Design process at the Ford Motor Company

This resource has been developed by Ford Motor Company Ltd and the Design Museum Education Department. It examines the design process used by Ford by showing how a car is developed from the original concept to the finished product. We also look at the changes in the design process brought about by computer modelling. We aim to show that car design is not just about styling, but also about engineering, testing and evaluating.

The pack includes 3 projects suitable for KS3, KS4 – GCSE/GNVQ and A/AS level.
Overview

There are many reasons for continually redesigning new cars. For example:

- Advances in technology in the fields of mechanical, electrical and production engineering
- Newly identified markets, such as for small, fuel-efficient, urban vehicles
- Changes of style to appeal to the consumer's changing requirements

For these reasons all vehicles need to be continually assessed - for their technology, aesthetics and cost-effectiveness - in order to be competitive in the world market place and meet the requirements of the potential customer.

In Europe, designing and testing takes place at Dunton in Essex, Merkenich near Cologne in Germany and at the Lommel test facility in Belgium. Here, vehicles and diesel and petrol engines are designed and developed. Sophisticated laboratories and simulators at Dunton and Merkenich test engine emissions, vehicle durability and safety.

The team

The concept for a car is developed from the outset by a multi-disciplinary team which will include specialists from Marketing, Research and Development (R&D), Design, Component and System Engineering and Manufacturing. Each of these different functions works simultaneously on different aspects of the product once the concept is agreed. Co-ordinating this effort will be the Programme Office who over-see product planning.

Designing

Identifying a need

No matter how successful a vehicle is, the time may eventually arrive when market research and user evaluation may call for a rethink. Typically in this case, Marketing will recommend a change to the Programme Office, who will set the process in motion. Changes fall into three categories:

1 Freshening
A superficial revision such as bumper or instrument panel redesign. This does not usually affect the major manufacturing processes involved other than the realignment of drill holes, wiring, etc.

2 Sheet metal
A more fundamental change involving, as the title suggests, changes in the design and manufacture of the sheet metal parts of the car body. When this kind of change is indicated, the team will try to retain the ‘platform’ or underbody of the car, as changing this is expensive.

- The Ford Fiesta is an example of a car which has undergone both ‘freshening’ and ‘sheet metal’ changes.
3 New model
This involves designing the car from scratch in response to a perceived user need.

- The Focus and the new Mondeo are examples of recent new models for which totally new designs and platforms were used.

Initial ideas - developing a concept
Once the concept has been agreed, a rough outline is provided to the Design Studio, who will produce ideas using a software program called Paintbox. Very little freehand sketching is done. The best ideas are selected and developed using clay models and Computer Aided Design (CAD).

2D CAD
An electronic pen on a pressure-sensitive pad, this system offers an array of drafting techniques from thin pencil lines to airbrushing. Corrections can be edited on-screen.

3D CAD
The 3D system creates mathematical surface models that can be rotated on screen for evaluation from various angles and perspectives. The mathematical framework for 3D CAD is based on engineering information allowing the designer to produce a realistic visualisation of the final design. From these a computer numerically controlled (CNC) milling machine cuts out a 3D model from clay, synthetic wood or foam.

User evaluation
A series of single 3D CAD renderings can be linked to construct animations. These can be enhanced by 'video compositing' (placing in a realistic setting) and high definition imaging, creating representations that can be projected full size onto a large format screen. This process allows the design to be evaluated by members of the public at an early stage in the design process.

- Using this system, market research on the Puma was conducted in four European cities in one weekend.
- Ford has more animation capacity than Walt Disney had for 'Toy Story'.

CNC milling machine cutting a clay model
Animation created using 3D CAD renderings
Designer at workstation
Ford Fiesta after ‘sheet metal’ change
Ford Mondeo

Designing and modelling

Once agreement has been reached on the design based on these early tests, computer simulations and mock-ups, a 3D model must be made. Ford’s seven design studios world-wide are linked together, allowing engineers to build virtual 3D prototypes using a system called C3P, which is explained below. The data can be sent to an automated milling machine anywhere in the world to create a clay model.

Clay models
Traditionally, these are made by technicians and consist of a steel framework covered by foam blocks that are then covered in clay. The Marketing Department will then show the models to focus groups of users, alongside competitors’ products and current Ford models, to find out how users respond to the new design.

