All solidification software packages use a similar three stage process route: model creation, simulation, and viewing results. The first stage is often the most laborious and time consuming however the Solstar software has its own "foundryman friendly" solid modeler and now also has a Unix and Windows interface. This interface, which is of use for foundries that get 'drawings' by disk from customers, uses stereolithography ASCII files generated by most 3D CAD modelling systems.

The essence of the Solstar system is its accuracy and speed. The latter is achieved by dividing the casting to be simulated and the surrounding moulding media into cubes or elements. Every element is surrounded by 26 nearest neighbours made up from six at the faces, 12 at the edges and eight at the corners. This can be seen in (fig 1). This makes the mathematics in the modelling system simpler therefore enabling the program to deal with many millions of elements rather than a few hundred thousand. This has the resultant effect of improving the accuracy compared with similar systems which have fewer elements. The speed of calculation and post-processing (viewing the results) are also more rapid as a result of this method of representing the solid.

The second stage of the process is where software packages differ most. There are two aspects which define the type of software. Firstly the mathematics used in the algorithms, secondly the type of materials' data used to make the calculation.

To achieve even faster results, algorithms used in Solstar make the mathematical assumption that the area through which heat can flow in each of the 26 directions is the same. In other words, a 26 faced polyhedron with faces of equal area is theoretically created. This type of mathematical assumption is often used when representing complex behaviour in physics. The assumption increases the accuracy over using simple cubes whilst keeping the mathematics relatively simple. It is not possible to visualise the polyhedron created by the maths. An irregular polyhedron consisting of rectangles, and irregular hexagons and octagons is the closest possible representation. The polyhedra are also all the same volume so they can be interchanged during the later stages of the analysis.

The other aspect of any solidification simulation software is the materials database and the properties contained within it. For the moulding media Solstar uses materials data obtained from tests designed in the 1960s by Foseco engineers to compare the thermal properties of different insulating materials. It was soon realised that this test, the Aminite, could also give data on exothermic and chilling materials. The Aminite test was a measure of power input as a function of time to reach a steady state condition. It is not difficult to then represent the properties of each of the moulding materials as a percentage heat loss against time. Examples of how different materials might be represented are given in fig 2. Any modelling process can be modelled including water cooling and oil heating such as might be used in diecasting.

After this first stage of thermal analysis the Solstar software creates a thermal history of the casting and its method which can be viewed in the form of two or three dimensional iso-chromal solidification contours. Using this history the software then physically simulates the solidification process in a unique stage representation of the metal flow that happens during the solidification. Elements mathematically move, thus simulating gravity, to take up the space vacated by shrinkage. When there are no liquid elements left to fill the shrinkage cavity a void is created. All the liquid paths are traced throughout the solidification process to determine when feed paths are cut off. This dynamic solidification simulation can be viewed on screen as it is happening in simulated time.

During this stage the alloy solidification characteristics, quality standard required and ingate effects are taken into account. For example, the size of cavities searched for can be controlled, the way in which the alloy solidifies at the beginning and end of the process can be defined, the effect of porosity regions is taken into account in a fluidity factor. Other additional modules exist for taking into account metallurgical effect in large castings and centric line shrinkage when applicable. All these parameters and more can be chosen and the default values for a specific alloy or user defined levels can be used during the processing. The flexibility of this part of the program enables virtually any alloy to be solidified providing its solidification characteristics are known.

After the solidification analysis is complete the user then needs to view the results. It is normal to view using 3D simulated X-ray pictures or to slice through the casting and show the porosity. It is also possible to electronically 'fettle' the casting model by removing the solids creating the feeding and running system thus giving a clearer picture of the defects predicted in the component.

The Solstar system first developed in the mid '80s has progressed from a tool with limited but valuable use in ferrous foundries to become suitable for use with all foundry alloys from steel through iron to aluminium. Initially only sand moulding was considered but now most of the major casting processes, including investment casting, gravity, low and high pressure diecasting, have been simulated in order to produce solidification defects. The next five years will hopefully show equally impressive changes. It is expected that mould filling and an expert methoding system will be developed to be ready for the next millennium.

