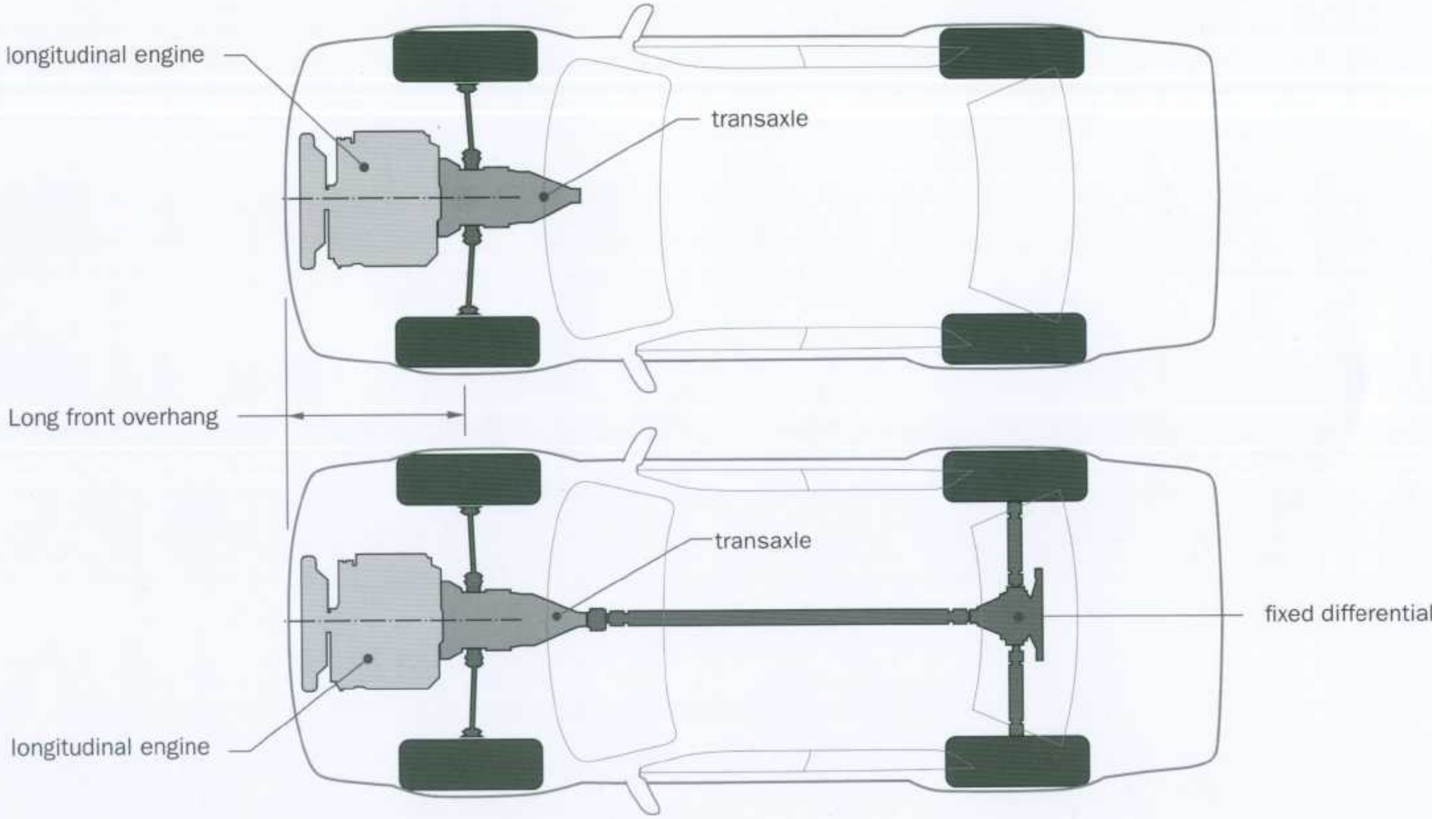


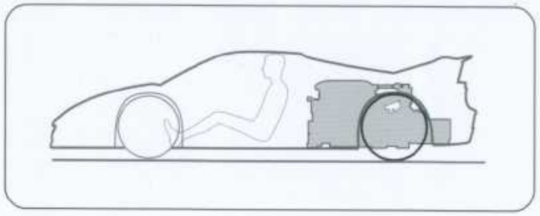
FRONT LONGITUDINAL ENGINE - FRONT-WHEEL DRIVE & AWD



This configuration is usually adopted by manufacturers who specialize in AWD passenger cars. It provides a lightweight, efficient way of getting drive to all four wheels. The main drawback of this configuration is the long front overhang caused by the relationship of the transmission to the front spindle. Unlike the transverse engine, the driveshafts are equal lengths and longer, allowing for more flexibility in engine location, but driveshaft angles are still limited.

The fixed differential reduces the "unsprung weight," helping to improve handling over solid axle configurations.

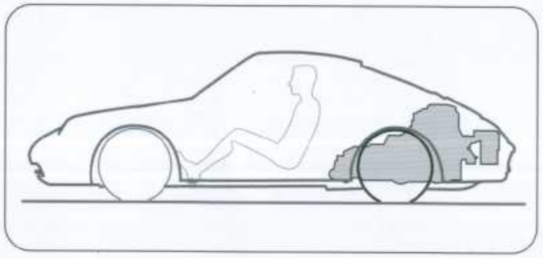


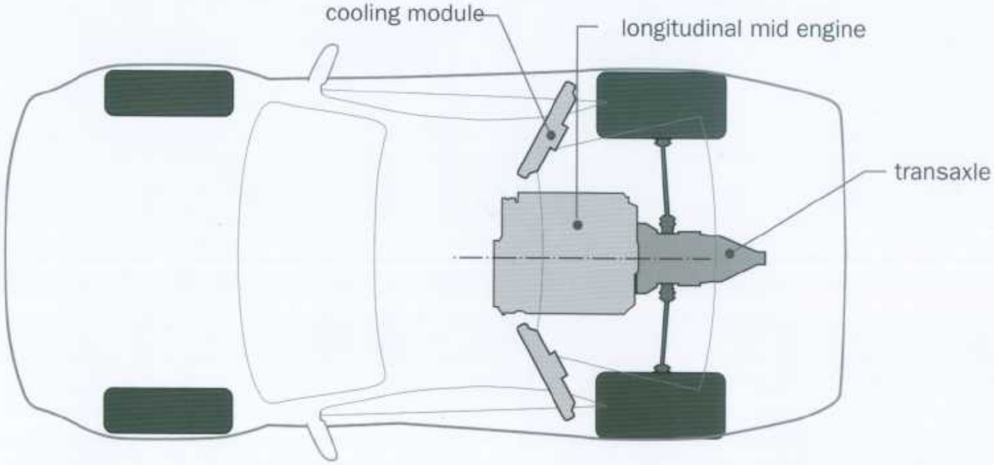


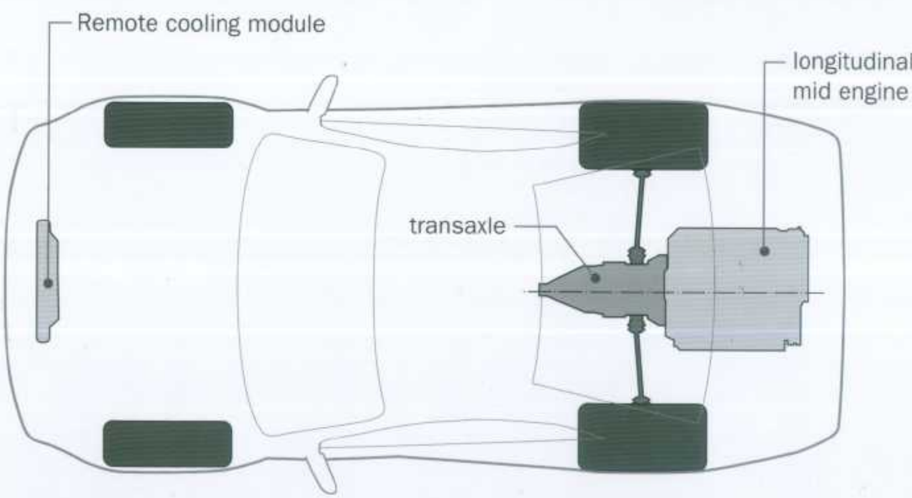
MID-REAR LONGITUDINAL ENGINE REAR-WHEEL DRIVE & AWD

This configuration is best suited to high-performance sports cars. Having the engine mounted longitudinally ahead of the rear wheels optimizes the weight distribution for handling and cornering capabilities but eliminates the possibility of rear passengers. All-wheel drive is also possible with this layout.

When the powertrain is located toward the rear of the vehicle, the cooling modules can be located remotely at the front or adjacent to the engine, usually in front of the rear tires. This will affect the location of the breathing apertures which will significantly affect the exterior design.





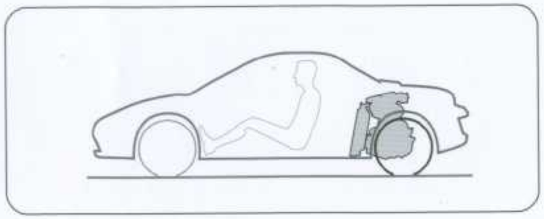


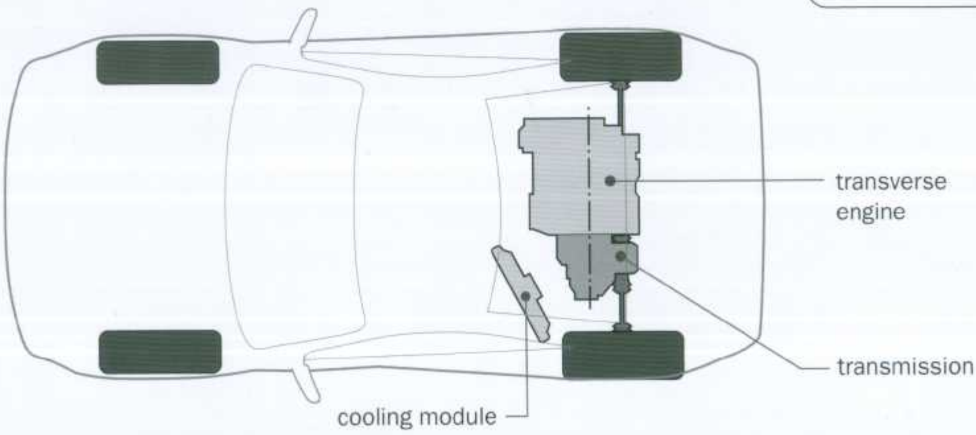
REAR LONGITUDINAL ENGINE REAR-WHEEL DRIVE & AWD

Once favored by many European makers for low-powered family cars, this layout is rarely used today. The rear-weight bias can make for tricky handling at the extreme, although electronic traction controls and tire technology have made rear-engine cars more forgiving to drive. Traction for acceleration though, is supreme. All-wheel drive is easy with this layout. Luggage accommodation under the hood and some rear passenger space are possible with this configuration.

MID TRANSVERSE ENGINE - REAR-WHEEL DRIVE

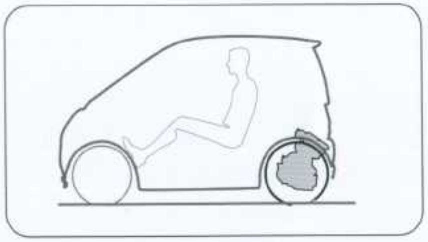
The mid transverse layout is often used on small sports cars. Engine size is limited by the track width, so these are usually found in lightweight, performance cars. The powertrains are often adapted from front-wheel drive vehicles. This provides great weight distribution in a car with a short wheelbase.

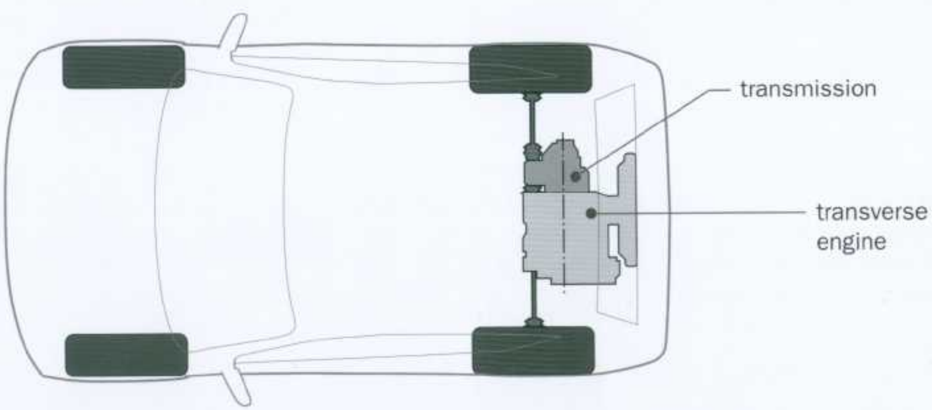




REAR TRANSVERSE ENGINE - REAR-WHEEL DRIVE

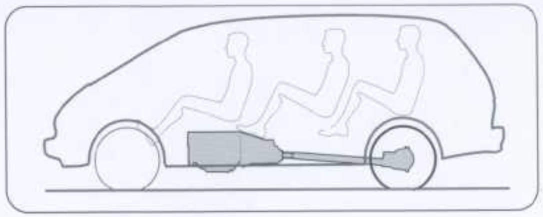
Rear transverse engine layouts are applied when space (length) is critical. It is ideal for micro cars where the engine size is small enough to package behind/under the driver seat, helping to reduce the length of the vehicle in front of the driver's feet. Frontal impact targets require vehicles to have free crush space between the bumper and driver's feet. Taking the engine out of the crush zone helps to create a more efficient package.

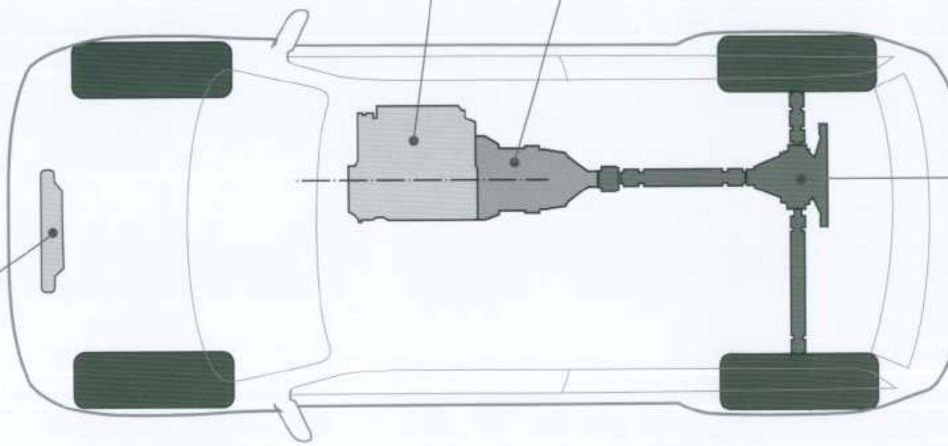




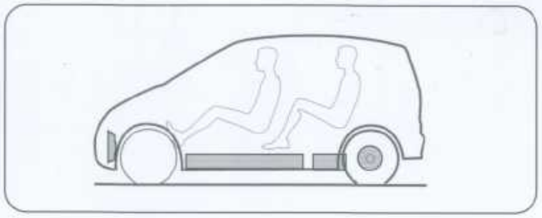
MID UNDER-FLOOR ENGINE - REAR-WHEEL DRIVE

This layout is used for space efficiency more than weight distribution and is usually applied to micro-utility vehicles. The engine is packaged under the passenger seat, which restricts its size and limits the weight of the vehicle. Access for maintenance can be an issue. AWD is possible through a transfer case.

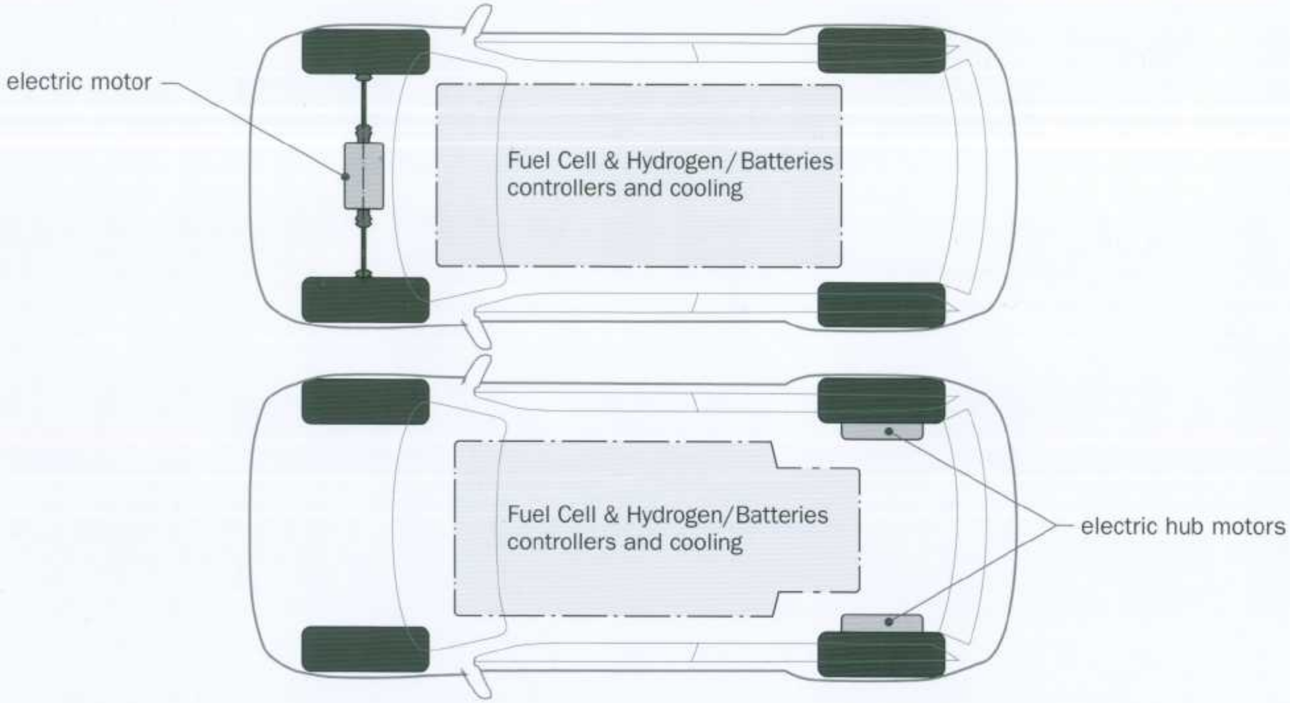




ELECTRIC DRIVE

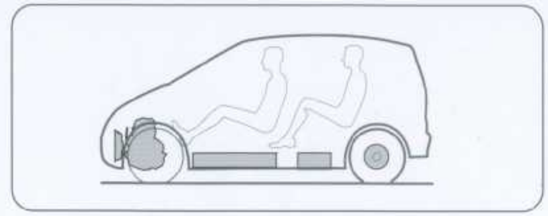


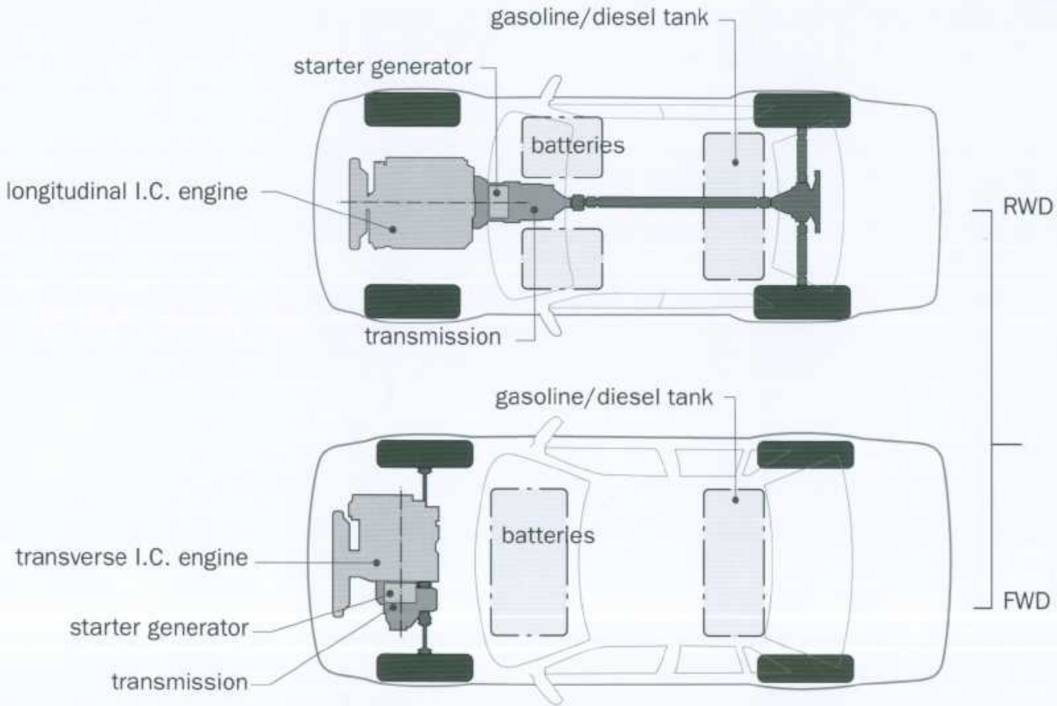
From a packaging perspective, electric drive offers a tremendous opportunity to design more space-efficient vehicles, mainly because the motors are so much smaller than internal combustion engines. The other components that make up the powertrain can be distributed throughout the package in remote locations, unlike conventional powertrain systems which are linked mechanically, creating a large, heavy assembly that has to be worked around. Another significant difference is the power source or fuel. Conventional cars have fuel tanks that are relatively small and can be molded to fit around other components, whereas the energy source for an electric system, either a battery or fuel cell, is quite large and in the case of batteries, very heavy. This can work as an advantage, lowering the center of gravity.



HYBRID DRIVE SYSTEMS

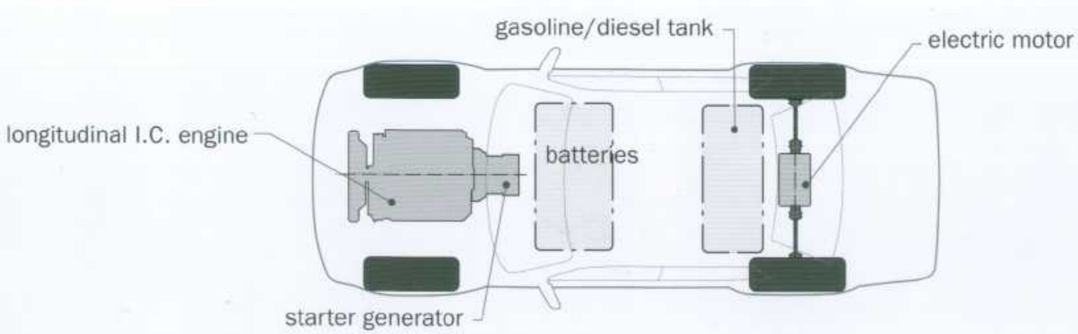
These systems are seen as a stepping-stone toward future all-electric powertrains. They mix the attributes of internal combustion engines and electric motors to provide a fuel-efficient powertrain with a long range. Although they have more components than conventional systems, the engines can be smaller because of the extra torque provided by the electric motor.





PARALLEL HYBRIDS

The internal combustion engine and electric motor (starter generator) are linked mechanically and the power is fed to the driven wheels through the transmission and final drive system.



SERIES HYBRIDS

The generator is turned by the internal combustion engine and the electricity is fed to the electric motor(s). This type of hybrid system offers packaging advantages by eliminating the need for a mechanical transmission and driveshafts as well as divorcing the internal combustion engine from the wheels.

FUEL AND ENERGY STORAGE

Traditionally, fuel tanks have been considered part of the "chassis" group of components, but with advanced alternative propulsion solutions, storing the energy or fuel is now often the responsibility of powertrain groups.

Whether the powertrain uses a traditional internal combustion engine or is driven by an alternative electric solution, the basic principles of storage remain similar.

Wherever possible, the fuel tank, batteries or fuel cell should not, in themselves, unduly influence the overall package of the vehicle. The fuel tank should be located wherever there is a natural open volume away from other key elements. For example, most passenger car fuel tanks are located under the rear seat in an open space created by the rear occupant's posture. Always look for a void space in the architecture and try to place the fuel there. Because the fuel storage usually takes up a significant volume, it should always be included in the initial package ideation sketches so that it does not become an afterthought.

Next, consider safety. This is actually the most important part of fuel packaging and should not be overlooked. Unlike other elements in the package, the fuel is combustible, so if the vehicle is in a high speed collision or rolls over, the fuel should remain inside the storage container and away from the occupants, on the other side of a firewall, such as a metal floor or bulkhead.

The fuel source, whether liquid, gas or solid, is dense and often heavy. In the case of gasoline or diesel, the mass of the fuel tank will vary as the fuel is consumed. On sports cars, this may lead to a noticeable variation in handling if the fuel tank is located in the wrong place. Keeping the fuel as low as possible and toward the center of the vehicle is always the objective.

Considering these three objectives usually pushes the fuel to an inboard, underfloor location often under the rear occupants' seat. It is always good to look for the strongest areas of the body structure and locate the fuel inboard of these. The main frame rails and cross members will help to protect the fuel from impact.

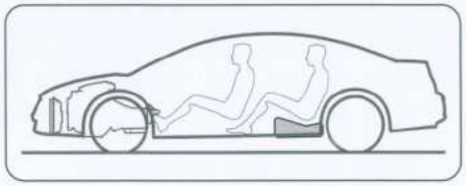
The amount of fuel required is going to depend on the functional objectives. Range and fuel consumption will be the two main factors, but packaging space may also limit fuel capacity. Benchmark existing vehicles for ideal fuel volumes.

Batteries generate heat as they provide energy and require cooling, so additional space should be allocated for cooling solutions. Hydrogen for fuel cells is stored under very high pressure (10,000 psi) and the tanks must be designed and located to avoid rupture on impact. Traditional fuel tanks will also require some space for the fuel pump and measurement systems.

The examples on the opposite page show some typical existing fuel/energy storage locations.

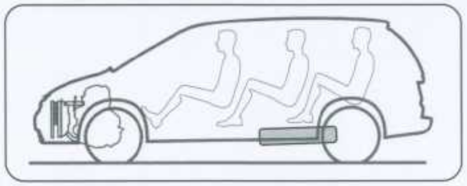
VARIOUS FUEL STORAGE LOCATIONS

PASSENGER CARS



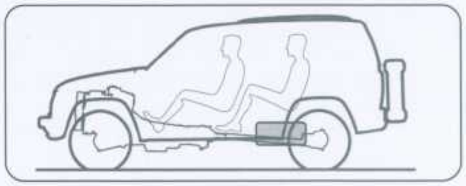
The most common location for passenger car fuel tanks is in the space under the rear occupants' seat. In rear-wheel drive cars, the tank has to straddle the prop shaft.

MINIVANS & TRUCKS



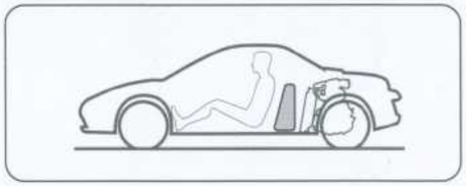
Minivan fuel tanks are quite large but usually package easily under the long high floor structure. Stowing seats can be an obstacle in some vans.

SUVS



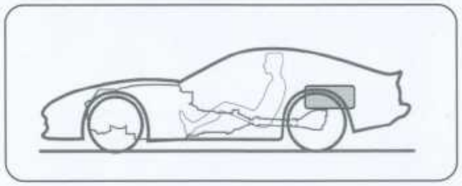
SUVs have been forced to move their fuel tanks from under the rear cargo floor to in front of the rear axle to comply with rear impact safety legislation.

SMALL SPORTS CARS



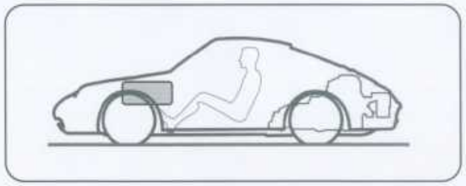
It is common to locate the fuel behind the driver in small front or mid-engine sports cars to help with good weight distribution.

LARGE SPORTS CARS



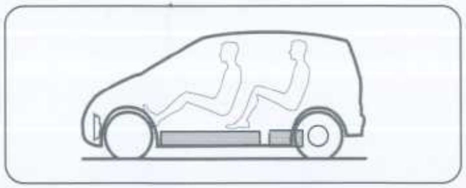
Larger sports cars may package the tank on top of the rear axle to help shorten the wheelbase.

REAR-ENGINE SPORTS CARS



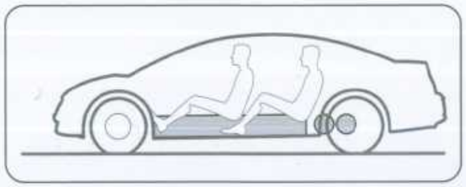
Packaging the fuel in front of the dash is uncommon but helps to distribute the masses in rear-engine sports cars.

ELECTRIC VEHICLES



Due to the large but low profile proportions of electric powertrains, it is common to package the whole system under the floor. This results in a high occupant package which may be desirable in some vehicles.

ELECTRIC SEDANS



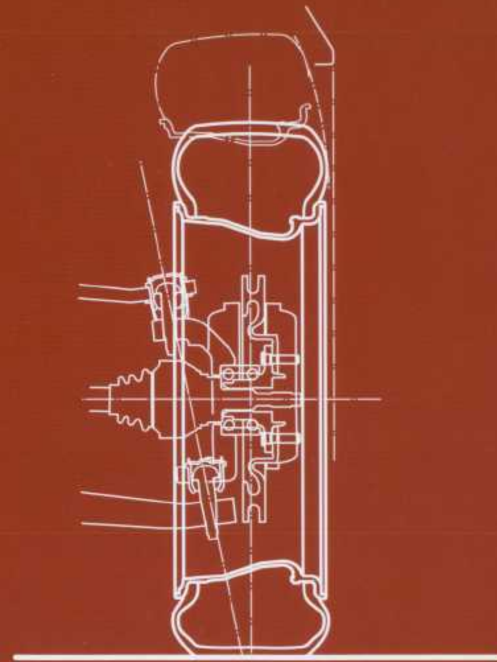
With the reduction in the size of fuel cells and batteries, it is possible to package an electric propulsion energy system in the tunnel and various locations to allow for a low passenger compartment floor.

GENERAL INFORMATION

All of these fuel storage solutions will be molded to fit into as small a space as possible, and mounted symmetrically about the vehicle centerline (where possible) to improve weight distribution.

Benchmark existing vehicles to understand the typical range and fuel consumption versus the tank capacity or battery volumes.

One small design feature to consider is that the fuel filler will need to be close to the tank location.



"The correct wheel and tire choice is not only critical to performance, but it is one of the few mechanical assemblies in the package that becomes a significant design element. In addition, their relationship to the body can make or break a great design."

WHEELS & TIRES | 08

WHEEL & TIRE SIZING

When the designer chooses the initial wheel and tire package, the main objective is to get a combination that works both aesthetically and functionally. The normal tendency is for designers to want the largest wheel diameter with a very low profile tire. For most cars and trucks this is not good.

For a particular vehicle, the outside diameter (O.D.) of the tire will be limited, so looking at this dimension is the starting point. Next, the sidewall depth should be established based on the loading and performance targets. The wheel diameter will be derived from these two factors. The tire width will depend on traction requirements for acceleration, braking and cornering. Rolling resistance, cost and package space should also be considered. It is not uncommon for high performance cars to have different sized front and rear tires to provide more traction at the driven wheels.

Approximate wheel and tire sizes should be established quite early on in the design process, usually after the preliminary occupant package has been set up.

Additionally, the suspension travel and steering angles should be predicted to determine the tire envelopes, which identify the total volumes occupied by the tires during extreme use.

Tires are manufactured in incremental sizes described with a formula for the tread width, sidewall aspect ratio and wheel size. The outside diameter is calculated from this. Light-truck tires use a different formula, part of which includes the O.D., simplifying the process.

Tire specifications are somewhat complex because they are a mixture of millimeters, inches and a percentage. After estimating the tire dimensions, the diameter should be adjusted to a correct available size calculated from a typical tire specification as shown on p. 141.

Sidewall height is governed by load carrying requirements, ride comfort and handling. Trucks and SUVs will have tall sidewalls to help increase their gross vehicle weight (GVW) and protect the rims on rough terrain. Low-profile tires are preferred on sports cars to minimize sidewall flex during cornering. Narrow tires actually work better in snow, so a winter tire package may be smaller than the one for summer.

Styling also plays a big part in wheel and tire size so getting the wheel diameter to work with the proportions of the car may be the final determining factor on the exact wheel and tire package.

TIRE SIDEWALL HEIGHTS (ASPECT RATIO)

TRUCK & SUV TIRE PROFILE

Vehicles that are designed to carry heavy loads or travel over rough terrain require a taller sidewall to distribute the load and protect the rim from rock damage.

The drawback of a taller aspect ratio is sidewall flex that will be detrimental to handling but will improve ride comfort.

PASSENGER CAR TIRE PROFILE

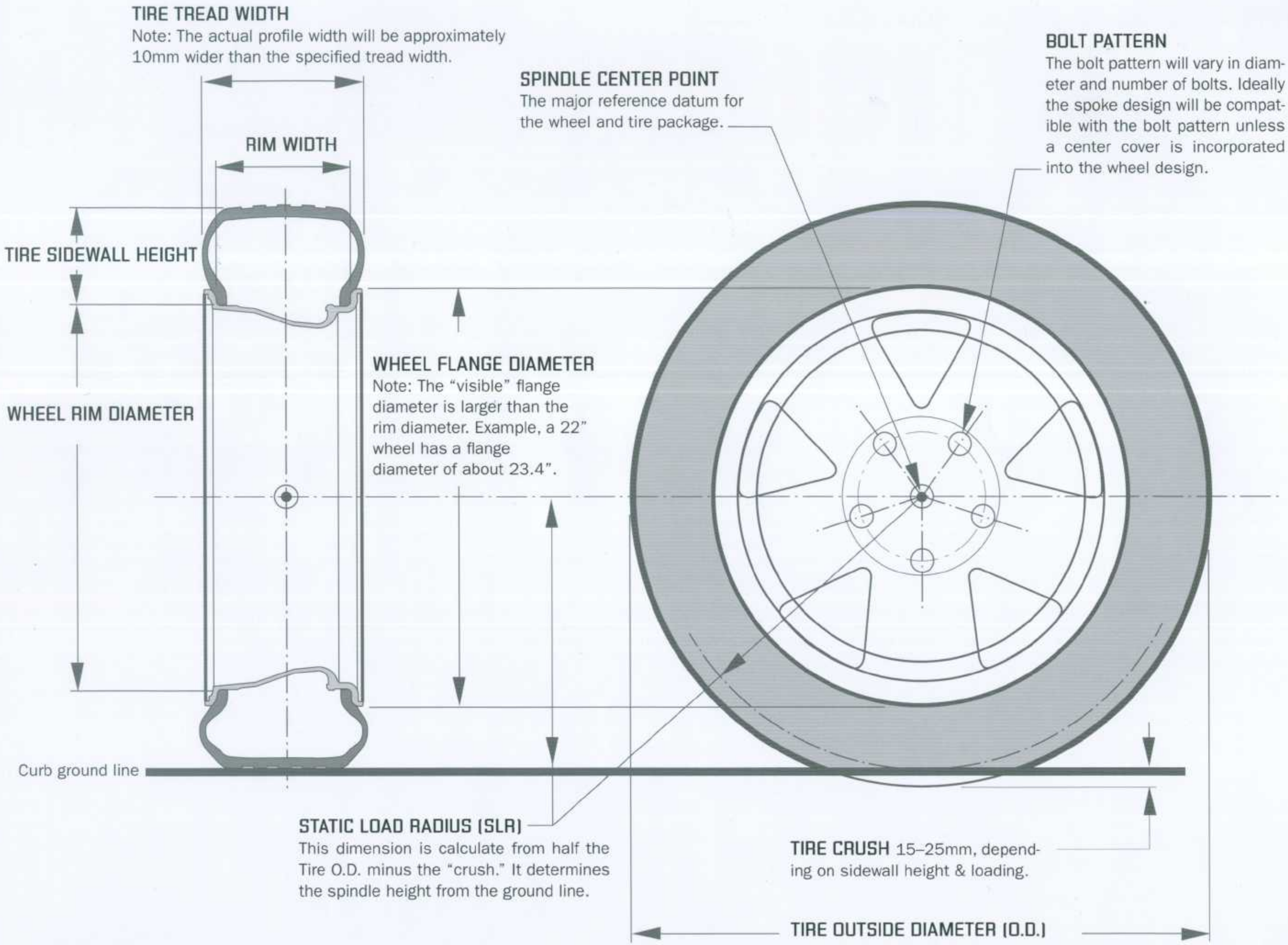
For cars that require a comfortable ride, an average sidewall height is advisable, providing a balance between comfort and handling.

This configuration is usually less expensive than a larger wheel and low profile tire combination.

SPORTS CAR TIRE PROFILE

Performance cars will sacrifice comfort to improve cornering capability. The low profile tire reduces tire wall deflection and allows for a larger diameter wheel which provides room for a larger brake rotor, if required. It also improves the exterior appearance.

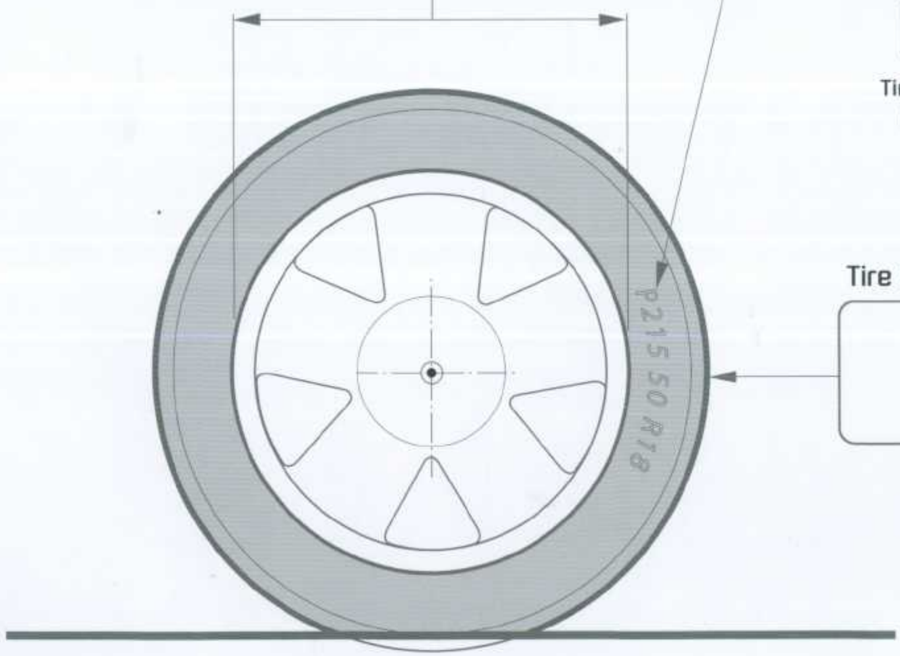
A drawback is that the minimized sidewall height leaves the wheel rim vulnerable to damage from curbs and potholes. Also, the total weight of tire and rim will be higher, which increases the unsprung weight. This will counter against the handling benefits.