CAD technology means that a designer can rework a clay model instantaneously. This reduces development time greatly compared with traditional hand-modelling techniques, and enables ‘rapid prototyping’ to take place. Traditional methods meant that a new design, from initial idea to clay model, would take a dozen people 12 weeks. Now one designer can produce a fully animated design in under three weeks. The final design is milled out into a full-size clay model, using CAD data, on one of two 5-axis mills in either England or Germany. This full-size model is then used for internal reviews with the senior management, having the knowledge and comments from market research clinics, supporting engineering studies and business projections.

Ergonomic testing

Ergonomic testing is one of a number of specialised studies that support design development. Aided by a sophisticated computer system called RAMSIS, Ford engineers are able to simulate how human shapes will interact with the vehicle design. This was a key tool in the early stages of the development of the Focus and the new Mondeo, allowing engineers to test their theories, refine them and test them again, without having to build time consuming prototypes.

Mock-up devices, known as ‘bucks’, are also brought in at this stage to verify theories developed using digital tools:

The adjustable package buck is a car-like device that can be programmed to simulate a proposed design. The height of the seats, the width of the doors, the amount of headroom and legroom, the location of the steering wheel, pedals and interior and exterior mirrors can all be specified individually and the buck reshaped accordingly.

The driveable buck simulates the vehicle in operation and is particularly useful in testing visibility for manoeuvres such as parking.

The eyepoint vehicle buck is equipped with the same roof and pillar design as the planned production vehicle. It provides a means to demonstrate to engineers how persons of differing heights will see out of the vehicle.

Bodysuits are also worn by engineers, to simulate different human conditions, and allow designs to be adapted to meet their needs better. The Third Age Suit consists of an all-in-one outfit incorporating padding and elasticated binding to stiffen and restrict body movement around the wrists, knees, neck and torso. Restrictive gloves and goggles to simulate deteriorating eyesight give the wearer an understanding of the needs of older
people. A similar suit simulates the restricted movements of a woman in late pregnancy.

- The taller profile of the Focus is the direct result of research using the Third Age Suit

**Specification**

Once Design, Engineering, Marketing and Manufacturing have agreed on a final design, the Programme Office will issue it as a product specification which covers every system in the vehicle (e.g. body style, engine, interior trim, chassis, electronics, etc). A timing plan with gateways, or decision points, sets interim targets for completion of engineering development and manufacture.

![Vehicle Development Life Cycle](image)

**Development of final design**

**Production of the prototype**

Designers and component, system and production engineers now work simultaneously to develop and produce the vehicle prototype, a one-off version of the final design. Some components and systems are ‘contracted out’ to other specialist companies (e.g. seats, brakes).

Before the prototype is produced, **Computer-Aided Engineering (CAE)** is used to ‘validate’ components. This means using computer aided technology to ensure that parts will fit together; it can even test clearances on-screen by rotating nuts and bolts where they will be fitted to ensure that there will be room to tighten them. Simultaneously with prototype-build **Computer Aided Manufacturer (CAM)** is being used to design and develop the production processes.

**C3P**

This combines a collection of computer-based tools in one operating environment. In other words, it incorporates CAD, CAE and CAM along with a product information database (PIM). It enables engineers to design and develop the engineering properties of a component, create a virtual model of its operation in the vehicle and simulate its manufacturing and assembly processes. Ford engineers anywhere in the world can work on the same component simultaneously as any change is automatically shared. Use of this system means that many prototypes - and the time and resources to create them - can be erased from the product development phase.

- Thanks to C3P, the new Mondeo was taken from ‘Appearance Approval’ to ‘Job One’ in just 24 months - a reduction of 13 months off the development time. No paper drawings were used; everything was created on computer.

**Development, testing and evaluation of prototypes**

Even with major advances in computing technology, ‘real world’ evaluation is still needed. Prototypes must be tested over special surfaces and in realistic challenging conditions to ensure that they reach the expected standards.

Engineers do not wait for the prototype to be completed before testing and evaluating. Vehicles are complex and it makes sense to test systems separately before assembling the complete car.

Much evaluation of prototypes can be done on testing rigs; for example, engine mounts are tested on a multi-axis simulator table (MAST), a shaking table which can be programmed to simulate a variety of difficult road surfaces. Systems and components
undergoing these kinds of durability tests - engine mounts, suspension, brakes, steering - are characteristically tested to 150,000 miles. Testing rigs are highly sophisticated; a new MAST at Dunton cost $3 million.