For a report on the Scottish BFJ Weekend where a number of presentations on the Solstar were made please see page 419

Author: Dr Mack Collie is product group manager technical software, Foseco (FS) Limited.
The benefits of PC-based solidification modelling of castings

Improvements in both computer hardware and software have finally brought full 3-D solidification modelling within the reach of every foundry. Today's generation of personal computers (PCs) now have the processing power necessary to make modelling by every foundry feasible. In conjunction with hardware developments, creation of the AFS Solidification System (3-D) now provides true 3-D heat transfer simulation of the casting process. This PC-based system makes it possible to predict problems in castings and make changes to the process, riser or process to optimise the manufacturing process before the first part is made. And, most importantly, this can be done quickly and at reasonable cost.

The system was developed by foundryman Larry Smiley to be usable by foundrymen. The system is constantly being refined and expanded to provide more capability. The latest addition is a mould filling simulation, used to refine the solidification model by adjusting the initial temperatures in the casting and mould, based on the results of the filling process.

This program uses the Finite Difference Method (FDM) to calculate the gain and loss of heat in all parts of a casting mould model over a period of time. This technique allows you to see the effect of chills, insulators, cooling channels and other materials that may be effective for only a portion of the total solidification time. The package can be used to simulate most casting processes including sand casting, investment, permanent mould and diecasting processes. But before describing the system itself, it is important to recognise why you would want to do solidification modelling at all.

Solidification modelling can be of great benefit to today's foundryman from process control through to employee training and market image enhancement.

Benefits of Modelling
Modelling can serve as a productive (ie, profitable) tool in eight major areas:

1) Process control and improvement and advance quality planning
Modelling can obviously be used for initial design of tooling, including gating, risering and part design. Modelling can be used to shorten product design time, reduce the lead time to acceptable parts, and improve the percentage of parts made 'right first time'. Simulations can also provide an outline for process parameter design and the development of process control plans. The sensitivity of the process to various parameter changes can even be studied using modelling.

2) Problem solving
If porosity defects are found in a casting, modelling can be used to experiment with ways to correct the problem. Model changes can be used to simulate the effects of changing such things as:
- Riser design — size, configuration and placement
- Wall design — section thickness, radii, etc
- Metal temperature
- Metal condition (gas, grain refinement, etc)
- Mould materials
- Chills
- Forced heating/cooling
- Insulating/thermic materials

3) Cost containment
There is now evidence that modelling can contain costs in materials, labour and energy by reducing the trial and error cycle of part modelling. Cost reductions can also be achieved by improved procedures, including yield improvement and scrap reduction. It should also be noted that solidification modelling assists in evaluating and optimising the use of alternate materials, processes and designs. Cycle times, pouring temperatures and the like can be modified and the results evaluated to produce an efficient casting/mould/process combination.

4) Employee training
Gone are the days when it was possible to just tell an employee to do a job and not explain why. High quality parts demand an understanding of the processes involved, and modelling provides an excellent way to improve everyone's understanding of the casting process. Simulations provide the ability to 'open up the mould' and literally see risers feed, hot spots form and shrinkage cavities form. When an employee can actually see the results of his/her actions, performances can be expected to improve.

5) Employee involvement teams
Modelling can be an effective tool for employee involvement teams. Along with such things as brainstorming, cause and effect analysis, data gathering and statistics, modelling can be invaluable in locating and solving problems, and in the quality planning process.

6) Customer service
In these days, customer service and support can be at least as important as the products themselves. Solidification modelling can provide a common language between the foundry and the customer. Customers can better understand the casting process, often through the use of seminars and case studies.
performed by the computer. An even more important concept fostered by modelling is the idea of design for manufacturability. A computer-based model gives the foundry the opportunity to actively participate at the forefront of the product design process. The ability to import customer's models into a system directly supports partnership building between customer and foundry, and provides unbiased documentation in support of such things as design changes.

7) Market image
While this item may be least connected with the technical abilities of a solidification model, many foundries have found that improvement of market image has been the most important reason for implementing solidification modelling. Modelling can put a 'high-tech' sheen on what many perceive to be a 'low-tech' industry. It can also represent to many customers your commitment to help reduce the 'total life cycle cost' of their parts, to your mutual benefit. Finally, it becomes one more 'component of excellence' as a casting supplier.