TIRE TREAD WIDTH
Note: The actual profile width will be approximately 10mm wider than the specified tread width.
SPINDLE CENTER POINT
The major reference datum for the wheel and tire package.
BOLT PATTERN
The bolt pattern will vary in diameter and number of bolts. Ideally the spoke design will be compatible with the bolt pattern unless a center cover is incorporated into the wheel design.
RIM WIDTH
TIRE SIDEWALL HEIGHT
WHEEL FLANGE DIAMETER
Note: The "visible" flange diameter is larger than the rim diameter. Example, a 22" wheel has a flange diameter of about 23.4".
WHEEL RIM DIAMETER
Curb ground line
STATIC LOAD RADIUS (SLR)
This dimension is calculate from half the Tire O.D. minus the "crush." It determines the spindle height from the ground line.
TIRE CRUSH 15–25mm, depending on sidewall height & loading.
TIRE OUTSIDE DIAMETER (O.D.)

WHEEL FLANGE DIAMETERS

The flange diameter represents the actual visible wheel sizes. Note: the rim diameter (measured in inches) is 30–35mm smaller than the flange diameter. This difference is shown in this chart.

rim diameter (inches)	flange diameter (mm)
12	333
13	358
14	381
15	413
16	440
17	471
18	497
19	522
20	547
21	568
22	594



Tire Size

Passenger Car Designation

Tread Width in millimeters, Changing in 10mm increments

Sidewall Aspect Ratio as a percentage of the tread width changing in increments of 5%

Speed rating and construction

Wheel Rim Diameter in inches, changing in 1" increments

P 215 50 R 16

Passenger Cars Tire Example

Light Truck Tire Example

31 x 10.5 16 LT

Tire Diameter in inches

Tread Width in inches

Wheel Rim in inches

Light Truck Designation

Tire Size Formula

To Calculate the O.D. in millimeters for the **215 50 R16 Tire**
(215 x 50% x 2) + (16 x 25.4) = **621 mm** (Tire O.D.)

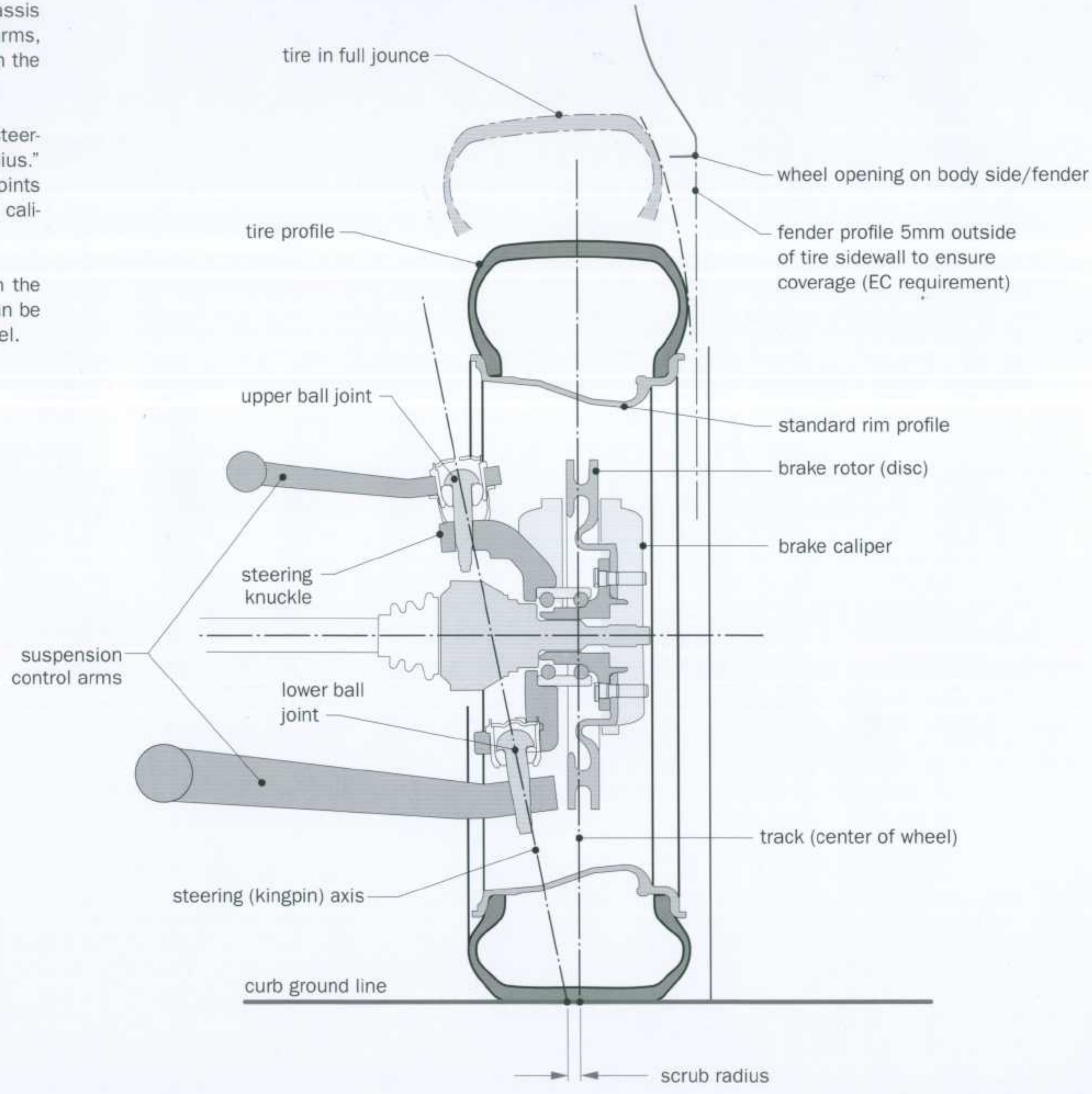
BRAKE PACKAGING

Wheel design is heavily influenced by the chassis components they are bolted to. Suspension arms, steering geometry and brake systems all push the wheel spokes outboard.

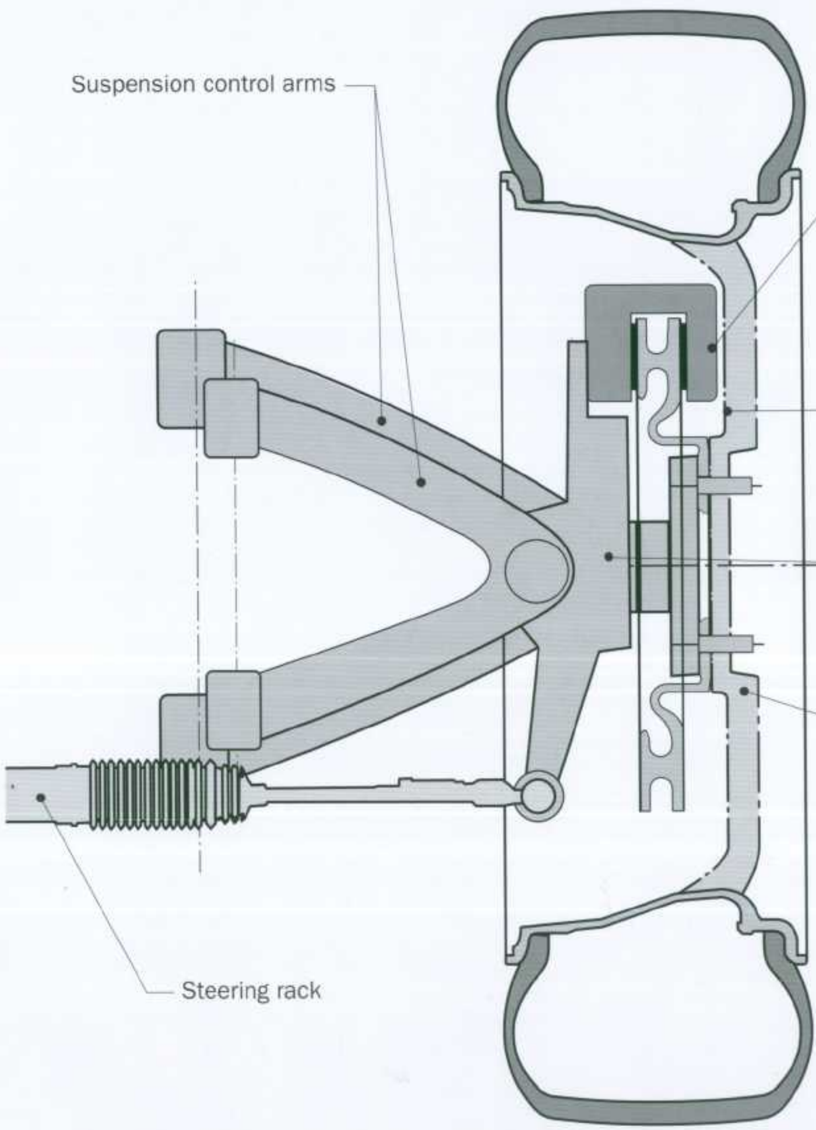
The section shown right, illustrates how the steering axis is set up to minimize the "scrub radius." The steering axis passes through the ball joints which subsequently force the brake rotor and caliper out past the center of the wheel.

Opposite page: note how the brake caliper in the section limits the amount of "dishing" that can be applied on the spoke design for the front wheel.

SECTIONAL VIEW THROUGH THE FRONT WHEEL, TIRE, SUSPENSION & BRAKES



SECTIONAL PLAN VIEW THROUGH THE BRAKE CALIPER & SPOKES



Brake caliper

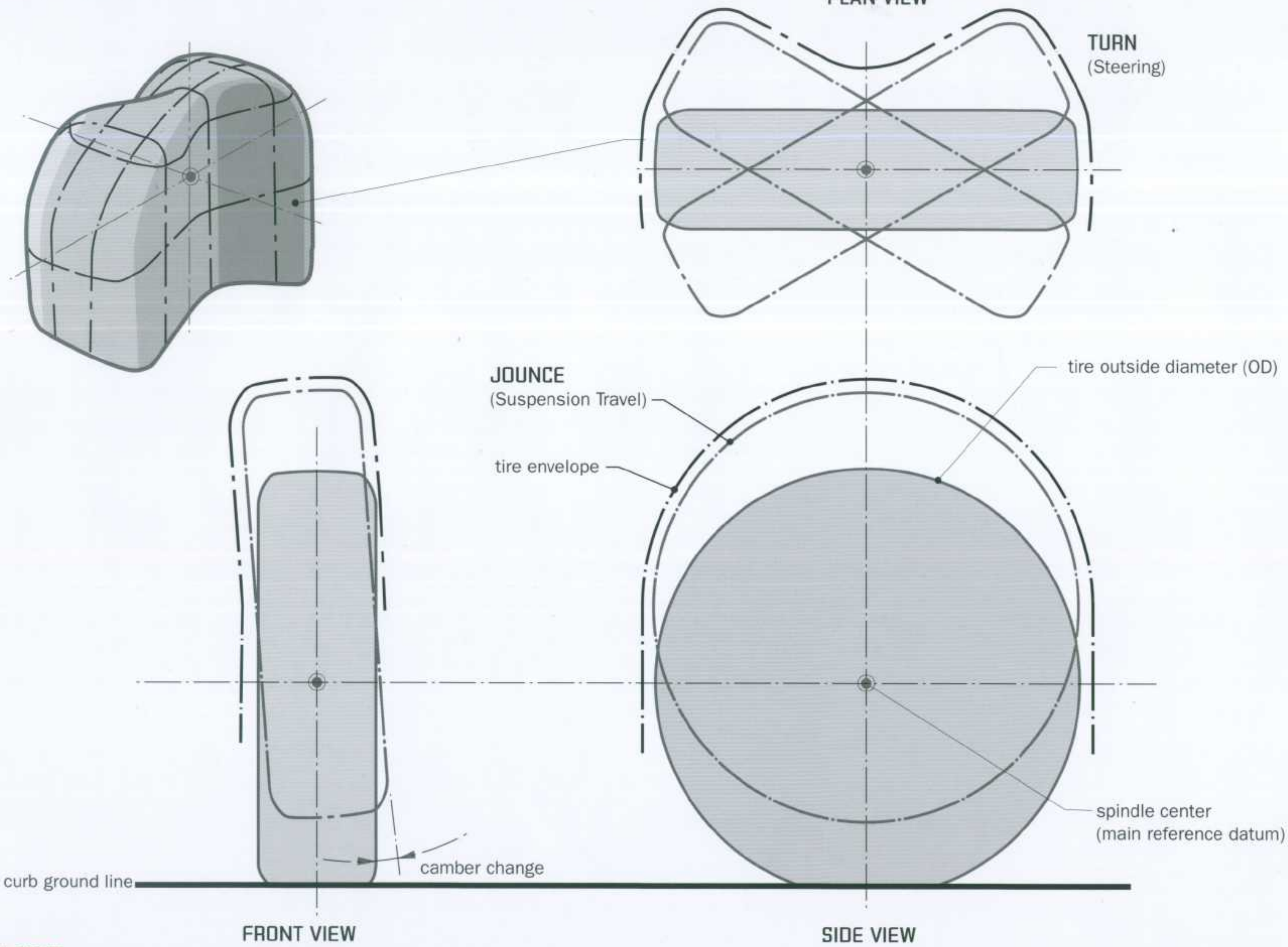
The brake caliper is often used as a design element on exotic sports cars. It is located at the opposite side of the spindle to the steering arm.

It limits the spoke design on the front wheels. More dishing can be achieved by using a wider rim or increasing the scrub radius, but these may be detrimental to performance and handling.

The spoke thickness is determined by structural requirements.

TIRE ENVELOPES

These 3D surfaces represent the sweep of the tire profile in turn and jounce, with clearances & tolerances added.

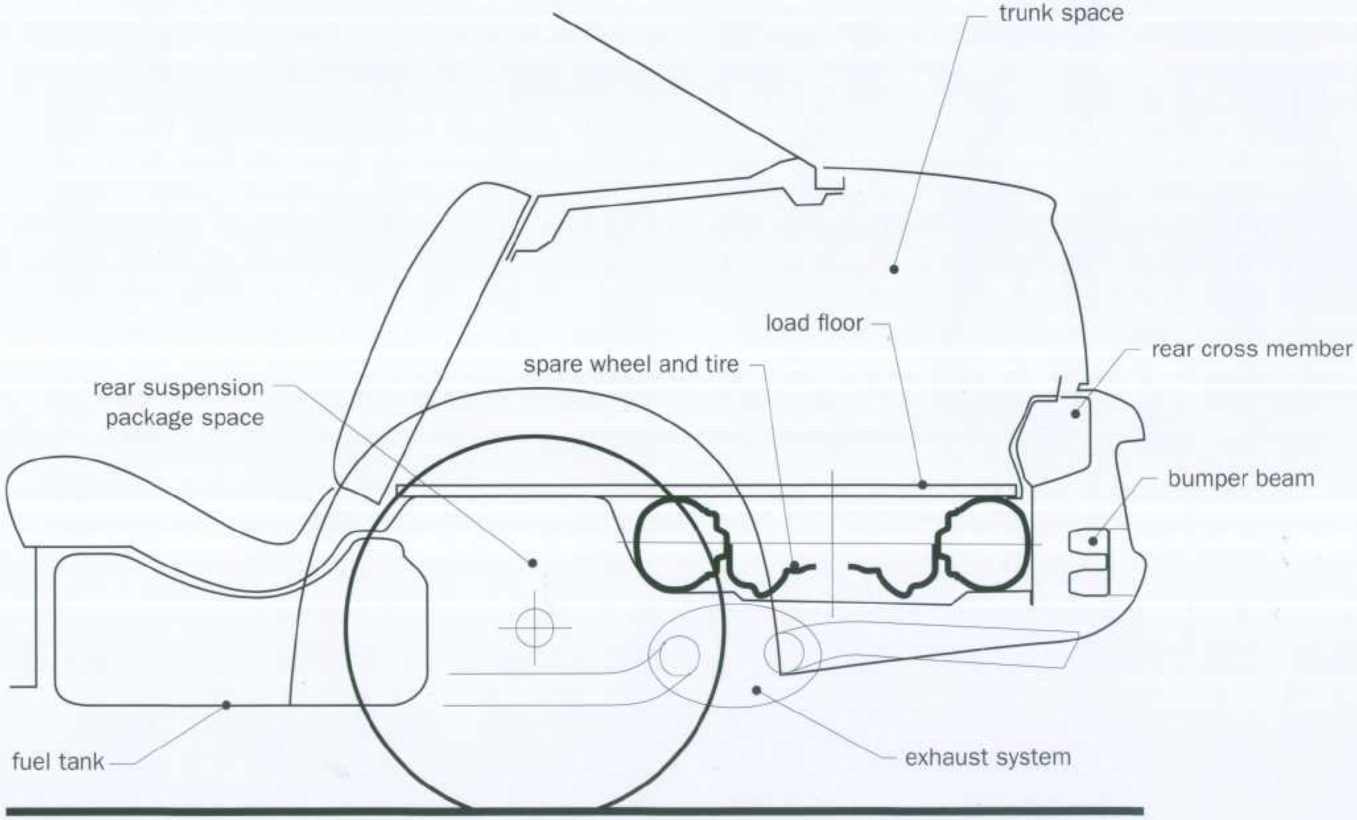


SPARE TIRE PACKAGING

Hopefully, spare tires will soon be a thing of the past and run-flat or airless tire technology will eliminate the need for vehicles to have 5 wheels. Until then, most cars and trucks will have a full-size or space-saving spare packaged somewhere in the architecture.

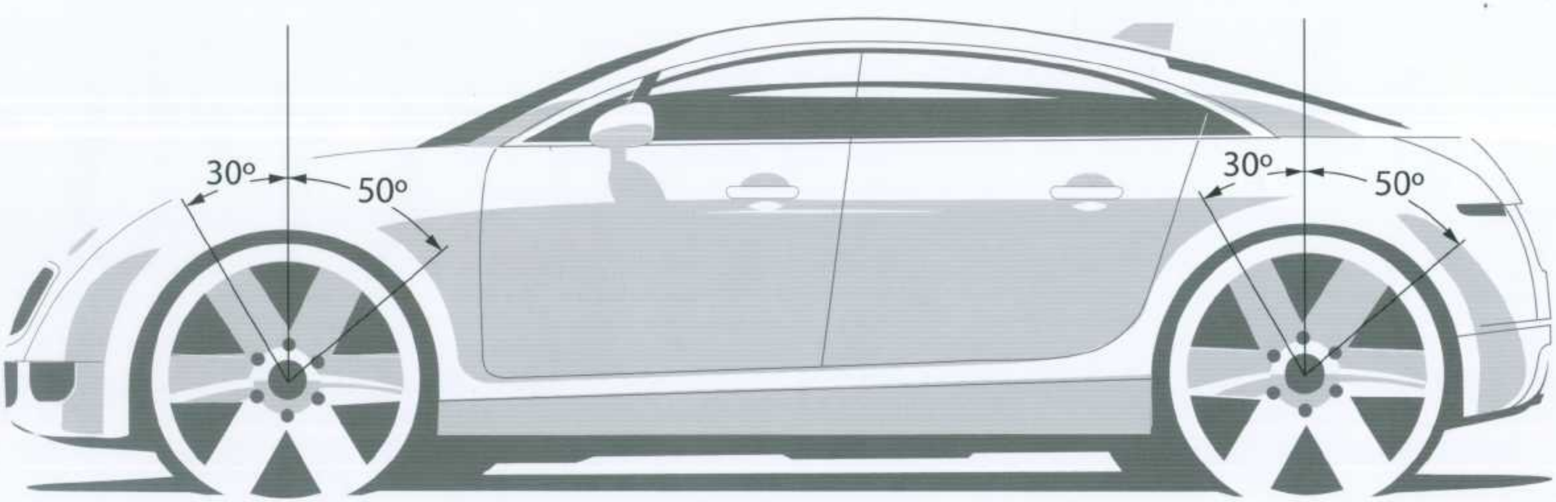
The example shown below is a typical sedan spare-tire package beneath the trunk load floor, between the rear suspension and bumper beam. This is a common location, allowing easy access in the event of a puncture. The rear overhang may be determined by the size of the spare. Many customers want a full-size spare, and if the vehicle has a large tire O.D., packaging this may be challenging. Often space-saver tires are used, but these can be no smaller than 80% of the original diameter to prevent wear on the differential.

Vehicles with higher floors (minivans and trucks) may package the spare further forward under the passenger compartment floor. SUVs often mount the spare on the rear swing gate.

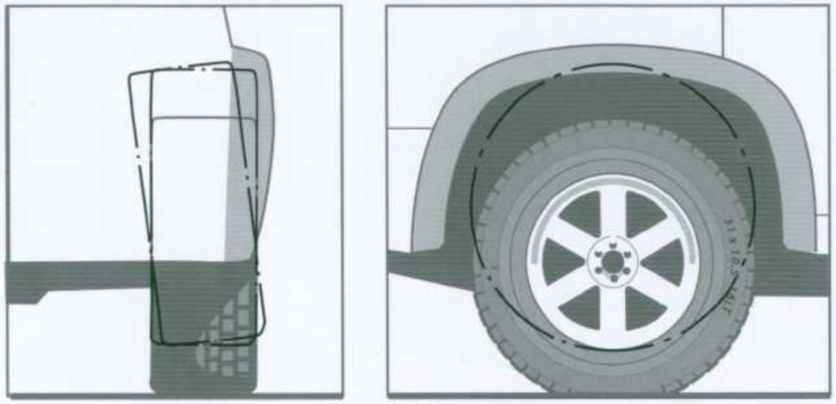


EC TIRE COVERAGE REQUIREMENTS

European legislation requires that the tires must be inboard of the body work in the zones shown below, 30° forward of the spindle center and 50° rearward.

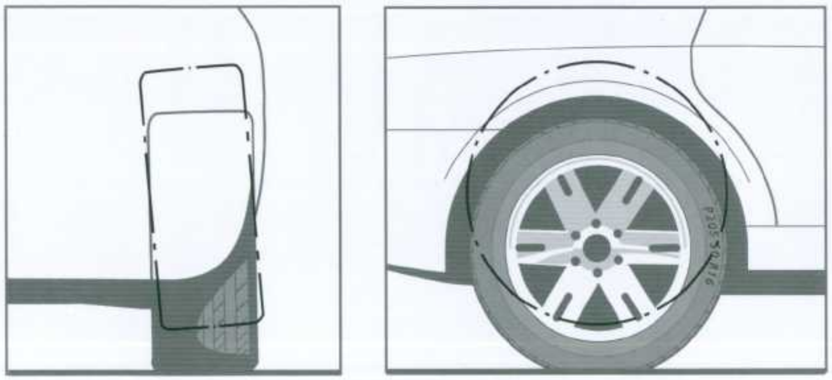


1.



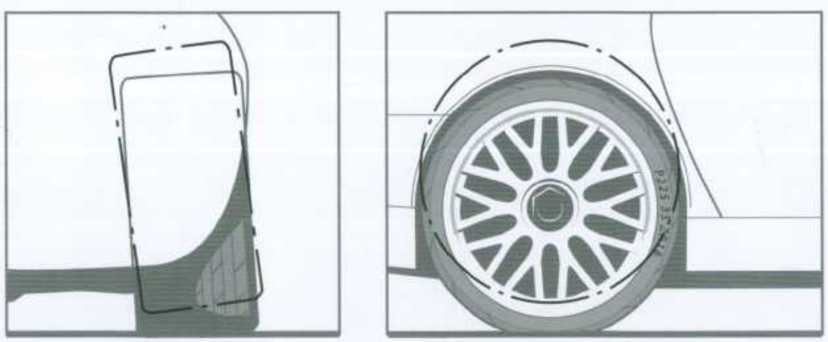
TRUCKS & SUVS

2.



PASSENGER CARS

3.



SPORTS CARS

TIRE-TO-BODY RELATIONSHIPS

The opening between the tire profile and the wheel arch will vary greatly depending on the function of the vehicle. This is mainly due to the geometry, jounce travel and tolerances built into each suspension system. Large openings and inset wheels are bad for aerodynamics and are not usually regarded as a desirable styling feature.

1. TRUCKS & SUVS

Suspension will have long travel (125–150mm+) and if a solid axle type is used the tire will move up and down vertically without camber change when the vehicle is loaded. Because of this, the tire sidewall will be set in from the body and have a large open space at the top of the tire.

2. PASSENGER CARS

These will have less travel (100–120mm) and often employ suspension systems that cause camber change. The relationship between tire and body can be reduced substantially in these cases. If trailing arm or McPherson strut systems are used, the tire will need to be set in more.

3. SPORTS CARS

These will often have negative camber at curb attitude and this will increase during jounce travel. The travel is usually limited (75–90mm) so it is easier and more desirable to keep the openings to a minimum.

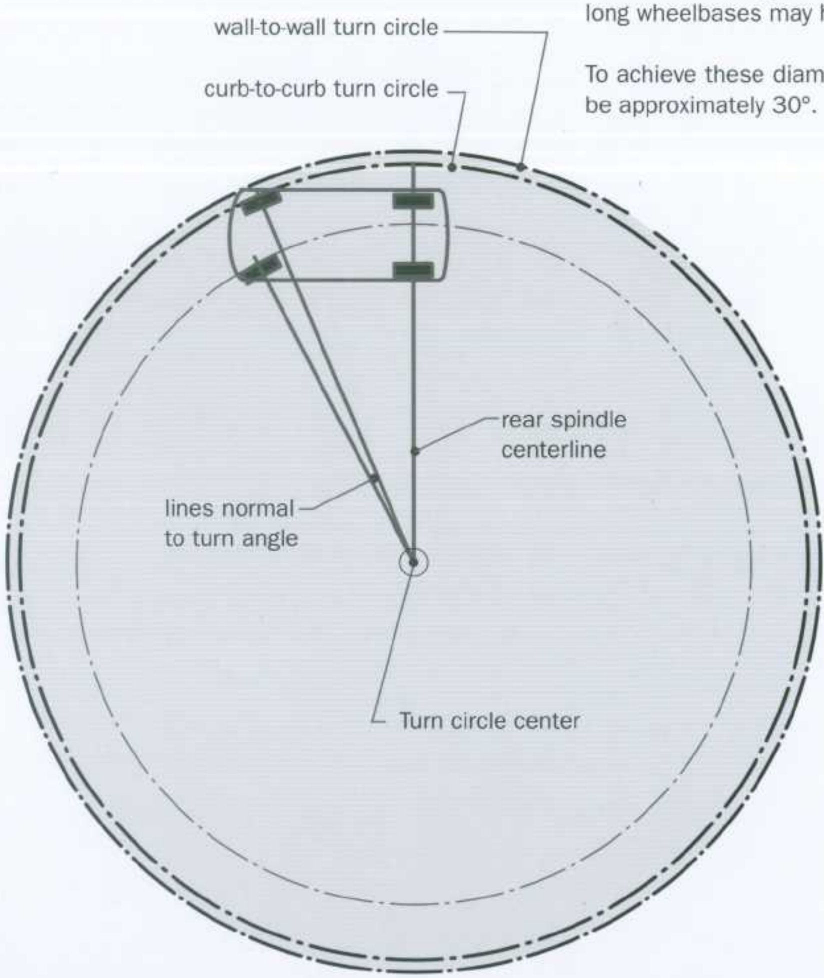
STEERING & TURN CIRCLES

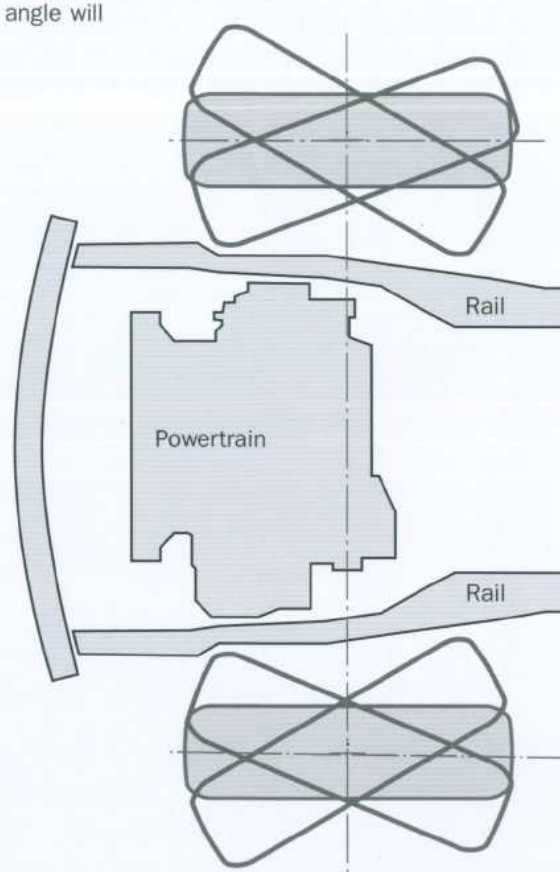
Steering objectives should be addressed at an early stage of the packaging process. The turn-circle requirements will have a major influence on the package. The diagrams below show the elements that control the turn circle. The front frame rails that run between the engine and the tires inhibit the steering angle. In the illustration below, if a larger (transverse) engine is required the track will have to be widened to maintain the same turn circle.

The two factors that control the turn circle are the wheelbase and the turn angle. Long-wheelbase vehicles will require a greater turn angle. This is often made possible by the longitudinal powertrain layout which allows the front frame rails to be moved inboard. Trucks with an extremely long wheelbase may also require the rear wheels to steer to get the turn circle to an acceptable diameter.

Turn circles are usually about 10 meters for small cars and 12 meters for larger cars. Large trucks and limousines with long wheelbases may have turn circles up to 15 meters.

To achieve these diameters the front wheel turn angle will be approximately 30°.





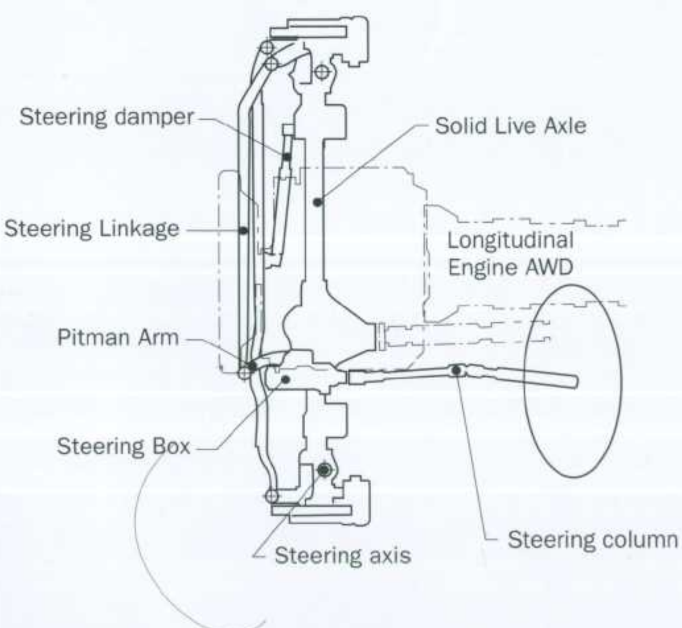
STEERING SYSTEMS

Two types of steering systems are commonly used: 1) rack and pinion, and 2) recirculating ball. The steering mechanisms are located just behind or forward of the front spindle, (creating front or rear steer). The steering wheel is directly linked to the mechanism through the input shafts or steering column, which is divided into several segments and angled to reduce steering-column movement in a frontal impact. Rack and pinion is the most common system, and works with most vehicles. Recirculating ball systems are usually applied when a lot of suspension articulation is required. The long track rods help to reduce "bump steer" (caused by the difference between the suspension and steering geometry) which results in the turn angle changing as the suspension travels in jounce or rebound.

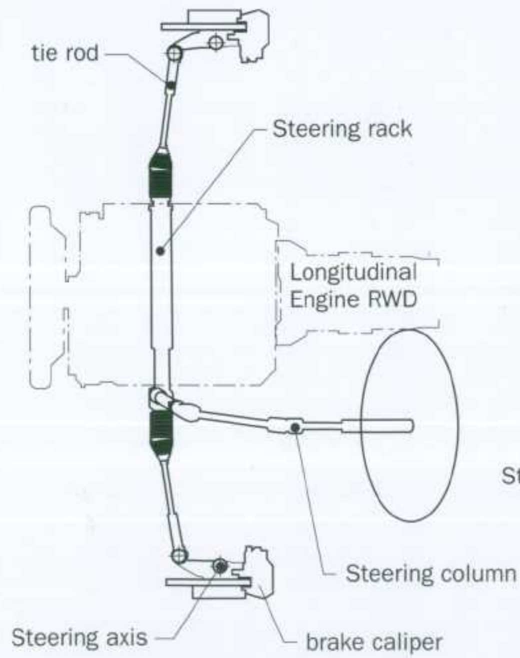
Below are three applications of the systems. Designers should note that the steering mechanism attachment to the knuckle will affect the location of the brake caliper which is often used as a design element.

Note: the steering systems may not feature in the initial package, as they rarely affect the exterior surface.

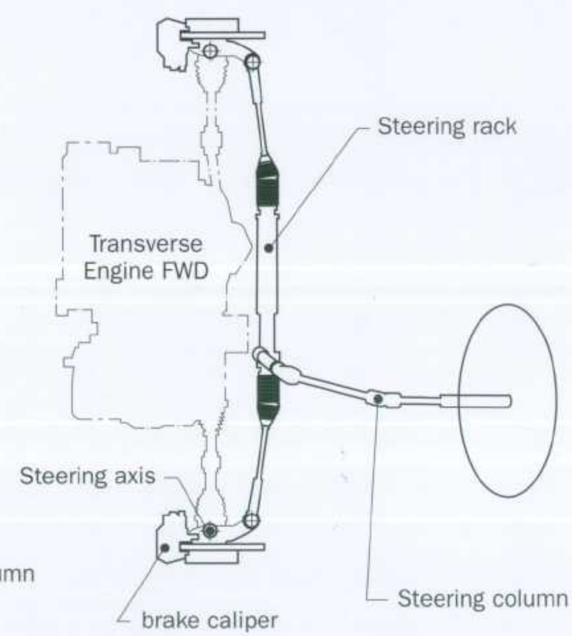
RECIRCULATING BALL

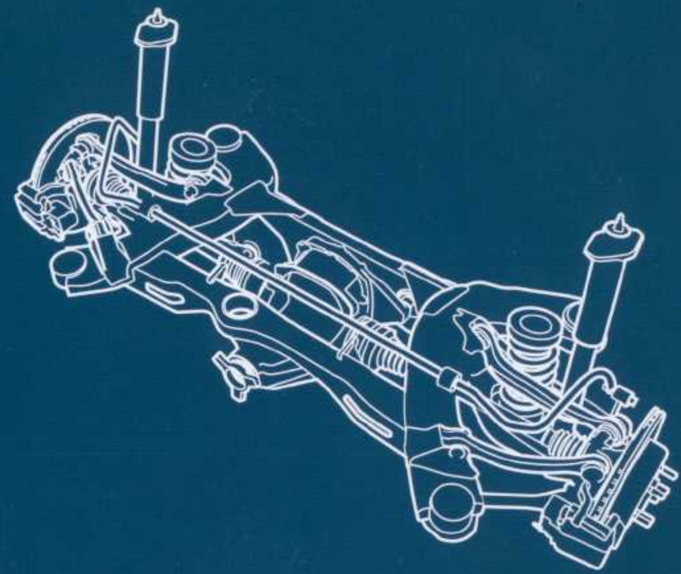


RACK & PINION (under the engine)



RACK & PINION (behind the engine)





"Designers do not have to fully understand how to set up suspension geometry, but it is important to know why a particular system is chosen and how they may affect the package and vehicle proportions."

SUSPENSION & CHASSIS | 09

INTRODUCTION TO SUSPENSION SYSTEMS

Choosing the type of suspension system that works with the functional objectives of the vehicle should be done at the ideation phase of the package.

The two main objectives for any suspension system are to provide ride comfort to the occupants and keep all four tires in contact with the road for optimum traction and handling. These can be achieved in many different ways. The effect that each kind of system has on the tire envelopes and adjacent package components should be understood so that the initial package study can be set up with these in mind. Here are some functions that will determine the type of mechanism and spring/damper units to employ:

1) Heavy Load Carrying

2) Travel & Articulation

3) Handling

4) Comfort

5) Cost

6) Package Constraints

A large chunk of the initial package process involves setting up the relationship between the tires and the occupants. This cannot be done accurately until the "Jounce and Turn" envelopes (see p. 144) have been established by the suspension engineers. These envelopes define the swept area of the tire profile, as the suspension articulates and the steering angles change. Full jounce and full lock conditions are usually the most important, although these two extremes do not always occur at the same time.

There are many different systems, each having positive and negative attributes depending on the application. Each is designed with three main elements, namely the springs, that support the weight of the vehicle and absorb the road shocks; the dampers or shock absorbers, that ensure the springs do not overreact; and, the mechanism that controls the geometry.

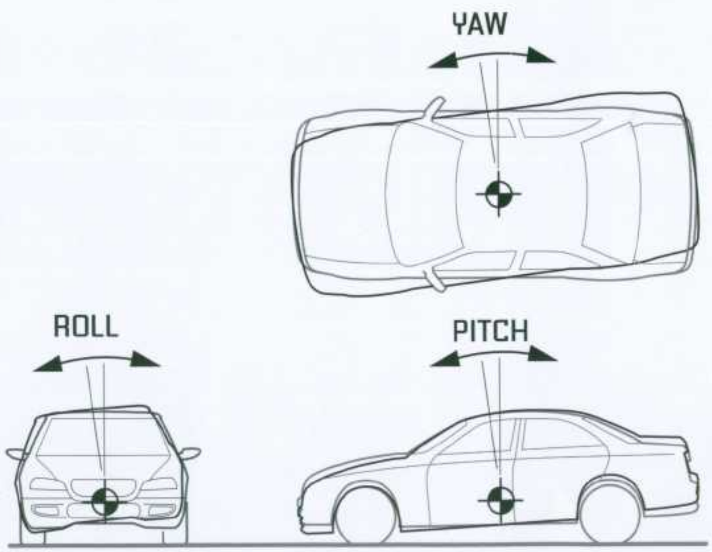
For each suspension mechanism type there may be several spring types which could work. For example, short- and long-arm (SLA) suspension can be sprung with coils, torsion bars or leaf springs. Solid axle types can be supported by coils, leaf springs or air bags, depending on the application and package constraints.

Some systems will package very well and almost disappear in the initial package, others will be massive and have a great influence on the architecture. Truck and off-road vehicles, for example, will require very strong components with long travel and articulation capabilities. Often solid axle configurations are used. These span the entire width of the vehicle and require lots of clearance to the floor and underbody structure. Sports and race car suspension is critical to handling, so the geometry cannot be compromised and is set up around the ideal pivot points. Golf carts on the other hand will employ the cheapest, smallest systems that can be found. Typical priorities for different vehicle types are shown opposite.

On pages 154–163 there are some examples of various systems, their applications, advantages and disadvantages. The main thing to note is that they each work well in several situations, so if your first choice does not fit your package well, there will be other options.

