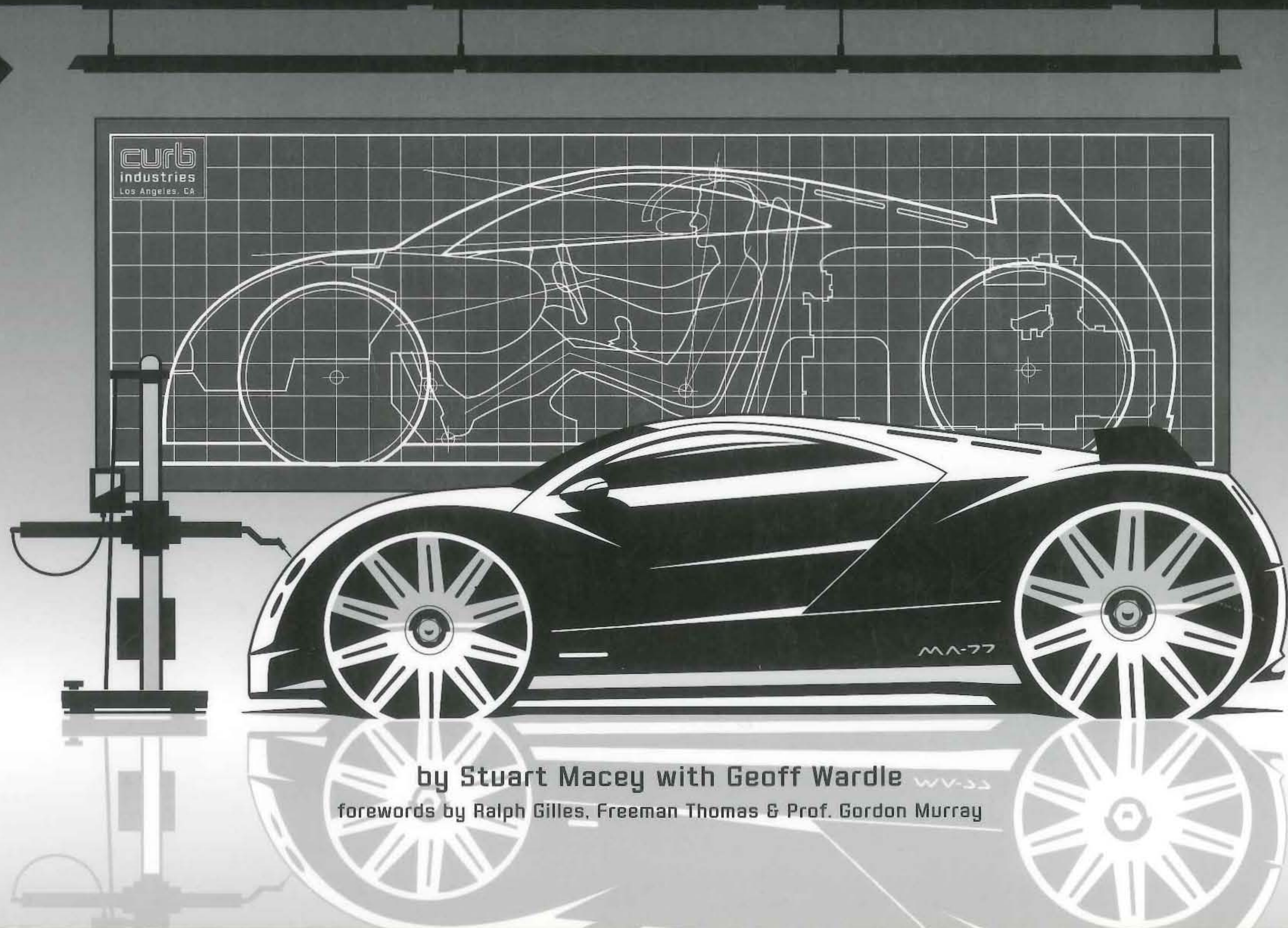
H-POINT

THE FUNDAMENTALS OF CAR DESIGN & PACKAGING



by Stuart Macey with Geoff Wardle

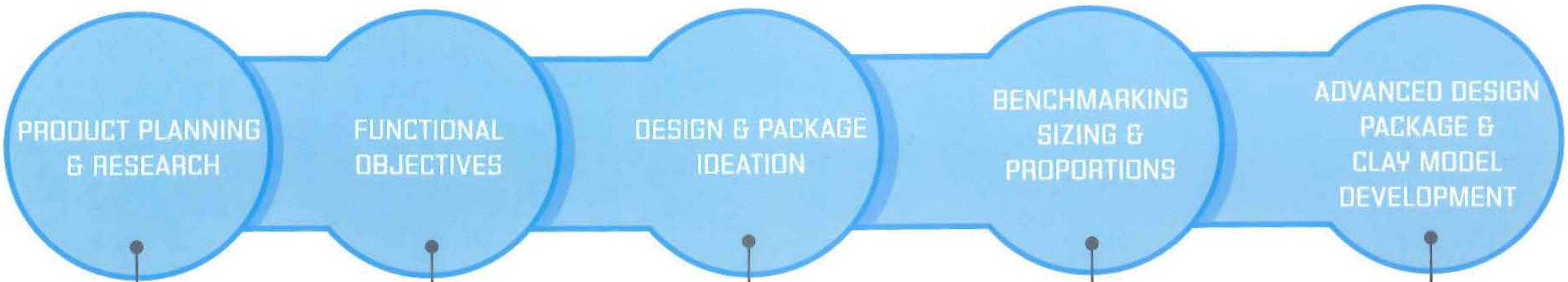
forewords by Ralph Gilles, Freeman Thomas & Prof. Gordon Murray

"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.

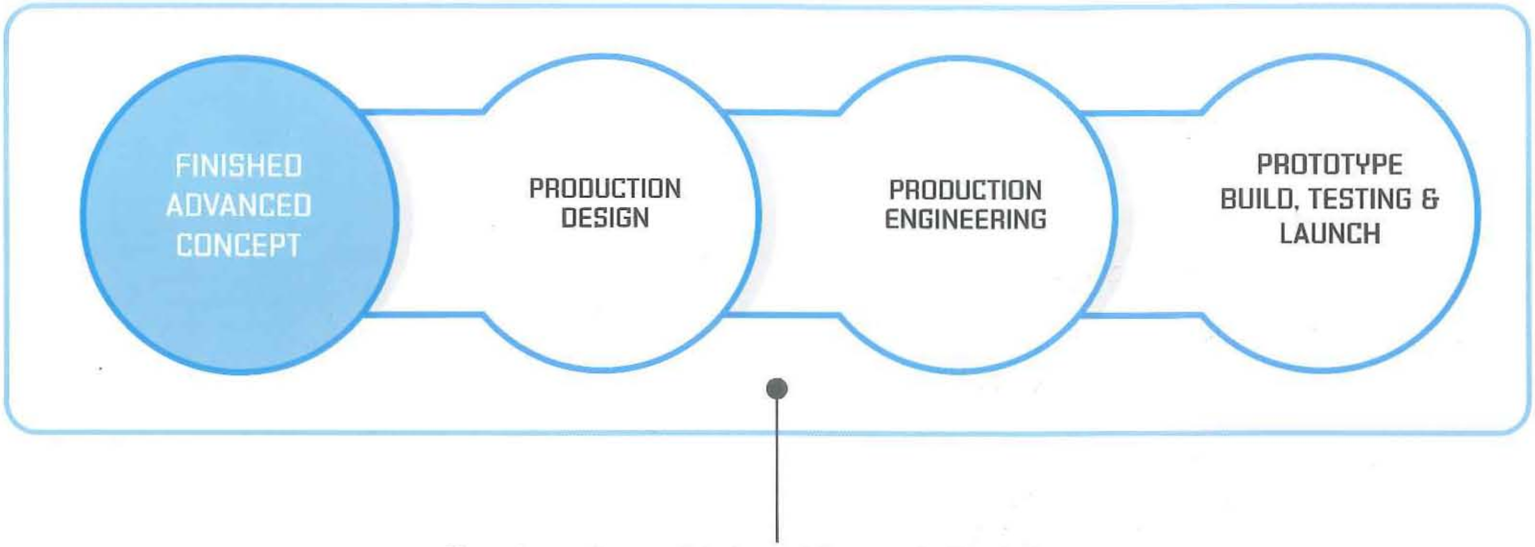
The basic layout of the major components and any innovative features are sketched loosely in various configurations.

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.