Not all testing rigs are expensive or complicated; keys, locks, hinges and catches all have to be tested too, and these rigs, though equally effective, have more of a ‘Blue Peter’ appearance, featuring simple mechanisms, flexible wire and bungee cord.

Powertrain Development Laboratory
Here all powertrain related systems can be brought together. Engines, transmissions, driveshafts and related components such as fuel injector systems and oil pumps can be tested under computer control 24 hours a day.

Trim - Tints, textures and aroma
Interior and exterior surface colour and trim are chosen by specialist designers based closely on information from the marketing department. As well as complementing the overall design of the car, the design team will investigate new yarn and weave technology and will explore new ‘reach’ or fashionable colours which may change during the production life of the car.

Attention to detail is illustrated by the ‘Aroma Sensing’ team where odours from combinations of materials under hot or humid conditions may prove unacceptable. Detecting and addressing these problems was formerly done by people with a well-developed sense of smell. Gas analysis of smells was subsequently found to be more reliable, and nowadays Ford use electronic noses in their production plants to anticipate problems.

Finished prototype tests
Once each system has been rigorously tested the car is assembled and a new series of tests are conducted on the finished prototype:-

Road load data collection involves setting up a car with an in-board computer to monitor performance under a variety of road conditions. This data is also used to operate the road simulation rigs, as discussed previously, giving high repeatability and also reducing development time.

Environmental testing is carried out to ensure that vehicles operate under all climatic conditions.

- Ford have recently opened a multi-million pound four storey environmental test laboratory in which vehicles can be tested for response to temperatures of -40 to +55 degrees C, directional wind speed of
225kph, pressure up to 12000 feet altitude, humidity and hot road conditions.

**Emissions testing** is conducted on the same vehicle every 5000 miles. Between tests the car is put in the mileage accumulation facility to be driven by a robot.

- It would take 68 Ford Focus cars today to produce the same amount of pollution emitted by one Ford Escort in 1968.

**Designing Noise**

*Noise Vibration and Harshness* is monitored on both Ford and competitors’ cars. Acoustic engineering is not just minimising unwelcome noise, such as engine rattle, but involves the design of particular sounds to satisfy customer needs and expectations about the sound a gear change or a light switch should make. These will differ according to the type of car and the potential customers.

- On the Ford Focus at least 20 sounds were specially designed.

**Crash testing** uses the Crash Test Dummy team to simulate impacts using computer-aided engineering. The dummies are packed with sophisticated electronics and take several hours to calibrate before each test. There is also a Head Impact Test Facility involving a robot arm fitted with a nitrogen-powered launcher which fires a dummy head at various locations in the car interior.

- Calculations for a crash simulation take Ford’s 16-processor Triton computer 15 minutes. The same calculations would take a home PC 15 weeks, a calculator 67,000 years and a person with a pen and paper 68,000,000 years.

- In 1985 a crash simulation cost £35,000. By 1997 it cost £120. Today it costs about £8.

The computer and test rig have in some instances superceded test driving simulations. However, prototypes are still driven in a wide range of road and weather conditions and left in salt baths and high temperatures.

- The Focus was tested by 2,500 Ford employees before its launch. Test driving was done mainly at night; bodywork disguises were used during the day to keep the design secret.
Manufacturing

The engine and the car body are produced on separate production lines. Each is matched with components for an individual customer’s order. The complex task of coordinating the arrival of components at exactly the right time and place (called Just In Time) is made possible by sophisticated computer programs. Thus every car on the production line is different, and no parts are stock-piled awaiting assembly.

The engine

An engine begins life as a number of rough castings and forgings. The engine block (shown above), pistons, crankshaft and camshaft are then machined to match each other exactly. Gaskets are applied by machine in a liquid form, looking rather like black toothpaste, and then the cylinder head, manifold and electrical parts are added. Whilst much of the engine assembly is by machine or by robot, many operations still need to be done by hand.

Testing

Once the engine is complete it is connected to fuel, oil and water and tested by computer.

The body

The body is constructed of sheet steel, which is delivered to the plant in rolls one kilometre long. The same computer-aided processes that enable designers to produce models from their 2D designs can also transform clay models into dies to stamp doors, wings, and other sheet metal parts. This is done in the Press Shop. Huge tri-axis and tandem presses can produce nearly 1000 parts an hour.

The parts are then moved to the Body Shop where they are assembled into a body shell. Parts travel on pallets and form ‘production islands’ to construct the larger body parts. Production is fully automated, with 4,000 welds in every vehicle, almost all of which are done by robots.