PITCH, YAW & ROLL

These three dynamic conditions happen during acceleration, braking and cornering. They are reactions to inertia, which cause the vehicle to rotate around the center of gravity. Generally speaking, minimizing these will improve the handling and in some cases, the ride comfort. The best way to control all three is to reduce the vehicle mass and distribute it evenly, as close to the vehicle center as possible and low to the ground. This reduces the "polar moment of inertia." Once the aerodynamics and major components are set in the package, the only way to further control the pitch, yaw and roll is with suspension design and tire choice.



SUSPENSION SYSTEM ATTRIBUTE PRIORITIES

Each vehicle will have its own set of priorities for both front and rear suspension. The systems should be matched up to these criteria.

cost
package

cost
package

cost
package

cost
package

cost
package
handling

cost
package
handling

handling

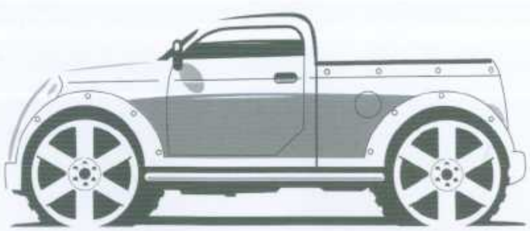
handling

comfort
handling

comfort
handling

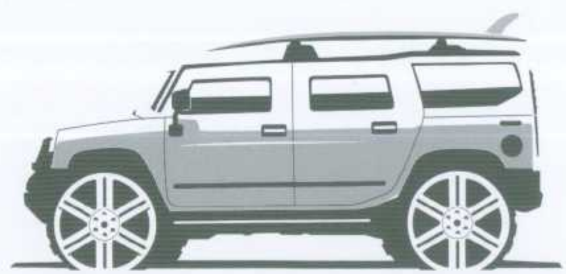
comfort
cost

loading
comfort
cost



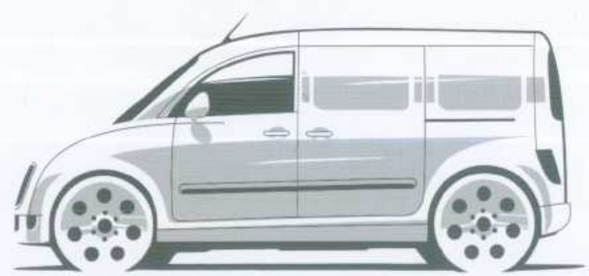
comfort
loading
travel

loading
travel



travel
comfort

travel
loading
comfort



cost
loading

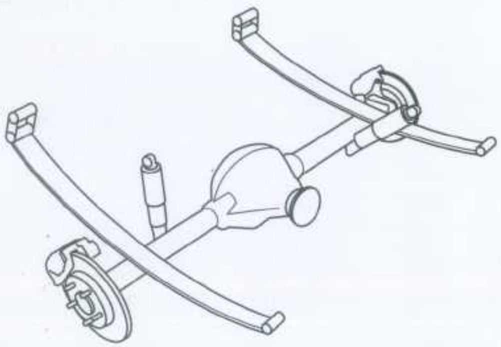
loading
cost

SUSPENSION TYPES

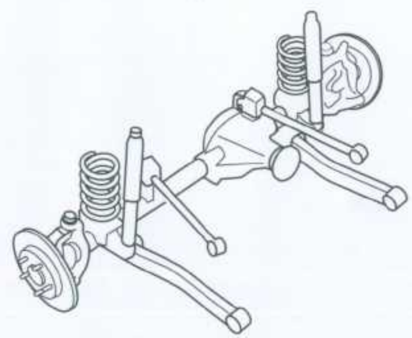
From the designer's perspective, it is important to know why a particular type of system will be applied and how its configuration will affect the vehicle's proportions and package. Understanding the geometry is not so important, but it helps to know the effect that the mechanism will have on the wheels as they travel in jounce (up) & rebound (down).

The illustrations below show some of the many systems currently in use. These are described in more detail on the following pages. Notice that they are divided into non-independent and independent. Generally speaking, the non-independent systems are used on vehicles that carry heavy loads or require extreme articulation in off-road environments. The independent systems are more sophisticated and provide better handling and ride comfort.

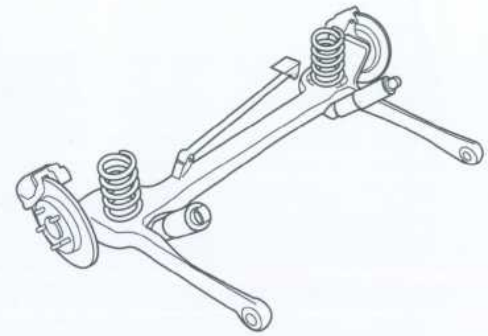
SOLID AXLE / LEAF SPRING



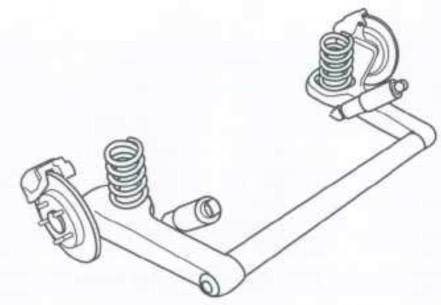
LINK / COIL



SOLID AXLE / TRAILING LINK

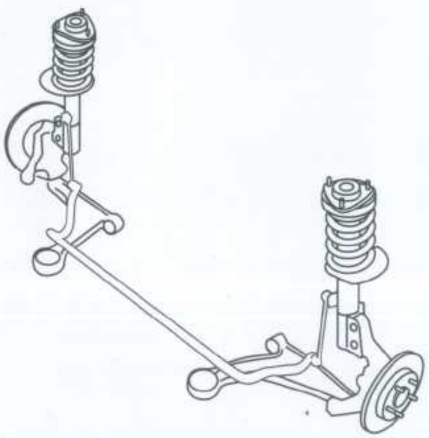


TRAILING ARM / COIL

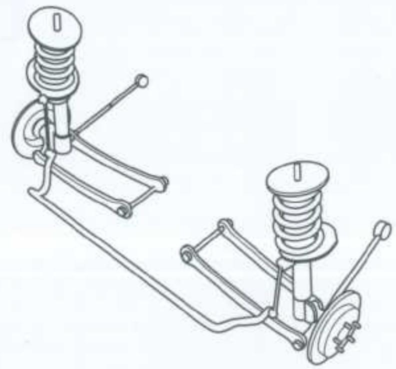


NON-INDEPENDENT SYSTEMS

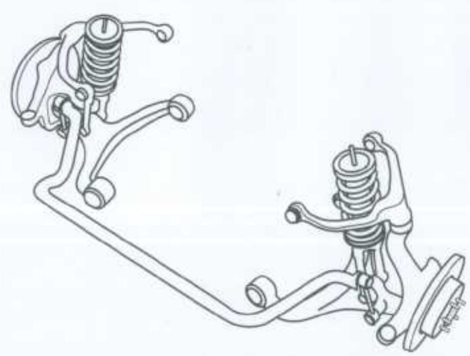
McPHERSON STRUT



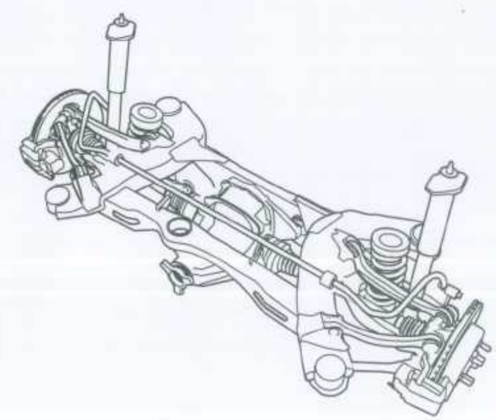
CHAPMAN STRUT



SLA / COIL



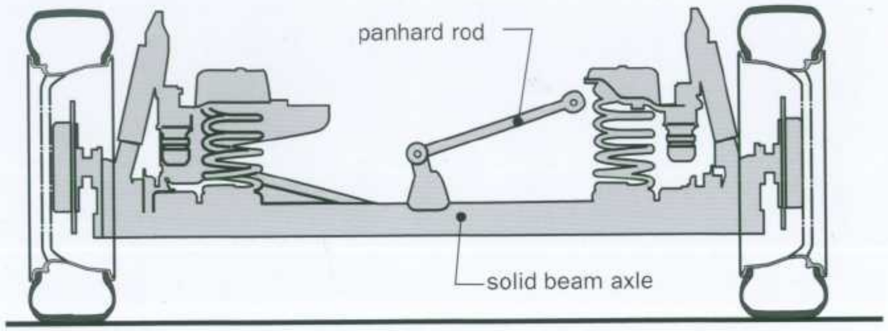
MULTI-LINK / COIL



INDEPENDENT SYSTEMS

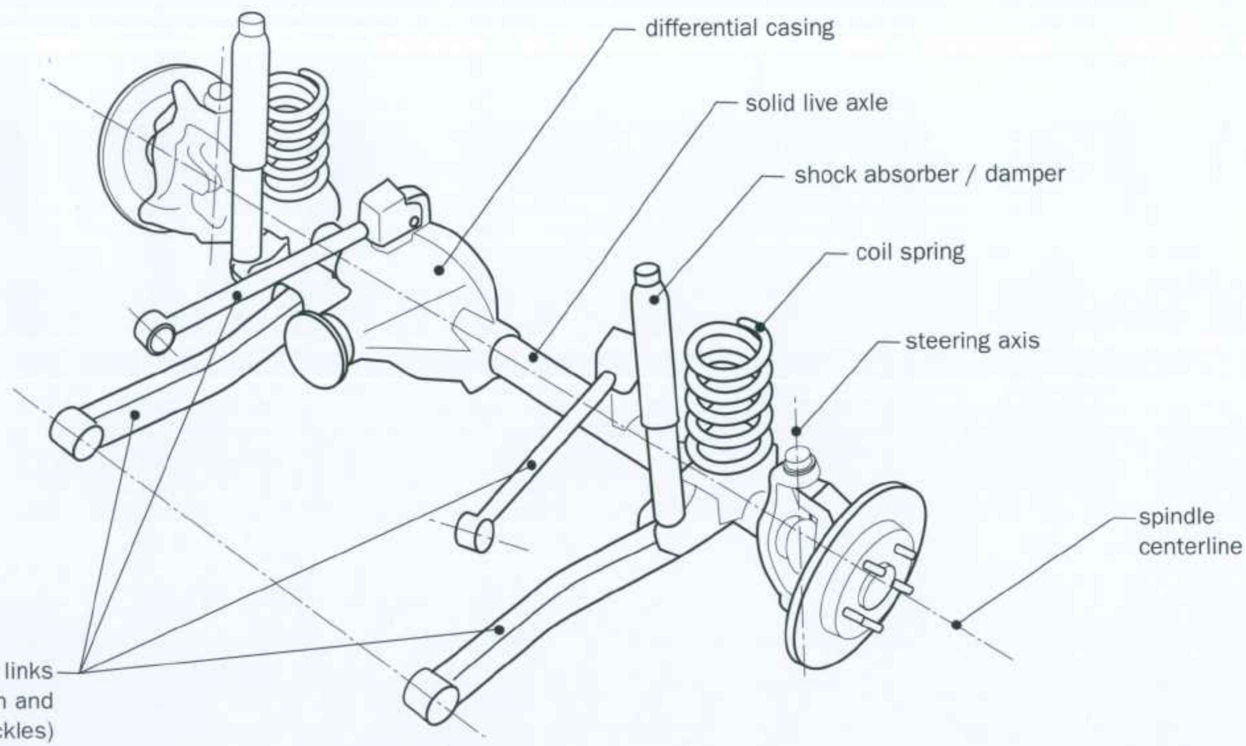
SOLID AXLE SUSPENSION SYSTEMS

Often used on utility vehicles that are designed to carry heavy loads. Most commonly used on rear suspension, but occasionally on the front. "Live" axles contain the final drive system (differential and driveshafts). Beam axles are applied if drive is not required. The advantages include low cost, strength, long articulation, efficient packaging, consistent ground clearance and adjustability. The main drawback is compromised handling due to the amount of unsprung weight.

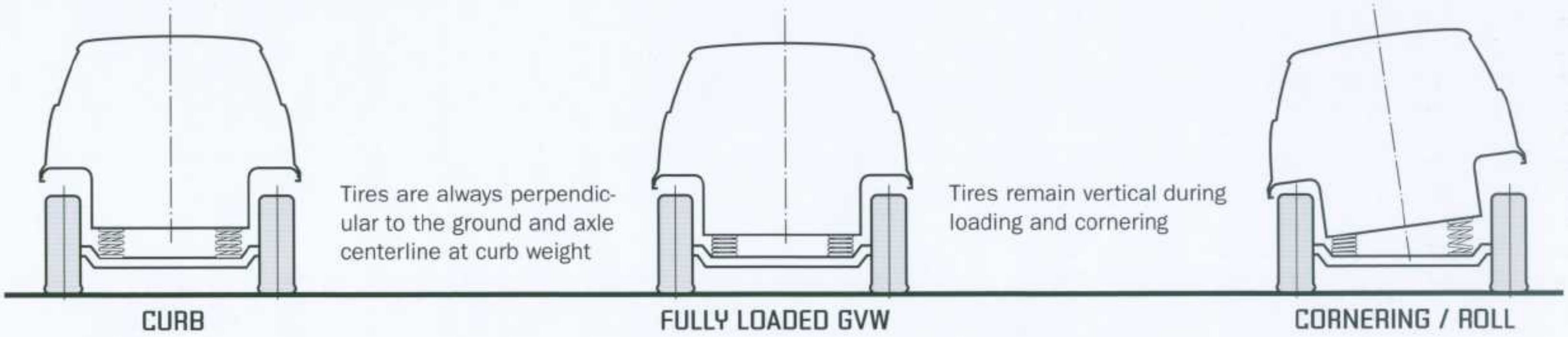


FRONT - SOLID LIVE AXLE / COIL SPRINGS (NON-INDEPENDENT)

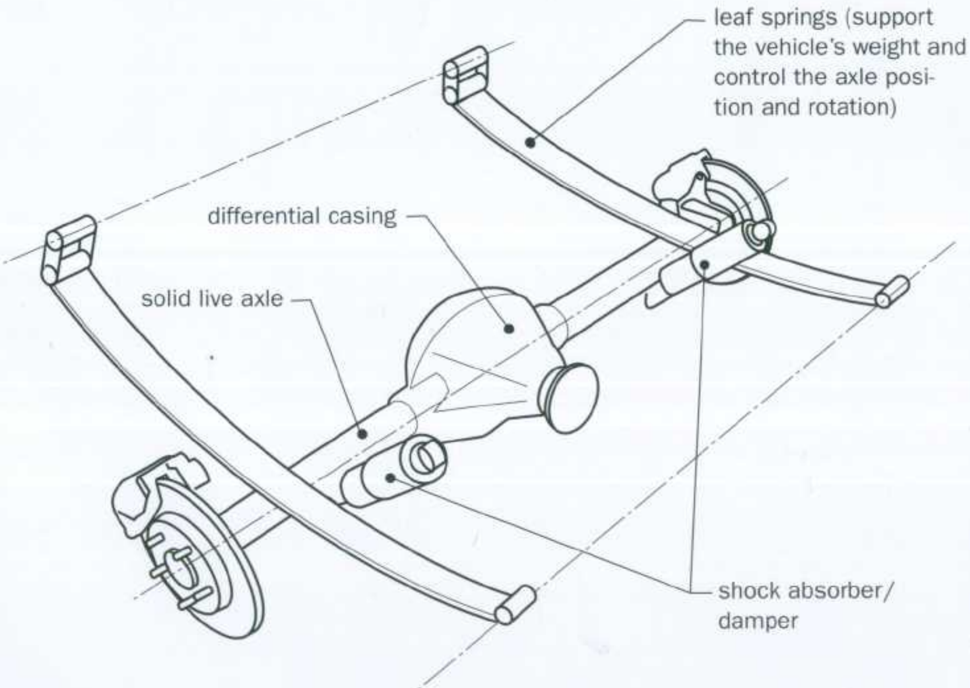
This system will often be applied to extreme SUVs, providing 4WD, strength and articulation. When setting up the package, allow for at least 150 mm of jounce travel for the axle assembly. The axle will usually be located directly underneath the engine, which will be mounted high enough to allow for the suspension travel. This will affect the driver's eye point which should be located high enough to see over the hood.



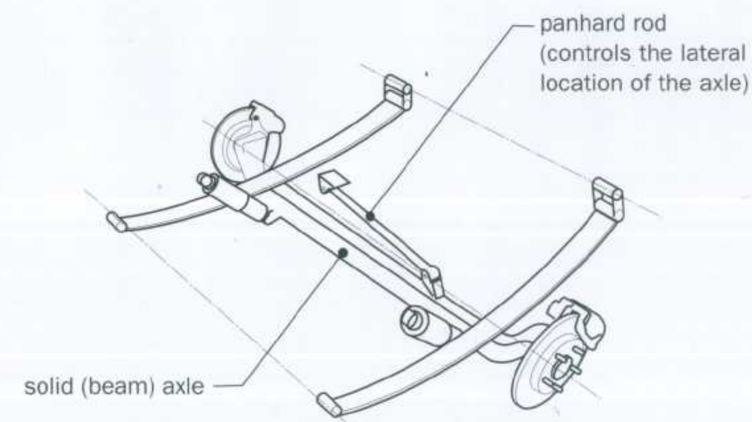
LOADING & DYNAMIC CONDITIONS



REAR - SOLID LIVE AXLE / LEAF SPRINGS (NON-INDEPENDENT)



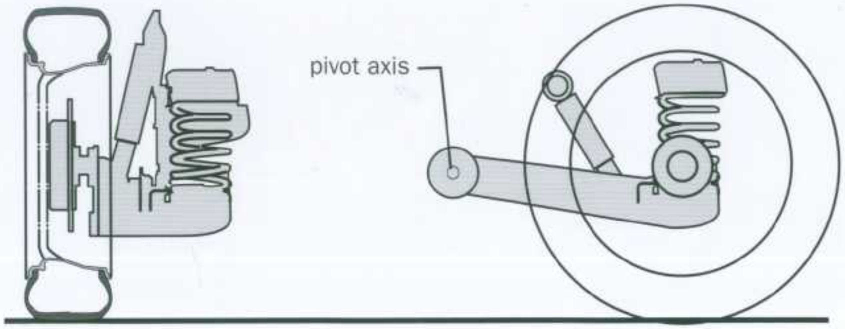
REAR - SOLID BEAM AXLE / LEAF SPRINGS (NON-INDEPENDENT)



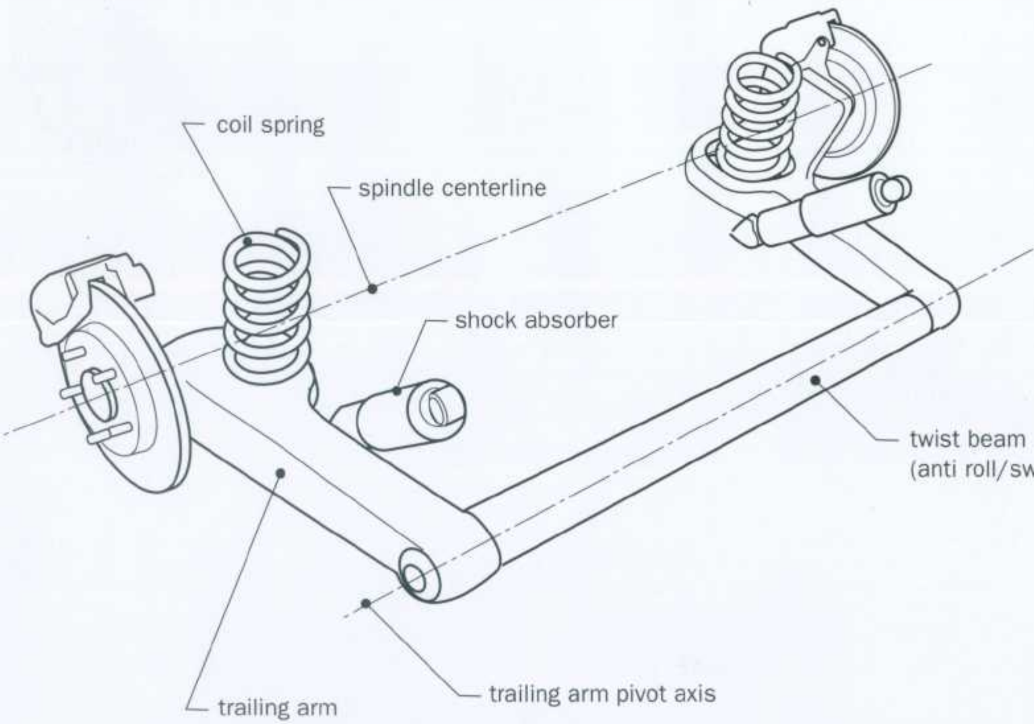
The solid beam axle center can be lower than the spindle height, helping to lower the vehicle's floor. The leaf springs package efficiently along the body frame rails, but require a long rear overhang to accommodate their length.

TRAILING ARM SUSPENSION SYSTEMS

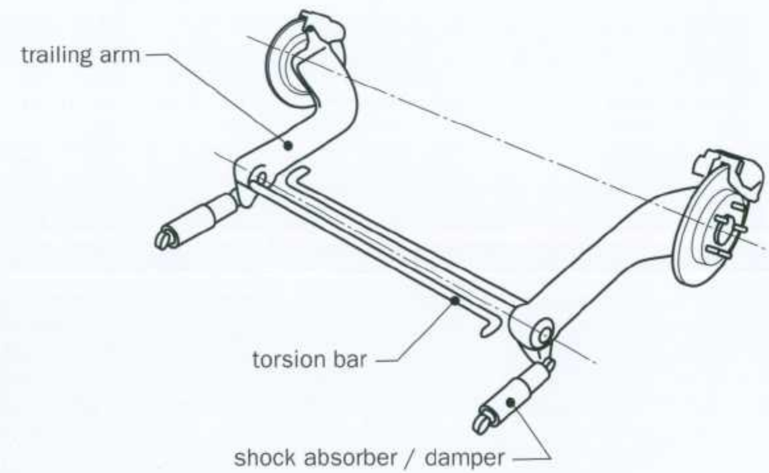
Often used on small cars because it packages efficiently in light vehicles with short rear overhangs and most configurations provide space for the spare tire. This system works well when loaded because the camber change is very limited. The swing arms are often linked by a twist beam which can be located along the pivot axis or the spindle centerline. These reduce body roll and the latter will help the tires remain vertical during cornering.



REAR - TRAILING ARM / COIL SPRINGS (INDEPENDENT)



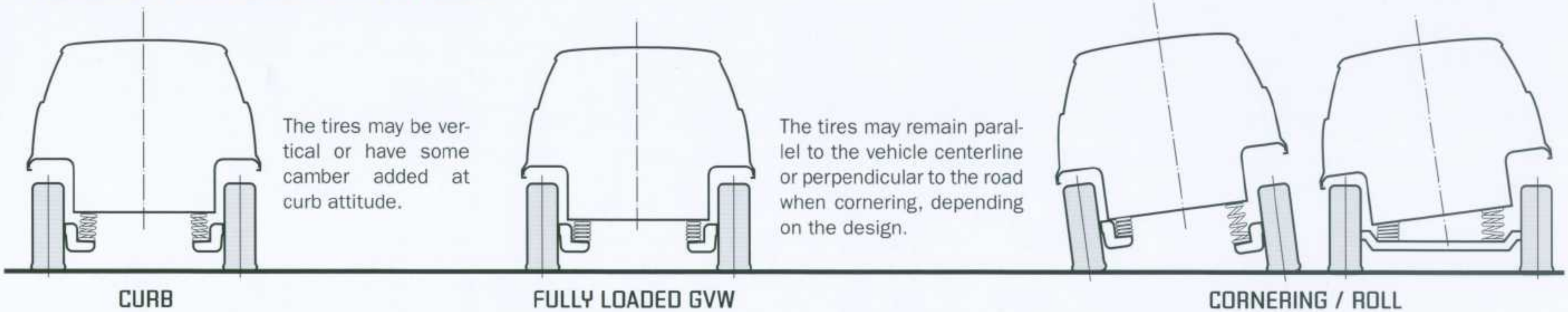
REAR - TRAILING ARM / TORSION BARS SPRINGS (INDEPENDENT)



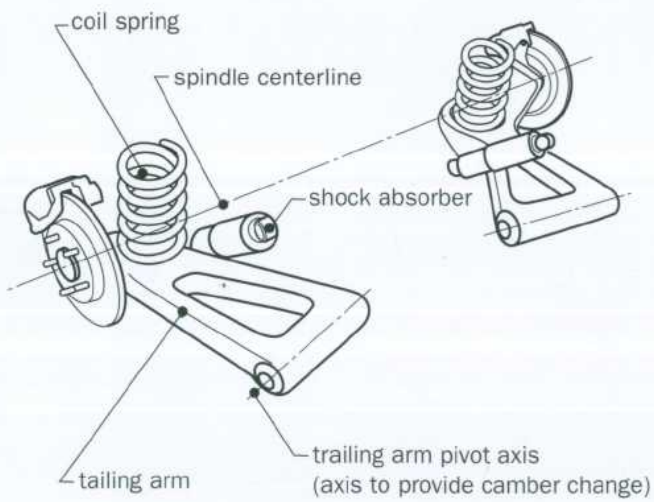
Using torsion bars and horizontal shock absorbers helps to lower the rear floor, improving cargo space.

One drawback of trailing arm suspension is lateral flexing during cornering. Lateral links can be added to the system to improve handling. Triangular trailing arms also help to minimize flexing.

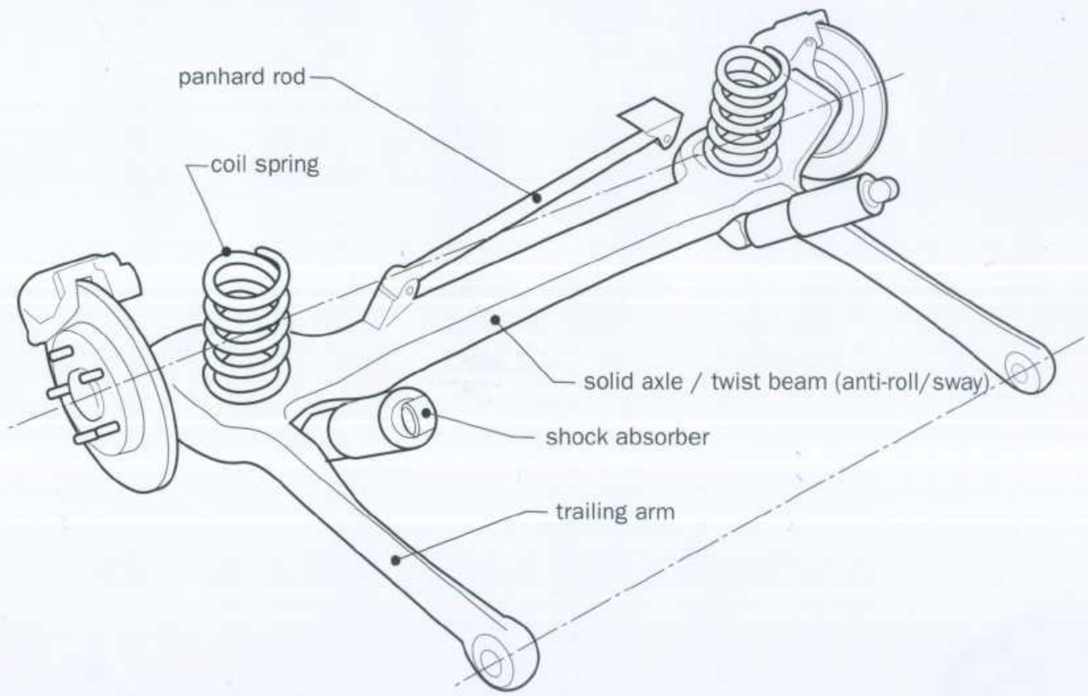
LOADING & DYNAMIC CONDITIONS



REAR - SEMI TRAILING ARM / COIL SPRINGS (INDEPENDENT)



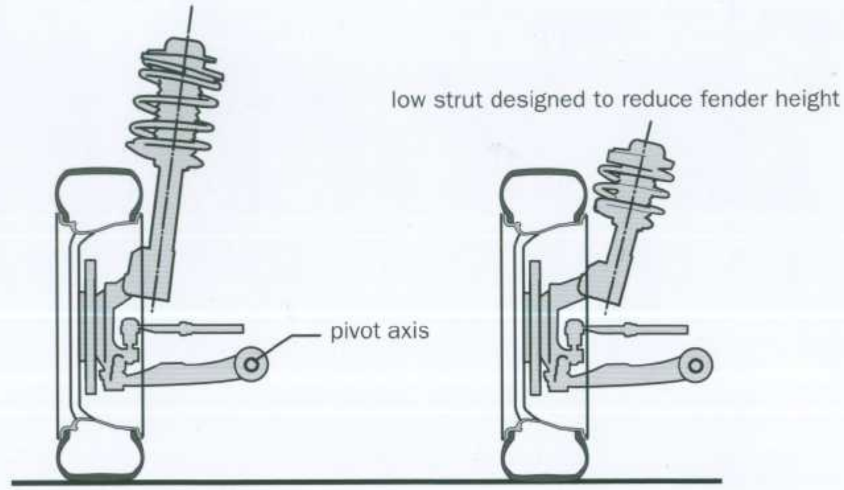
REAR - SOLID BEAM AXLE, TRAILING LINK / COIL SPRINGS (NON-INDEPENDENT)



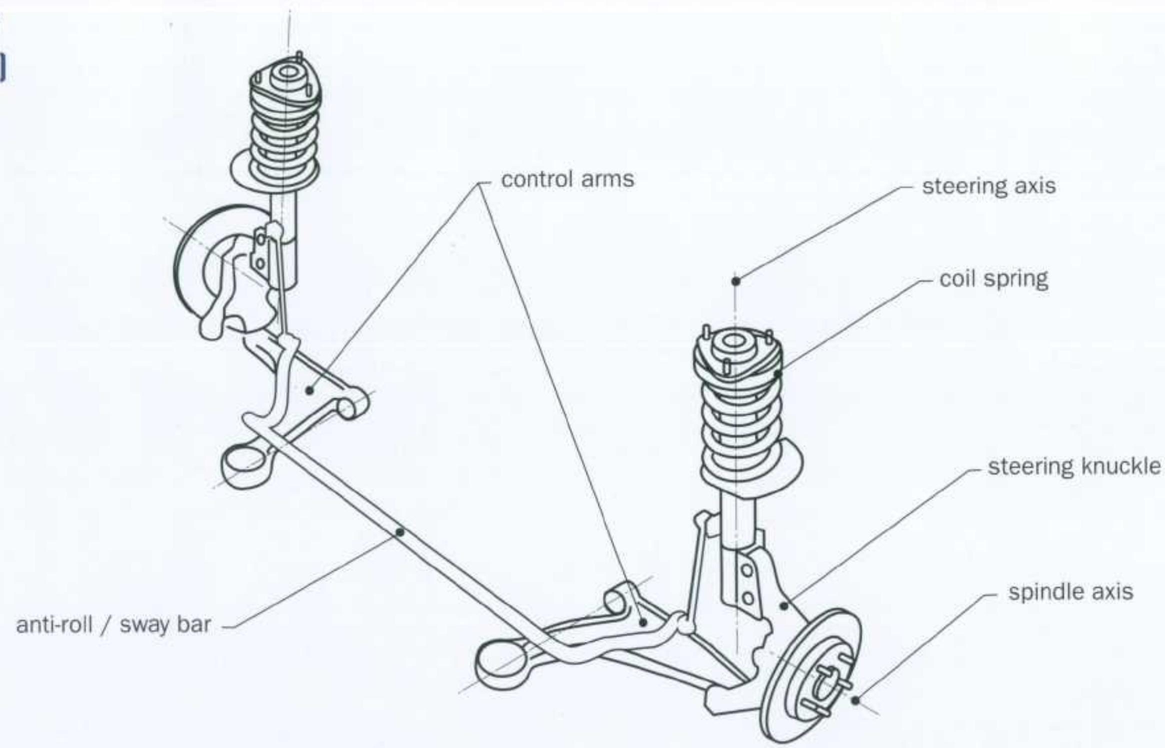
Semi trailing arms create a slight camber change during cornering which can optimize the handling attributes during hard driving.
A solid beam axle can be mounted to trailing arms to create a simple lightweight system. A panhard rod or Watt's link controls lateral movement of the beam.

STRUT SUSPENSION SYSTEMS

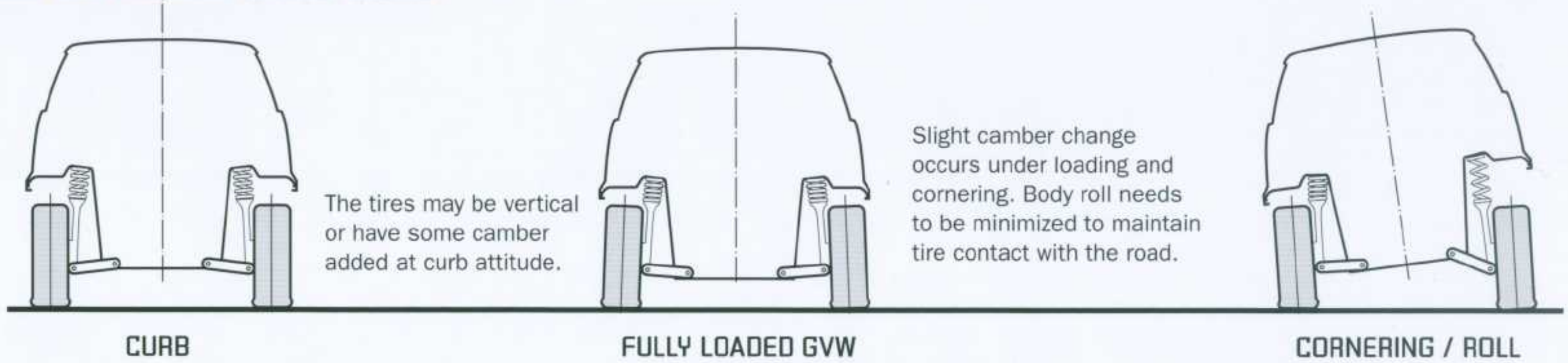
Very common front suspension on passenger cars. McPherson struts incorporate the steering axis into the strut centerline, reducing cost. This system packages well with transverse engines but usually requires a high fender to fit the spring above the tire. Chapman struts are used on rear applications where steering is not required.



FRONT - MCPHERSON STRUT/ COIL SPRINGS (INDEPENDENT)

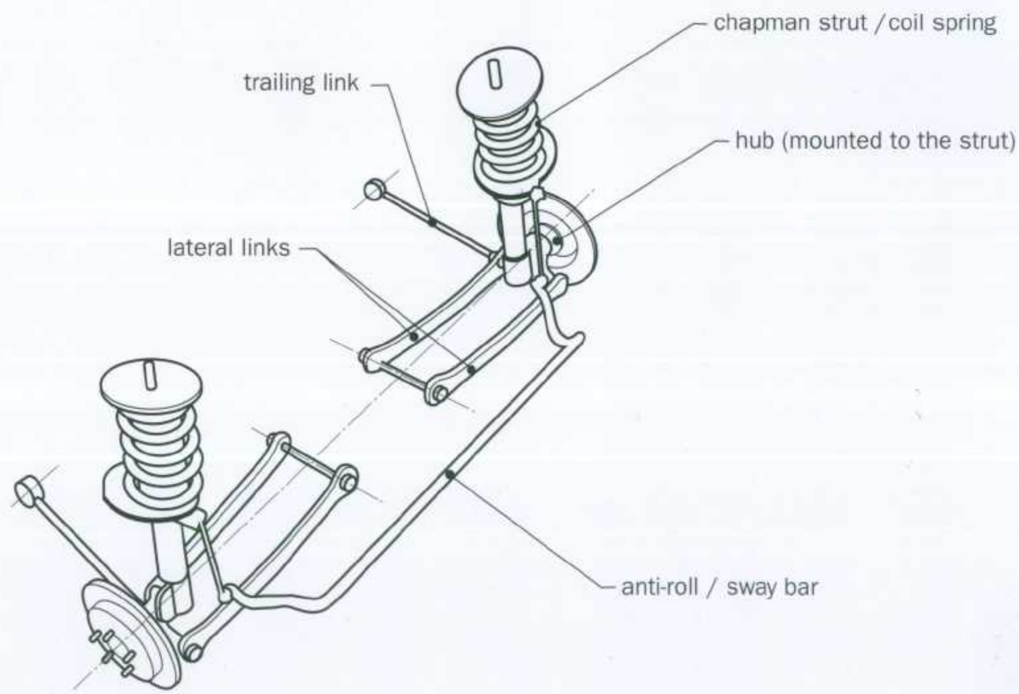


LOADING & DYNAMIC CONDITIONS



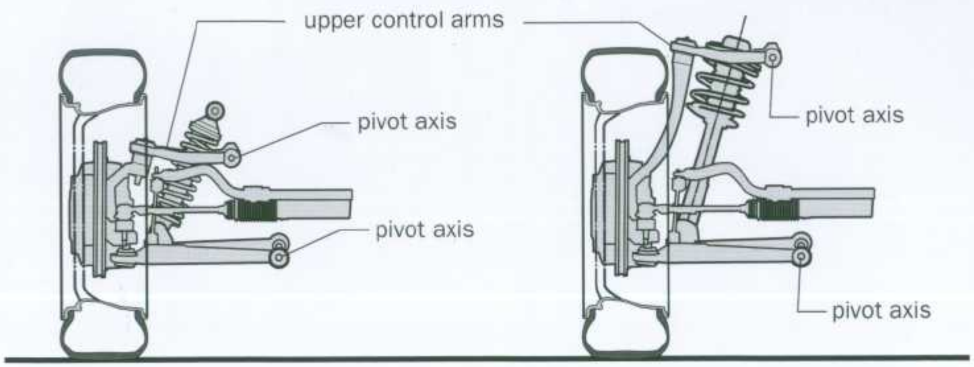
REAR - CHAPMAN STRUT / COIL SPRINGS (INDEPENDENT)

This system can be very simple, inexpensive and lightweight (as shown). It also packages very efficiently. It is ideal for lightweight, entry-level sports cars. More robust versions can be applied to larger, more capable cars and SUVs. In these applications the hub may be attached to the control arm rather than the strut.