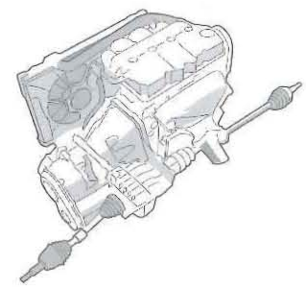
The advanced concept is handed to a production-design team. This group will develop the exterior and interior surfaces over a package that is 100% feasible for production and meets all of the cost targets, as well as the needs of the intended markets. After testing, a few minor design changes may be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

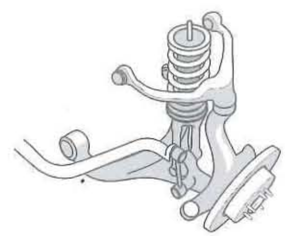
OCCUPANTS

INTERIORS & CARGO

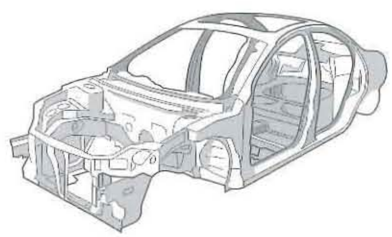


POWERTRAIN

WHEELS & TIRES



SUSPENSION & CHASSIS



BODY

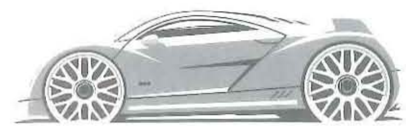
VEHICLE TYPES & MARKET SEGMENTS

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

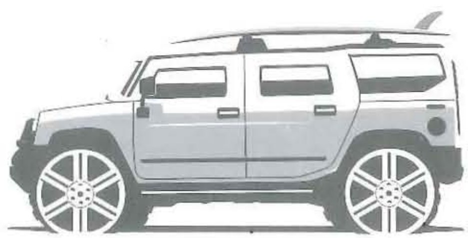
ECONOMY CARS

LUXURY CARS

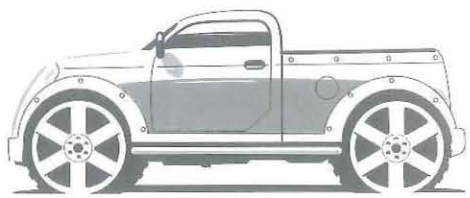


SPECIALTY CARS

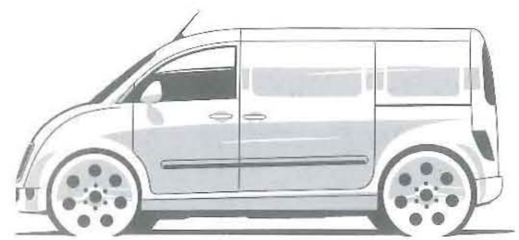
MINIVANS



SUVS



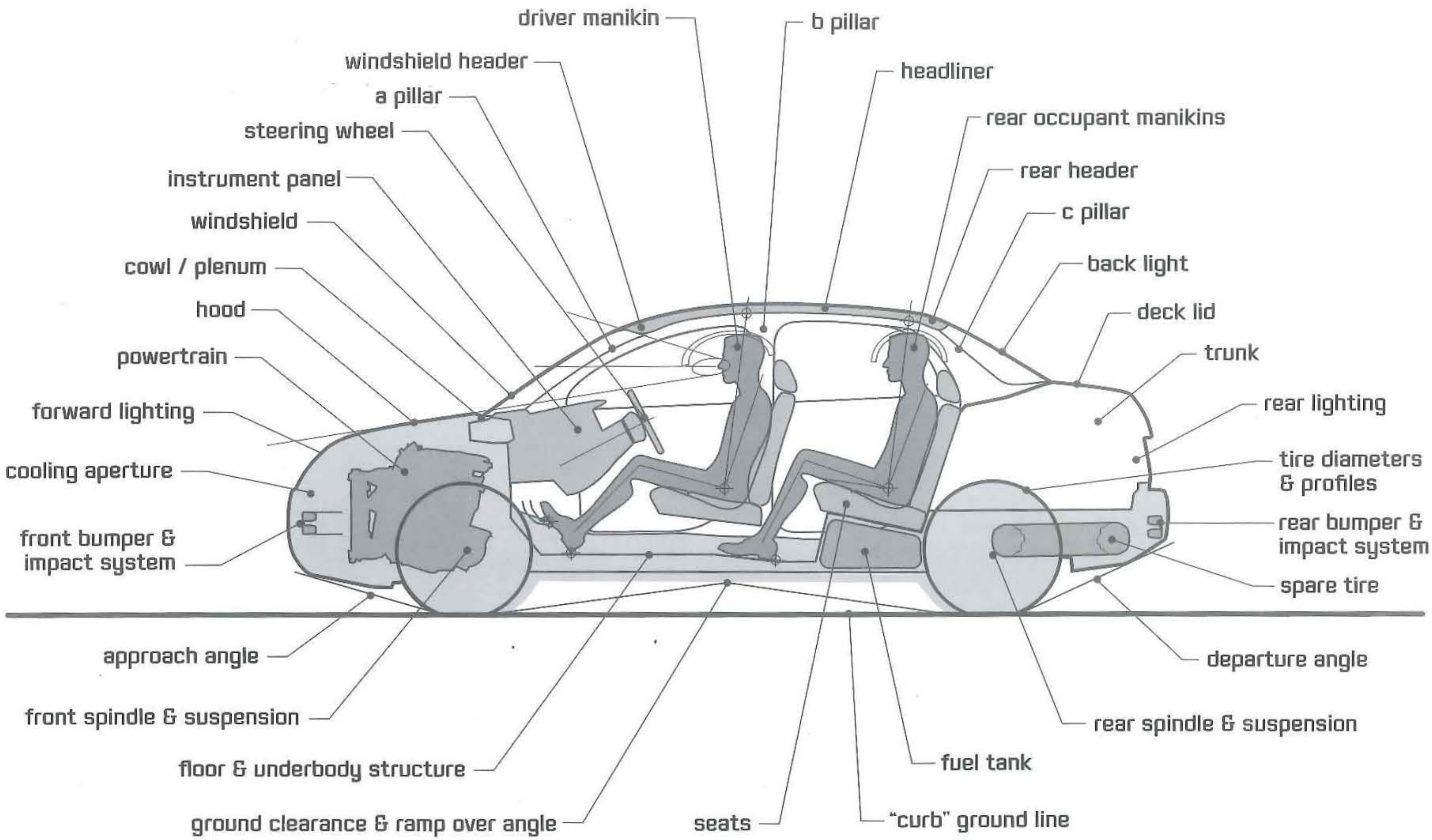
PICKUP TRUCKS

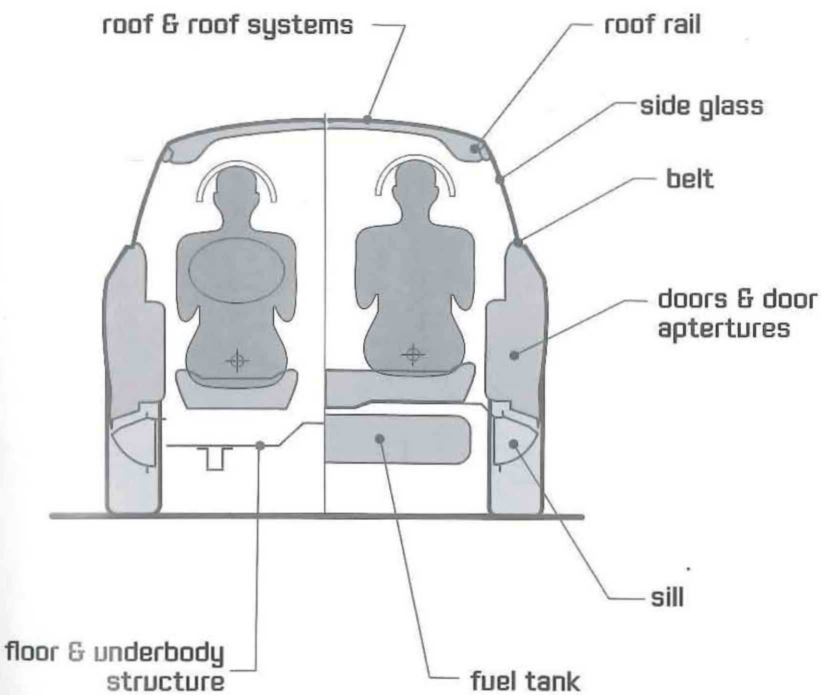


COMMERCIAL VANS

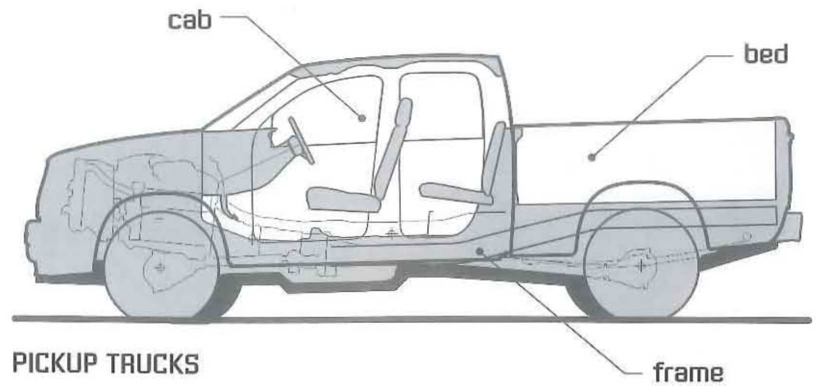
ANATOMY OF THE PASSENGER CAR PACKAGE

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.