8) Revenue improvement
Along with a generally improved market image, modelling can be used to enhance the quoting process to improve the 'success' on quotes. Modelling can be included in the quoting process as part of a sophisticated package. Solidification modelling has already been linked directly with one well-known estimating and production management system. As a point of interest, some US casting buyers are already requiring solidification modelling capability of foundries in order for them to even submit a quotation.

Modelling improves the accuracy of quotes by improving knowledge of the manufacturing process before the part is made. Weight estimates and casting yield can be determined beforehand with great confidence. And, with a 3-D model, it is even possible to provide a customer with a 'picture' of his part before it has been made. Quotes produced by those shops actively using modelling will have a feel of professionalism and confidence that will put them ahead and shoulders above the rest.

Now that you know why you should model, let's see how.

**The modelling process**
Using the system to model a casting is a three step process. First, select what materials are going to be used in the simulation from the material database included with the system. This database has the ability to hold information on up to 400 casting and 400 mould materials. Each simulation can utilise one casting material and up to seven different mould materials. At this stage you can also set default heat transfer coefficients, which affect how heat is transferred from one material to another. This is particularly important for diecasting processes.

Second, build a 3-D model of the casting and mould. The system contains its own model builder, so you can create the entire geometry within the system. Or, you can import both 2-D and 3-D objects from CAD systems to help build up your model. You can even trace sections from a blueprint using a digitiser, then extrude or rotate those sections into 3-D solids. Once the geometry has been input, the model is meshed, or broken into a large number of small cubes. This meshed model is then used for the simulation itself.

Step three combines the material data from step one and the geometry data from step two, adds any initial conditions such as hot spots near gates, and runs the actual simulation. While the simulation is running the system provides a graphic display to follow the progression of solidification.

Once a simulation is complete, the system provides a wide array of tools to analyse the results. You can plot solidification time, cooling rate, shrinkage and various criteria functions, such as the Nyman Criterion, that can highlight problem areas in your casting. You can then adjust your model, by changing casting geometry, riser size or placement, or process parameters such as pouring temperature. Then run your modified model and check results.

**Model features**
Materials database — Up to 400 casting materials and 400 mould materials can be stored on the system. New materials can be added at any time, and property data can be adjusted for each simulation.

Heat Transfer Coefficients — The system maintains a table of default heat transfer coefficients for use during simulations. This allows you to fine tune your model for, say, an insulating mould wash used on a permanent mould die. In addition to the default values, you can adjust the coefficient on any surface.

Model Builder — A comprehensive model builder is provided with the system, allowing you to create complex geometries quickly and easily (fig. 1). The model builder has several pre-defined shapes such as plates and cylinders. You can draw sections using a mouse, then extrude or rotate the sections to create solid objects. These sections can be rotated to any angle in space. You can import both 2-D and 3-D objects from CAD systems, using various file formats. This function is being expanded to allow even more file types to be accepted directly by the system. The model builder also allows you to specify planes of symmetry, a method used to reduce model size and speed simulations.

Automatic Meshing — To mesh the model, all you specify is the number of elements or nodes that you wish. The size of the model is limited only by the amount of memory your computer has. You can adjust the heat transfer coefficient on any meshed surface. The system will automatically calculate the weight of any materials in your casting/mould system. In fact, the system can automatically create a mould for a casting model of either conventional flask type or shell/investment (fig. 2).

Initial Conditions — You can improve your simulations by setting initial conditions in one of two ways. You can point to in-gate locations and specify a temperature drop, which the system will use to create an initial temperature gradient across the casting. This does not affect the mould and is quite fast. A more rigorous approach is to run a 'mould fill' simulation, which will predict the actual filling sequence, including the heat lost in the gating system and mould as the casting fills. This technique not only shows heat loss in the metal, but also identifies heat gains and hot spot formation in in-gate locations.

**Simulation features**
The system can provide many types of simulations to fit different situations.

QUICK Simulation — This simulation is used for first pass calculations or to determine initial riser locations. This is essentially a modulus, or geometric calculation, and is not sensitive to chill or other materials. Its chief advantage is that it is almost instantaneous.