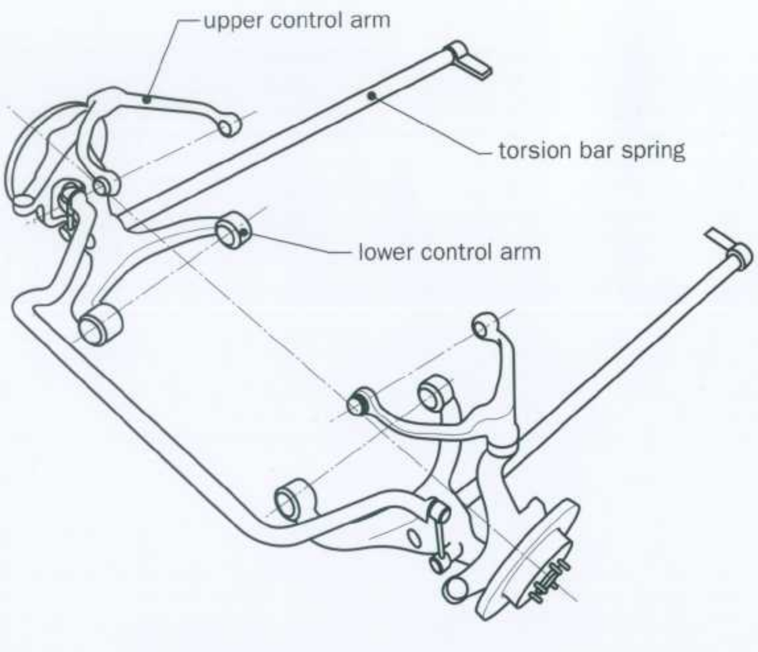


SLA & MULTI-LINK SUSPENSION SYSTEMS

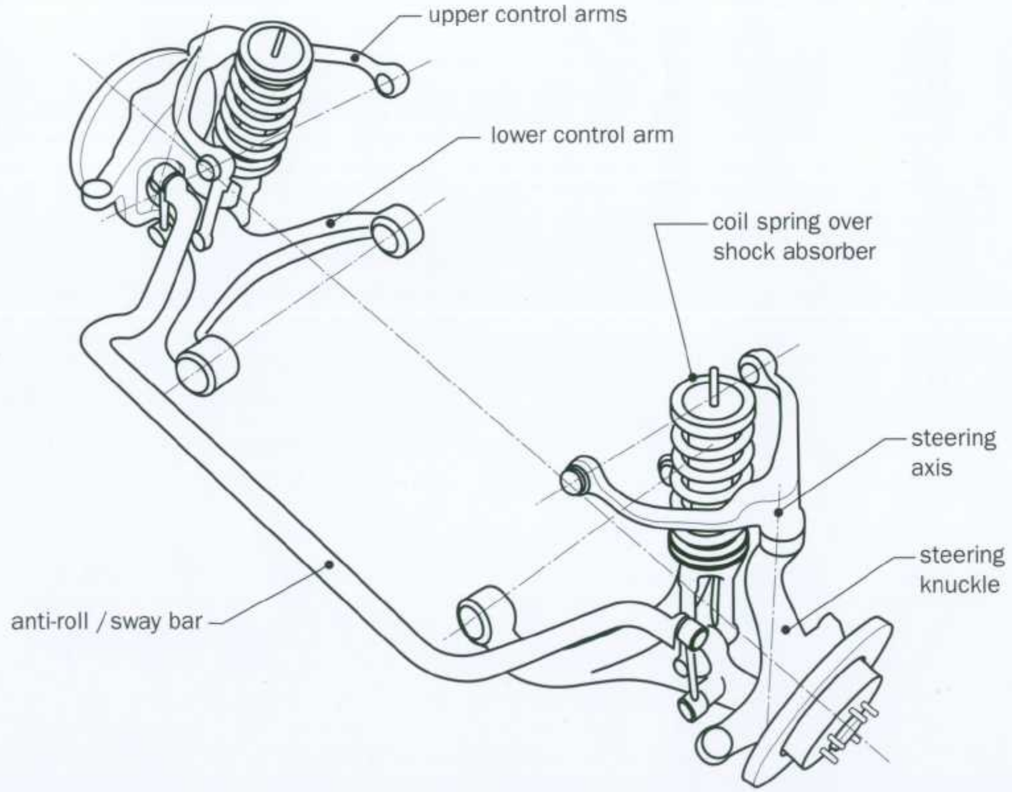
These are the most sophisticated systems, mainly used on high-performance and luxury cars, at both front and rear. Trucks and SUVs often use the SLA (short and long arm) system for their front suspension. The geometry of the control arms is designed to control camber change to maintain each tire's contact patch as the body rolls during cornering. Packaging the inner pivots axis can be a challenge on some vehicles. Note that the upper control arm can be mounted in a low or high location depending on the ideal attachment position and drive shaft configurations. Springs are usually coils but torsion bars and leaf springs can also be used to suit the application. On open-wheel race cars the coils are often mounted longitudinally inside the body to improve aerodynamics. These are actuated by a push rod and bell crank.



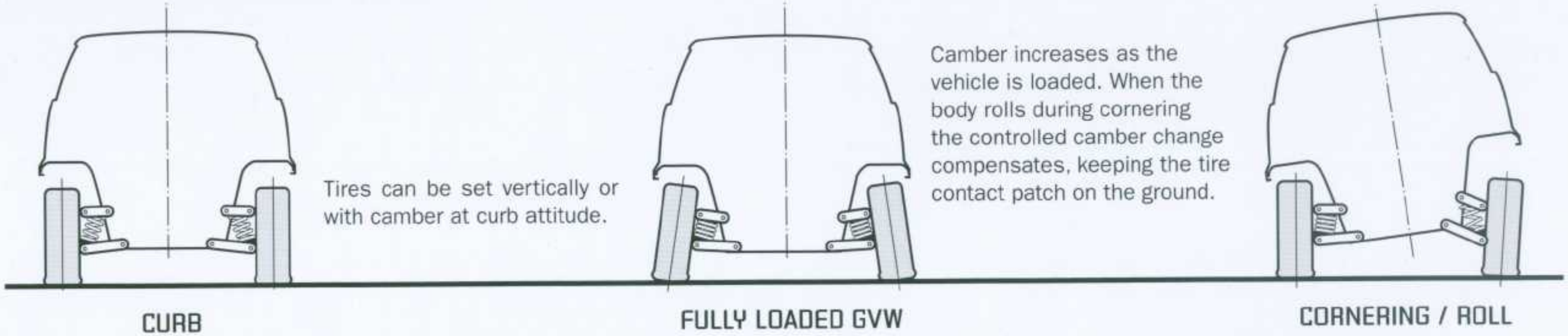
FRONT - SLA TORSION BAR (INDEPENDENT)



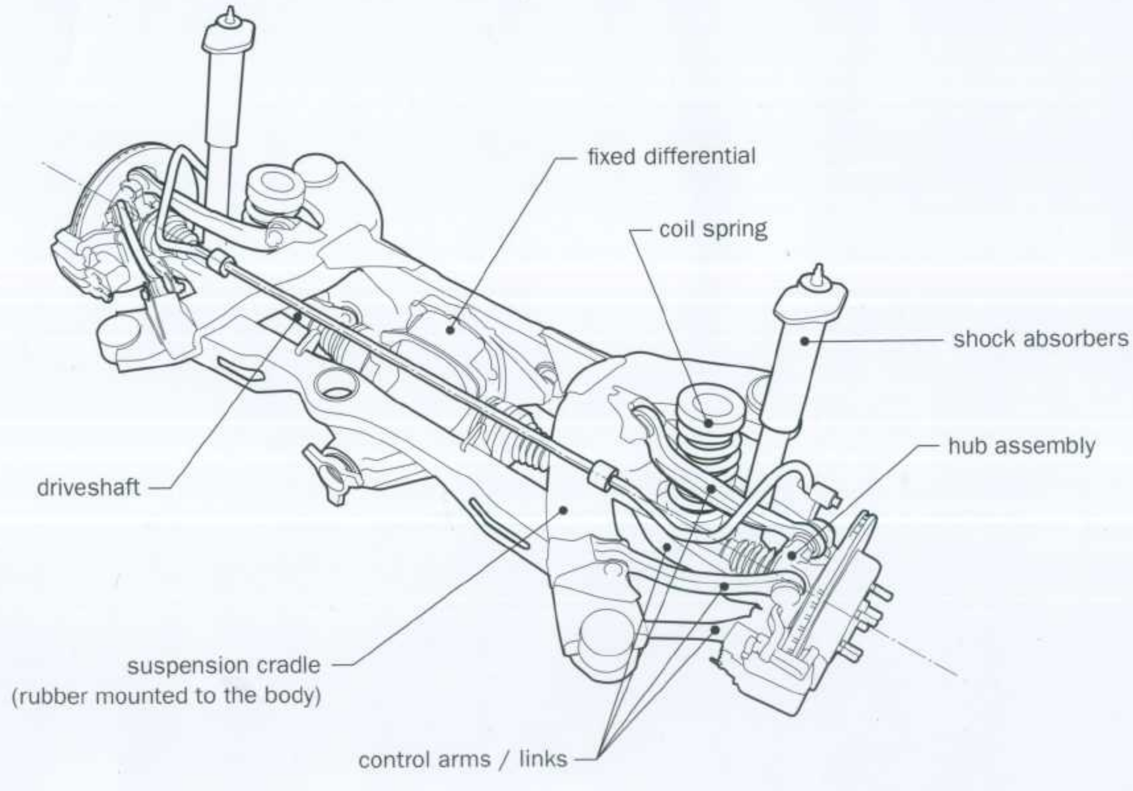
FRONT - SLA COIL OVER SHOCK (INDEPENDENT)

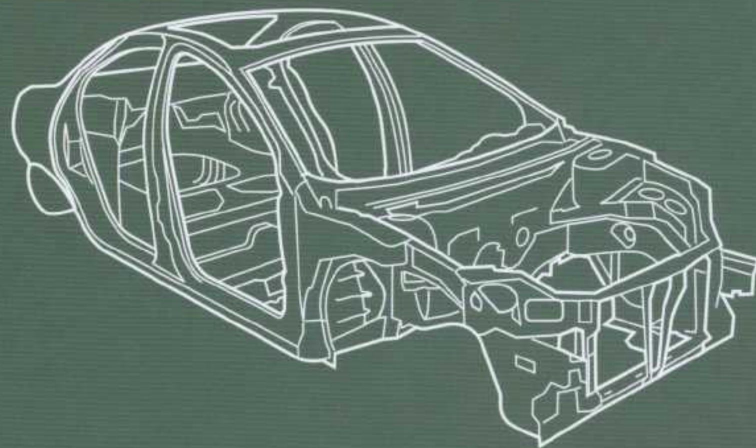


LOADING & DYNAMIC CONDITIONS



REAR - MULTI-LINK / COIL SPRINGS (INDEPENDENT)





"The body is a very complex system, which threads throughout the architecture, holding all the elements together. The package is developed in a series of sections cut through the body structure and doors."

BODIES | 10

INTRODUCTION TO BODY STRUCTURES

The body is one of the most complex assemblies of a passenger vehicle, consuming a large portion of a project's resources, both manpower and investment. Besides being a complex piece of engineering, it is also the element most tied to the vehicle's overall architecture and its appearance.

The body structure and outer skin have four main functions:

1) **Protect the occupants and cargo.**

2) **Provide attachment points for all other major components and manage the stress between them.**

3) **Provide an appealing appearance and image for the product.**

4) **Provide an aerodynamic form to improve performance and reduce noise.**

A car or truck body can be broken down into three main groups of assemblies, namely: the underbody, upper body and closures.

The underbody consists mainly of the floor panels and dash structure which are stiffened by a number of box sections to form a substructure. These box sections comprise the main longitudinal frame rails, the sills and the cross members. The powertrain and chassis components are attached to this substructure which also serves as the primary crash structure, running out to the extremities of the body.

The upper body can be thought of as a framework surrounding a series of apertures and supporting the outer skin of the vehicle. Each aperture or opening is designed to provide access into the vehicle or visibility out of it.

The closures include the doors, hood, and trunk lid/tailgate. These represent a large portion of the exterior surface and feature extensively in the early packaging studies.

The combination of box sections and "shear" panels serve to meet the four functional requirements listed above. The bulk of the work is done by the box sections (or beams) that are designed to withstand the enormous stresses that a vehicle will endure throughout its life. The design of the beams (pillars, sills, rails, cross members, etc.) are developed in a series of typical sections which are strategically cut through the main structure. The path and size (cross-sectional area and material thickness) of each section is determined by a structural analyst. He or she will use computer applications to ensure the body meets all of the requirements for torsional stiffness, durability, vibrational frequency and weight. The illustration on the opposite page shows a very primitive load path diagram which may be used to set up the structure. The bodies of nearly all mass-produced cars, minivans, trucks and SUVs are made from stamped steel although this might change as weight reduction becomes more and more important to increase energy efficiency. Some premium vehicles substitute steel for pressed aluminum and, in some cases, extruded aluminum sections.

In addition to the box sections, contoured panels (floor, dash, roof, wheel houses, etc.) close off the structure, creating a weatherproof and fireproof compartment for the passengers and cargo. These and some of the glazing panels also add to the structural integrity of the body and manage shear loads.

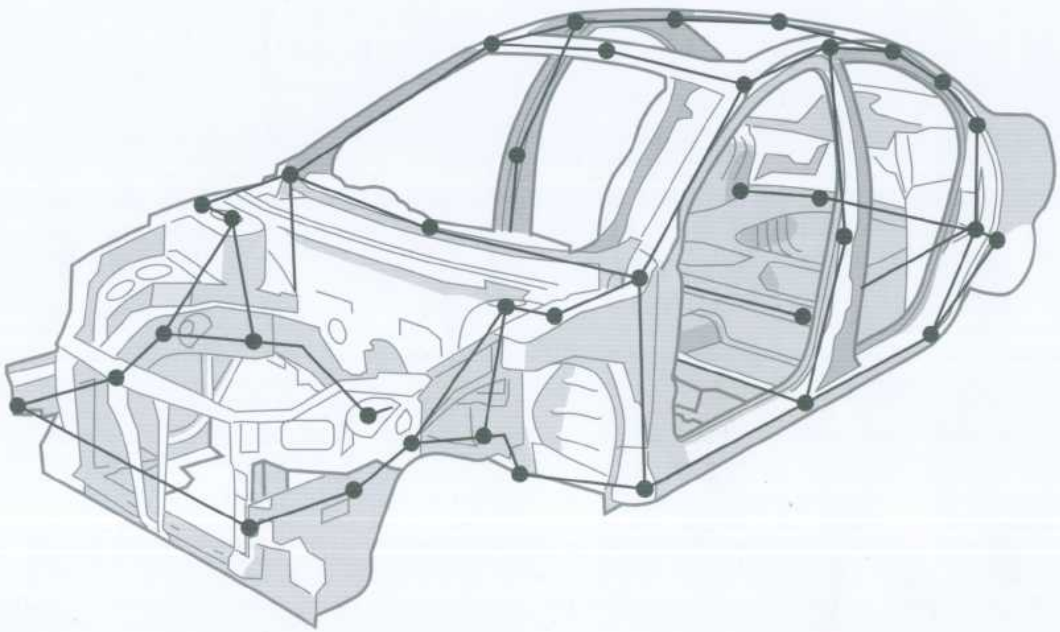
The closures such as the hood, trunk lid and tailgate do not add much to the dynamic structure, but they can play a major role in crash protection. These are often made from materials that differ from the main structure (such as plastic) to reduce weight or provide attributes such as dent resistance while improving formability.

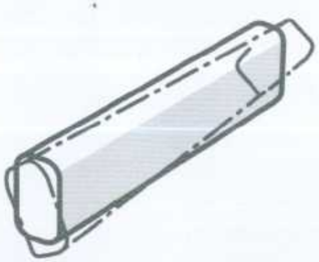
Bumper or fascia panels are usually made from damage resistant plastics to meet low-speed impact requirements which are mandatory in many markets. Using plastics also helps to form shapes that are difficult to create in metal. It also allows several components such as grills, lamp housings, scoops and badges to be made in one part, helping to reduce complexity and assembly time.

The remaining exterior panels serve only to create an appealing, aerodynamic exterior form. The other exterior features and components such as glass, lighting, breathing apertures and license-plate pockets all need to be considered in the development of the body and its typical sections.

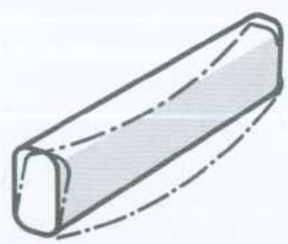
LOAD PATHS

This simple node diagram is created around the package by the structural analysts. The main load inputs from the suspension mounts and crash systems create the major load paths which thread through the body. From this the required cross-sectional areas of the main box sections are calculated. These sections feature prominently in the vehicle package. Each box section or structural panel may be subject to one or more of the forces shown below.

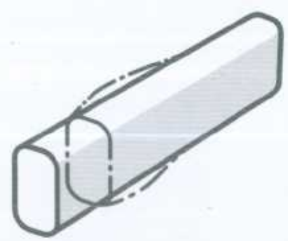




TWISTING



BENDING



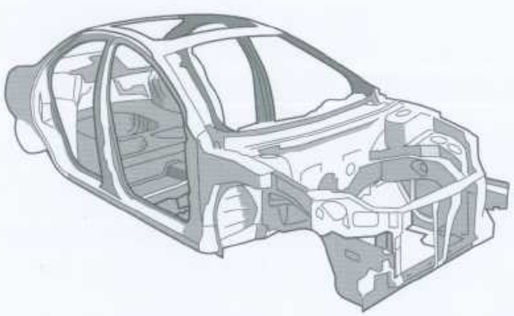
COMPRESSION

SHEARING

TYPES OF BODY STRUCTURES

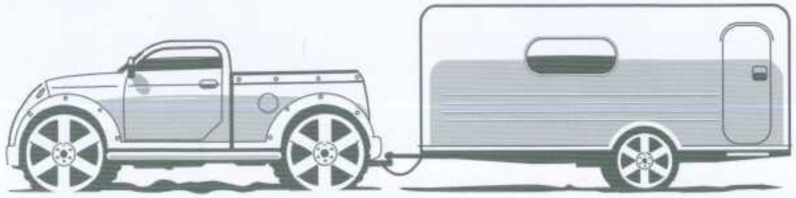
UNIBODY

The most efficient and cost-effective type of construction process for mass-produced cars, minivans and SUVs. The structure is made from steel or aluminum panels (0.7–2.0mm thick). The panels are stamped into shape and then spot welded together to form a series of box sections and contoured panels. Exterior panels can be made of metal or plastic depending on low-speed impact requirements.

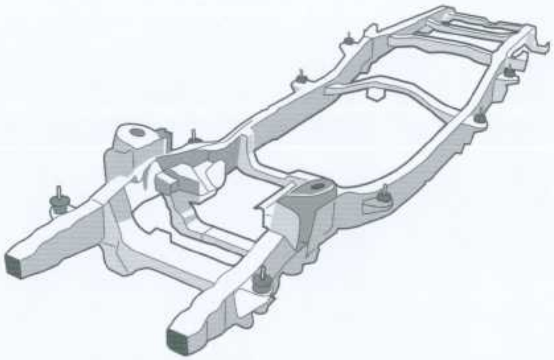


Unitary body, less doors, structure made from steel stampings that are spot welded together.

BODY ON FRAME



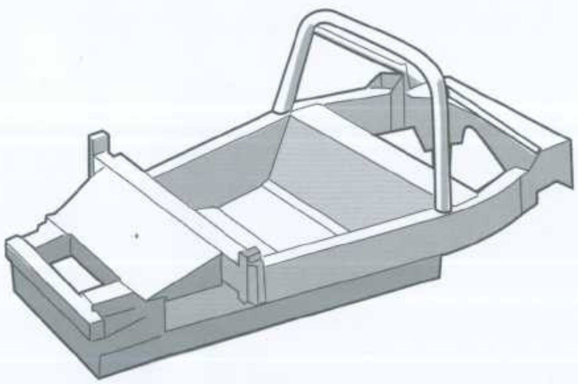
This type of construction is often used on pickup trucks and large SUVs, helping to manage heavy loads and drive over rough terrain. It also provides strength for increased towing capacity. The powertrain, suspension and main body are all mounted separately to a high-strength frame on rubber isolators to improve the ride quality, noise and vibration. Significant drawbacks of this type of structure are increased weight, higher floor height and poor torsional rigidity, which is important for good handling and road holding.



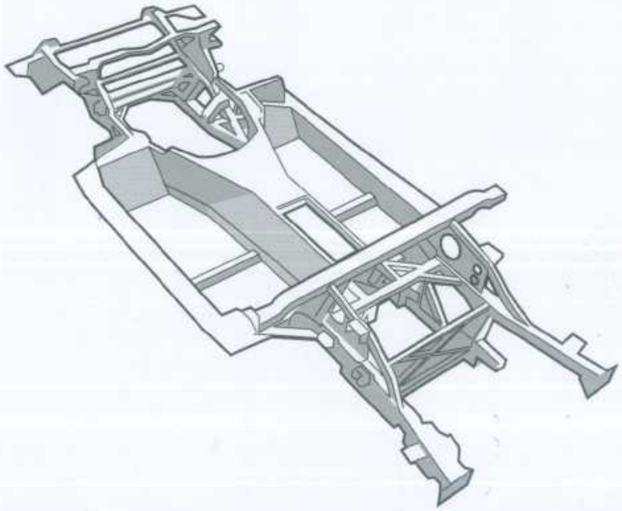
A high-strength steel truck frame that supports the unitary cab and bed assemblies mounted on top. This combination creates a structure that is very tough and durable, albeit poor in torsional rigidity.

SPACE FRAMES

Space frames are typically used for low-volume-production performance cars, where high stiffness, weight and low tooling investment are paramount. The space frame acts as the structural "skeleton" to which the mechanical components and outer, visible skin panels are attached. A space frame can be constructed from a variety or combination of materials such as steel tubes, aluminum extrusions or plastic composites.



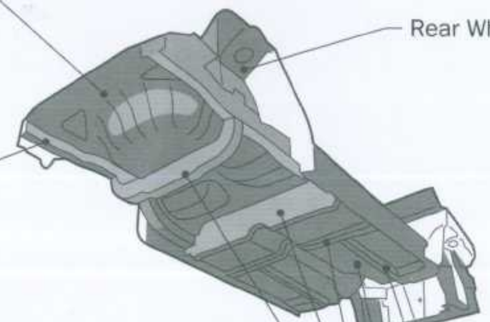
This extruded aluminum alloy space frame is welded or bonded together to form a stiff lightweight structure where much of the stress is managed by the sill sections. This type of design is ideal for mid- or rear-engine cars that do not require a tunnel for driveshafts.



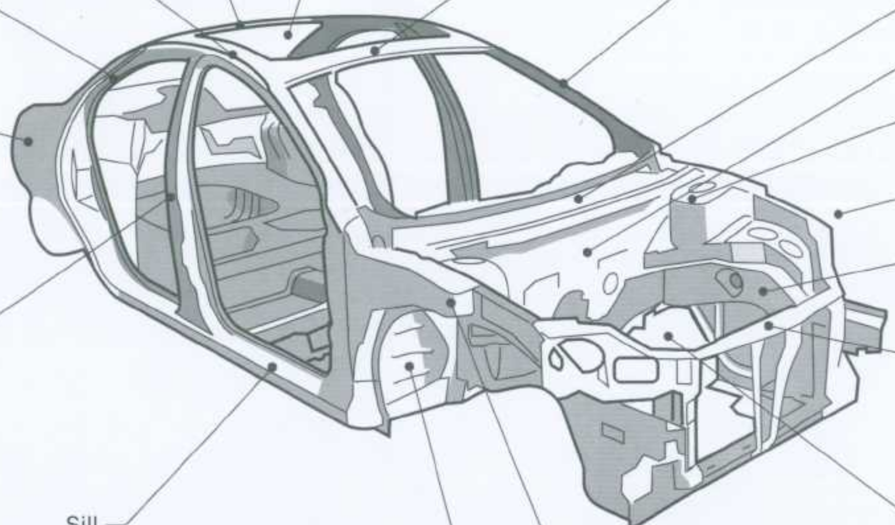
In this space frame solution, high-strength steel or aluminum alloy tubing is welded together to form a "backbone" frame where most of the torsional rigidity comes from the tunnel structure. Shear panels are added to stiffen the structure and close off the floor and dash. Plastic outer panels complete the body assembly. This type of design lends itself to front-engine, RWD cars that require a tunnel for the transmission and driveshaft.

TYPICAL ELEMENTS OF THE BODY STRUCTURE

UNDERBODY ASSEMBLY



BODY, LESS DOORS, ASSEMBLY

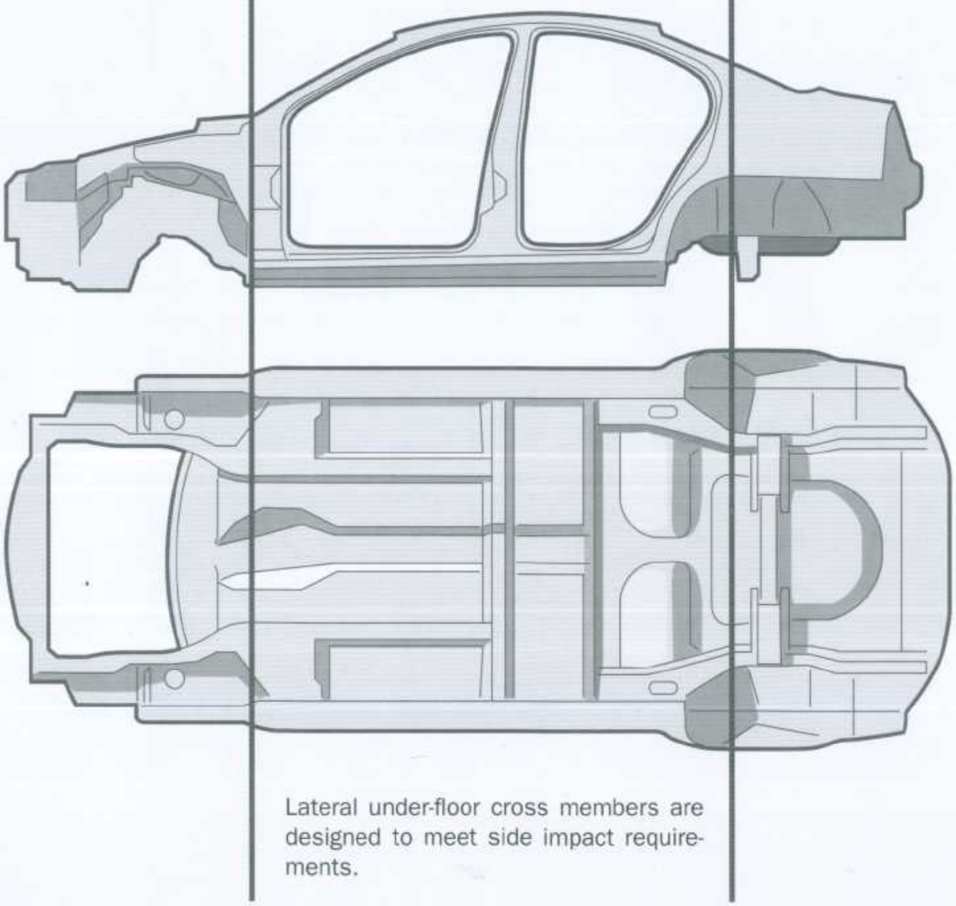


EFFICIENT DESIGN FOR HIGH-SPEED IMPACT

The front-end structure is designed to crush at a specific rate to absorb energy. Clear crush space around any solid components such as the engine, transmission and steering is required to pass a 40mph impact test.

The passenger compartment is very rigid to protect the occupants from being crushed during a high-speed impact or rollover. After the impact, the doors should still open.

The rear-end structure is designed to crush in a similar way to the front.



Lateral under-floor cross members are designed to meet side impact requirements.

Protecting the occupants from injury is the highest priority when designing a vehicle.

The most stressful event that a human body will endure is a high-speed crash. Meeting various government impact testing requirements and consumer-group standards provides a set of clear objectives for the structure. These tests involve the vehicle being driven into barriers at specific speeds or being hit with test devices in various zones with specific forces being applied. After each test, measurements are taken on the body structure and crash dummies to confirm the integrity of the design. Visit www.euroncap.com for more information on this.

The main passenger compartment is very rigid and is configured to remain intact after a serious accident with little or no deformation. The front and rear structures are designed to crumple at a controlled rate to absorb energy, thereby reducing trauma to the occupants.

Many of the key elements of the crash structure feature frequently in the typical sections that run through the package.

Note that many of the main structural elements such as the sills, rails and cross members are designed to be as straight as possible. By being straight, they can manage very high (compression) loads efficiently along their axes.

SAFETY REGULATIONS

Many elements in the package are controlled by legislation, none more so than the body structure and exterior features such as lighting, bumpers and license plates. Each market (country/region) has a slightly different set of rules and guidelines, which for the most part serve to make vehicles safer. Because cars generally serve the same purpose all over the world, similar safety regulations apply everywhere.

Additionally, consumer groups keep customers very well informed about safety issues, so most manufacturers will look to exceed the local safety regulations to gain an advantage in the market. To sell vehicles in global markets, each product will have to meet the strictest regulations in all countries.

The governing bodies of the three major car-manufacturing countries/continents—USA, Europe and Japan—set most of the significant standards that automotive manufacturers strive to meet.

North America
The Department of Transportation has an organization called the National Highway Transportation Safety Association (NHTSA). They establish the Federal Motor Vehicle Safety Standards (FMVSS). These govern the design of cars in the USA. Canada has a similar set of standards, the Canadian Motor Vehicle Safety Standards (CMVSS). These vary from the US regulations, so most American cars are designed to meet both sets of requirements. The Environmental Protection Agency (EPA) also sets standards to help maintain and improve the environment. One significant area controlled by the EPA is the fuel consumption of various types of vehicles.

European Union (EU)
Regulations are set by the European Commission (EC). These vary from the North American regulations, mainly due to geographic and economic concerns, which lead to greater traffic density. Various European national governments have also set rules to suit the requirements of their own country. Many of these rules were carried over from an earlier era. In addition to governmental legislation, organizations like the New Car Assessment Program (NCAP) serve to provide impartial crashworthiness information to customers. They conduct comprehensive crash tests and report to the consumer exactly how each vehicle performed. They issue a star rating to each model and most manufacturers strive to achieve the highest "5-star rating." Visit www.euroncap.com for more information.

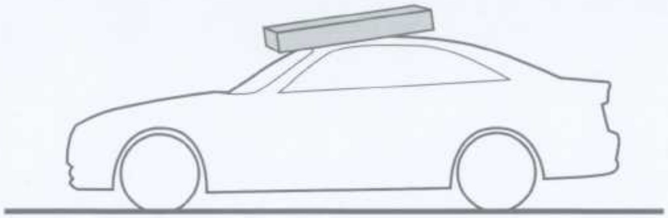
Japan
Legislation is similar to Europe due to similar traffic-density issues. However, controlling the size of vehicles to help improve parking is more important in this market than in the other two.

Worldwide
Most other countries in the world will look to these governments to establish their own standards. They may also use International Standard Organization (ISO) standards to help regulate products on their roads.

So the overall vehicle size, powertrain layout, occupant package, body architecture, exterior lighting and interior design are heavily influenced by government legislation and customer advocate groups. Although this subject is very complex, it is worth understanding the basic requirements before developing a package.

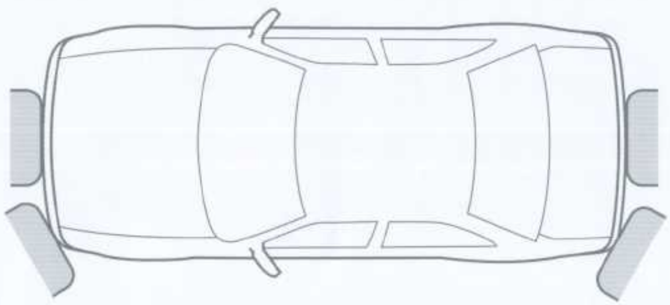
Looking around at vehicles that are on the road today, you can see there is a lot of uniformity, which is due mainly to legislation. As you work through this book, you will notice that various regulations are mentioned when they are significant to the design. Features like bumpers, lights, and pillars are strictly controlled, so if you are designing a concept that looks dramatically different in these areas, check the appropriate chapter for legislation.

On the opposite page is a list of some major impact tests that will shape cars and trucks in the near future. These change with time, usually getting more demanding.



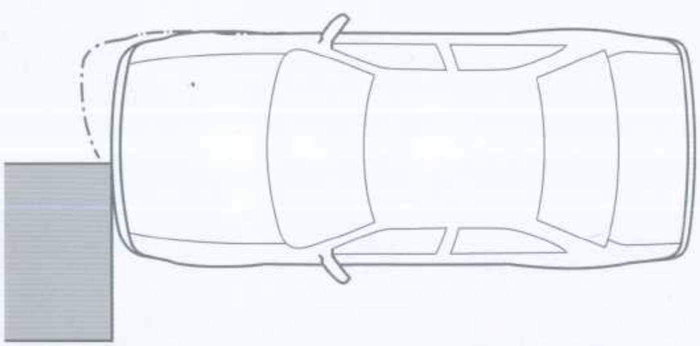
ROOF CRUSH TEST (1.5 Times the Vehicle Weight)

This test ensures that the structure will protect the occupants in the event of a rollover. This test influences the design of the A pillar and windshield header.



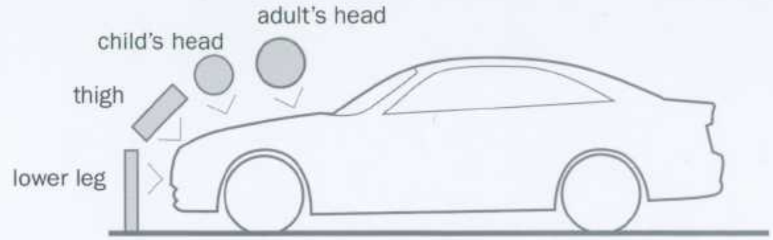
LOW SPEED (2.5–5mph) IMPACT TEST

These tests help to create bumper systems that resist damage during low-speed impacts (under 5mph) and protect adjacent components such as lights, grilles and the hood panel. The bumper heights are determined by these tests.



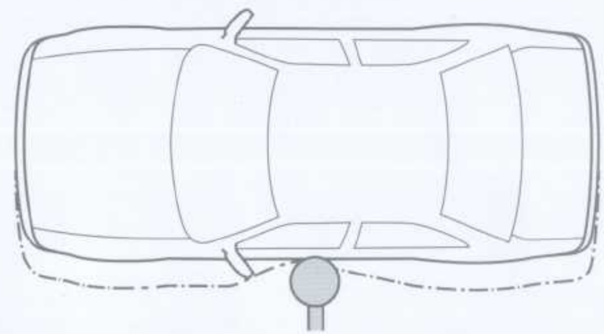
HIGH SPEED (40mph) OFFSET IMPACT TEST

The most demanding test, affecting the front end and interior design. It ensures the driver and passengers can walk away from a high-speed impact. This test most resembles a typical head-on collision which typically is slightly offset.



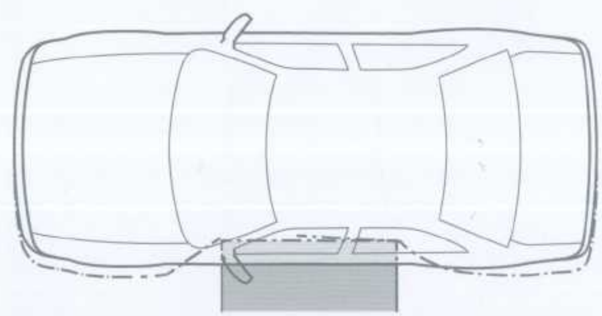
PEDESTRIAN (PROTECTION) IMPACT TEST

These tests help to create a more pedestrian-friendly front end. A rounded profile and adequate clearance between the outer skin and hard components underneath are required to pass the tests.



SIDE IMPACT (18mph) POLE TEST

This test affects the door packaging and sill design. It ensures the driver is protected if the vehicle slides into a pole.



SIDE (30mph) IMPACT TEST

This test simulates one vehicle driving into the side of another. It affects the design of the doors, their apertures and the underbody structure.

MATERIALS

Material choice may have a major affect on the package, so the basic properties of each material and manufacturing limitations should be understood.

As with every aspect of advanced concept design, traditional practices and applications should be considered before applying new technology. If the new material does not play a part in changing the exterior and interior design or create opportunities for a more efficient package, the designer may decide not to focus on the materials during the early phase of the project.

The type of construction methods, however, will usually influence the package, so it is always important to note how material choice may affect construction or vice-versa. Below is a brief overview of some of the common materials used in body construction today. Most car bodies will be a mixture of these, to meet all of the requirements placed on them by the customers, manufacturers and legislation.

Steel

Steel is an amazing and versatile material, which is why it is used so extensively in body construction. It has many properties which give it an advantage over other materials.

First, it is one of the cheapest materials, and although commodity prices do fluctuate, it will probably remain much cheaper than the alternatives. It is also ideal for inexpensive (piece cost), high-volume manufacturing processes.

It is very strong and when used in an efficient unibody type of construction it can provide a surprisingly light solution. High-strength steel alloys can also be utilized if weight takes a higher priority than cost in the product.

It is also very ductile (formable) allowing it to be drawn into very complex and deep panels. Most body side apertures are now stamped in one piece from the "A" pillar to the rear of the vehicle, reducing complexity and tolerance issues.

Steel is very easy to spot weld, having a much higher resistance to electric current than aluminum, its main competitor. Steel structures are also more durable than aluminum, which can be an advantage in truck frames where their flexibility requires resistance to cracking.

In the past, a major drawback of using steel was corrosion, but with new coatings and construction methods, this is no longer an issue. Recycling is now an important part of automotive design, and steel's propensity to revert to its original state, (i.e., rust or ferrous oxide), makes it even more attractive. It can, of course, also be melted down and reused.

Aluminum

Aluminum alloy's strength-to-weight ratio is better than steel but often ends up requiring larger "box sections" or thicker panels. They are also more expensive, so usually only applied when light weight is a high priority for the product. An aluminum hood assembly, for example, may be about half the weight of a steel equivalent, but will be twice the cost.

Although aluminum is seen as a softer material than steel, it "work hardens" much quicker due to its grain structure, so it is not as formable in a cold state as steel. There are, however, low-production-volume manufacturing processes that require heating the material to create the desired forms.

Aluminum sections can be extruded with very low investment and are often applied to lightweight, low-production-volume body structures, mainly for sports cars where light, stiff structures are desirable. Due to its resistance to electric current it is also more difficult to spot weld, so adhesive and riveted joints are common in aluminum structures. New welding processes and adhesives are facilitating a greater mix of aluminum and steel panels in car bodies.

Like steel, it will corrode if not coated but is more resistant to oxidation.

Plastics

Plastics come in many types with various properties. Some lend themselves to high production volume manufacturing while others are only suitable for smaller production runs.

Thermoplastics such as polypropylene are often used when low-speed impact dent resistance is required. This is a popular choice for bumper fascias and door exterior panels. These are also very formable so very complex and deep sections can be easily manufactured from these materials. Several components can be manufactured in one plastic piece, like the bumper and grill, which reduces assembly complexity and can improve design flexibility.