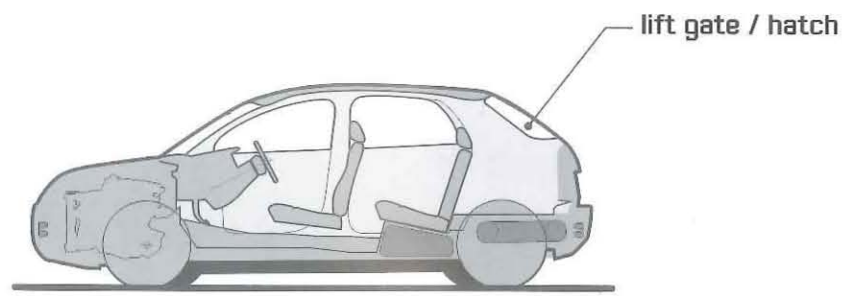




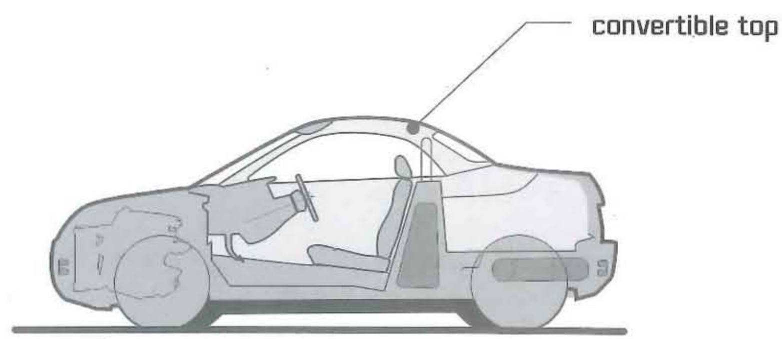
UNIQUE, VEHICLE-SPECIFIC FEATURES



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.

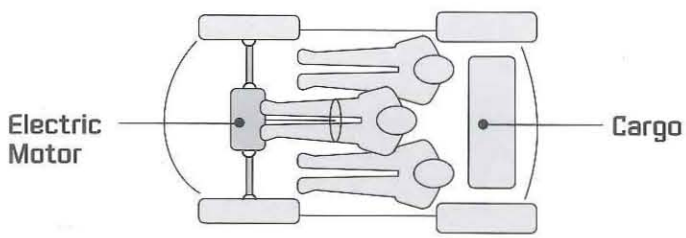
As each system is added, it is going to affect the elements already located in the package, so do not be afraid to start piecing the package together and making adjustments as the concept develops. Always be sure to reference the functional objectives that are driving the architecture. Usually, if you 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.

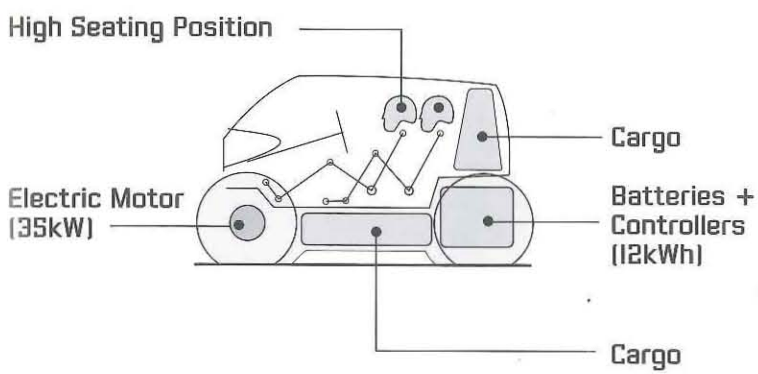
The examples, on the following nine pages, show how different types of vehicles can be approached with the same fundamental process even though they require totally different package solutions. Before creating the package geometry, loosely sketch out the package and arrange the major components based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

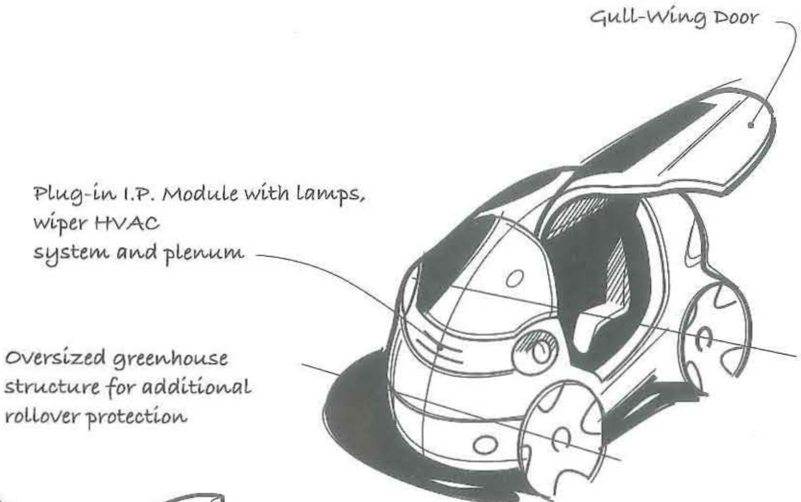
STEP I

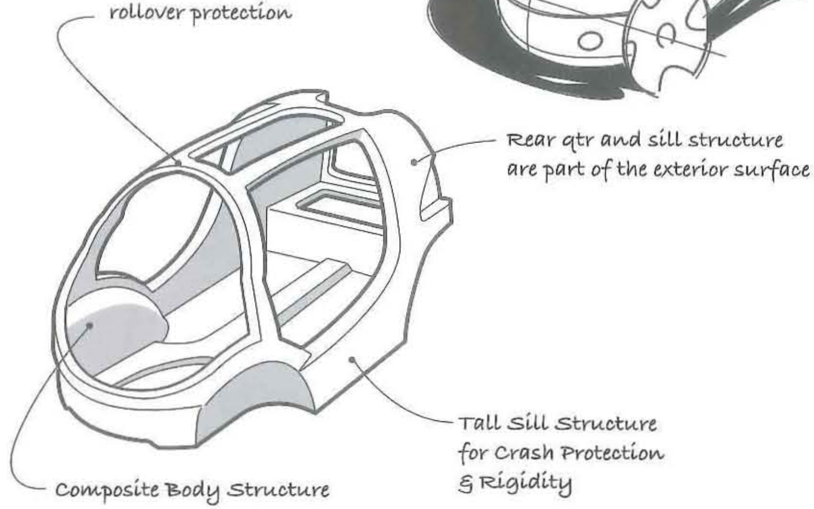
PACKAGE & DESIGN IDEATION

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

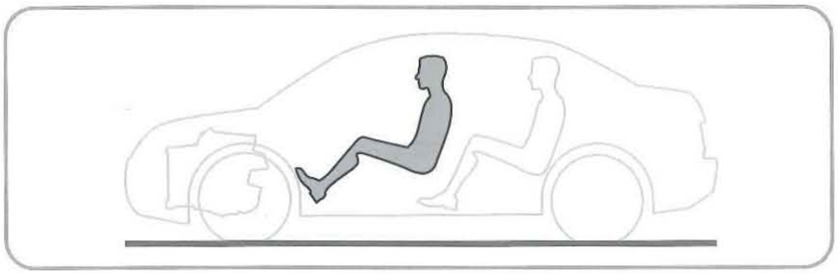
SET UP THE DRIVER'S HEIGHT & POSTURE

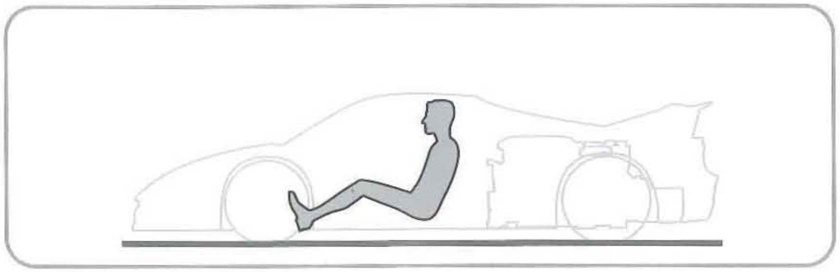
Start by positioning the driver using the SAE 95th percentile manikin. Establish the heel height from the ground and then the seating posture.