Heat Transfer Simulation — This is the normal simulation, which calculates the loss of heat overtime for the casting/mould system. Up to 100 simulations can be run at one time without operator resistance. This allows you to set up simulations to run overnight.
when others are not using the computer. Volumetric Shrinkage Simulation — This takes the results of either a Quick Simulation or Heat Transfer Simulation and adds the movement of metal due to solidification shrinkage. This technique shows how a riser would pipe and what internal shrinkage will look like. Both the part and its shrinkage can be displayed.

Permanent Mould Auto-Cycle — The permanent mould or diecasting process is unique in that it is cyclical and the die is not consumed in the process. This simulation takes into account the heating of the die due to the casting process and also simulates the ejection phase of the cycle.

Analysis of results

The results of a simulation can be interpreted in many ways, depending on the process and the information required. Such analyses include:

Solidification Time — Plots the end of solidification at all points in the casting. This can be viewed in slices to see how different parts of the casting 'stack up' against their neighbours. Isolated 'hot spots' can be seen in hidden sections via this plot.

Critical Fraction Solid Time — Some alloys are more difficult to feed than others. The critical fraction solid is a way to describe how quickly these alloys effectively stop feeding. For example, if an alloy stopped feeding halfway through solidification, its critical fraction solid value would be 0.5. This plot shows the time it takes each element to reach the critical fraction solid value. The plot is displayed in a similar fashion to Solidification Time.

Temperature — A plot of temperature in both the casting and the mould can be created. Additionally, up to 16 simultaneous thermocouples can be placed in the casting/mould model, and data from these thermocouples can be plotted on a graph at any time (fig 3).

Temperature Gradient at Solidification (G); Cooling Rate at Solidification (r); Niyana Criterion G/V — These three plots are known as Criteria Functions, and are used to predict potential shrinkage in different types of castings. In general, if a value for a Criteria Function is below a critical value for that casting process, shrinkage would be expected to occur. These functions are plotted on 3-D views to show shrinkage would be most likely to occur in the casting.

Hot Spots — This is a plot of local casting areas that have 'pinched off' and cannot get feed metal. This can be plotted for either Solidification Time or Critical Fraction Solid.

Reurn — This is a 3-D plot showing the remaining liquid metal at various stages of solidification. The plot allows you to actually see feeding paths 'pinch off' and separate. Using these analyses it is easy to spot problem castings. Once the problem has been located, you can adjust your model and simulate to evaluate these changes. For example, you might use a chill or a different facing sand to 'chase' shrinkage from a critical area. In the model you can effectively change any part of the process you could change on the shop floor.

Summary

There is little doubt that solidification modelling can be of benefit to today's foundrymen. Some of the areas where benefits can be realised are:

— Process control
— Problem solving
— Cost containment
— Employee training
— Employee involvement teams
— Customer service
— Market image
— Revenue improvement

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A three way look at 3D modelling

One of the fastest growing activities in the castings business is the use of computer-aided design and computer-aided manufacturing systems. These are used to perform mechanical design and production simulations, enabling a variety of design options to be considered before making large commitments to the creation of manufacturing tooling. The tooling itself is increasingly being manufactured with computer-aided machining systems. Design, simulation and computer-aided tooling manufacture all have a dependence upon the concept of modelling. Several modelling systems have evolved over the years and modern solid and surface modelling systems have enabled a much wider appreciation and application of extremely powerful and user-friendly software packages in many sectors of industry.

As far as castings are concerned, the modelling activities relating to the design, simulation and tool operations are seen mainly as providers of stress analysis, mould filling/solidification simulations and CNC/DNC machining instructions for patterns or dies. This is an over-simplification of the potential offered by modelling systems but it allows some practical examples to be considered to illustrate the power of modelling techniques.

The first example (fig 1) considers the need to know how some fundamental changes in design concept affect the capability of a casting to perform its mechanical role. The part in question is one of a range of cast iron electric motor bodies which incorporate removable feet. This simple concept has significant advantages from a marketing and utility viewpoint but the departure from integral mounting demands a thorough review of how the part performs under a wide range of service conditions.