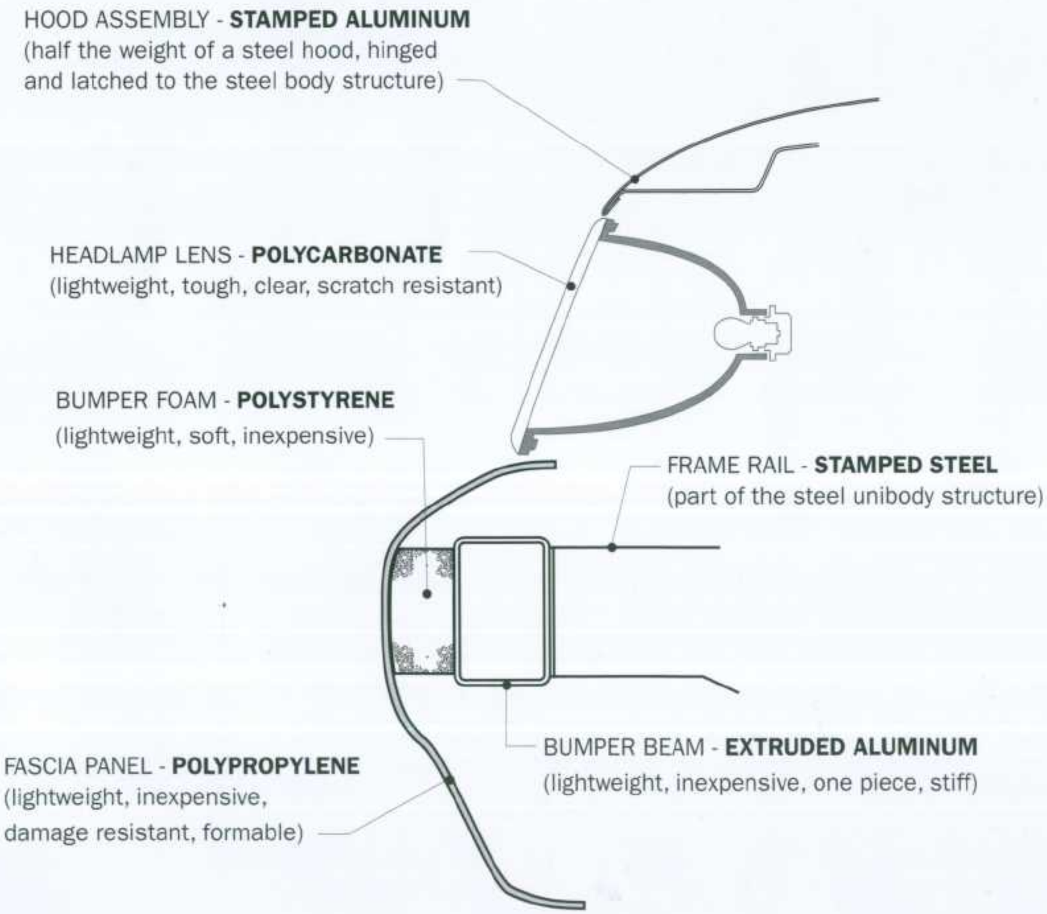
Plastics such as SMC (sheet-moulded compounds) or RIM (reaction-injection mouldings) are also often used in the manufacture of exterior panels that are fastened to space-frame structures.

Carbon fiber is only used on specialist applications such as exotic, lightweight sports cars, due to the cost and labor-intensive production processes. These materials are very light, strong and stiff, resulting in the size reduction or elimination of box sections. They are often used in conjunction with other materials to make up a stiff, lightweight body.

MATERIAL APPLICATION EXAMPLES

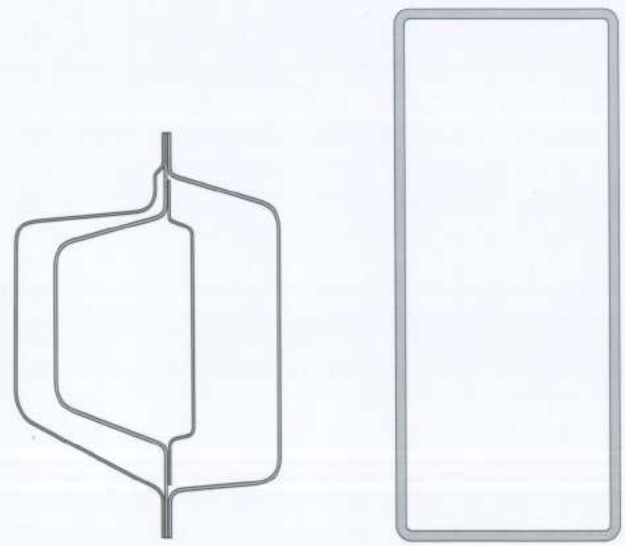
SECTION THROUGH THE FRONT BUMPER & HOOD

Illustrating some of the various materials used in body and exterior components.



TYPICAL CAR SILL SECTIONS

These two sill sections below show how various materials and manufacturing processes can be applied to the same area of the vehicle, affecting a key area of the package.

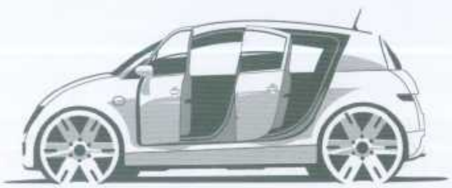


Stamped steel & spot welded, part of a unibody structure.

Extruded aluminum sill, part of a space-frame structure.

BODY CLOSURES

The closures and their apertures are designed to provide access to the passenger compartment, engine bay and cargo area. The various solutions are illustrated below. Their outlines are a design element, so breaking up the exterior panels and closures should be considered early in the process.

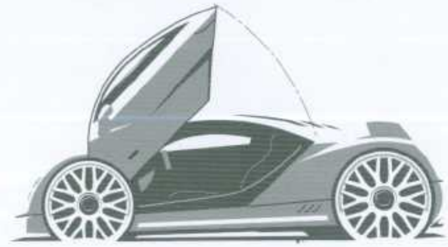


FRONT HINGED

This conventional layout is applied to most cars. It provides independent closures for front and rear passengers that are inexpensive and simple to operate. It also requires a B pillar which is essential for an efficient structure, side impact and seat belt mounting. Longer doors may have four bar-link hinges to help push the front of the door outboard in tight parking situations.

FRONT & REAR HINGED

Occasionally applied to vehicles with a short cab or wheelbase, which reduces the rear-door length. This system is an improvement over a two-door solution. Removing the B pillar improves rear foot swing and creates a large aperture which may be desirable for lifestyle vehicles.

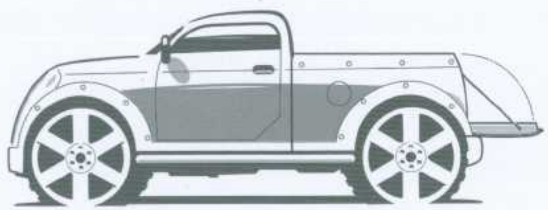


SCISSOR

This type of door system adds drama to the design of exotic cars but also has some practical advantages. For wide sports cars with deep sill sections, it eliminates the problems caused by out-swinging doors in tight parking situations, improving ingress and egress.

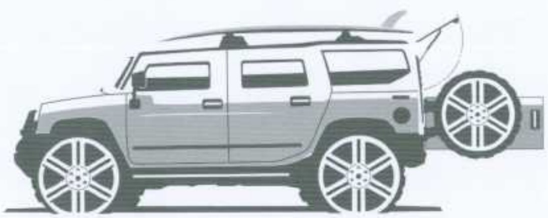
LIFTGATE (HATCH)

The most common rear aperture closure for minivans, hatchbacks and SUVs. Providing good access from all angles and cover from rain. Also eliminates doors from opening into parking lot traffic. The backlight glass can also lift independently. Electric operation can help shorter people close the gate on vehicles with a tall roof.



TAILGATE

Used extensively on pickup trucks, tailgates are designed to remain dropped while the vehicle is in use to extend the bed floor. These are usually removable to aid loading of large heavy objects.

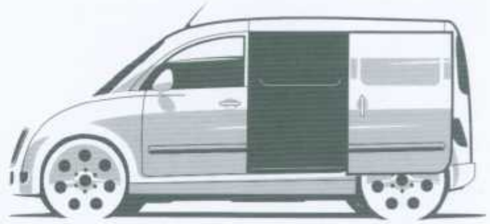


LIFT & SWING

Often applied to vehicles that carry their spare wheel on the rear gate, making a lift gate impractical. Sealing the two-piece closure is more complex than a single gate.

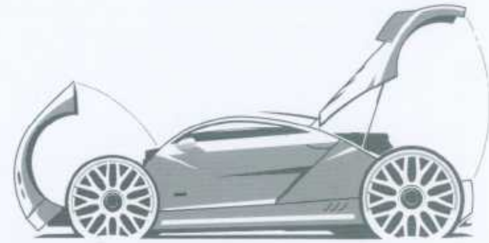
GULL WING

Similar application and advantages as the scissor door. This system can only be applied to low vehicles because it increases the overall height with the doors open, making garage parking a problem. The inherent design geometry cuts into the roof, improving ingress and egress into an inboard seat location, over a tall sill section.



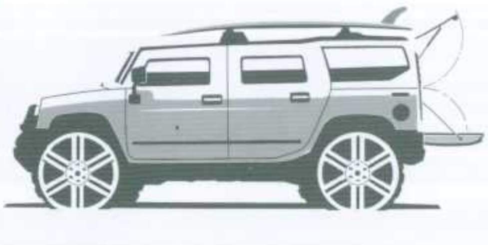
SLIDING

Often applied to minivans and commercial vans. Ideal for situations where an out swinging door is dangerous or impractical. Sliding door systems require enough room behind the door to build in a straight, horizontal track which will carry the door to the fully opened position. These systems can be electrically operated.



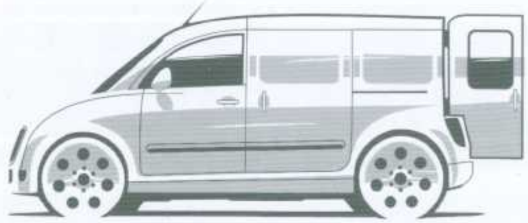
ACCESS COVERS

For performance or race cars, good access to all of the powertrain and suspension components is important to allow quick adjustment to these systems. Hinged or removable covers with side cut lines provide large open apertures.



LIFT & TAILGATE

This split closure system provides a flexible loading solution allowing the lift glass to be opened without the cargo spilling out. It also provides an opening to improve passenger compartment airflow. The tailgate provides an exterior seating area and extends the load floor.



REAR SWING DOORS

Used mostly on commercial applications. The double doors are designed to be used individually or together. They are often designed to open to 180 or 270 degrees to provide easy access from the side.

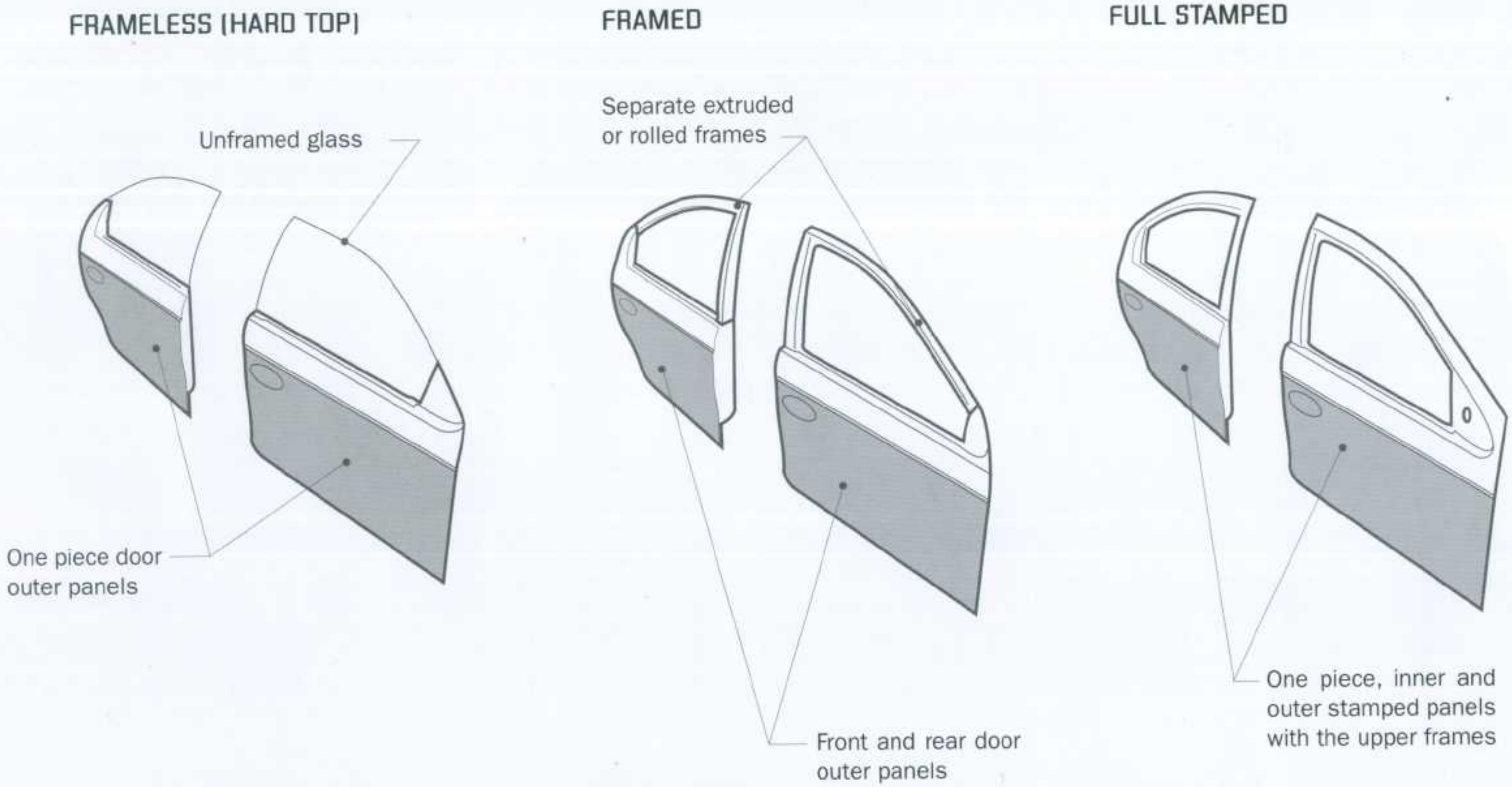
HOOD & TRUNK LID

For most cars, a simple hood and trunk lid provide access to the engine bay and rear cargo area. Cut lines should be designed as far outboard as possible to create wide apertures. "Clamshell" hoods have cut lines on the side and are more pedestrian impact friendly.

SIDE DOORS

The doors set up the body side design. They are attached to the body structure by hinges or rollers and latched into position. This separation allows them to be made of different materials from the structure, such as aluminum and plastics, creating the opportunity to make them lighter or dent resistant.

The three types of door construction shown below are typical to most production cars and trucks. Choosing a type of door system will depend on the various derivatives that are being considered for the vehicle range—i.e., sedan, coupe, convertible, wagon, etc. Keeping the same door system for every vehicle will reduce investment. Cost, appearance and head clearance may also affect the choice.



BODY SIDE APERTURE DESIGN CRITERIA

The door apertures will have a major influence on the exterior design. Some basic parameters need to be addressed before the design concept moves forward too far. Definitely, door feasibility should be very advanced before the full-size clay model is started. The size and shape of the door apertures will be affected by the following considerations:

1) A rigid overall passenger cell structure
2) Easy ingress/egress for the passengers
3) Good visibility around the pillars (greenhouse structure)

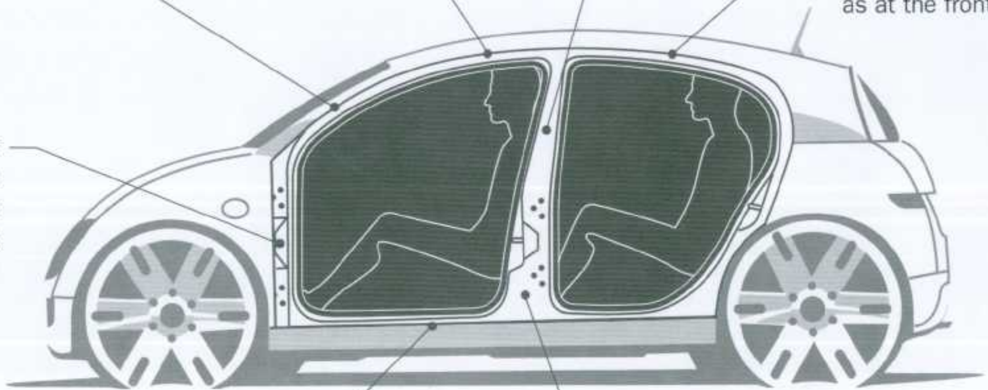
ROOF RAIL
Helps to add torsional rigidity to the body. The seals should be at least 760mm above the H-point to provide adequate head-swing clearance.

B PILLAR UPPER
Helps to support the roof during rollover. It is located behind the driver's eye point. The front seat belts are attached to this structure.

A PILLAR UPPER
Designed to resist roof crush during rollover. Its section has to meet visibility requirements.

REAR ROOF RAIL
Similar design constraints as at the front door.

A PILLAR LOWER
A major component in the front-end structure. It forms part of the front wheel aperture and is also used to mount the front door hinges. The driver's foot should be set up to allow for easy foot swing past the door seals.



SILL
Designed to resist compression during high-speed frontal impact, helping to maintain the passenger-compartment shape. The top of the section is kept as low as possible to improve the step over.

B PILLAR LOWER
Pushed forward to improve rear foot swing, it is an integral part of the structure for side impact. Door hinges and latching require room for mounting and additional reinforcement.

CLOSURE PERIMETER "CUT LINES"

Closure cut lines refer to the external panel gaps around the hinged or articulating panels, like doors, hoods or trunk lids. They can be an important design element and if they are not considered at an early stage of design, they may end up looking untidy or awkward. Their location and shape are driven by several factors:

INGRESS, EGRESS & ACCESS

The main function for the closure is to allow people or objects to pass through an aperture, so this will be a primary driver for the cut line location. See side door aperture design on p. 179 for reference.

HINGING, SWING AND ARTICULATION

The hinge axis location and orientation or path of the closure assembly (sliding doors) will have a great influence on the shape of the cut lines. For doors that swing, the surface profile swung into the open position is often used to help determine the cut-line shape adjacent to the hinges. Sliding doors travel in the direction of the tracks and need to have openings that are sympathetic to the door travel path at the start of their motion.

STRUCTURE

The body structure will also influence the design of the cut lines. Often the door boundaries will fall inside the aperture structure as it tracks around the wheel openings, sills and roof rails. In some cases the door's outer surface may overlap the structure to clean up the exterior design or simplify tolerancing between the doors and body panels.

EXTERIOR DESIGN

The relative location of the upper-body structure (pillars) and the wheel-house openings will have a dramatic effect on the cut-line shape. The examples on the opposite page show how these elements, in conjunction with the occupant location, will affect the door perimeter design.

Additionally, the hood, trunk lid and tailgate boundaries may coincide with other elements on the exterior such as glass panels, lamps, and grills. Pay particular attention to the corners of the windshield and backlight glass. Their design will affect the adjacent panel shapes, often influencing the closure boundaries. It is easier to keep the cut lines tidy if the corners of the glass panels are sharp and do not have large radii.

Example 1

The examples above illustrate how different the side door cut lines can be on a similar vehicle. Example 1 shows the door perimeters within the structure. This allows the structural box sections to be fully optimized, which is always helpful in small vehicles. The smaller upper door frame is especially helpful to improve head clearance to the roof-rail structure.

Example 2

Example 2 shows the doors overlaping the sills, roof rails and rear wheel house ("dog leg") structure. This solution cleans up the design and reduces the number of visible elements in side view. It also simplifies the door gap tolerancing and helps to keep the door apertures clean, which is important in luxury cars and off-road vehicles.

SIDE DOOR, CUT LINE EXAMPLES

CONVENTIONAL HINGING

Setting up the cut lines adjacent to the hinge axis line is more of a geometry exercise than a design study. Note how the cut line in side view sympathizes with the end-view, body-side surface contour. The front edge of the door will swing in toward the structure unless the hinges are mounted on the exterior surface.

UNCONVENTIONALHINGING

In this example the horizontal hinge axis in the roof allows design freedom for the side cut lines, notably at the front.

FRAMELESS TWO DOORS

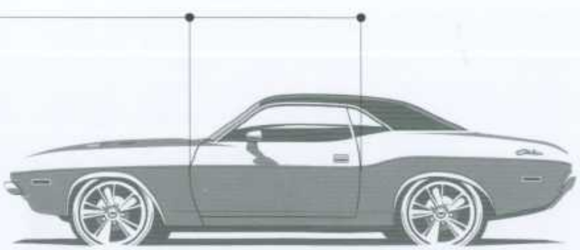
One small detail to note with this type of door is that the rear cut line will usually curve rearward just below the belt to provide room for latch and drop glass packaging.

EXPOSED STRUCTURES

Sometimes the door cut lines will follow the body structure to optimize the box sections and communicate strehgth in the exterior design.

LARGE TWO DOORS

Large two-door cars need long doors to help break up their proportions. The approximate length of the door should be less than 1400mm to reduce stress on the hinges and minimize the outward swing of the door.

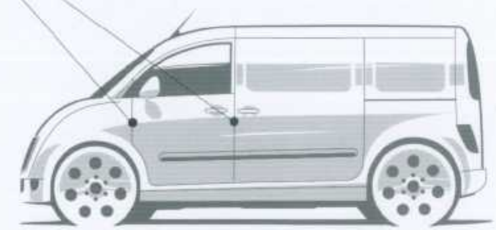


REARWARD A PILLARS

In this example, the A pillar is pulled rearward in relation to the driver to improve cornering visibility. The front cut lines step forward to improve foot swing.

COMMERCIAL VEHICLES

To optimize the vehicle length, the driver is often pushed forward in the package. To improve foot swing, the forward cut line will track around the wheel house. This is only possible with a high floor structure. Note the straight, vertical cut line at the front of the sliding cargo door. This is not possible with a conventional swinging door.



CAB FORWARD

Here the A pillar is pulled forward so the door cut has to depart from the pillar and cut through it to fall behind the front wheel-house structure.

FORWARD CONTROL

Forward control vehicles are becoming rare in most markets because of frontal impact issues. One thing to consider on the front door cut is allowing space for the driver's feet to pass between the A pillar and front wheelhouse structure.

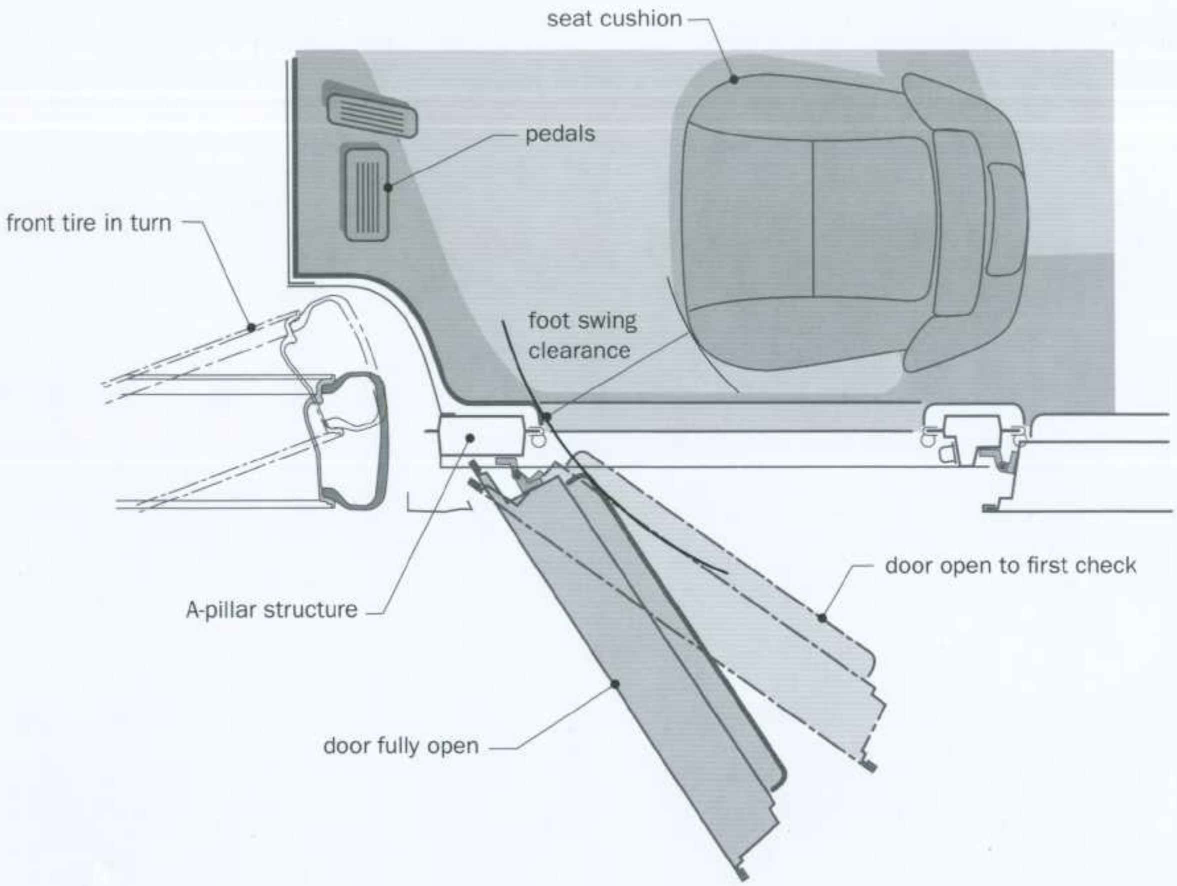
FOOT SWING

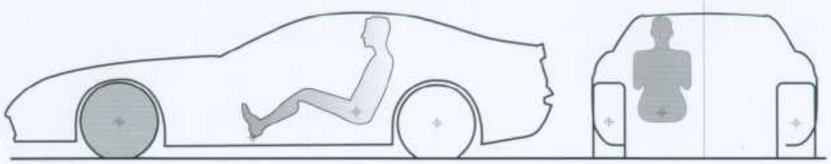
The relationship of the driver's foot and the front tire can be very influential to the package and exterior design. For some vehicles this relationship is critical; for others, the two elements are independent of each other.

The six examples at right show various vehicles with significantly different architectures. Note that in each package the relationship between the foot and the tire O.D. (outside diameter) is different, and this is also reflected in the location of the windshield to the front spindle and the overall front-end silhouette.

From a designer's perspective, it is very difficult and time-consuming to get this relationship fully optimized on your own. If your concept calls for a close relationship of the foot and tire in side view, find an existing vehicle with an efficient package and a similar lateral relationship of the driver and front track, and benchmark it. Tire turn (turn circle) may need to be considered here, as well as the size of the pillar structure. The A-pillar lower section is the cornerstone of the body structure, and along with the driver foot swing, simply cannot be compromised.

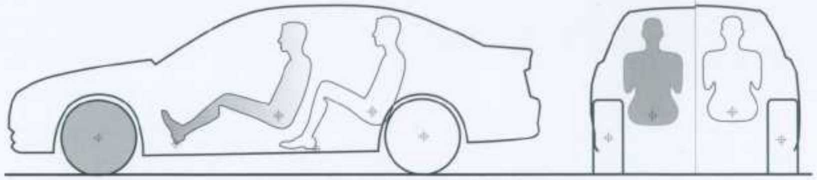
The illustration below shows how the seat, the door trim and the A-pillar trim need adequate clearance, allowing the drivers to swing their feet through the opening.





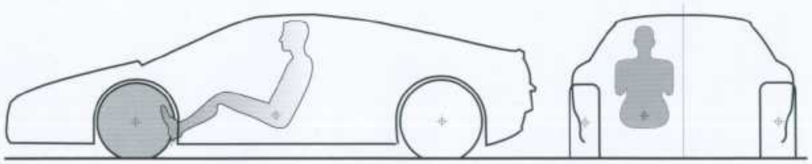
1. EXOTIC SPORTS CAR - FRONT LONGITUDINAL ENGINE RWD

In this example there is no relationship between the foot and the tire. This high-performance, two-passenger-car front spindle is set up for optimum weight distribution, resulting in a long "dash-to-axle" which is common for most rear-wheel drive cars with a longitudinal engine. Here foot swing is seldom an issue.



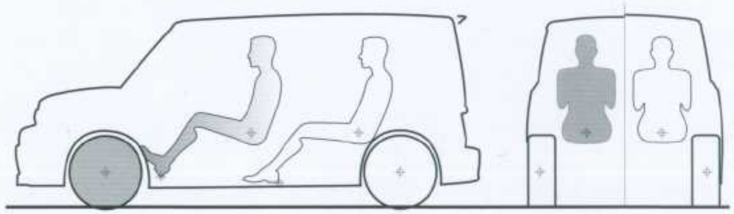
2. LUXURY SEDAN - FRONT-LONGITUDINAL ENGINE RWD

This rear-wheel-drive car also has a longitudinal engine but is much shorter and has a much more space efficient package than example 1. Weight distribution is still a priority but the front wheel is pulled further rearward.



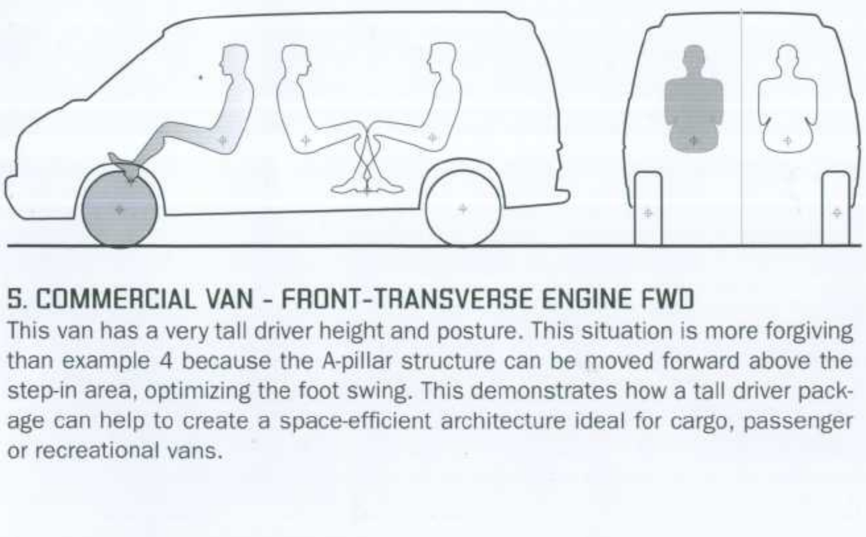
3. EXOTIC SPORTS CAR - MID-LONGITUDINAL ENGINE RWD

This exotic mid-engine sports car packages the foot forward of the tire O.D. There are several elements in this architecture that make it possible. The first is a wide track which pushes the tire outboard for greater stability and handling. Next, the driver may be located inboard to reduce the width of the greenhouse, which reduces drag and the polar moment. This is the opposite of example 4 where the vehicle is narrow and the driver pushed outboard for interior space efficiency. Lastly, the exotic sports-car owner will be more forgiving of poor ingress and egress if the package improves performance. An unorthodox door opening may also improve the situation.



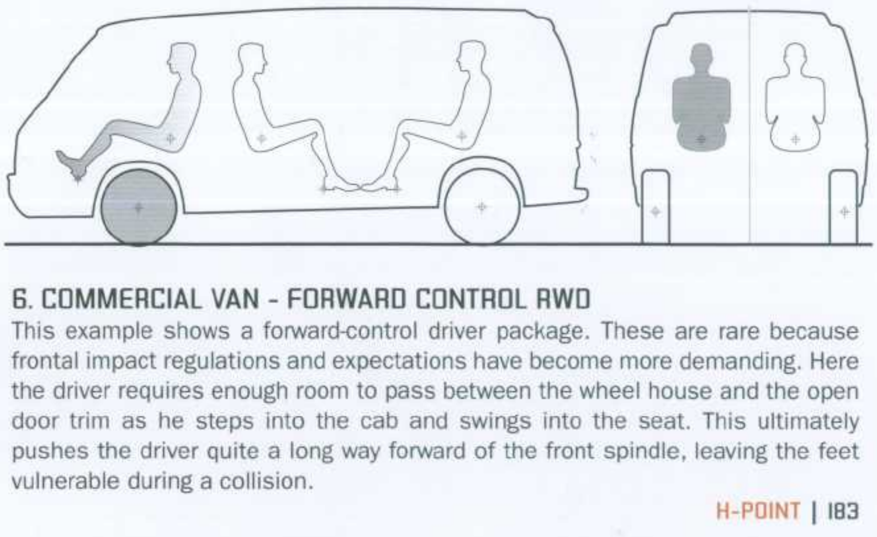
4. ECONOMY CAR - FRONT TRANSVERSE ENGINE FWD

A typical front-wheel drive vehicle with a transverse engine places a high priority on package efficiency. The driver is pushed as far forward as possible in the wheelbase to create a spacious interior in a very short overall length. In this type of architecture, it is very important not to push the driver too close to the tire or it will create an ingress/egress issue. Although the main issue here appears to be a potential clash between the driver or foot pedals and front wheel house, the actual problem is the foot swing past the A-pillar structure, which is rearward of the wheel opening.



5. COMMERCIAL VAN - FRONT-TRANSVERSE ENGINE FWD

This van has a very tall driver height and posture. This situation is more forgiving than example 4 because the A-pillar structure can be moved forward above the step-in area, optimizing the foot swing. This demonstrates how a tall driver package can help to create a space-efficient architecture ideal for cargo, passenger or recreational vans.



6. COMMERCIAL VAN - FORWARD CONTROL RWD

This example shows a forward-control driver package. These are rare because frontal impact regulations and expectations have become more demanding. Here the driver requires enough room to pass between the wheel house and the open door trim as he steps into the cab and swings into the seat. This ultimately pushes the driver quite a long way forward of the front spindle, leaving the feet vulnerable during a collision.

DOOR AND APERTURE DESIGN

The door apertures are developed through about nine typical body sections. These are cut through the pillars, roof rails and sill at critical areas such as the hinge and latch locations.

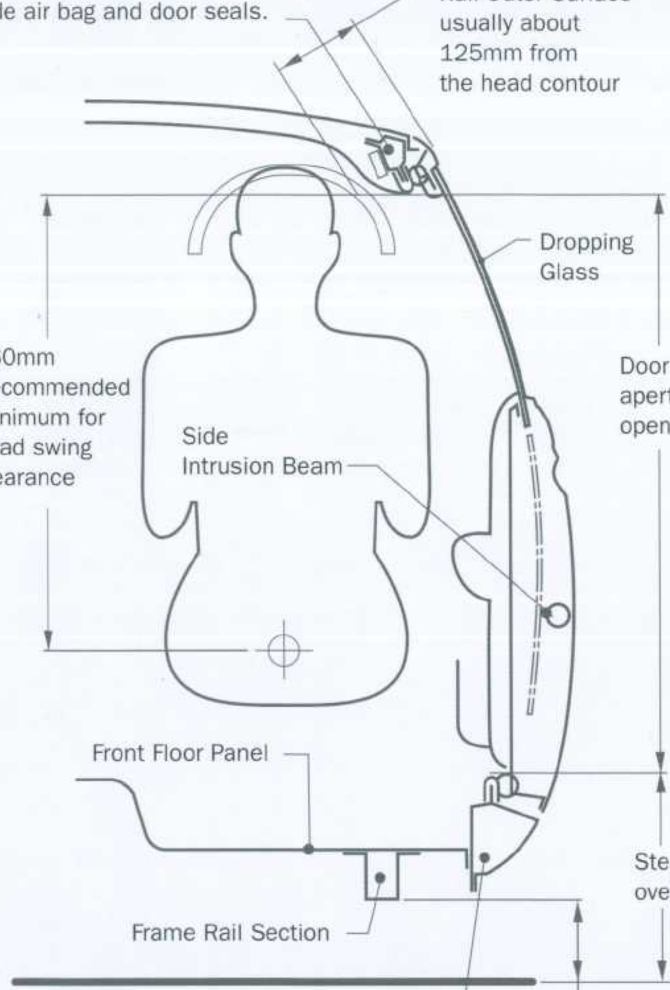
An "X" section through the H-point is used to set up the body-side profile through the roof rails, drop glass, door inner/outer panels and the sill structure. This is a very important section in the early stages of the package development.

Particular attention is given to the drop glass. Working in conjunction with the side view DLOs (daylight openings), the end-view section is developed to set up the tumblehome (angle of the glass) along the upper-body side (greenhouse) and the profile of the door outer panels.

Door seals are usually mounted over the weld flanges on the box sections around the apertures, creating a clean, soft opening. The openings created by the weld flanges are often referred to as the P1 & P2 curves.

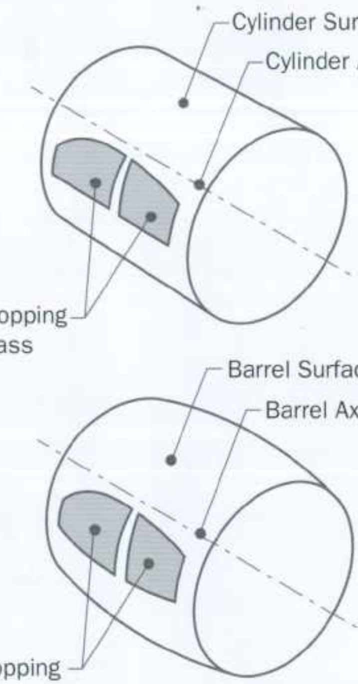
The illustrations on the opposite page show how the drop glass and glass perimeters (daylight openings/DLOs) are designed to clear the door hardware. This hardware includes hinges, latches, side intrusion beams and the door inner panels. Note how the mirror flag on the front door and the rear-door fixed glass help to reduce the size of the dropping glasses and allow them to track down at an advantageous angle.