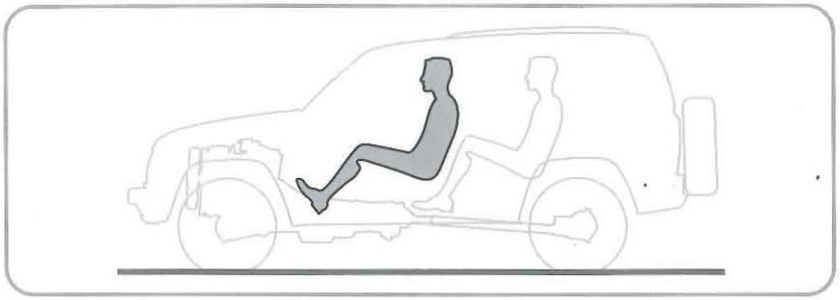
Consider the ground clearance and underbody structure when positioning the heel points. Before setting up the seating posture, think about the following: downward visibility, command-of-the-road seating (eye point from ground), center of gravity, ingress/egress and aerodynamics.

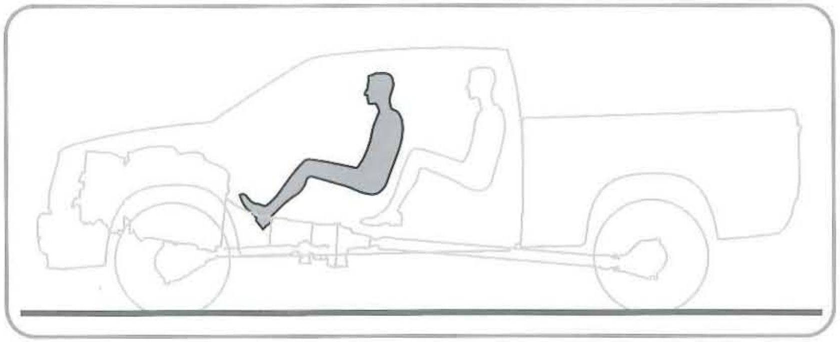
Probably the best way to get the driver location close is to look at existing vehicles with the same attributes and benchmark them.

See Chapter 4 for more information on benchmarking.









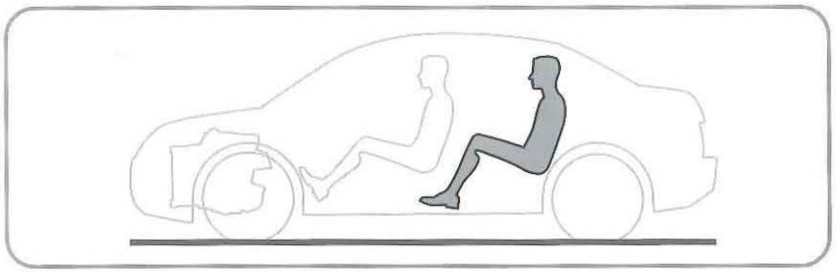
STEP 3

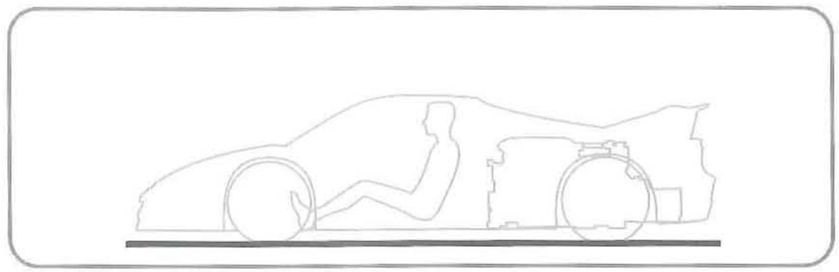
SET UP THE REAR OCCUPANTS

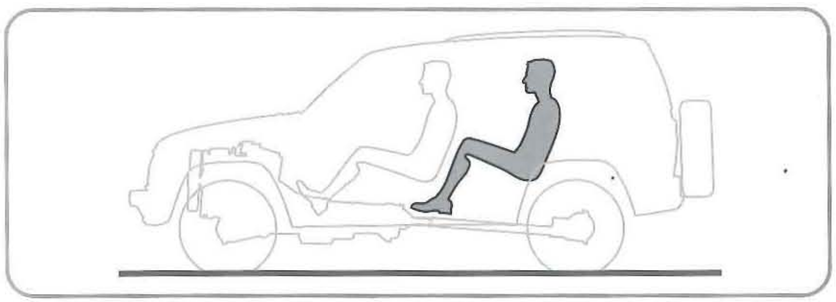
Add the rear occupants if there are any. Again, use a 95th percentile manikin with consideration for leg room and "theater" seating, if appropriate, to give the rear occupants better forward visibility.

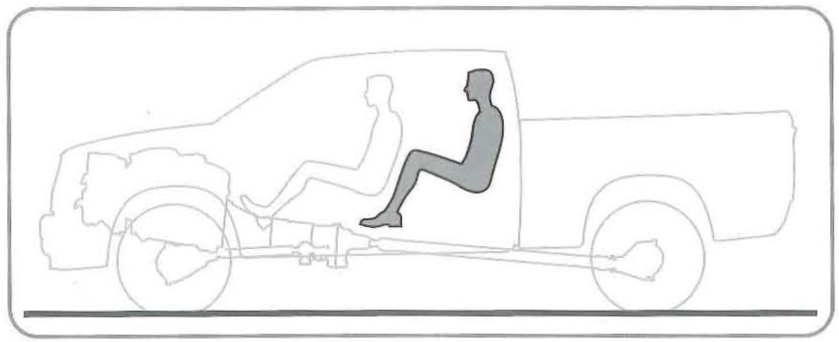
Note that some specialty cars, such as coupes or very small sedans will not fully accommodate a 95th percentile manikin in the rear.

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.







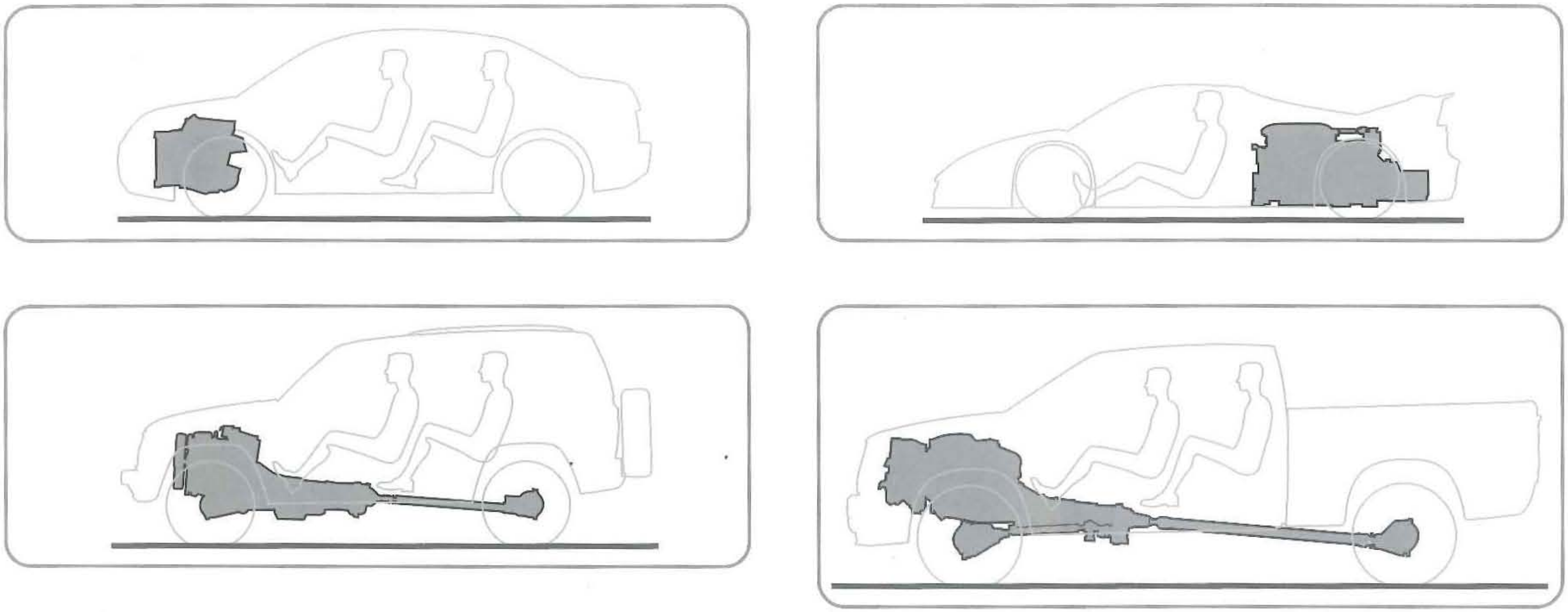


STEP 4

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.