Body in white

Tri-axis press

Robot welding
Once the body is assembled it is united with the underbody. Like the engine, each body is destined for a particular customer, and computers identify the body sides and roof which match each underbody by means of bar codes.

**Testing**
A selection of the day’s output is measured against the manufacturing specification; there is no margin of error.

**Sub-assemblies**
At this stage on the production line, many sub-assemblies are added, including rear axles, seats and bumpers. These arrive on separate assembly lines or from suppliers. *Just In Time* also operates here, enabling suppliers to link directly to production control at the plant via an on-line computer system. Many thousands of components are delivered daily directly to the assembly station where they will be fitted.

**Finishing**
Once complete, the body shell is cleaned, de-greased, phosphate-coated and immersed in electro-static primer. PVC sealant and wax is then applied to specific areas of the underbody by robots. Automatic spraying produces a high quality finish; spray guns spin hundreds of times a minute to adjust distance and angle, and seven coats of paint are applied. Difficult corners, however, are still sprayed by hand.

Vehicle shells then proceed to the Final Assembly Line, where they are fitted with electrical and mechanical systems (engine, suspension, transmission), and are glazed using polyurethane adhesive.

**Testing**
Once in place electrical circuits such as airbags, screen wash and wipe and illumination are tested. After wheels, trim and badges have been added, vehicles undergo final checks before delivery.
Accessory Design -
Suggested Tasks

A /AS Level and GNVQ Advanced
Engineering/Manufacturing

Problem
Motorists often encounter difficulties changing
a wheel at the roadside because wheel nuts
which have been tightened pneumatically in
a garage may be too tight to undo using the
standard tool provided.

Design brief
Design an effective wheelbrace usable by drivers
of any age and physical strength. It should be
provided with the standard wheel-changing tools
and be stored permanently in an accessible
place in the vehicle.

Tasks
1 Research wheelbraces supplied in
a range of vehicles.

2 Research the principles of forces, levers
and mechanical advantage, materials
and ergonomics.

3 Experiment using combinations of tools,
components and materials to establish the
most effective and economical (in terms of
effort) method of loosening wheel nuts.

4 Using prototypes or test rigs you have
modelled, conduct tests on drivers with
a range of ages and physical strength.

5 Present data and photographs from 1-4 in
the form of a report and a working prototype
which demonstrates the principle of
your solution.

6 Develop a final design.
KS4 - GCSE Resistant Materials and GNVQ Foundation and Intermediate Engineering/Manufacturing

Problem
Breaking down on the road can be dangerous for the car occupants and for other drivers. Motoring organisations recommend the use of a warning triangle to reduce the risk.

Design brief
Design a slimline foldable triangle with a stowage box. The triangle should be capable of standing securely when assembled and should be made of reflective materials for use after dark.

Tasks
1 Evaluate different warning triangles from retailers and car manufacturers. Record the different ways of opening/folding and how they are supported.
2 Conduct a survey of users’ responses to different types of triangle and methods of opening.
3 Investigate a range of materials and evaluate their effectiveness by modelling and testing them.
4 Sketch a number of ideas and then make the best ones in card, plastic or wood. Ask a number of drivers to try them.
5 Choose your best design and make a finished prototype of it.
KS3 Resistant Materials

Problem
Ford want to display their new range of wheel trims in their showrooms but they take up too much room. They have decided to ask your company to design a display using scale models.

Design brief
In groups of four, choose a car and design and make a range of four different wheel trims for it. Your finished designs will be vacuum-formed scale models which must be small enough for all four to come out of a single sheet of plastic. You will display them on a single sheet of A3 card which must also show clearly the make of car and the size.

Tasks
1. Collect pictures of your chosen car from Ford showrooms, magazines and the Internet. Sketch some ideas which reflect the style and shapes used in the design of the car and which would appeal to the kind of people who would buy it.

2. Designs for wheel trims have to be carefully constructed from geometrical shapes. Before you try to draw yours, you may need some practice. A design is built up using lines, circles, angles and arcs. Try breaking some existing designs down into basic geometrical shapes first.

3. Now draw your design to the correct scale. You will need to know the size of your vacuum-former to work out how big the four trims will be.

4. Stick a photocopy of your drawing to the modelling material (MDF or wood will be best for this). Saw, drill and file it to shape, and when you have a perfect finish, vacuum-form all four together.

5. Cut the trims out carefully from the plastic sheet. Design the card background for the display and draw, print or plot on to the card.