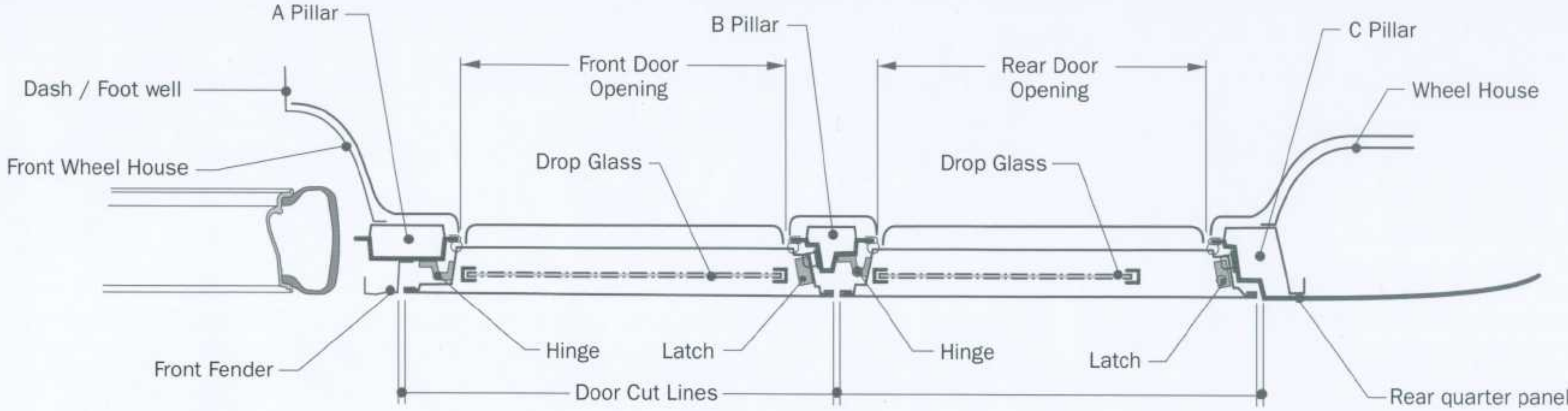
SECTIONAL VIEW THROUGH THE DRIVER H-POINT / HEAD CONTOUR



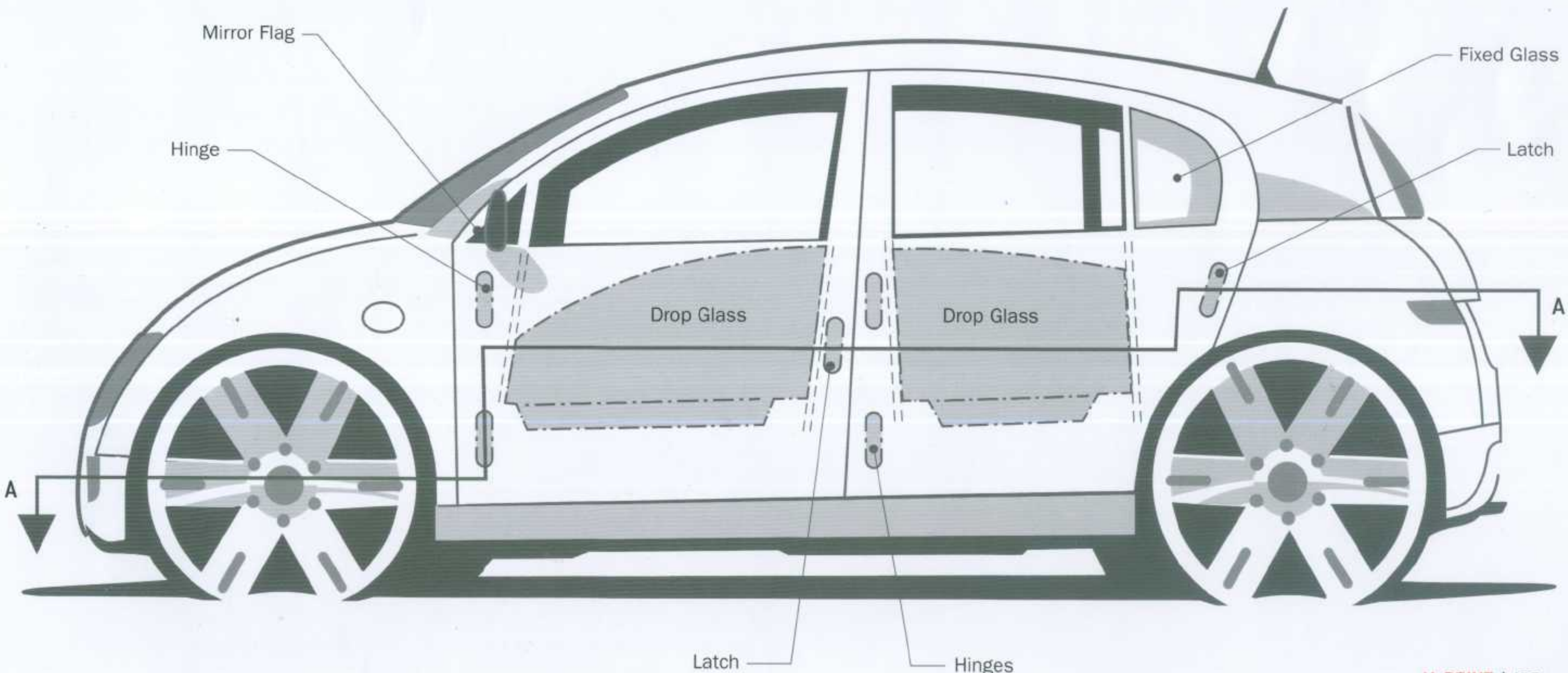
SIDE GLASS SURFACING

The glass surface must lie on a cylinder or a barrel surface. This allows the dropping panel to slide down the run channels and between the belt molding without binding. A twisting surface (in plan view) or an accelerating surface (in end view) will not drop. The side glass surface is usually the first surface to be set up on the full-size clay model.





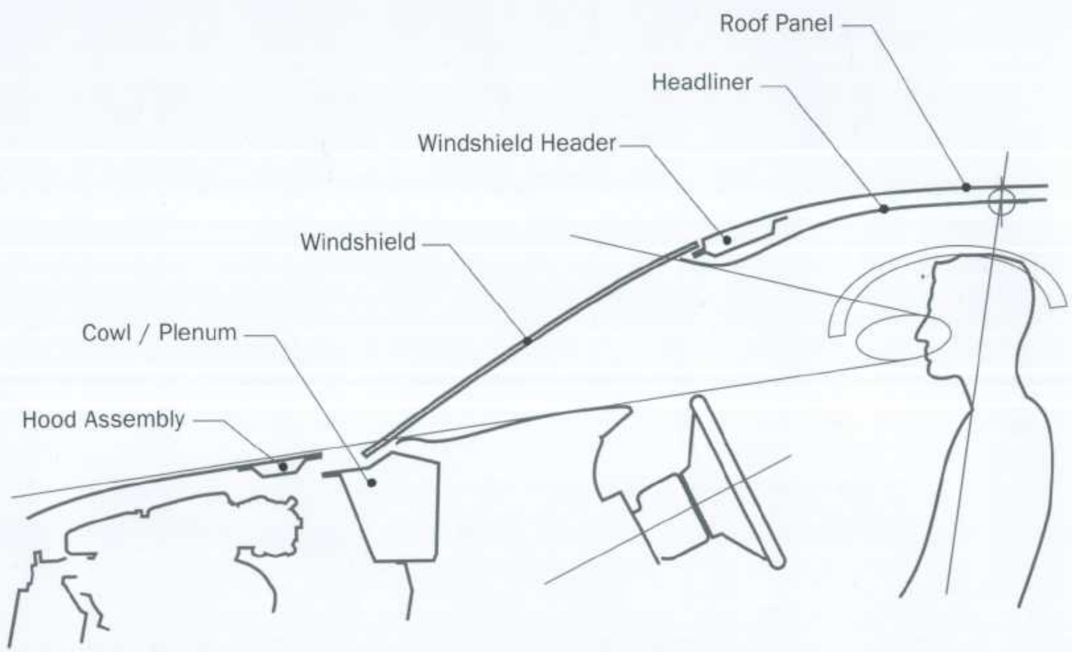
SECTIONAL VIEW A-A



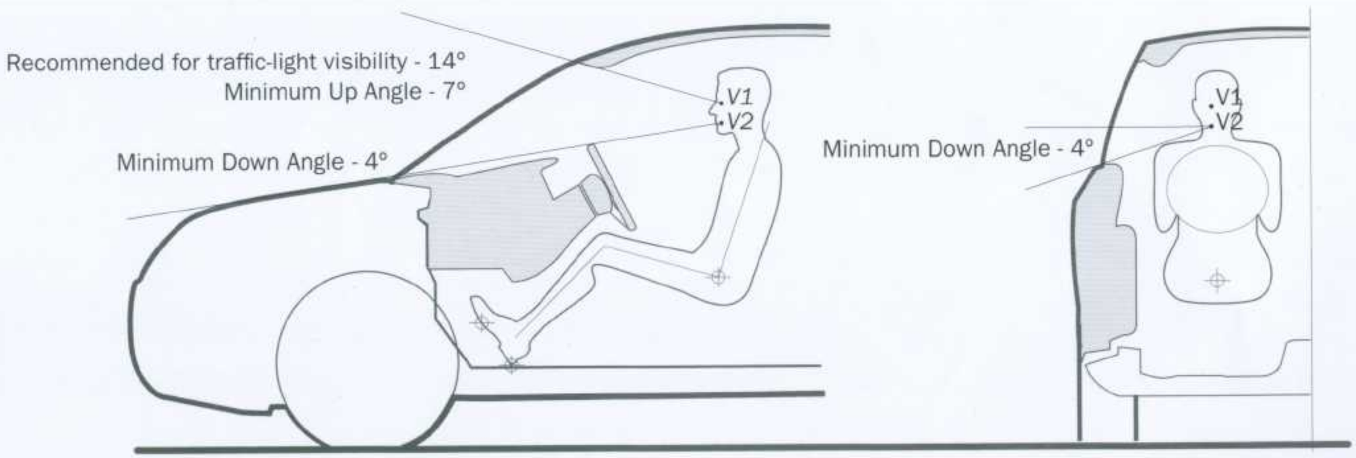
WINDSHIELD APERTURE DESIGN

This study shows how typical sections, cut through various elements around the package, are used to set up the windshield aperture. Notice that elements of the body structure—i.e., the header and cowl/plenum—are shown together with the interior trim and windshield. The engine and hood are also drawn and the section is completed with the inclusion of the driver manikin to check forward visibility. The exterior shape and location of the top of the windshield is a particularly sensitive design element to the exterior designer.

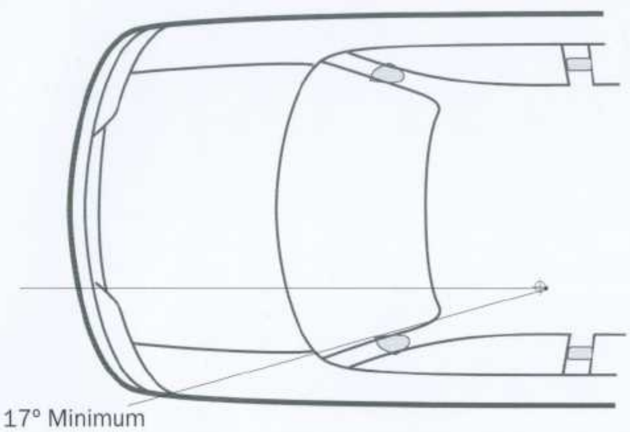
SECTION THROUGH THE WINDSHIELD APERTURES AT THE DRIVER'S CENTERLINE

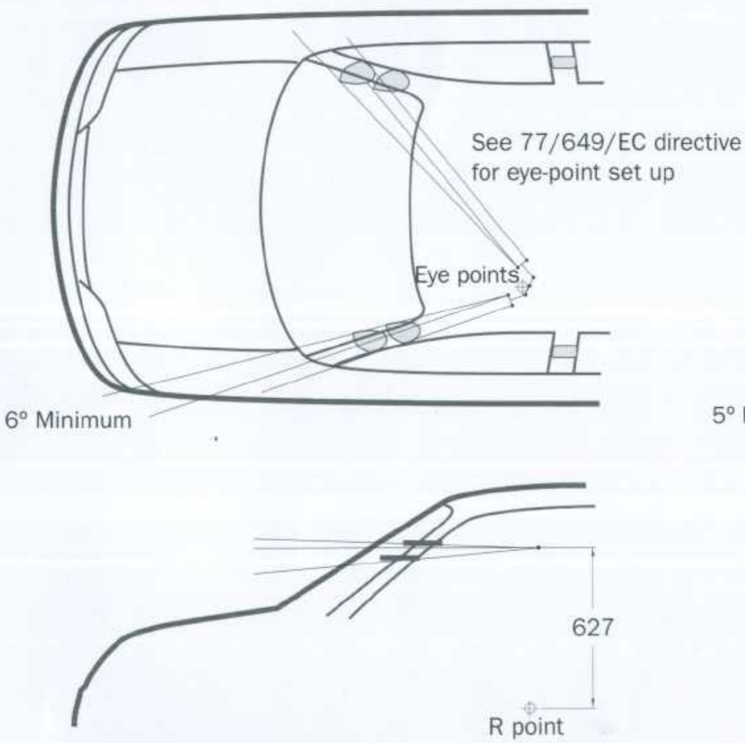


EC FORWARD & SIDE VISION REQUIREMENTS (UP & DOWN)

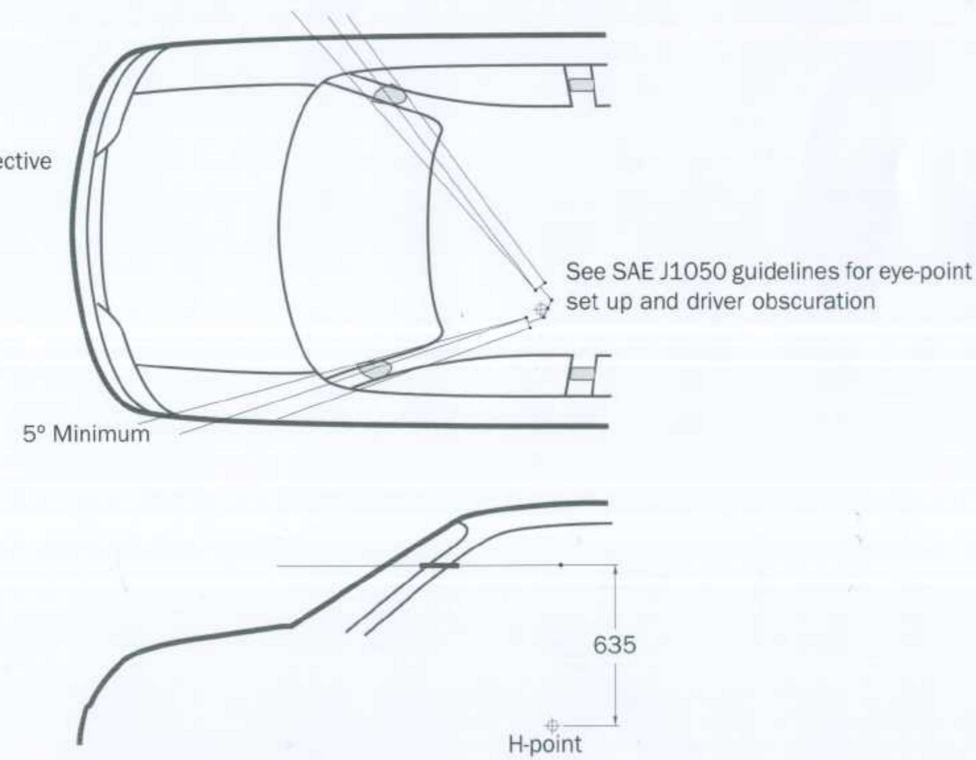


Below is a basic outline of the pillar obscuration geometry studies, illustrating how the pillar structure and trim are designed to meet specific obscuration parameters. These are usually set up in a computer system. Most designers will never have to execute these studies, but need to understand that there are limitations on the size and location of the A pillars. The main objective for the A-pillar design is to create a strong enough structure to meet roof crush targets but make it easy to see around it. A full description of the geometry and eye points (E1, E2, E3 & E4) set up can be found in the 77/649/EC directive and SAE J1050 recommendation.





EC A-PILLAR OBSCURATION



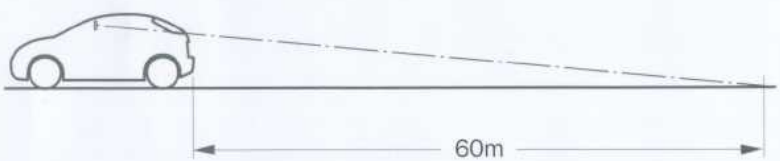
SAE A-PILLAR OBSCURATION

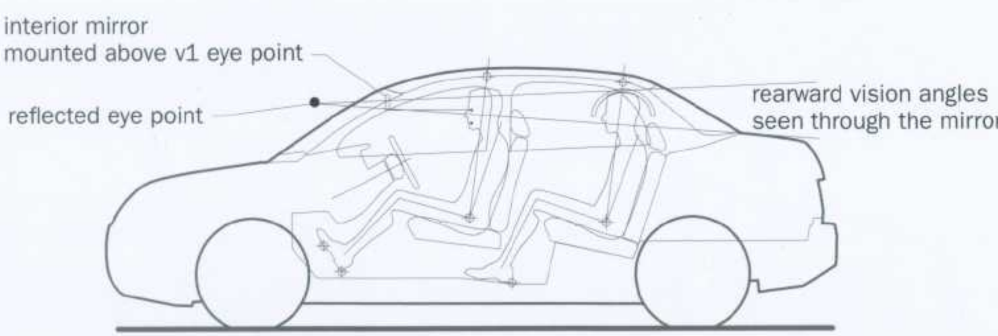
BACKLIGHT APERTURE DESIGN

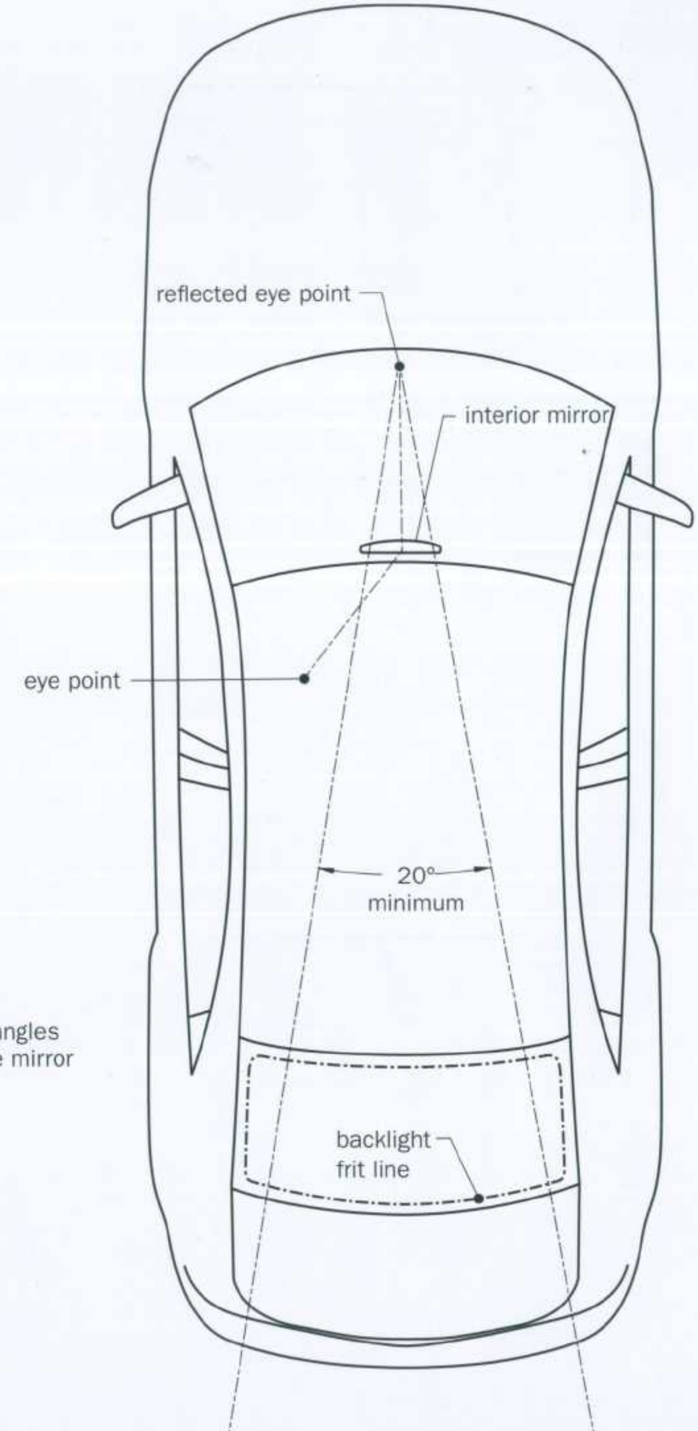
The regulations affecting rear visibility and the backlight aperture are not as strict as the windshield aperture. Mostly, they require an additional exterior mirror if visibility does not meet the regulations.

Ultimately, the design is usually guided by customer requirements and how comfortable they are driving with compromised rearward vision. Backup cameras and sensors are providing a greater sense of security for cars with challenging rear aperture designs.

Most of the requirements or recommendations concern the rearview mirror. The illustration below shows the requirement to be able to see the road within 60 meters of the rear of the vehicle. The sections at the right and bottom illustrate how up, down and side-to-side vision angles are generated from the reflected eye points forward of the interior mirror.



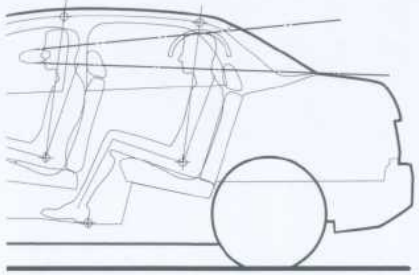




SECTIONS THROUGH BACKLIGHT APERTURES

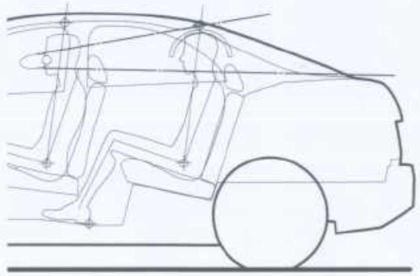
SEDAN

Typically the sedan backlight aperture does not present a problem at the header because it is lifted by the rear headroom requirements. The deck lid however can often be quite high, making rearward visibility while backing up a challenge. Benchmark other vehicles in this area to avoid an issue.



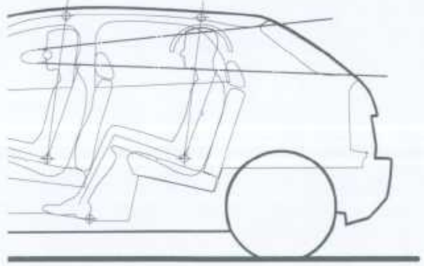
COUPE & FASTBACK

Coupes and fastbacks may have a problem with the rear header height due to the desire for a low roof, which often leads to compromised rear headroom. Notice in the section that the rear header is forward of the occupant's head. This is a common condition, putting the head under the glass, improving head clearance. Visibility over the deck lid may be worse than the sedan because the driver eye point is often lower to the ground.



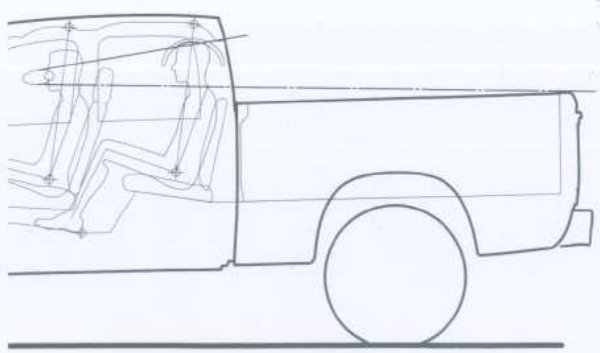
HATCHBACK & SUVS

Hatchbacks and utility vehicles do not usually have an issue with rear visibility because the roof height is often tall and there is no deck lid. The rear header structure is much larger than the other cars because of the lift gate frame and hinge packaging. Occasionally, on SUVs, the spare tire is mounted on the rear swing gate which may obscure the rear view.



PICKUP TRUCKS

Truck rearward visibility is rarely an issue. Most trucks are fitted with large exterior mirrors because the cargo in the bed often obscures the view through the backlight. Here the glass usually slides open for ventilation and bed access.

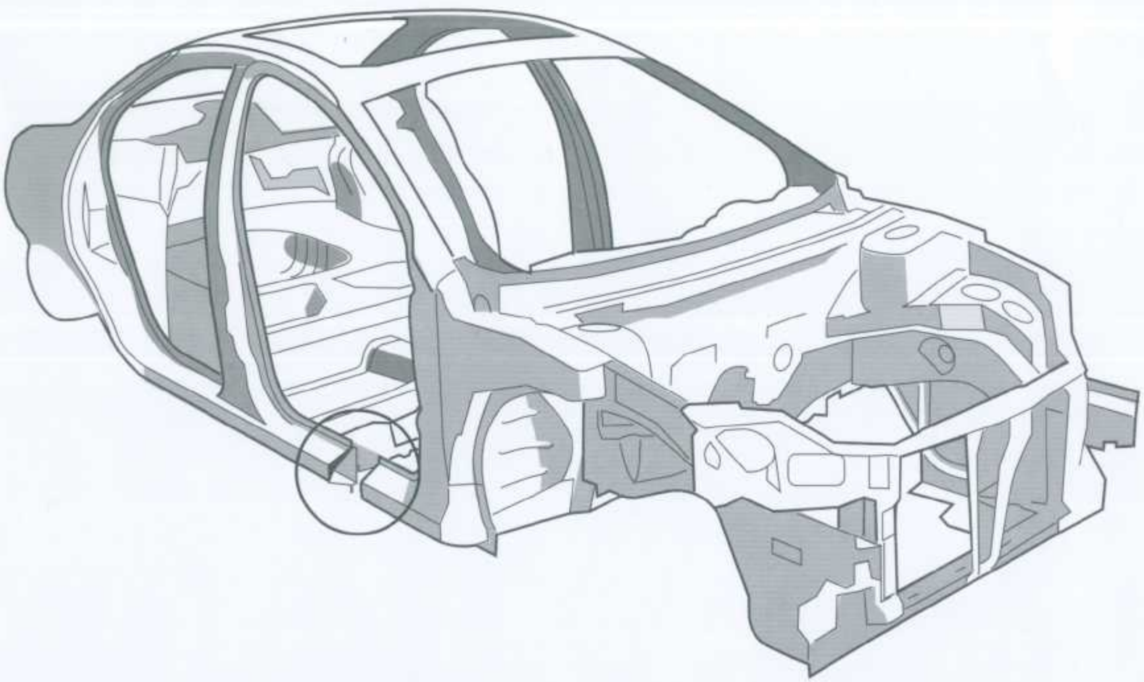


TYPICAL SECTION DETAIL

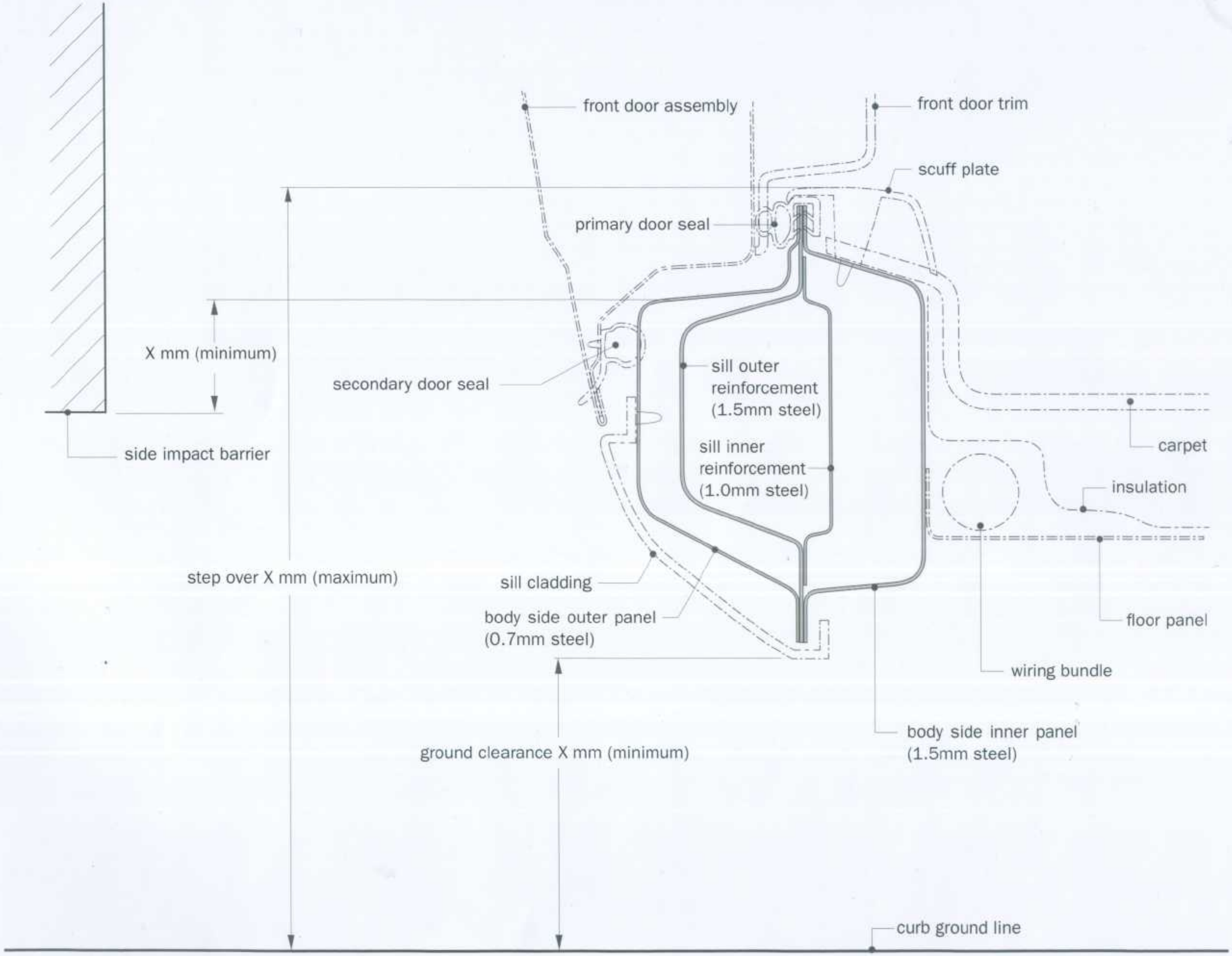
This Typical Section example illustrates how complex the final body assembly can be. Each section is developed by several specialists. In the case of this sill section, structural analysts will determine the cross-sectional areas of the box section, its material specifications, thickness and topology. The manufacturing group will determine the panels' assembly sequence, flange lengths (for spot welding) and the shape requirements for forming.

Other elements that may influence the section design are included in the detail drawings, such as the door, seals, trim components, floor panel, carpet, insulation and wiring. This ensures that consideration is always given to the adjacent components. Additional information may also be added to put the section in context with the package. In this case, ground clearance, step-over requirements and side-impact test-barrier heights are included. The studio engineering group will construct the section initially and work with the design team to create the exterior and interior profiles.

From the designer's perspective, the basic criteria for each section needs to be understood because this will influence the exterior form. In this case, the sill height may be governed by ground clearance, step-over or floor-height requirements. The exterior width may be controlled by overall vehicle dimension targets, and the shape of the sill section will vary greatly depending on the body type and construction method. The main thing to note here is that every vehicle will incorporate such box sections to manage the stresses and load paths throughout the body structure.



TYPICAL SECTION CUT THROUGH THE SILL AT THE FRONT DOOR



BASICS OF AERODYNAMICS

Aerodynamics is a very complex subject and needs a great deal more attention than this book can provide. However, as with other technical subjects, there are some basic principles that can be applied to help the vehicle meet its functional objectives. In the case of aerodynamics, each package should be set up to allow the vehicle to travel through the air as efficiently as possible.

First, look at the importance that aerodynamics will play in the type of vehicle you are designing. A sports car with a high top speed, superior handling and cooling requirements will have a greater emphasis put on airflow and down force. Environmentally-friendly vehicles, looking to reduce fuel consumption, will also need to slip through the air as easily as possible. Trucks, on the other hand, are usually an aerodynamic disaster, with every aspect of their exterior surface working against good aerodynamic principles.

Two factors to consider are the drag coefficient (Cd) and the total drag. The drag coefficient is a factor that defines the "slipperiness" of a particular shape, regardless of its scale. The total drag multiplies this coefficient by the cross-sectional area (A) of the vehicle to determine its aerodynamic resistance (force) that must be overcome to propel it (CdA). A full-size car and its quarter scale model will have the same drag coefficient, but the full-size car will have sixteen times the total drag of the quarter-scale model.

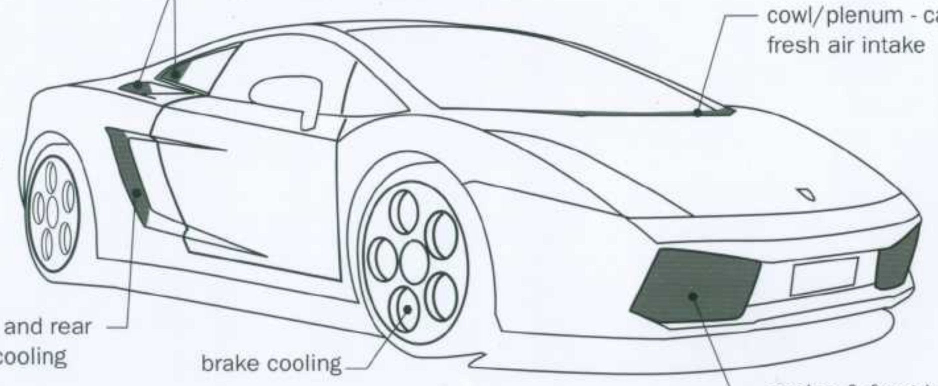
From the vehicle-architecture perspective, making the vehicle smaller in the front view should always be considered if low aerodynamic drag is a priority. Down force should also be a consideration. With most vehicles expected to be driven at 70mph or more, keeping more air pressure on top of the vehicle than underneath will help maintain handling characteristics regardless of speed. For high-speed cars it is also critical that the balance of the car is not affected by speed; spoilers are often applied to help maintain consistent down force on the front and rear tires.

Additionally, vehicles need to breathe to perform several different functions. Engine cooling requires a substantial airflow through the cooling modules or radiators. The breathing apertures that allow this airflow are usually very evident in the styling of most cars and trucks. The size of the body opening for the engine is usually about two-thirds the size of the cooling module (radiator). Openings in the front of the car for brake cooling are also common, with ducting to the brake rotors on high-performance cars. The heating, ventilation & air conditioning (HVAC) system usually takes air in through the "cowl screen" at the base of the windshield. The outside air enters the car at this low pressure area and travels through the plenum chamber to remove moisture and other large particles. The plenum chamber often serves as part of the body structure and runs across the base of the windshield between the A pillars. Some very high-performance cars may require unique ram-air vents to push more air into the engine induction system.

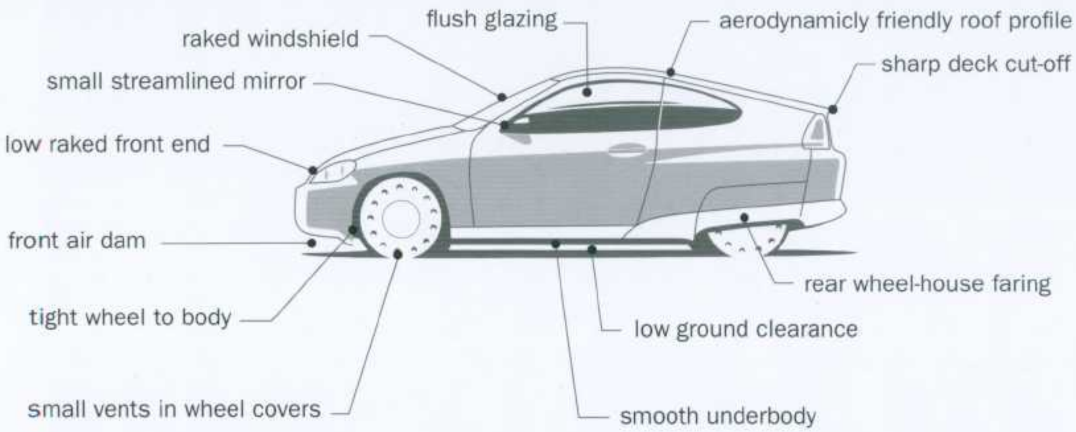
Other factors like wind-noise reduction and water removal are high considerations in luxury cars, but these are often addressed with localized surface contours and hardware details, which will not affect the package.

The two illustrations opposite show some of the fundamental dos and don'ts of packaging to create good aerodynamics.

BREATHING APERTURES
These can be major exterior design elements in exotic sports cars

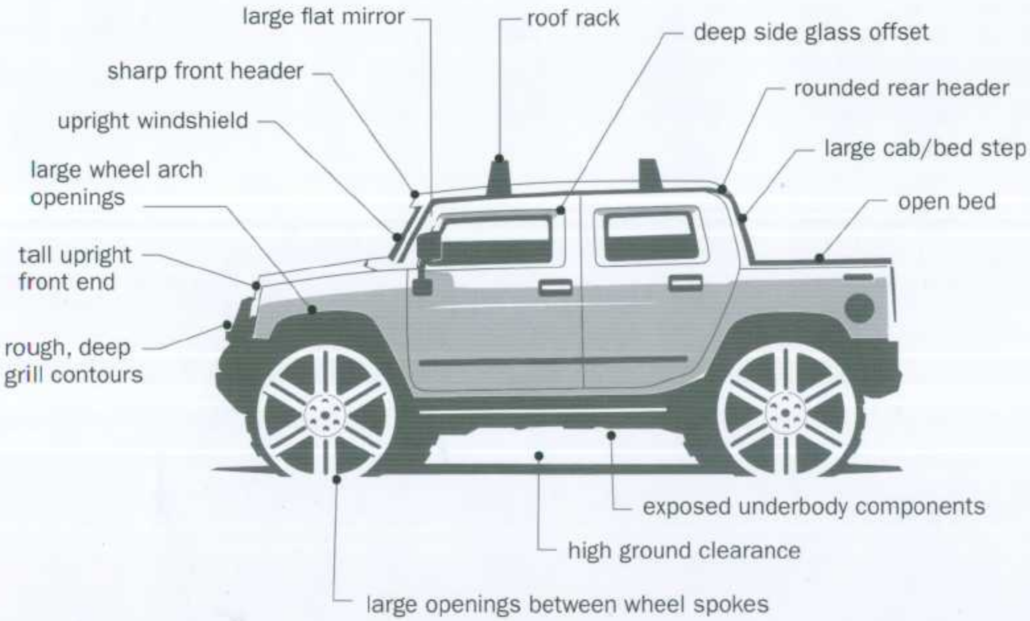


EFFICIENT DESIGN



Being small, low and narrow, the car above has already reduced drag. Additionally, the low front, gently contoured roof line, sides tapered in toward the rear, a sharp rear cut-off creating minimal turbulence, and fared-in rear wheels further contribute to low drag.

INEFFICIENT DESIGN



This is an aerodynamic nightmare. With the large, high and wide body, the vehicle above will have to push a lot of air out of the way as it travels at speed. The other features on the body will disrupt the airflow, creating additional drag, particularly the abrupt changes of body shape and untidy underside.

LIGHTING BASICS

The lights are an important safety feature, so their design is strictly controlled by legislation in all markets. This aspect of vehicle design can be quite complicated, so it is advisable to get a good basic understanding of the purpose and function of each light first, then learn the specific details later.

Each light serves a specific function, either to illuminate the road at night, to make the vehicle visible in the dark or bad weather, or to communicate to other drivers what the vehicle is about to do: stop, turn or back up.

The size and location of each light will depend on illumination targets or specific surface-area requirements set out in the legislations of different parts of the world. European lighting legislation differs, for instance, from US requirements.

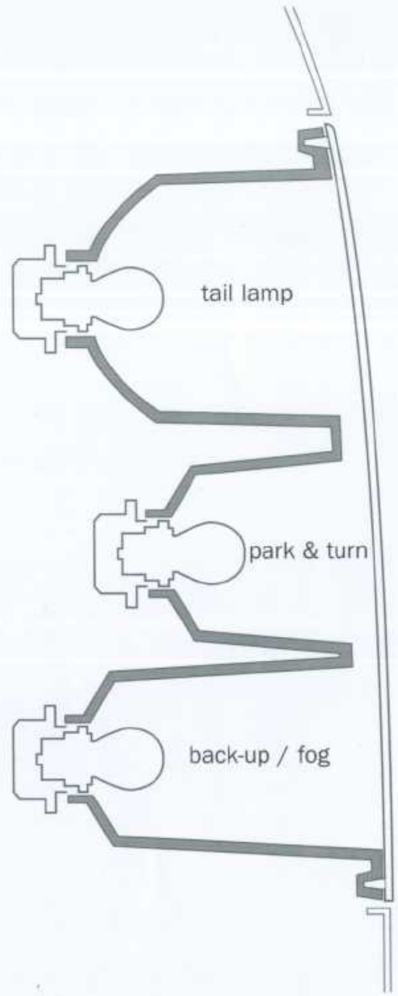
The headlights are designed to pass various tests and their size will depend on the technology applied, whereas most of the other lights and reflectors need to meet minimum lens surface-area and visibility requirements.