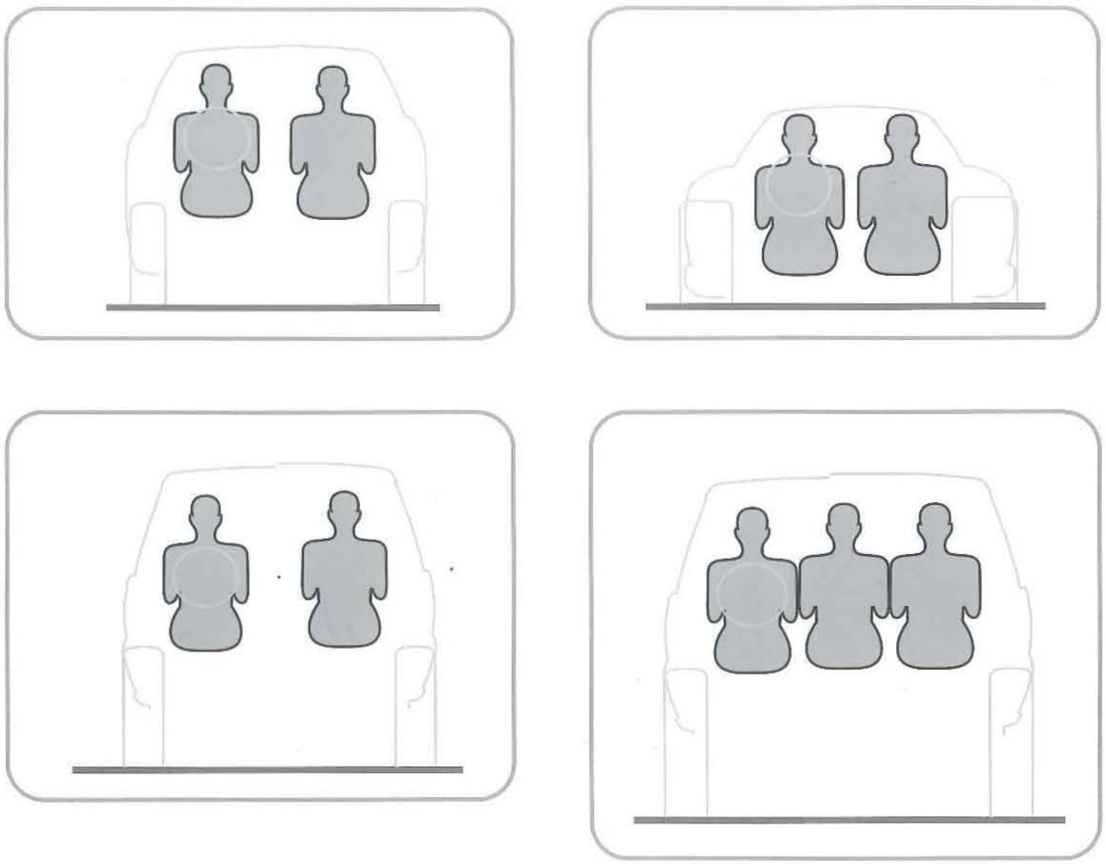
See Chapter 7 for more information on powertrain packaging.



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.

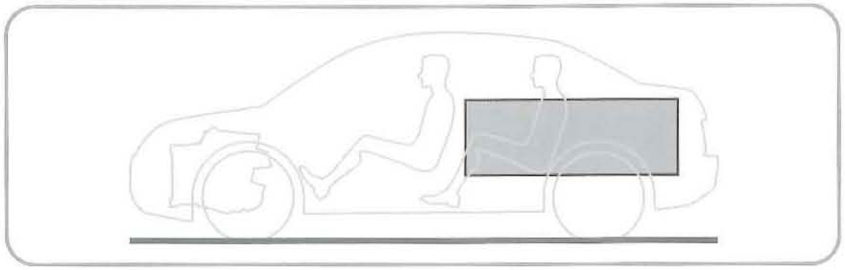


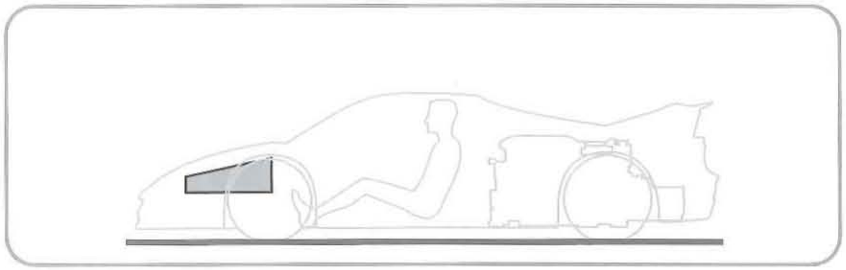
STEP 6

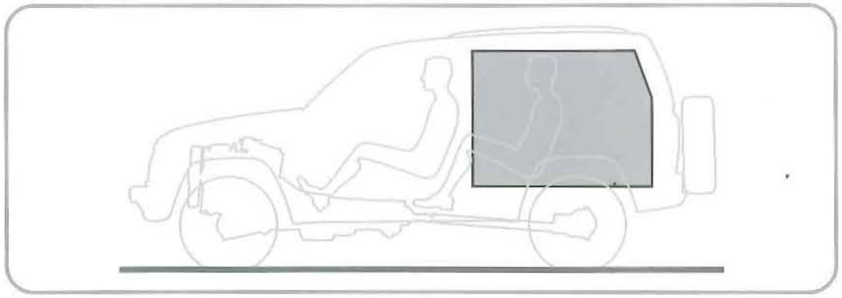
CREATE SPACE FOR THE CARGO

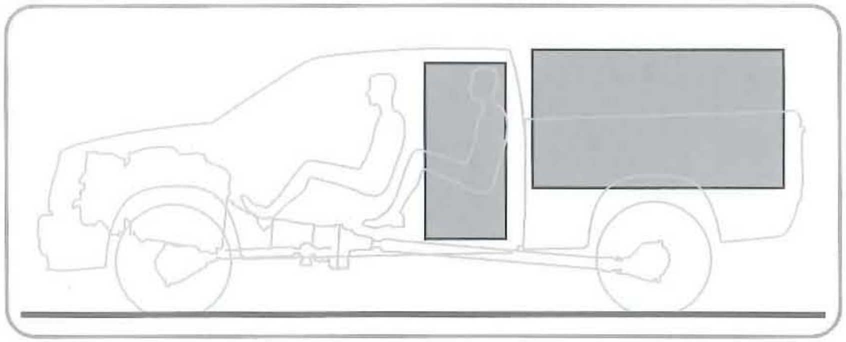
The cargo space may be designed around specific objects or a volume target. Look to create a flexible interior environment with folding seats and bulkheads. Weight will also be a consideration and this may affect the location and other elements in the architecture such as the body structure and suspension.

Refer to Chapter 6 for more information on cargo packaging.









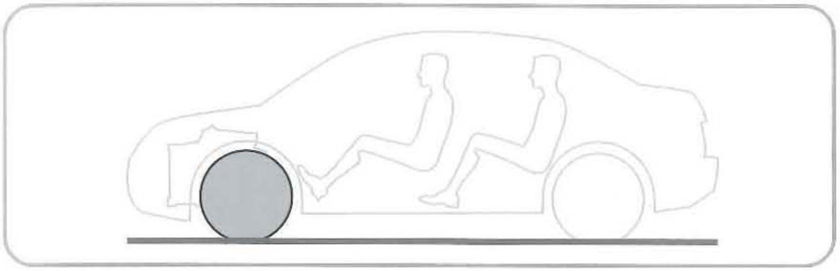
STEP 7

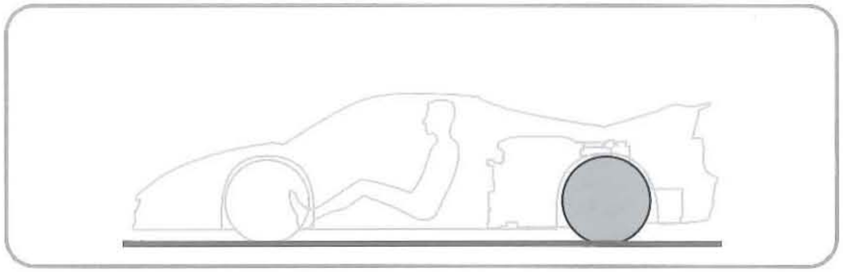
SIZE & POSITION THE (PRIMARY) DRIVEN WHEEL

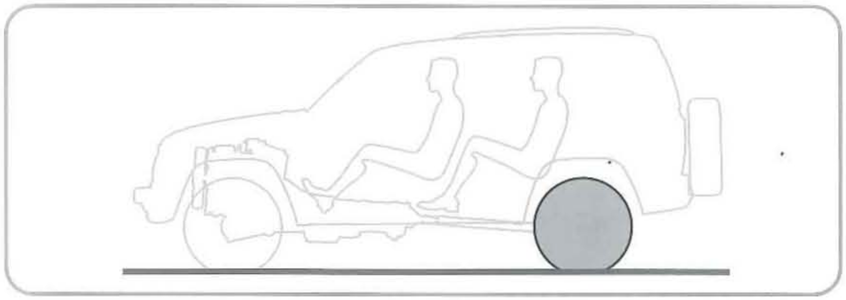
Determine the size of the wheel and tire package and locate the spindles of the driven wheels relative to the occupants and powertrain.