Each lamp is made from three components: the bulb, reflector and lens. Some assemblies occupy large volumes and need to be considered early in the package process. Additionally, because they are a safety item, they need to be protected and their relationship to the bumper systems is an important element in the exterior design.

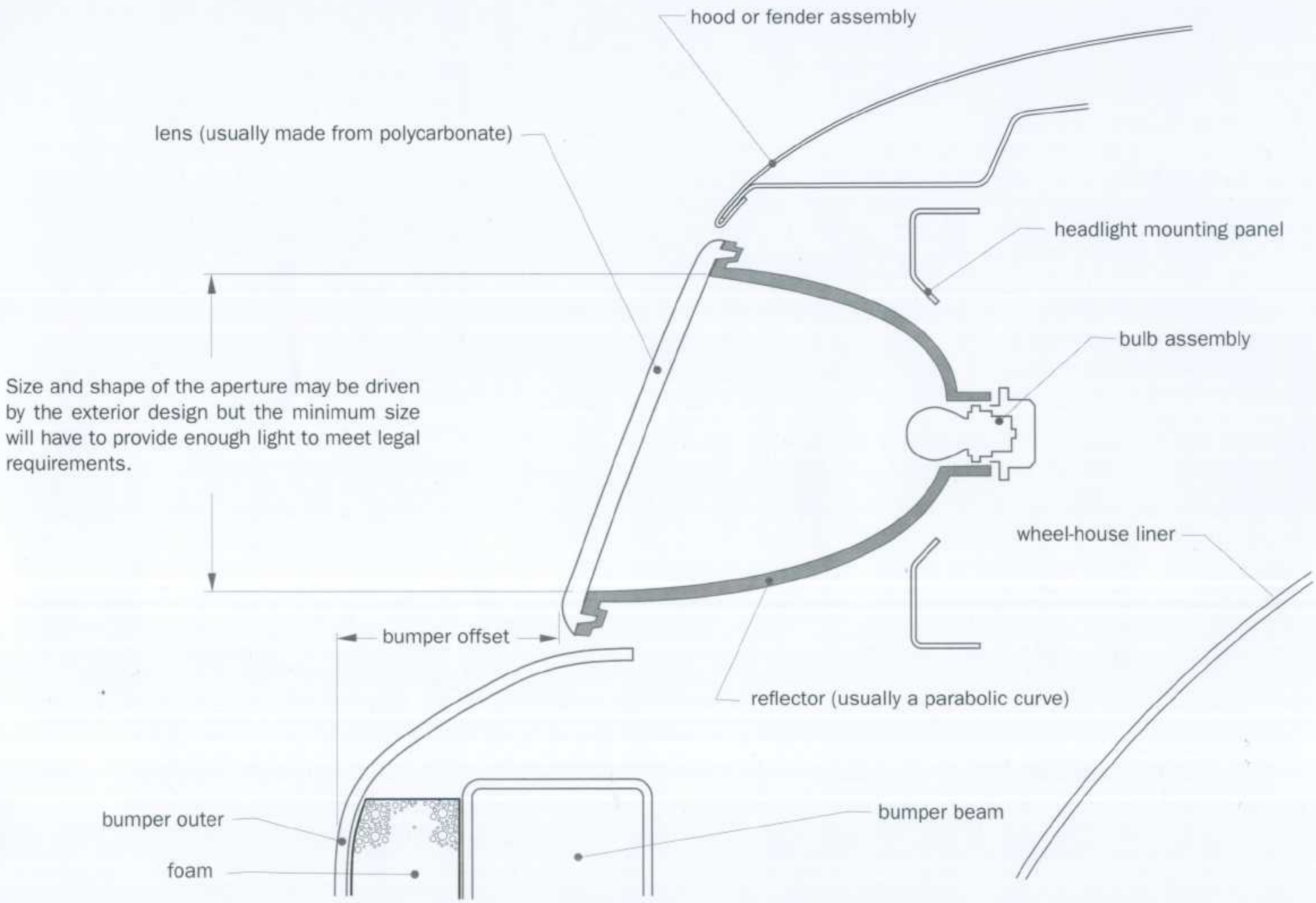
Widespread adoption of light-emitting diode (LED) technology is changing the approach to the engineering design of lamps. This is giving designers new opportunities for the shape and appearance of lighting, although the positioning of the lamps remains regulated.

TYPICAL SECTION THROUGH A MULTI-CAVITY REAR-LAMP ASSEMBLY

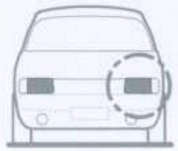
Note the depth of the lamp cavities. These will intrude into the trunk space and may be a challenge to package if mounted on the rear pillars.



TYPICAL SECTION THROUGH A GENERIC HEADLIGHT ASSEMBLY



EXTERIOR LIGHTING REQUIREMENTS



HEADLIGHTS

GENERAL

- Consisting of a high and low beam to illuminate the environment in front of the vehicle.
- Lens minimum sizes are determined by photometric requirements and lamp technology.

US REQUIREMENTS (FMVSS108)

- Two or four lamps set symmetrically about centerline as far apart as practical.
- High beam must be produced by inboard or lower lamps
- Center of lamp height from ground 585*min–1346max
- Approximate reflector diameter to meet photometric requirements: 140 low beam, 110 high beam (projector lamps, 60 LB & 70 HB)

EUROPEAN REQUIREMENTS
(EC - European Commission)

- Bottom-lit edge of low-beam height from ground 500min–1200max
- Outer-lit edge to widest point of vehicle, 400max
- Low beam to be visible 10° inboard, 45° outboard, 15° up and 10°down

PARK AND TURN

GENERAL

Park - Indicates the vehicle's position when parked or during headlight failure.

Turn - Flashes to indicate the driver's intent to turn, and can be used together for hazard warning. Mounted symmetrically about centerline.

US REQUIREMENTS

- Minimum separation between bulb centers, 635mm
- Height from ground 406min–1803max (park) & 2083max (turn)
- Approximate reflector diameter -70 to meet photometric requirements

EUROPEAN REQUIREMENTS (EC)

- Bottom-lit edge height from ground 500min–1200max
- Outer-lit edge to widest point of vehicle, 400max
- Low beam to be visible 10° inboard, 45° outboard, 5° up and 10° down

FRONT FOG

GENERAL

Two forward-facing lights mounted symmetrically about centerline. Fog-light function is separate from headlight.

US REQUIREMENTS
(SAE - Society of Automotive Engineers)

- Bulb center from ground, 304min–763max
- The lit edges of the two lights should be 508min apart

(IIHS - Insurance Institute for Highway Safety)

- Recommended setback from fascia surface, 25min

EUROPEAN REQUIREMENTS (EC)

- Edge of reflector to ground, 250min - 800max
- Edge of reflector to outboard edge of vehicle, 400max

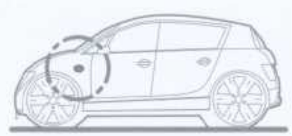
SIDE MARKER

GENERAL

Side markers indicate the overall length of the vehicle (not permitted in Europe)

US REQUIREMENTS

- Minimum window 13x20 must be visible at 47° forward and rearward of the bulb, 12° up and down
- Height from ground, 406min
- Located as far forward as possible
- Colors: front - amber, rear - red



SIDE REPEATER LAMPS

GENERAL

Work with turn signals to show intent to turn or change lanes to vehicles traveling alongside. (not required in US)

EUROPEAN REQUIREMENTS (EC)

- Bulb center height from ground, 525min–1475max
- Distance from front of vehicle, 1800max
- Must be visible from between 5°–65° from Y plane at the bulb center

*All measurements in millimeters unless otherwise noted.

CENTER HIGH-MOUNTED STOP LIGHT (CHMSL)

GENERAL

- One red light mounted on the vehicle centerline facing rearward, activated with brake lights.
- Not permitted in Europe

US INFORMATION

- Illuminated lens at least 29cm^2
- No part of the lens to be more than 76mm from the bottom edge of glass (152mm below the rear window on convertibles.)
- Should be visible from 47° either side of centerline, 12° up and 7° down. (Lens visible surface to be at least 6.25cm^2 when viewed at 45°).

BACK-UP LIGHTS

GENERAL

- For illumination behind the vehicle, and they provide a warning signal when in reverse.
- Only one required, two optional (must be symmetrical)
- White in color

US INFORMATION

- Must be visible to a pedestrian eye point which is 1830mm above the ground & 915mm behind the vehicle.
- Must be visible 47° either side of the bulb.

EUROPEAN INFORMATION

- Height from ground to illuminated area, 275min–1175max

REAR FOG LIGHTS

GENERAL

- Red in color - For making the vehicle more visible in fog
- Only one required, mounted on centerline or driver's side
- Two optional (must be symmetrical)
- Not permitted in USA

EUROPEAN REQUIREMENTS

- Height from ground to illuminated area 275min–975max
- Separation to stop lamp (a.k.a. brake light), 100min

TAIL, STOP, PARK & TURN-SIGNAL LIGHTS

GENERAL

Taillights - (Red) Mark the presence of a vehicle and work with the headlights or park.

Brake lights - (Red) Indicate the vehicle is slowing down/stopping.

Turn Signal - (US: red or amber. Europe: amber) Flash to indicate driver's intent to turn, or for hazard warning.

- All mounted symmetrically about centerline and must be fixed to the body, not closures.

US REQUIREMENTS

- May be combined into a single light
- Located at the rear of the vehicle, within the outer 25% of the vehicle width
- Height from ground, 406min–1803max (turn signals, 208max)
- Illuminated area of the brake light or tail/stop to be at least 50cm^2. For multiple compartment lamps each lens must be at least 22cm^2 with a total of at least 50cm^2. Vehicles over 2030 wide, must have at least 75cm^2.
- The lens must be visible at 47° either side and unobstructed 12° up and down. The illuminated area of 13cm^2 at 45°
- Separate turn signals should be visible at 47° outboard–22° inboard.

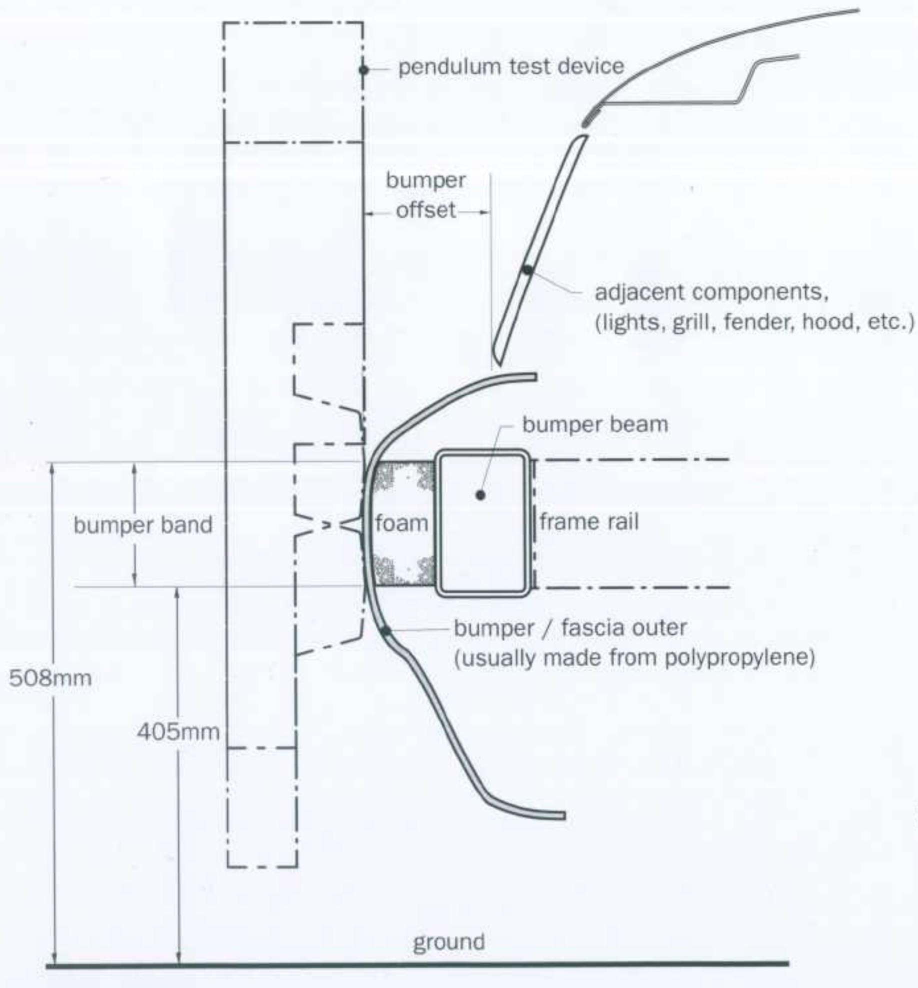
EUROPEAN REQUIREMENTS

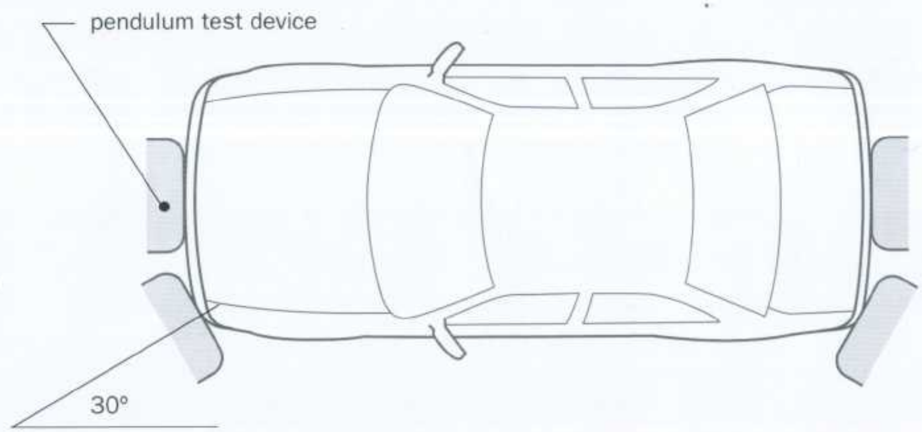
- Tail and turn to be located at the rear of the vehicle, within 400 of the edge of the outer edge.
- The turn signal should be the furthest outboard if clustered horizontally
- Inboard lit edges should be positioned at least 600mm apart
- Height from ground, 375min–1475max (rear reflex 875max)
- Must be visible from:
  Tail - 80° outboard, 45° inboard
  Stop - 45° outboard, 45° inboard
  Turn - 80° outboard, 45° inboard and unobstructed 15° up and 5° down
- Minimum illuminated lens area of 13cm^2 at extremes of visibility angles
- Brake and fog lights must have a separation of 100min
- Tail and fog can be combined

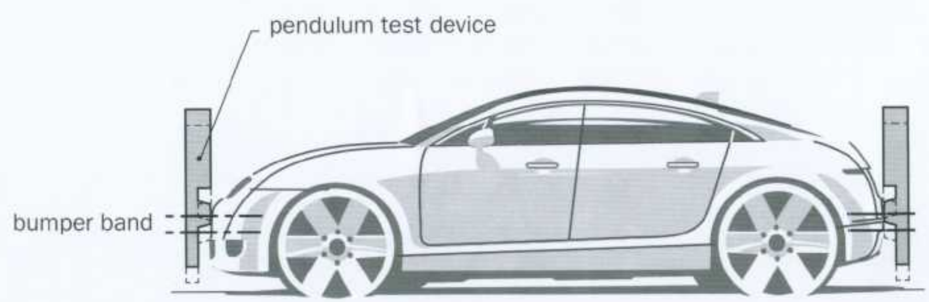
BUMPER DESIGN (FOR LOW-SPEED IMPACT TESTING)

The US and Canadian governments both require passenger car (trucks are exempt) bumpers to meet low-speed impact tests. The tests range from speeds of 2.5mph to 5mph and aim to minimize damage caused in minor accidents. The requirements differ slightly for each country, but essentially call for the front and rear bumper systems to protect the adjacent areas from damage, especially the safety items such as lights. The car is hit by a steel "pendulum" at 405mm and 508mm above the ground. This is applied at centerline and at the corners. To pass the tests the bumper profile is offset from the surrounding surfaces. To set up the bumper offsets, benchmark existing cars to get the ideal or minimum condition. Offsets will vary depending on the vehicle weight and the cost of the bumper system, so always compare similar types of cars. Getting the bumper offsets to look good and meet the impact tests is usually a challenge to a design team.

TYPICAL GENERIC SECTION THROUGH A FRONT PASSENGER CAR BUMPER SYSTEM

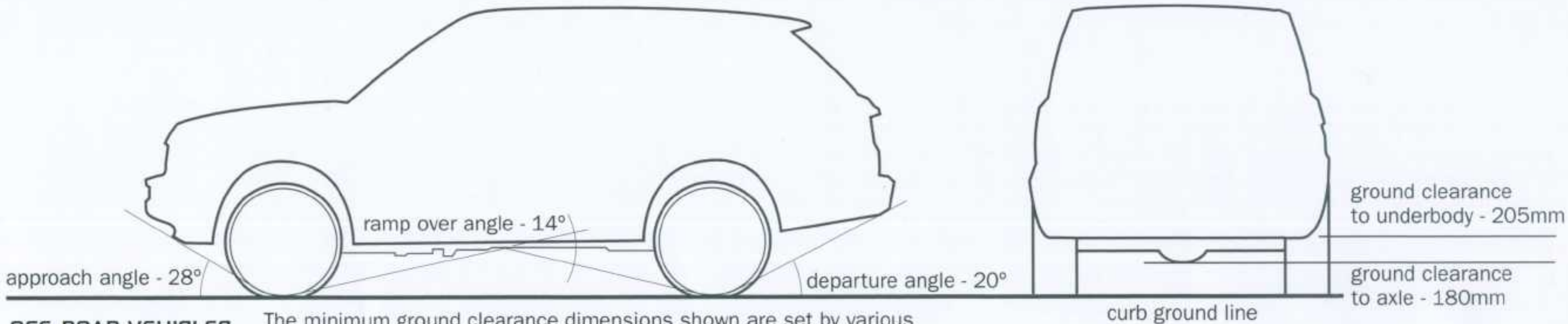




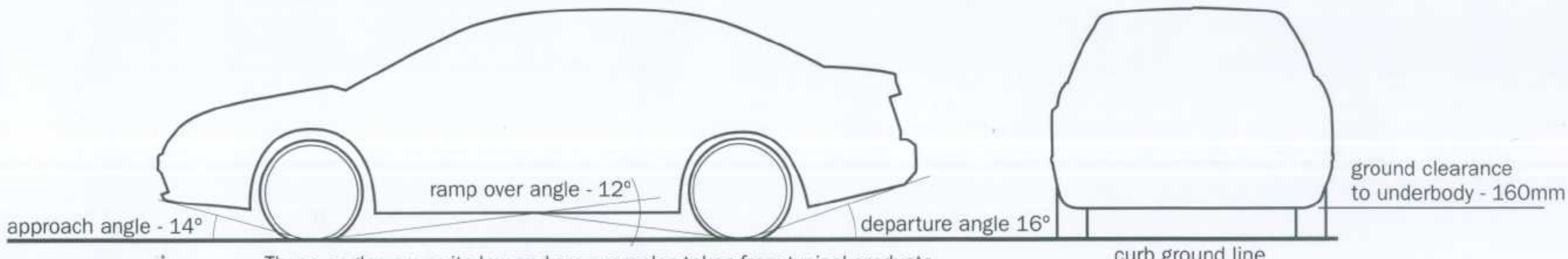


GROUND CLEARANCE

The relationship of the body and underbody components to the ground should be appropriate to the use of the vehicle. Road-going passenger cars are set up to be driven without contact to the ground when fully loaded. Off-road vehicles will need to be raised according to their intended capability, which may also include being driven through water. Some sports cars can be designed with compromised ground clearance to improve aerodynamics, but the owners will need to accept the limitations of their vehicle in some situations.

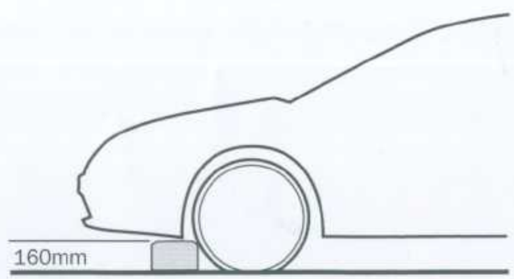


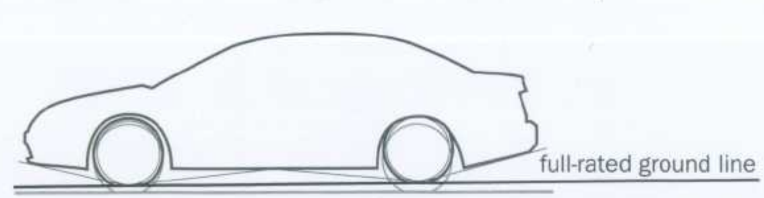
OFF-ROAD VEHICLES The minimum ground clearance dimensions shown are set by various governments to determine that the vehicle is suitable for off-road use.



PASSENGER CARS These angles are quite low and are examples taken from typical products at curb attitude. Some specialty sports cars may be lower.

PARKING BLOCK





Note: See the SAE J689 for ground-clearance recommendations. These are measured with the vehicle at compressed suspension attitudes.

GLAZING

The main objectives for the glass panels are to protect the occupants and allow them to see out. In many cases, they also articulate to provide ventilation or access.

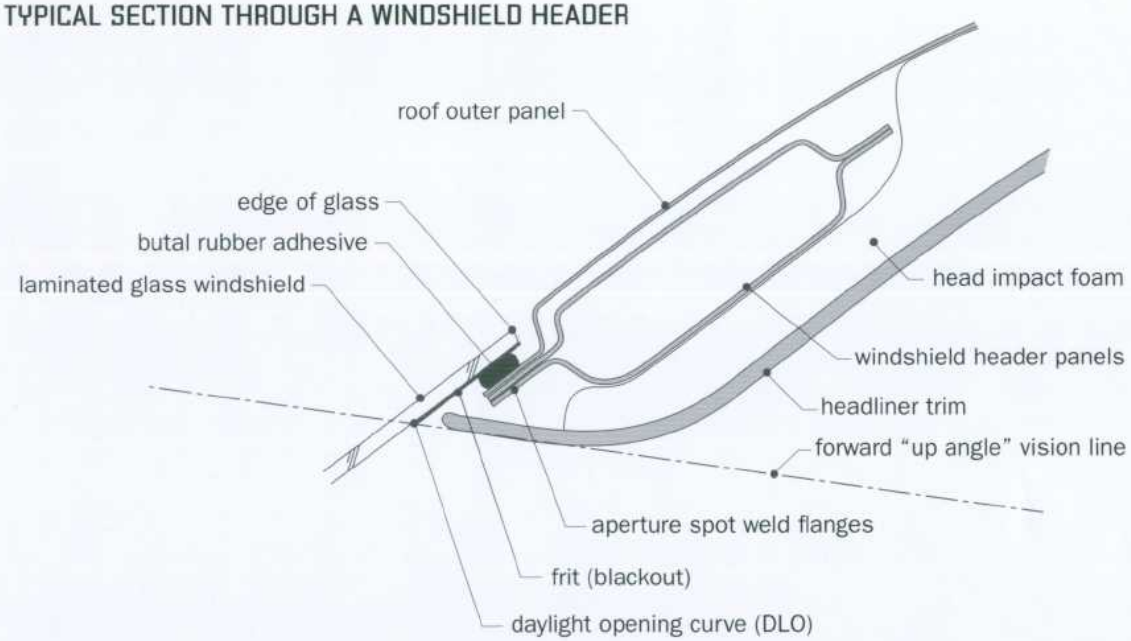
Glass is one of the oldest materials used in vehicle design and is still manufactured using traditional processes, which can limit the design of each panel. The main reason it is still used extensively is because of its optical qualities and hardness (scratch resistance), unlike some plastics. This makes it ideal for applications where it contacts other abrasive components, such as windshield wipers and belt moldings.

Two types of glass are used, laminated (for windshields) and toughened (for side glass and backlights). The laminated glass is thicker, usually 5–6mm, and is therefore quite heavy but will not shatter when struck, unlike the tempered glass which is usually about 3mm thick and designed to shatter into small pieces on impact.

The section below shows how a typical glass aperture is configured. Each aperture is surrounded by a box section, and the glass is mounted on the spot weld flange, in a rebate and held in place with adhesive or rubber molding. A blackout, or frit, is painted around the perimeter to hide the adhesive and interior trim.

The main thing to note here is the distance between the edge of glass on the exterior surface and the "daylight opening" (DLO) on the frit. Because of this, the section has to be designed before accurate vision studies can be completed and the edge of glass set up.

TYPICAL SECTION THROUGH A WINDSHIELD HEADER



WINDSHIELD

The main objective for the windshield is to get the optics as clear and free from distortion as possible. The more aggressive the installation angle, the greater the potential is for distortion. Most exotic sports-car glass is quite flat to counter this.

Side-view curvature is usually kept to a minimum, but plan-view curvature is common, especially on vehicles with more upright windshields.

SIDE GLASS (DROPPING)

The surface contour is engineered to drop into the door through the belt molding. See pages 184–185 for more details.

SIDE GLASS (FIXED)

Similar to the dropping glass, but its shape is not restricted by the dropping function. These may pivot out for ventilation or be bonded to the body.

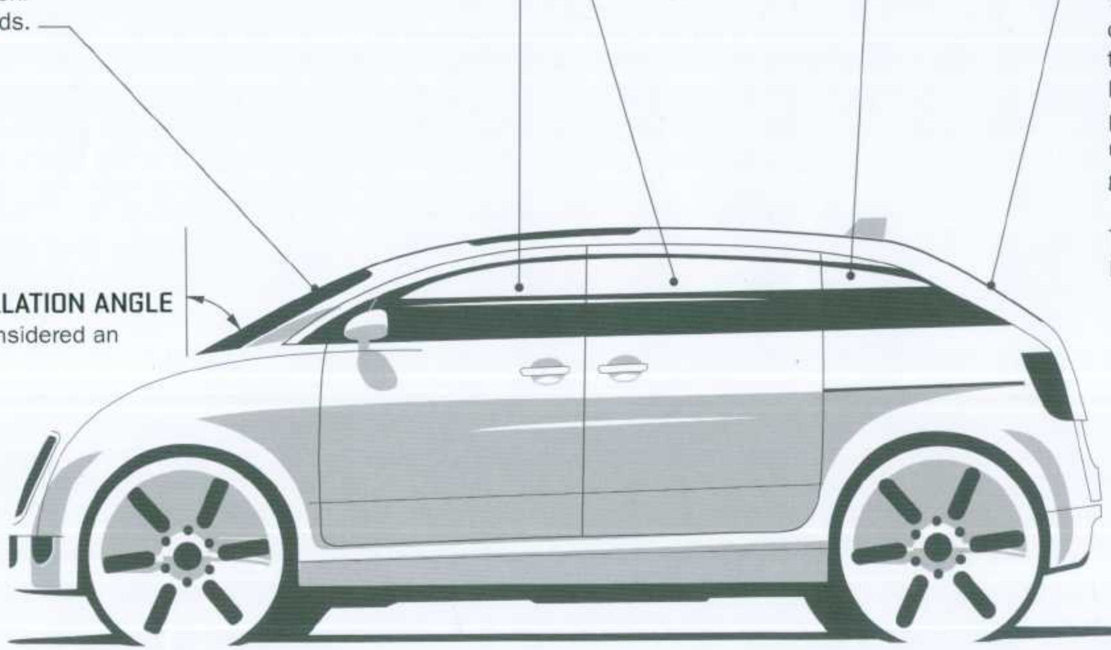
BACKLIGHT

This glass panel does not have optical or mechanical criteria to restrict its shape and is only limited by its manufacturing process. Heating elements are usually applied to the backlight glass panel.

These are often hinged, frameless freestanding panels.

WINDSHIELD INSTALLATION ANGLE

Greater than 60° is considered an aggressive angle.



LICENSE PLATE MOUNTING

License plates are mandatory for all road vehicles in every market. Their size, location and illumination are governed by legislation. They are often an afterthought to the vehicle design, but due to their size and positional requirements should not be overlooked for too long.

FRONT

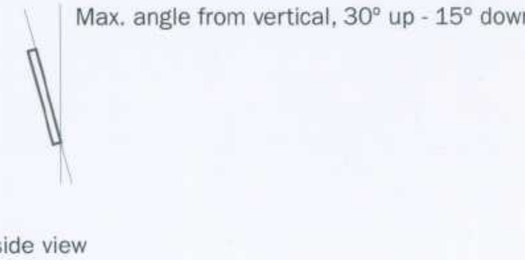
Front license plates are optional in some regions of the USA but required in most markets so are usually included in production packages. These are often located in front of the bumper beam or below, in the front spoiler. One main issue to consider is engine cooling. The breathing apertures for cooling are normally designed above and below the bumper beam so placing the license plate over the bumper beam is often a logical location.

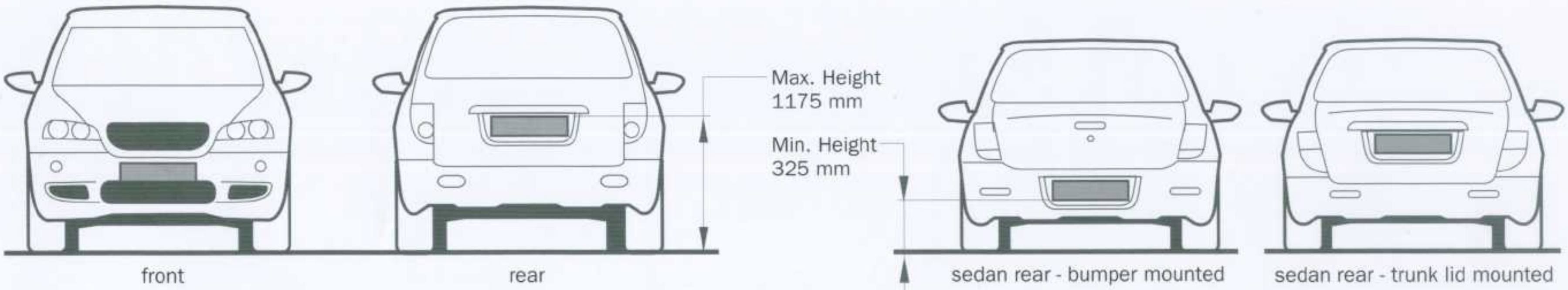
REAR

Rear license plates require illumination and are usually placed in a pocket to make this possible. The location, size, depth and angle of the pocket can vary a great deal depending on the market and styling requirements. The plate is allowed to be lifted with the rear closure (trunk lid, tailgate etc.) and is often mounted above the rear bumper on the lift gate or trunk lid.

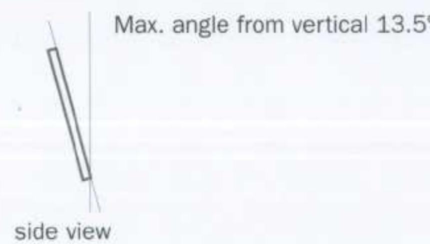
The diagrams on the opposite page illustrate the requirements and possible solutions for license plate accommodation.

LICENSE PLATE SIZE & LOCATIONS

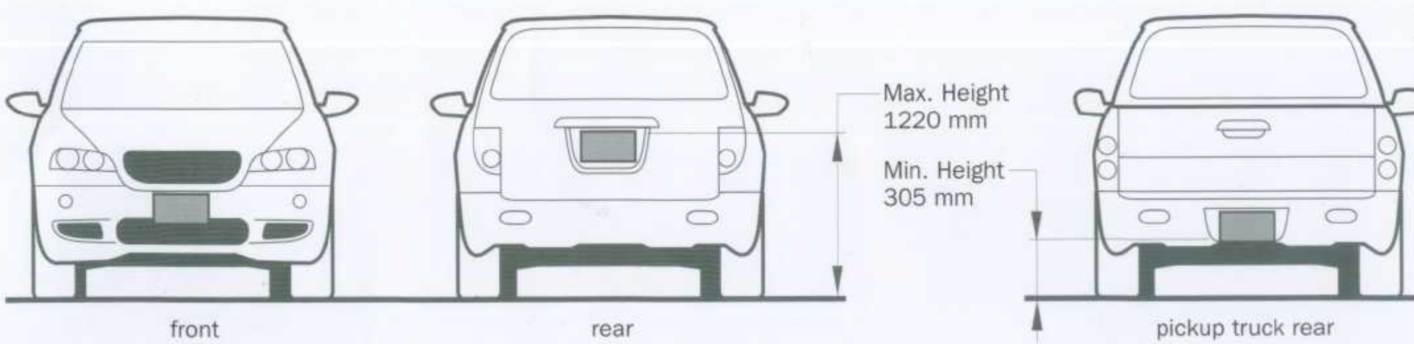


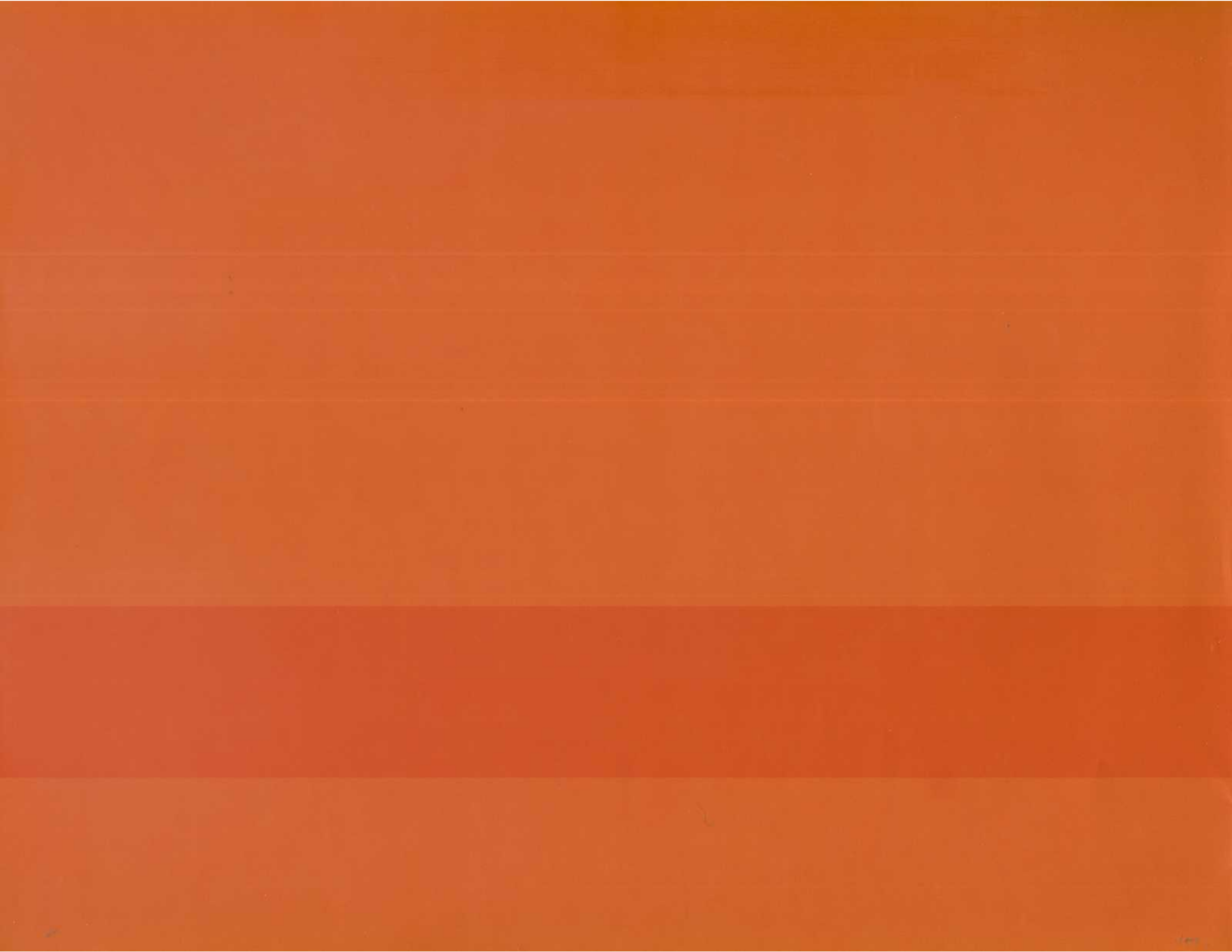


The front license plates should not block airflow to the engine-cooling apertures. Vehicles sold in global markets will have a license pocket to accommodate the largest plates in all dimensions or make separate panels for each market. European plates are the widest (520mm), and US plates are the tallest (152mm), so a minimum pocket size of 520mm x 152mm will work in all markets.

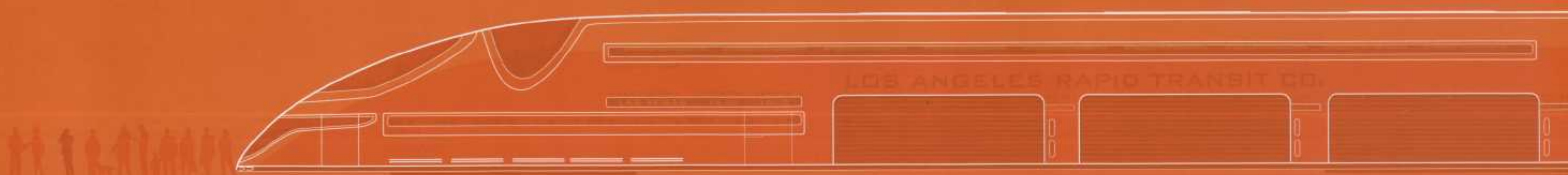


Trucks with removable tailgates should locate the license plate on the bumper.





"Societies all over the world are looking for alternative solutions to their transportation needs. In developed markets, infrastructure has become saturated, while emerging economies are planning their future, hoping to learn from the mistakes of others. With global warming a reality, growing ecological awareness and a dramatic increase in demand for energy, there is a huge need for more efficient vehicles and transportation systems."



INTRODUCTION TO MOBILITY

INTRODUCTION TO MOBILITY

It is quite certain that the automotive industry will undergo major changes in the coming years due to many factors. Not least among them will be the need to provide ever more sustainable transportation and personal mobility, particularly in our urban environments. It is in everyone's interests to encourage designers to be thinking hard about what these innovative transportation solutions could be, so that whatever they are, they are compelling, convenient and really cool to use.

All of the information in this book can be equally applied to these new kinds of transportation devices. So when you find yourselves being asked to design unusual or groundbreaking new types of vehicles, you can still approach the architectural ideation in the ways that we suggest, even if the functional objectives and mechanical components might be very different from a regular car or truck. For example, there is a compelling argument to be made for single seat, urban commuter vehicles for the 80% of drivers who typically travel alone to and from work. Such vehicles could be extremely energy-efficient and take up very little space to park. However they would still need to be safe mixed in with regular traffic and they need to be fun, comfortable and convenient to use to encourage as many people as possible to use them. How would you go about figuring out the architecture? Would they be tall and narrow or low and wide? How would people get in and out of them? How much protection would people expect and how much structure would actually be needed to give that protection?

If designers are totally comfortable with using the packaging tools in this book for familiar kinds of road vehicles, they can make a huge contribution to innovation within the industry with exciting new kinds of transportation that people really want.

The ability to successfully package a complete car or truck is really about understanding a vehicle as a system; seeing the complete product as a complex arrangement of interrelated subsystems. Car designers, indeed designers in all disciplines, will increasingly hear the term "systems thinking." As the world within which we live becomes more interconnected and more complex, professional car designers can no longer think just about the specific product that they are working on. They are increasingly required to understand the context within which their vehicle is going to operate, whether that relates to the need to reduce emissions, use less oil-based fuel, be manufactured for total disassembly at the end of its life or to be sold in a market that taxes footprint or weight. They have to become systems designers as much as product designers. When car designers take this understanding of systems thinking to the next scale, and combine it with their instinctive skills and passion for creating great-looking cars, they will find themselves better equipped than anyone else to propose exciting alternative solutions to personal mobility and transportation.

The illustration below outlines some of the modes of transportation that could work in combination to provide exciting opportunities for futuristic transportation systems. For each mode—Segways, bicycles, motorcycles, electric scoot-

ers, neighborhood electric vehicles, the list is endless—there is an opportunity for designers to create exciting-looking products that fit into a total system and are hugely fun to use. The truth is that most transportation devices that are not cars or trucks do not get designed in automotive studios—and they look like it! Car designers have abundant possibilities to apply their skills and passions to all these other kinds of transportation products as well as to cars.

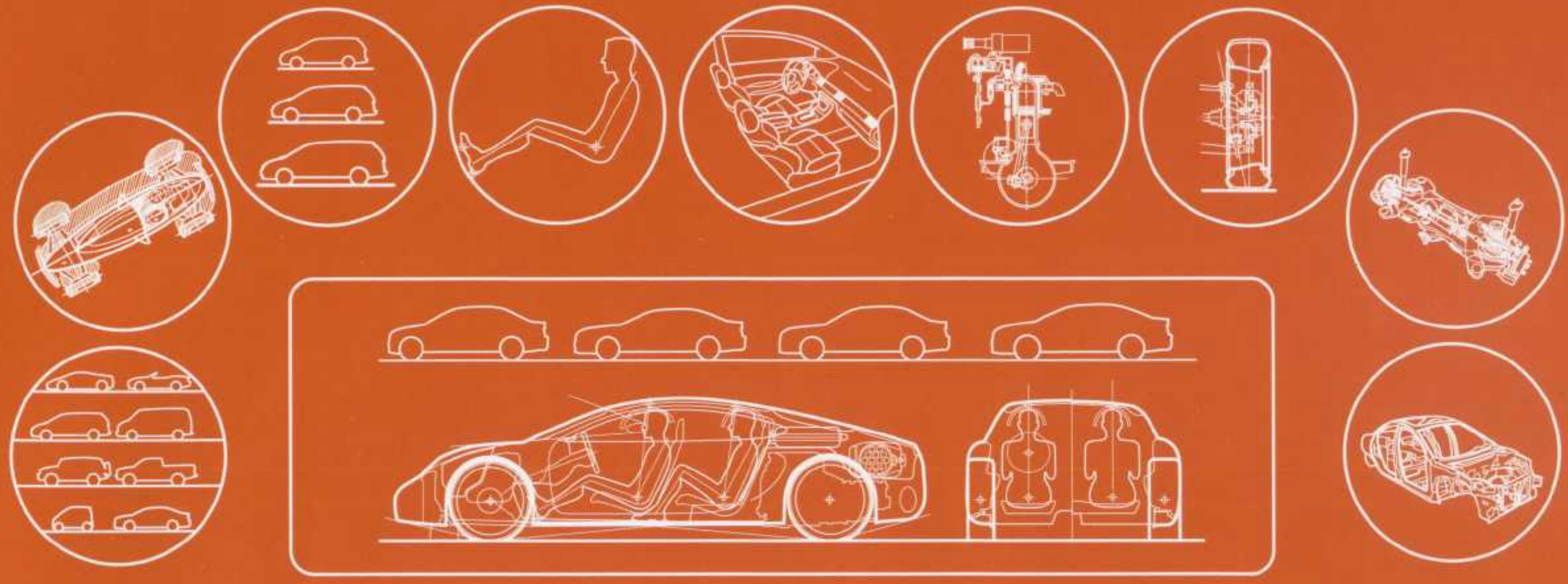
Thinking about advanced mobility systems is fascinating. It involves thinking about human needs in a holistic way, and then reinventing urban and suburban landscapes without the baggage of past eras. These total solutions require an understanding of not only the vehicle designers' knowledge, but the skills and wisdom of others too: urban planners, infrastructure engineers, energy experts, government policy makers to name just a few. Transportation designers need to be right in the middle of all this, thinking and using their passions to inspire everyone else involved.

Of course, we often have to walk backwards into the future, settling for compromises forced on us by the redundant elements in our environment. The Industrial Revolution has been an enormous science experiment from which have grown some massive cities. Many of these cities are beginning to contract and decay as the world moves into a new era, driven by an increased understanding of the need for sustainability and supported by advanced technologies, communications and constantly changing political will. Centralized manufacturing and employment, as well as inefficient use of rapidly depleting oil reserves, belong to our past.

The scenario below looks at a 2030 infrastructure solution. The foundation of this concept is the "sunshine economy" focused on the sun as a source of infinite power and an ideal living environment. Naturally, this concept is based in the desert joining the two cities of Los Angeles and Las Vegas. The 270 mile stretch of rail line is a solar collector not only feeding the high-speed mass transit system, but also the cities that are developed along its route. Feeding on many peoples desire to live in idyllic resort communities which are connected to large cities for commerce and culture, the high-speed rail link traveling at 250mph allows this new society to have the best of both worlds.

Looking at the personal mobility vehicles for this scenario requires a new perspective and a fresh set of functional objectives. Each car will only need to travel short distances between stations and outlying districts. Government subsidies will encourage battery-energy storage to completely eliminate air pollution and oil dependency. The cargo bays on the train will limit the footprint of each vehicle to provide optimized carrying capacity. Communication and entertainment will change the way the interiors are designed.

The possibilities are endless, constrained only by our imagination and the will to live in a perfect world created by intelligent choices.



"Develop your architecture one step at a time, piecing together all the elements to build the package."

DESIGN EXERCISES

Exercise 1 - SETTING FUNCTIONAL OBJECTIVES

Set out some clear functional objectives for the three entities: customers, brand and market environment.

CUSTOMERS:
- Purpose of the vehicle
- Number of occupants
- Type of occupants (gender, age, nationality, physical disabilities, etc.)
- Performance and capability expectations (acceleration, top speed, handling, off-road capability, GVW, towing capacity)
- Purchase cost & cost of ownership (economical, luxurious, exotic, practical)
- Image (modern, retro, prestigious, ecological, safe, bold, high-performance)

MANUFACTURER / BRAND:
- Vehicle position in the brand portfolio
- Investment & manufacturing costs
- Annual sales volumes (1–100; 100–5,000; 5000–50,000; 50,000–100,000; 100,000–1,000,000)
- Marketing strategy (traditional dealerships, Internet, loss leader, halo, concept)
- Technology (traditional, advanced)

MARKET / ENVIRONMENT:
- Infrastructure, terrain & climate
- Size limitations (length, width, height, tire size, engine size & output)
- Legislation (safety, emissions, fuel consumption, lighting)
- Crashworthiness (front & side impact, rollover, low-speed impact)
- Consumer advocate groups (JD Power, MSN Autos, EuroNCAP, Insurance Institute for Highway Safety, *Consumer Reports*)

Exercise 2 - PACKAGE IDEATION

Loosely sketch some basic package concepts based on the functional objectives which drive the architecture. Each sketch should only take a few minutes. Don't worry too much about scale and keep sketching until you have exhausted all the possibilities.

Focus on the following elements:
- The occupant package
- Cargo
- Powertrain & Fuel Storage
- Wheels & Tires
- Special features (doors, flexible seating, aerodynamics, alternative body construction, convertible top, etc.)

Sketch each package concept in at least two orthographic views and add isometric illustrations where necessary.
Continually revisit the functional objectives to make sure that they are feeding your ideation. Work out which systems are important to the success of the concept and begin to establish a hierarchy. Determine which elements are subordinate and which ones lead.

Exercise 3 - SIZE AND PROPORTION / BENCHMARKING

Choose a direction from the package ideation sketches and establish the size and proportion of that concept. Look again at the functional objectives to see which key dimensions deserve the most focus. Use known benchmark products to help build the package in chunks, using a separate product for each chunk if required.

Set up comparisons for:

1) Occupant package and interior environment. Look at occupant location and posture. Also focus on the space around the manikins.
2) Cargo. Think about volume, size and weight of the items to be transported, and set up space around the occupant package.
3) Powertrain package. Choose a product with a similar propulsion system and note the spacial envelopes around the major components.
4) Ground clearance. Look at vehicles with similar capabilities (off-road vs. on-road) to your concept, and note the relationship of the underbody components to the ground.
5) Crashworthiness. Study vehicles that meet the appropriate safety standards and note the "crush space" and structure allocated to protect the occupants.
6) Wheel and Tire package. Compare the tire outside diameter and profile to vehicles of similar size and capability.
7) Other Elements. Study other significant components in the concept, such as windshield placement, closure articulation and cut lines, lighting, and seating flexibility.

Establish some key target dimensions:

LENGTH

WIDTH

HEIGHT

WHEELBASE

TIRE O.D.

GROUND CLEARANCE

Exercise 4 - OCCUPANT PACKAGING

Set up the occupant package based on the functional objectives and benchmark studies. Accurately position the SAE 95th percentile male driver in front and rear views. Include all of the theoretical construction lines and datums, including the H-point, Heel point, ball of foot, shin and thigh centerlines, back angle, effective headroom (8 degree) line, headform and eye ellipse with vision angle lines. Next locate the rear passengers also using the 95th percentile manikins.

To help set up the occupants prioritize the following:

Aerodynamics and Handling • Comfort and space • Ingress /Egress • Safety & Security • Package Efficiency • Ground Clearance • Durability • Load Carrying

Establish some key target dimensions for each row of occupants

H-POINT HEIGHT FROM GROUND

CHAIR HEIGHT (H-Pt. to Heel)

BACK ANGLE

FORWARD VISION ANGLES

EFFECTIVE HEADROOM

SHOULDER ROOM

LATERAL LOCATION

COUPLES (if applicable)

Exercise 5 - INTERIOR AND CARGO

Set up the interior environment around the occupants. Look at each major component/system and establish its relationship to the occupants.

Focus on the following:

- Headliner and door trim (use these to set up the exterior hardpoints)
- Cargo storage areas
- Steering wheel, controls and instrument panel
- Telematics
- Seating systems
- Floor consoles

To help set up the storage areas, list the items to be carried and note the size and weight where appropriate.

Examples:

Purse • Cell Phone • Briefcase • Groceries • Dry Cleaning • Weekend Luggage • Family Vacation Luggage • Dog • Tools • Bikes • Skis/Snowboard • Strollers • Building/Landscaping Materials • Golf Clubs

To help allocate additional space and provide other attributes, also note interior functions that may require special consideration.

Examples:

Outside visibility • Reclined Sleeping • Video screen visibility • Face-to-Face seating • Tables and Work surfaces • Cooking • Work/Business Meetings Automated Driving • Interior Flexibility (i.e., stowing seats)

Exercise 6 - POWERTRAIN PACKAGING

Select and lay out the propulsion system. Look carefully at the functional objectives and benchmark studies to understand the concept's performance requirements, which include top speed, acceleration, weight, fuel consumption, emissions and traction requirements. If a traditional internal-combustion-type system is chosen, this process should be quite straightforward, by benchmarking existing products. Specifying a less conventional, electric or hybrid powertrain will be a more complex process and involves calculations to establish a power-to-weight (and vehicle efficiency) ratio vs. speed and range.

Set out the priorities for the powertrain.
Organize the following in order of priority.

Power and Image • Handling and Aerodynamics • Off-road capability • Cost
Fuel Consumption and Environment • Package efficiency and occupants

List Target Specifications for the following:

Top Speed
Acceleration 0–60mph
Fuel Consumption (MPG or equivalent)
Emission Requirements (i.e., Zero)

Specify the type of system and the components:

- Type (internal combustion, electric, hybrid or other)

- Fuel type (Gasoline, Diesel, Hydrogen, Biofuel, Electric, etc.)

- Motor:

  Size (cubic capacity)
  Configuration (V8, Flat 4, straight 6, etc.)
  Location
  Orientation
  Power output. BHP or kW
  Torque

Exercise 7 - WHEELS AND TIRES

Establish the wheel and tire sizes for your project and position them in the package. Start by setting an approximate target tire diameter and profile width. Also state the desired wheel size. Locate the spindle centers and establish the track width.

Check the functional objectives to establish the priorities for this task. Organize the following nine factors in order of priority:

On-road handling • Off-road capability • High GVW • Package efficiency • Ride comfort • Appearance/Image • Adverse weather • Brake packaging • Rolling resistance

List the following specifications for the Front and Rear Wheels and Tires:

- Technology and Tire type (conventional, run flat, airless, passenger car, truck, off-road, variable inflation, etc)
- Tire-size specification (i.e., P 225 / 45 R 17)
- Tire O.D.
- Wheel rim width

Also confirm:

- Wheelbase
- Track
- Turn Circle

Exercise 8 - SUSPENSION AND CHASSIS

Select a front and rear suspension system for your concept. Look at the functional objectives and prioritize the following:

On-road handling • Off-road capability • High GVW • Package efficiency • Ride comfort • Exterior Design • Cost

Based on the priorities, choose the appropriate systems and describe the following:

- FRONT - System name or mechanism and Spring type

- REAR - System name or mechanism and Spring type

- Suspension travel dimension front and rear (curb attitude to full jounce)

- Steering System

- Braking System

Exercise 9 - BODY AND EXTERIOR FEATURES

Determine the body style for your concept and choose a type of construction. Think about the following before making these decisions:

The vehicle's purpose and function, annual sales volumes, weight targets, cost, investment, paint, durability, towing capacity, closures, load-carrying capacity.

State the following:

- Body style (sedan, hatchback, minivan, pickup truck, coupe, convertible, etc.)
- Number and type of doors (sliding, gull wing, rear-hinged, etc.)
- Other significant closures (tail gate, hatchback)
- Estimated Annual Sales volumes (custom, low, medium, high)
- Type of construction (unibody, body on frame, space frame)
- Materials for the structure, exterior panels and closures
- Special glazing requirements (tall belt height, extreme windshield angle, dropping side glass, etc.)
- Consider the size and location for the other exterior features (lights, breathing apertures and license-plate pockets)

Exercise 10 - CREATE A PACKAGE LOGIC DRAWING

Compile the information gathered in the previous nine exercises and clearly communicate the package with a clean and graphically appealing drawing which should be created in Adobe Illustrator or a similar computer graphic system. Reference the layout on pages 216–217.

Include the following information:

- Functional objectives for the concept and a brief description of the vehicle
- Target Specifications
- Orthographic side and end views showing the vehicle outlines and the basic layout of all of the systems. (Add a plan view if required to clarify the story).
- Benchmark comparisons that illustrate the overall proportions, the occupant package, powertrain layout and any other significant features.
- The key exterior and interior dimensions
- A basic description of each system

The size, scale and layout of the drawing should be determined by its use (with other design work) as part of a studio presentation, but should also work in a portfolio. This may require it to be set up on several sheets and printed out at various scales to suit each specific purpose.

RESOURCES

H-POINT only scratches the surface of automotive design. The rest of the vehicle creation process is very complex, so use all of the resources available to you online or in book form.

At the end of the initial stage of the project go back and check your work. Now that the design possibilities have been narrowed down it is more effective to look deeper into each aspect of the vehicle architecture. Try to cross-reference two or more sources to validate your information.

Below is a list of resources you may want to use to gather information.

General vehicle design guidlines and practices

Society of Automotive Engineers .... www.sae.org

General information on current products

Manufacturers' websites, i.e. .... www.audi.com

Customer advocate websites .... www.jdpowers.com
Consumer information .... www.autos.msn.com
Encyclopedic information .... www.wikipedia.org

Materials

Steel .... www.autosteel.org
Aluminum .... www.autoaluminum.org
Plastics .... www.plastics-car.com

Vehicle Package Reference Data & Information

Road & Track Magazine (Data Panels) .... www.roadandtrack.com
Autograph Dimensions GmbH .... www.autograph.de

Safety & Crashworthiness

US Government Organization .... www.nhtsa.dot.gov
Independant safety assessment .... www.safecarguide.com
Europe .... www.euroncap.com
USA .... www.safecar.gov
The Insurance Insitute for Highway Safety .... www.iihs.org

Vehicle Systems

Many vehicle systems are manufactured by suppliers. Try to build a database of suppliers for each type of system or process. Here are a few.

All systems .... www.magna.com
Interior systems .... www.johnsoncontrols.com
Powertrains .... www.ricardo.com
Fuel Cells .... www.ballard.com
Electric Motors .... www.uqm.com
Batteries www.a123systems.com
Manufacturing .... www.automation.siemens.com
Ergonomics .... www.mreed.umtri.umich.edu
Wheels and Tires (Tire & Rim Association) .... www.us-tra.org

Vehicle Design & Engineering Books

Fundamentals of Vehicle Dynamics .... by Thomas D. Gillespie
An Introduction to Modern Vehicle Design .... by Julian Happian Smith (SAE)
Automotive Ergonomics .... by B. Peacock
Power Behind the Wheel .... by Walter Boyne
Alec Issigonis: The Man Who Made the Mini .... by Jonathan Wood
Buggatti- "Le Pur-Sang Des Automobiles" .... by H.G. Conway
Streamlined .... by C. Lictenstein

Other Useful Design websites

www.cardesignnews.com
www.cardesignonline.com
www.carbodydesign.com
www.conceptcar.co.uk

SAMPLE CONCEPT PACKAGE LOGIC DRAWING

WORD PICTURE (A Very Brief Description of the Concept)

BENTLEY CONTINENTAL GT

Similar overall length and width

EXTERIOR HARDPOINTS		
Length	4810	4820
Width	1920	1925
Height	1390	1300
Wheelbase	2745	3070
Frt Track	1625	1635
Rr Track	1610	1630
Max. Tire Size	275/40R19	285/40R20

(lined up at ground and bumpers)

ASTON MARTIN DB9

Similar Height & driver seat height

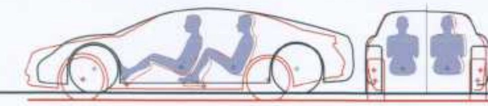
EXTERIOR HARDPOINTS		
Length	4810	4820
Width	1920	1925
Height	1390	1300
Wheel Base	2745	3070
Frt Track	1625	1635
Rr Track	1610	1630
Max. Tire Size	275/40R19	285/40R20

(lined up at ground and driver H point)

MERCEDES CLS

Similar head environment

INTERIOR HARDPOINTS		
Front Head Room	940	950
Front Shoulder Room	1430	1430
Couple	850	815
Rear Head Room	920	930
Front Shoulder Room	1420	1420



(lined up at drivers head)

BODY CONSTRUCTION

Describe the type of body construction and materials. Also state where each material is used. If the body shares the same "platform" as other cars or has derivatives, include this in the note.

BODY CLOSURES

Add information about the doors and other closures such as the hood and tailgate. Describe any unusual hinging, articulation or cut lines.

CRASHWORTHINESS

Meeting safety legislation and expectations will influence the vehicle architecture a great deal. The package logic board should illustrate that the various crash requirements (high-speed front and rear impact, side impact, roll-over, pedestrian impact and interior protection) have been considered.

FORWARD VISIBILITY

The upper body or "Greenhouse" is designed to withstand roof crush testing and provide clear visibility for the driver and other occupants. State the forward vision angles (that helps to set up the windshield aperture), but also reference other areas if visibility is challenging, such as the belt height, rear header, rear deck, or pillars.

INTERIOR

Draw the basic outlines for the main interior components such as the floor, I.P., steering wheel, seats, headliner and door trims. Show unique features such as folding seats or storage systems in the main view, or draw a separate view to show them in different configurations. Showing the head environment in the side and rear view is important to prove the roof and side glass will work with the occupant package.

DRIVER

Use the SAE 95th percentile male driver manikin. Show the the main datum points, i.e., the H point and heel point. Also include other theoretical lines that represent the shin, thigh and torso (back angle, head form & eye ellipse). Describe the driver seating position, lateral location and environment.

REAR OCCUPANT

Use the SAE 95th percentile male passenger manikin. Show the the main datum points, i.e., the H point and heel point. Also include other theoretical lines that represent the shin, thigh and torso (back angle & head form. Describe the seating position, lateral location and environment. Note the relationship to the driver (couple).

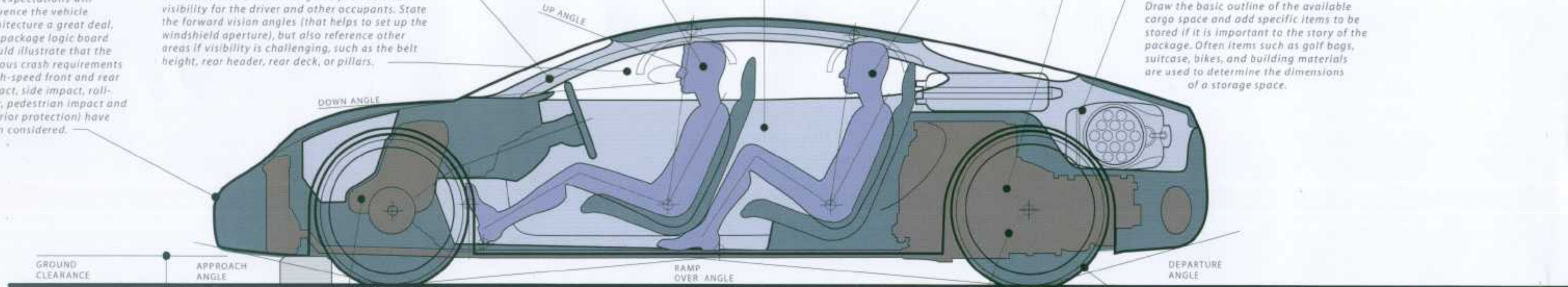
POWERTRAIN

Most vehicles will have an internal combustion engine. In this case draw a basic outline of the main components including the engine, transmission, final drive system and cooling module. Describe the engine size, configuration and orientation. Add information about power output, number of gears (speeds) and which wheels are driven.

For alternative powertrains such as battery or fuel-cell powered electric, draw the basic outline of the major components such as the motors, controllers, batteries/fuel-cell system and cooling. Add information about power output.

CARGO

Draw the basic outline of the available cargo space and add specific items to be stored if it is important to the story of the package. Often items such as golf bags, suitcase, bikes, and building materials are used to determine the dimensions of a storage space.



GROUND CLEARANCE

Each vehicle will need to meet ground clearance requirements or expectations for its market segment. The ground-clearance dimension together with the approach, ramp over and departure angles should be added to the package. This is especially important for off-road vehicles. Also add parking blocks, curb stones, ramps, etc. where appropriate.

FUEL STORAGE

Most vehicles will need to store gasoline or diesel fuel. Draw the basic outline of the realistic size fuel tank that matches the target range of the vehicle. For electric vehicles draw an outline of the battery pack or fuel cell system.

FRONT AND REAR SUSPENSION SYSTEMS

Drawing the suspension in the layout is time consuming and tends to complicate the views, so it is recommended that they be left off. However the proposed systems should be described. Include the name of the suspension and the spring type. For extreme off road vehicles add jounce travel information also.

WHEELS & TIRES

Add the tire dimensions (tread width, aspect ratio & wheel diameter) and include the tire outside diameter also. Front and rear tires are often different sizes on high-performance sports cars. In that case add two separate notes.

EXTERIOR DIMENSIONS

LENGTH	4820
WIDTH	1925
HEIGHT	1300
WHEELBASE	3070
FRONT TRACK	1635
REAR TRACK	1625

INTERIOR DIMENSIONS

FRONT HEADROOM	950
FRONT SHOULDER ROOM	1430
COUPLE	815
REAR HEADROOM	930
REAR SHOULDER ROOM	1420
CARGO VOLUME (est.)	200 liters

TARGET SPECIFICATIONS

COST	$95,000
SPEED	175 mph
ACCELERATION	5.0 sec., 0-60mph
WEIGHT	1800 kg
FUEL ECONOMY	25 city - 30 highway
SALES VOLUMES	25,000 per year

BRAND LOGO

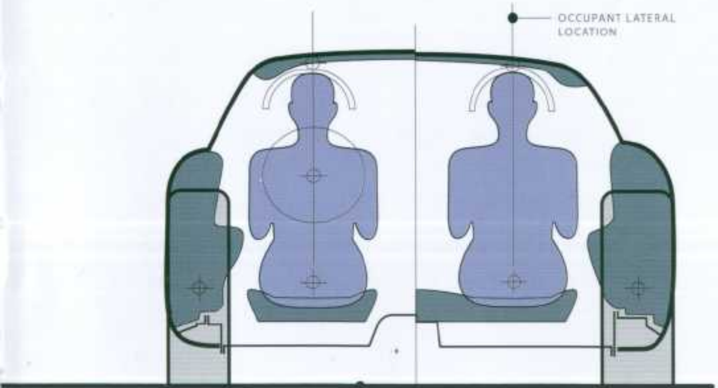
PORSCHE BOXSTER

Similar powertrain layout and relationship to the occupant.
Similar occupant height from ground.

(lined up at H-point or rear spindle)

ALTERNATIVE ARCHITECTURE

Show additional scaled down views to illustrate alternative solutions or different package configurations. The view above shows another powertrain solution. It could also show such things as folding seats or truck bed-storage configurations.



CURB GROUND LINE

The initial package is developed at "curb" attitude. (The ride height is set with an empty vehicle - no passengers - with all fluids tanks full).

DESIGNER, NAME & DATE

Always add your name and date to your work

FUNCTIONAL OBJECTIVES

Create some goals for your project. The information in the package drawing will relate directly back to these.
Describe the customer, market (country or continent), environment (city, mountain, farm, etc.), main uses and any other information that may affect the package. Set some appropriate target specifications for your vehicle also, these will depend on the vehicle type. For a sports-car concept, speed and handling are important targets to set. For SUVs & trucks, load carrying capacity and ground clearance will be the main focus.

CONCEPT TITLE

Write a brief description of the concept. Include the brand logo and a word picture.

BENCHMARK STUDIES

Show several product benchmark studies.

1. Communicate the overall exterior dimensions and proportions.
2. Show the occupant package with interior dimensions
3. Illustrate how the exterior proportions are influenced by the powertrain
4. Provide additional studies that show attributes or unique features, such as cargo storage and interior flexibility.

These studies may also show how the concept differs from other products in the same market segment or vehicles in a brand product line up. Add a description to each study to communicate why the two vehicles have been compared.

MAIN PACKAGE LOGIC DRAWING

Show the side and end sectional views. Add a plan view if required. Show enough detail to describe the basic vehicle architecture and each system. Include the powertrain outline, occupants and interior features. Add a brief written description of the various systems and any special features that are significant to the exterior proportions and the interior design.

GENERAL PROJECT INFORMATION

Include functional objectives, target specifications and dimensions.

ABOUT THE AUTHORS

Stuart Macey

Stuart Macey's career in the automotive industry has spanned three decades, designing cars and trucks for over thirty brands in five countries. He is currently Chief Engineer for Ken Okuyama Design USA in Southern California.

Like most car guys, his passion for cars came from his dad who co–owned a garage (Bailey & Macey) in Portsmouth on the South Coast of England. Some of Stuart's earliest memories were of watching their Formula-3 race car, driven by Rod Banting, at Goodwood in the early '60s.

As a child he spent many evenings working on cars with his dad, usually holding the torch. Alf was a big fan of Sir Alec Issigonis and would only drive Morris cars and vans. Stuart would spend hours staring into the engine bay of their Minis and marvel at how Issi packed so much into such a small space.

At 16, Stuart started work as an apprentice for Vosper Thorneycroft, building and designing hovercraft structures. In 1979, he transitioned into the car industry as a body engineer and after a few years of training with Pressed Steel Fisher and then Ford Trucks, decided to work freelance overseas as the British car industry went into a rapid decline.

At 22, Stuart joined an independent design consultancy in Southern Germany designing for Daimler–Benz and Audi, then at 23 moved to Detroit and worked for Chevrolet until 1983.

For the next seven years Stuart worked for International Automotive Design, with such clients as Porsche, Volvo, Honda, Renault, Kia, Opel, Mazda, Ford, Daf trucks and Freight Rover. The experience gained from working in studios across Europe was priceless, helping him to understand that although every brand has its own perspective on design and the process, the basic principles are the same everywhere.

One of his proudest moments was the unveiling of the "Mini MPV" at the 1990 Turin Auto Show. He had packaged and styled this small van for IAD (a rare opportunity for an engineer) which has subsequently helped him to support design teams with much greater creativity, sympathy and passion.

In 1991, he returned to the USA, working with Chrysler at the Design Office at their new technical center in Auburn Hills. After ten years in Michigan, he was transferred to their Pacifica Advanced Design Center in Carlsbad, California for the next seven years.

In 2002, Art Center College of Design in Pasadena invited Stuart to develop a new syllabus for their Vehicle Architecture class and teach it to the transportation design students. Ken Okuyama was the newly appointed department chair, and having just finished designing the Ferrari Enzo, he wanted to put a stronger emphasis on vehicle packaging in the design curriculum. Geoff Wardle and Stuart taught the class together for several years and the notes they developed have been compiled for this book.

Geoff Wardle

Since graduating from the Royal College of Art in 1977, Geoff Wardle has worked as a designer at British Leyland, Chrysler, Peugeot, Saab and Ford of Australia. In addition, he has worked as a consultant designer with a number of companies including Tatra in the Czech Republic and TVS Motors, a large Indian motorcycle company.

In 1993, Geoff was invited to become the Chair of Transportation Design at the Swiss campus of Art Center Europe, before moving to their Pasadena campus in California where he is now Director of Advanced Mobility Research.

Growing up in England, he knew from a very early age that he wanted to be involved in creating new kinds of transportation. Surrounded by Dinky Toy models of Foden trucks, Triumph Heralds, London Transport Routemaster buses and Hornby-Dublo Castle class locomotives, he did not really care what kind of transportation they represented because he loved them all.

Nobody in Geoff's life knew what a transportation designer was in those days, and so following advice from others and his own instincts, he focused on technical subjects at school and sought a place at an engineering university. Sponsored by the then British Leyland Motor Corporation, and given the choice of studying with their heavy truck division or their car-body engineering division (Pressed Steel Fisher), the perceived glamour of the car industry won out. However, even to this day, Geoff has equal passion for large trucks, buses and trains.

Ten minutes into his first engineering lecture at Hatfield Polytechnic, he knew that he did not want to be an engineer—too much math. Fortunately, through the auspices of one of his tutors, he discovered the world of industrial design and the Automotive Design program at the Royal College of Art in London. This program required a prior degree, which gave him the motivation to successfully complete his bachelor's degree in mechanical and vehicle engineering, specializing in car-body engineering and structural analysis. However, as throughout his education, when classmates were busy with their slide rules and calculators, Geoff would more likely be busy sketching cars or trucks on the back of his thermodynamics notes!

Although British Leyland became much maligned, this corporation had many talented designers and engineers working amongst its many divisions, and some of these people encouraged Geoff and taught him many things.

Geoff believes that in any successful design team, a variety of designers and studio engineers are needed who contribute different skills or viewpoints to a program. There is no doubt that his combination of engineering and design has set him in good stead during his design career, allowing him to push really hard for technical solutions that enabled some of his design proposals to be successfully executed. He has taught the subject of vehicle architecture over several years with Stuart Macey.

GLOSSARY

There are quite a few terms that are unique to the auto industry, below is a list of words that car designers should be familiar with. These are mainly used in design studios in the USA, many of them are universal in most English speaking offices, but expect to hear some variations depending on the company and country you are working in.

Axis. (pl.axes) Theoretical line about which a mechanism or wheel rotates. Also, the intersection of the X,Y and Z axes create the origin point for the vehicle's master grid system and determine the grid orientation.

Apertures. Openings in the body structure that are used for access into the various compartments, i.e., passenger cabin, engine box and trunk.

Body in White (BIW). A complete unpainted body assembly usually made from steel or aluminum.

Backlight. The rear window, not to be confused with the rear lamp.

Box sections. Load-bearing elements in the body assembly that help to form a strong, light weight structure.

Chassis. Traditionally this refers to the entire underbody structure and the components attached, i.e, the suspension, steering, brakes, fuel tank, etc. Since the introduction of unit body construction, most design teams will use this term to reference the mechanical components only.

Closures. Parts of the body assembly that open to allow access, but complete the structure or exterior shape when closed (doors, hoods, trunk lids and some movable glazing).

Cowl. The assembly of panels that create the base of the windshield aperture.

Cross Members. Beams that run across the body structure mostly under the floor.

Curb Weight. The mass of a vehicles including all fluids, i.e., fuel, lubricants, coolants, etc. with no occupants or cargo. Most vehicles are designed at "Curb Attitude" sitting on a "Curb Ground Line."

Datum (Planes, lines & points). Used for reference during the design and build process. These are very important theoretical elements that feature extensively in the package.

Designer. In the auto industry this term is usually reserved for the staff who develop the aesthetics.

Final drive. The drive shafts and differential assembly that transfer power from the transmission to the wheels.

Fire wall. The bulkhead between the interior and the engine compartment, separating the passengers from heat generated by the engine and a possible fire. For most (front engined cars, this panel is in front of the driver's feet and is called the dash and footwell.

Fuel cell. A system that converts hydrogen fuel into electricity without producing harmful emissions.
This term is also often used in the race car design to describe the gasoline or diesel fuel tank.

Greenhouse. The upper body of a vehicle body structure, glazing, roof systems and trim.

GVW. The "Gross Vehicle Weight" which needs to be considered when setting up ground clearance, brakes, powertrain and suspension. The "full rated" ground line is used to show the vehicle attitude when it is loaded to the maximum weight.

H-point. The reference datum point on the manikin that represents the hip joint. Also known as the SgRP (seating reference point) or R point in Europe.

Hard points. Theoretical points in space that represent parts of system envelopes. These are set up by the engineering team for the designers to create the CAD or clay models over.

HVAC. Acronym for heating, ventilation and air conditioning system. This includes the heater box, AC condenser, air distribution box, vent ducting and air outlets and evacuation vents.

Homologation. To sell cars into any market they must be "Homologated" to verify that they meet local "vehicle type approval" for safety and emissions.

Hybrids. Vehicles with more than one power source, usually a combination of internal combustion and electric motors.

Jounce. Upward suspension travel."Full jounce" occurs when the suspension is fully compressed.

Knee blockers. An area in the instrument panel, in front of the occupants knees, designed to prevent the passengers from sliding forward off the seat during a frontal collision when they are not wearing seat belts.

Internal Combustion Engine (I.C.E..). Most vehicles are powered by engines that produce power from the combustion of fossil fuels either gasoline or diesel.

Instrument Panel. Often referred to as the I.P. this assembly contains the instruments, switches, air vents, glove box, etc and spans the width of the vehicle interior, in front of the front occupants.

Mono-volume. A term used to describe a vehicle that has one main shape (no hood or trunk) in its side view silhouette. Typically micro cars and minivans.

NCAP. New Car Assessment Program. An independent safety program to inform customers about how safe various vehicles are. Most manufactures design to meet the "5 star" NCAP standards, which are higher than most government requirements, to market their cars to educated consumers.

Package (Packaging). All of the elements in the vehicle architecture that are driven by function, not style. Packaging is a function performed by the members of the design team who set up the vehicle architecture.

Pillars ("A, B ,C, D, etc"). The elements in the body structure that create the door or glazing apertures, between the underbody structure and the roof.

P1 & P2 Curves. The curves that represent the opening of the side door aperture panels in the body structure. They are usually the "heel and toe" of the weld flange which the seals are mounted to.

Plenum. The enclosed chamber usually at the base of the windshield that helps to remove moisture and large particles from fresh air that is drawn into the vehicle's heating and ventilation system. This often becomes a structural element.

Powertrain. The combination of the engine, gearbox and final drive system that create and transmit power to the wheels.

Rails. Beams that run longitudinally in the body structure, i.e., roof rails, underbody frame rails, etc.

Reach Zones. Theoretical surfaces that represent the limits of where the driver's hands will comfortably reach controls.

Rebound. Downward suspension travel.

S.A.E. (Society of Automobile Engineers) An international, network of vehicle engineers, that works to share and publish information, to improve vehicle functionality and design processes.

Sections. These are cut on flat planes through the architecture to show how the components are configured. They are also used as a 2D media for design and manufacture. "Car Line" sections are cut parallel to the grid planes (X,Y and Z) If they are cut out of grid they are called "radial or "compound radial" sections. A sectional view is similar to a section but also shows visible details behind the section plane.

Sills. The structural box sections under the doors that stretch from the front to the rear wheels.

Spindles. The shafts that the wheels revolve around Because these are not always square to the grid, they are often represented as points which are used as main reference datums to represent the wheel centers.

Telematics. Information or data that is relayed by wireless means. The telematic systems include satellite navigation and audio/video equipment .

Tire Envelopes. These are volumes calculated by the chassis engineers to describe the tire profile as it is translated by suspension travel and steering. The envelopes also include build tolerancing, flex(compliance) and snow chains if required.

Three-box. A term used to describe a car or vehicle that comprises three main volumes: hood, passenger compartment and trunk.

Transmission. Transmits the power from the engine to the final drive through a series of reduction gears speeds can be changed automatically or manually.

Tumblehome. The angle and curvature of the upper body side as the surface leans in towards the center line. Vehicles with upright side glass are said to have "stiff tumblehome". This term has been used in the shipbuilding industry for hundreds of years to describe hull curvature above the water line.

Two-Box. A term used to describe a vehicle that comprises two main volumes; typically a hatchback or station wagon.

Unibody. (Unit-body or monocoque) A car body structure made entirely from pressed-steel or aluminum sheets that is rigid enough not to require a separate chassis frame. Mechanical components are attached to subframes (cradles) or directly to the unibody structure.

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Art Center College of Design

In 1930, when Art Center College of Design was first established, Los Angeles was already a destination for art and entertainment, architecture and even aircraft development. Given the desirable climate and geography, it was also a center for experimentation in automotive performance, as well as beautifully designed coach-built cars for clients desiring personal expression.

Automobile design was part of the design education at Art Center in the 1930s with graduates joining the new General Motors styling activity. In 1948, when Strother MacMinn joined Art Center, the program was formalized. Emphasis on the complete vehicle layout or architecture was an important part of the education from the beginning.

The automotive and transportation industry is in a time of profound change. The designer's role now engages many technologies, as well as influencing marketing and business innovation. This book was conceived to help Art Center students continue to be successful and innovative designers by complementing their vehicle architecture classes. We are confident many others will find it very useful as well.

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