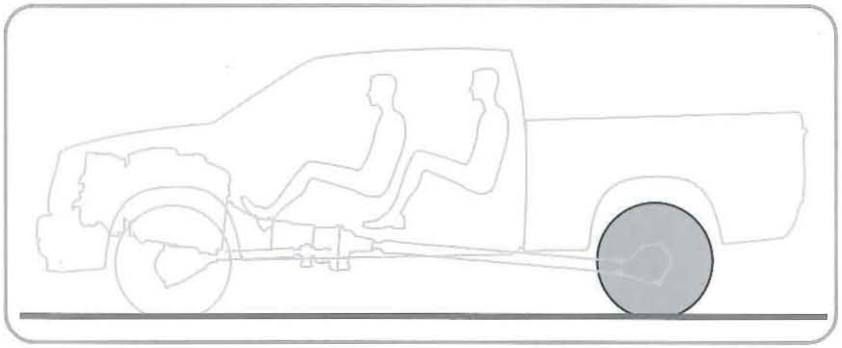
Study the packages below and note the relationship of these elements. They will differ greatly depending on the powertrain layout.

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







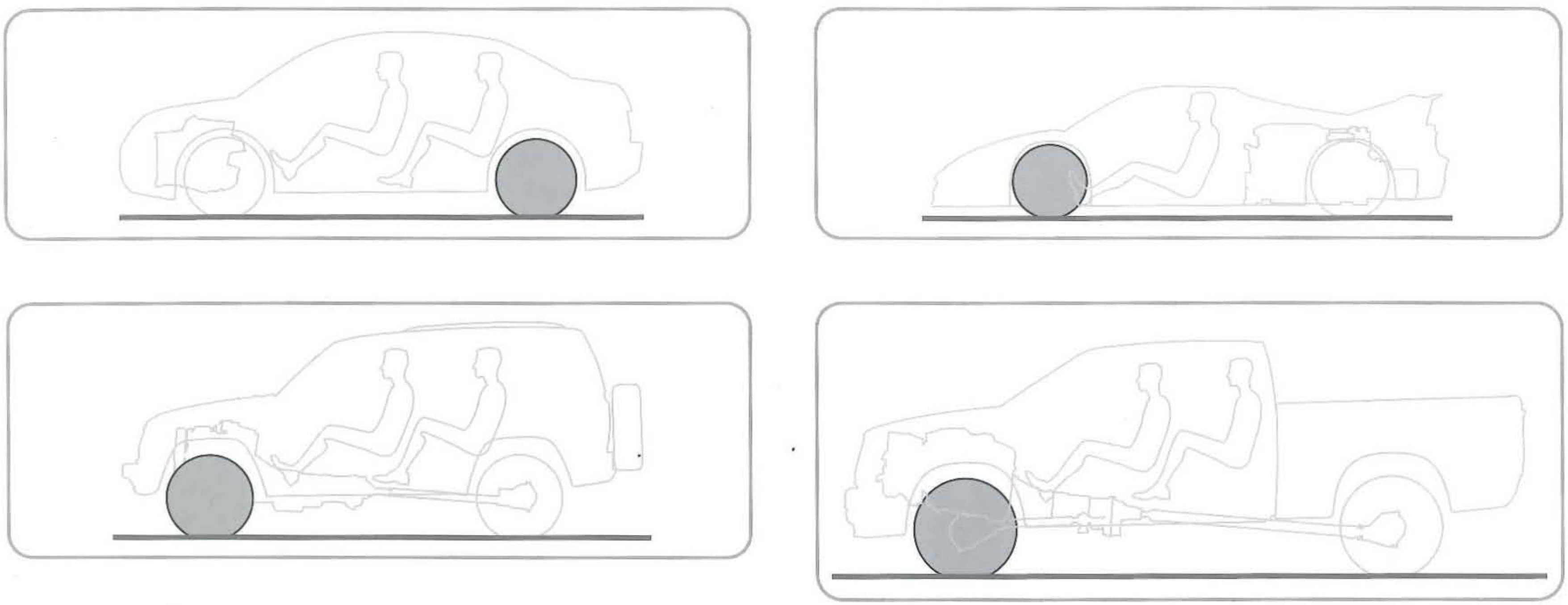


STEP 8

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.

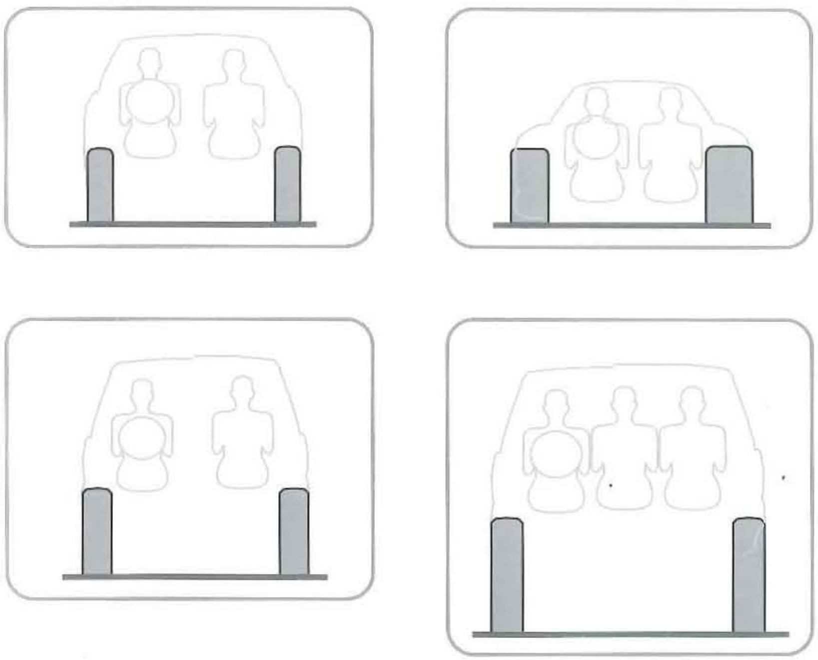


STEP 9

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.

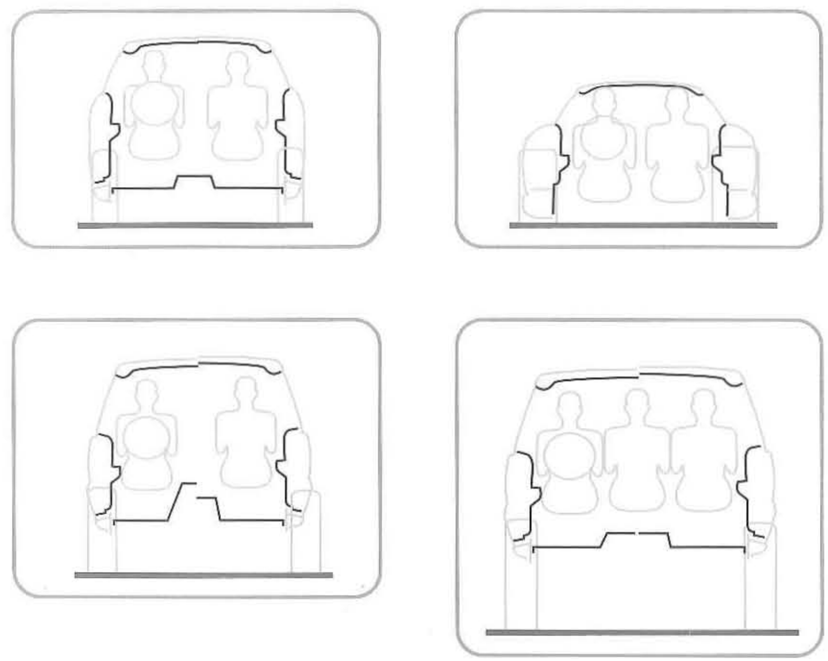


STEP 10

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.



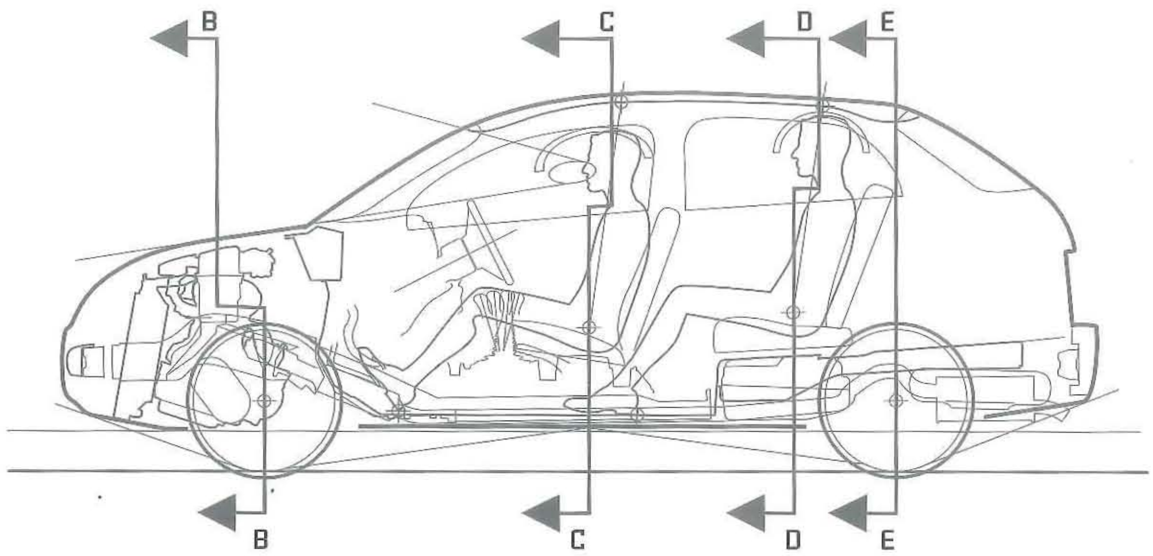
DESIGNING WITH SECTIONS

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.

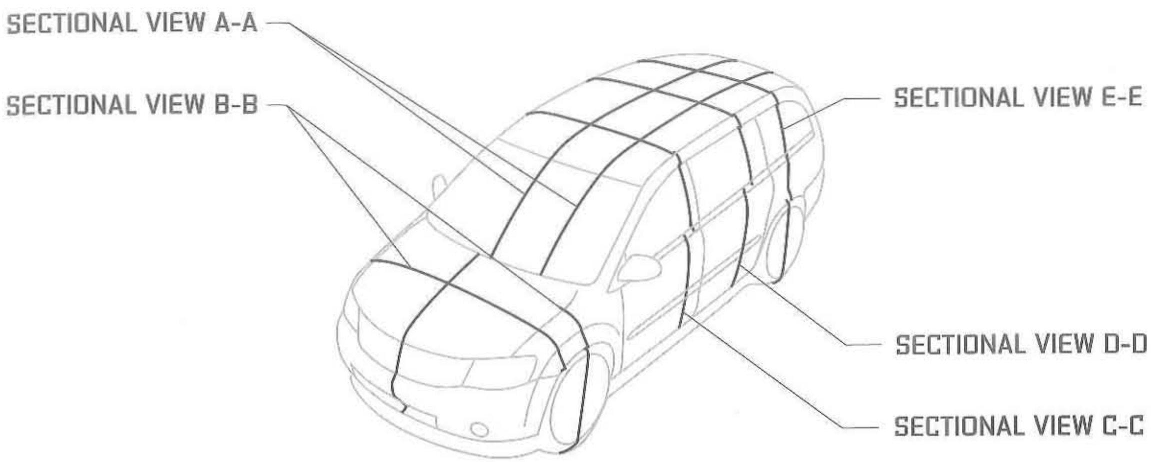
The main objective here is to establish some of the main hard points, so that the exterior design can be modeled over the key elements of the package, developing the body structure as each section is constructed.

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

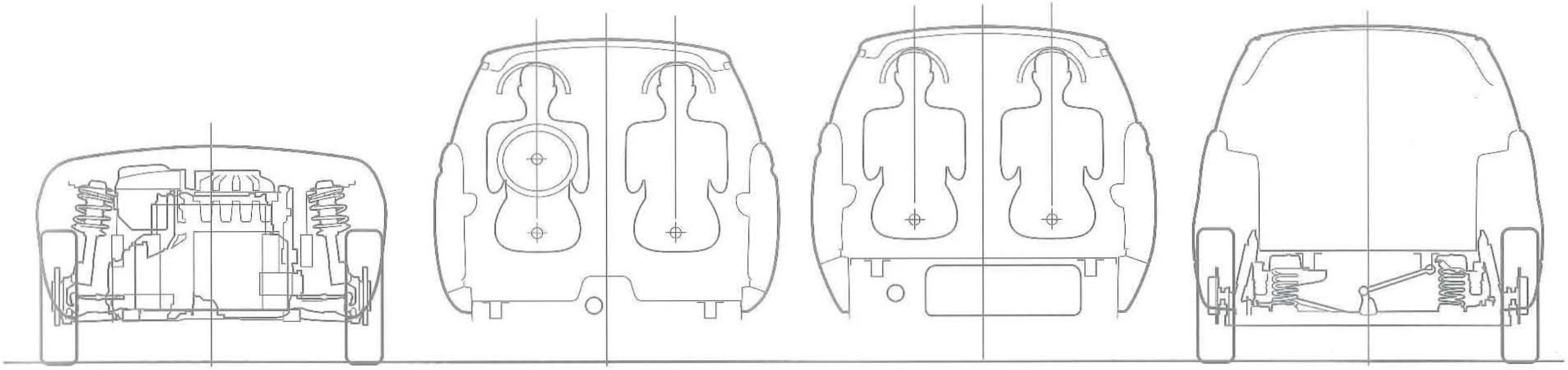
This sectional side view is cut through the centerline of the body and the occupants. The other elements are shown to create a "picture" of the initial package layout.



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 Y0 (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 Y0.



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.

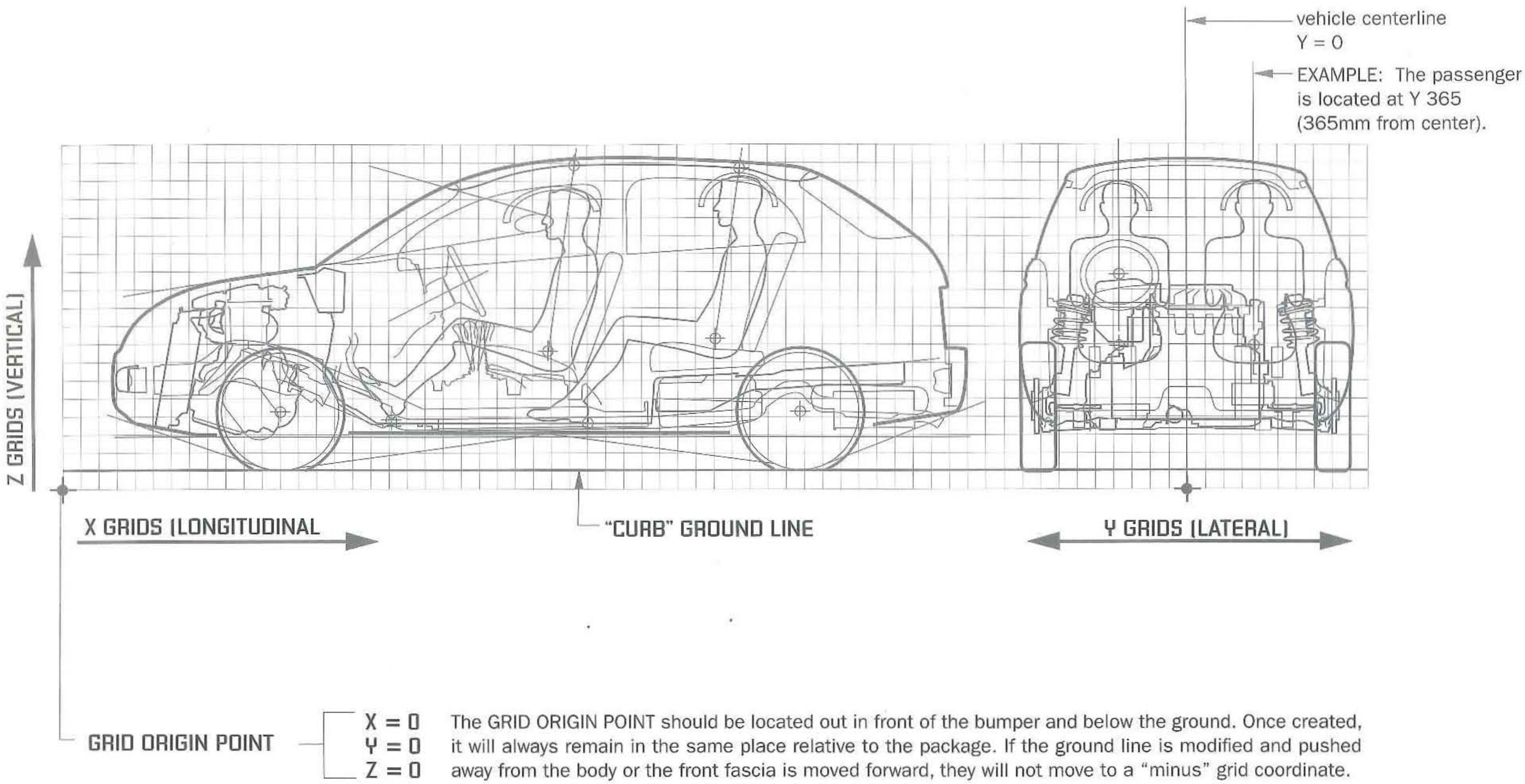
SECTIONAL VIEW C-C
Cut through the front occupants' H-points and head contours, this key section is created to set up the door panels, side glass and roof-rail sections. Other elements like the roof over the head environment, sills, floor and underbody structure are also included here.

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.



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.

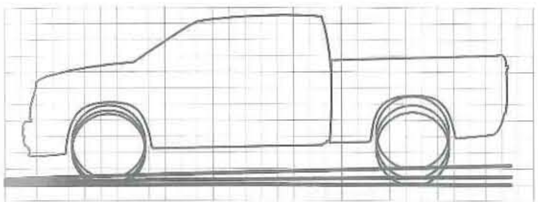
GROUND PLANES (LINES)

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.

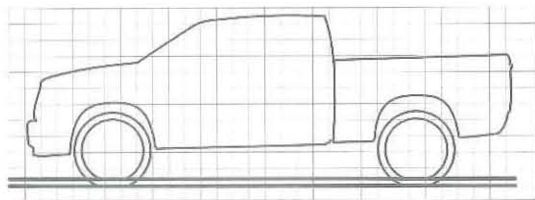


VEHICLE ATTITUDES

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

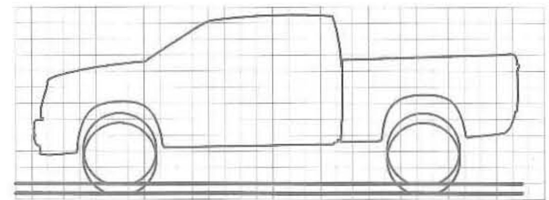
1. Curb — no passengers, full fluids.
2. Full rated — fully loaded to the gross vehicle weight (GVW).
3. Full jounce — fully compressed suspension.

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.

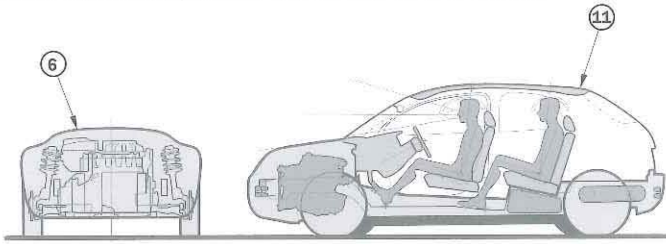


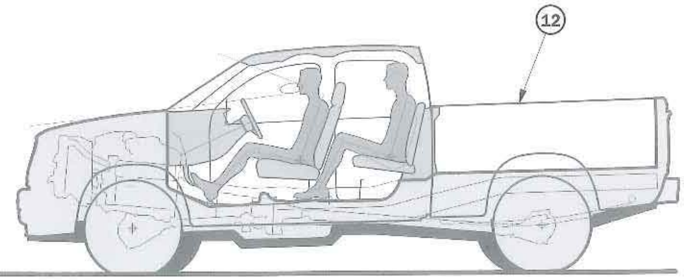
RIDE HEIGHT

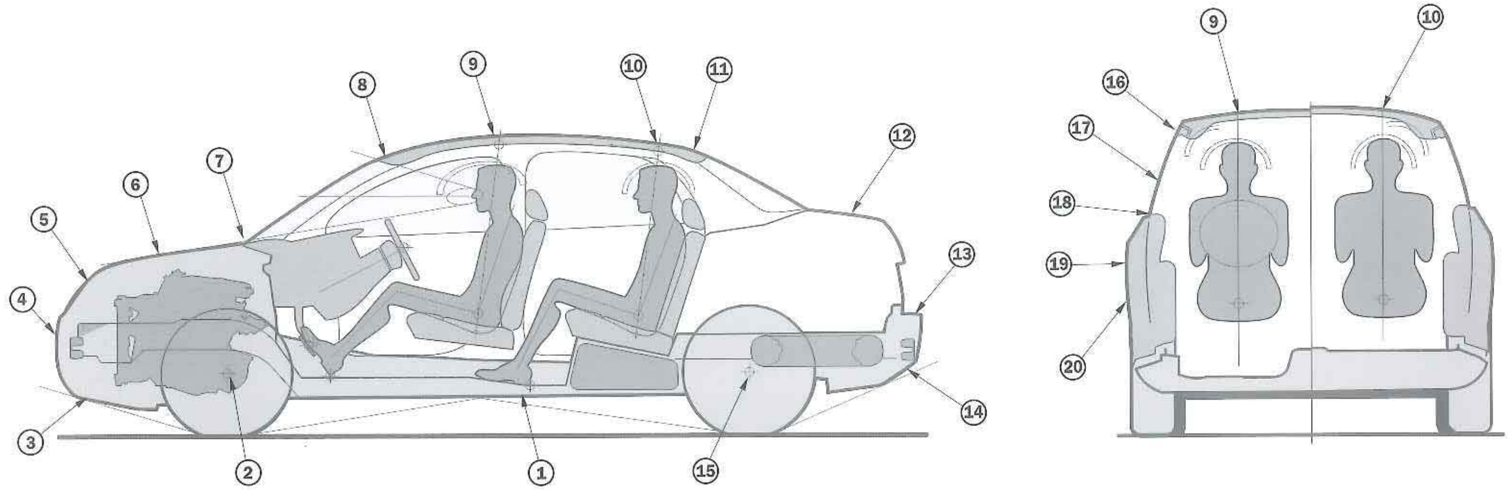
Vehicles with on-road and off-road packages will usually have two or more suspension settings to improve the vehicle's performance in its intended environment.

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

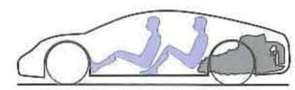
BENTLEY CONTINENTAL GT — *Similar overall length and width*

ASTON MARTIN DB9 — *Similar Height & driver seat height*

MERCEDES CLS — *Similar head environment*

PORSCHE BOXSTER — *Similar powertrain layout and relationship to the occupant. Similar occupant height from ground.*

(lined up at ground and bumpers) *(lined up at ground and driver H point)* *(lined up at drivers head)* *(lined up at H point or rear spindle)*



ALTERN ATIVE A RCHITECTURE

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

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.

CARGO

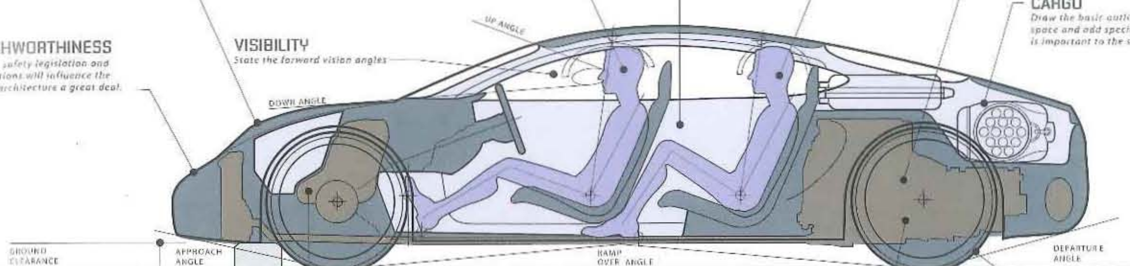
Draw the basic outline of the available cargo space and add specific items to be stored if it is important to the story of the package.

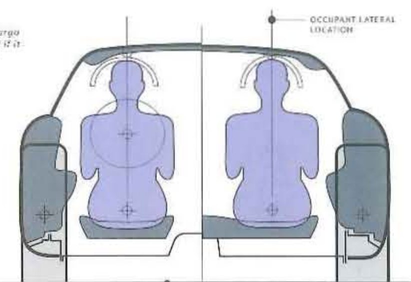
CRASHWORTHINESS

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	1420
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.