The Casting Design Centre* was able, with its I-DEAS software from SDRC, to carry out a full 3D stress analysis based on service information supplied by the motor manufacturer. A variety of different loading conditions were considered and all of the components which contributed to the mechanical integrity of the motor unit were modelled. In common with all design and simulation activities, iterative procedures were adopted to optimise the shapes of individual components. The optimisation process involves the redistribution of non load-bearing material to areas under highest stresses, having regard for the manufacturability of the part. This process is far more efficient using CAD systems than it is by iterative prototype manufacture and testing. CAD systems also allow a greater degree of concurrent engineering to occur, exemplified by the overlapping of basic design and casting simulation activities. An example of the latter (fig 2) indicates how the 3D modelling process is, again, pivotal in ensuring a successful introduction of a new product. In this case, the casting is a steel gear segment weighing approximately 25,000kg. The 'manufacturability' of the part was investigated using a mould filling and solidification simulation software package (MAGMAsoft). The objective of using such software is to demonstrate the likelihood of achieving the desired mould filling and subsequent solidification patterns which give rise to a sound product ex-mould. Such predictive techniques bring additional quantification of the manufacturing variables to bear on foundry operations. This has enormous benefits to both the supplier and end user, not least of which is a more credible design overall. Casting simulation systems are advancing at a very fast pace and it is the Casting Design Centre's experience that many more users of castings are appreciating not only the power of this technique but the opportunity it affords for improving understanding be-

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Fig 1 Examples of solid model and FE stress analysis.

Fig 2 Illustration of typical output from 3D casting simulation software.
between the supplier and user. Each has (sometimes contrary) specific desires, but the use of 3D simulations provides a vehicle for objective debate and assessment of design and manufacturing options.

The third example of how 3D modelling provides clear advantages over other methods relates to the manufacture of patterns or tools. One of the strongest selling points for the adoption of a casting is the ability to get near net shape in essentially a single manufacturing step. Complexity of shape is not normally a barrier but it is essential that the shape which has been agreed during the design (and simulation) phases should be achieved in production. This is particularly so if the design has been ‘honed’ for efficiency and cost effectiveness. Repeatable production of castings to agreed tolerances (dimensional and others) requires accurately constructed patterns or tooling which correctly represents the agreed design. Repeatability, as far as patterns and dies are concerned, is more readily achieved if the machining operations are controlled by computers. The derivation of the numerical instructions for the machining of complex surfaces is the role of engineers who use surface modelling software such as Delcam’s DUCT program. At the Casting Design Centre, DUCT is used as the basis of machining operations which can produce a wide variety of patterns and tools. The example shown in fig 3 is a cast steel idler wheel arm weighing approximately 15kg. Onerous dimensional, weight and quality tolerances were best achieved with a ceramic shell process which, in turn, needed very accurate tooling to produce casting preforms.

Although 3D modelling relies heavily on complex calculations, carried out essentially “out of sight”, a primary attraction of modelling to most organisations and professionals who use the technique is that it allows visualisation of the product and its characteristics. The appeal of visualisation is universal and it is no accident that stress distributions, shrinkage predictions and cutter tool paths are all presented in ways which the viewer can assimilate easily.

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**FOUNDRY TRADE JOURNAL – JULY 23 1993**
During the last few years a number of commercial computer simulation packages for use as design aids in the foundry industry have become available. One such package is the Mavis gravity casting simulation system developed at the Department of Materials Engineering, University College Swansea, to be a rapid and user-friendly package running on a standard IBM compatible PC. The Mavis system was only released onto the market in January 1992. This paper describes the experiences of W Lucy & Co which was one of the first UK foundries to purchase the software. The system has been shown to provide significant benefits in terms of improved design of castings and sizeable financial savings in terms of reduced materials and scrap costs.

The package has also been used as a tool to help gain design concessions and modifications from the casting purchaser by highlighting likely problems before castings are produced, or by helping to explain current problems and suggesting remedial design modifications.

**Use of the software**

The program allows the operator to construct a 3-dimensional model of a component using a 2-dimensional engineering drawing. This obviously requires good knowledge of engineering drawings but it has been found that a competent operator can readily model complex shapes such as the thermostat housing shown in (Fig 2). Within the first month the operator was able to model casting shapes quickly and consistently. The most difficult part of the operation when the operator was familiar with 3D modelling was the choice of optimum casting orientation within the 3D computer grid.

Once the component has been modelled in 3D its orientation can be changed to present the optimum configuration within the limits of the moulding process to obtain a sound casting. This enables the feeder head to be designed into the most advantageous position to give maximum effect and yield. At the same time, either for components requiring feeding or ones that should not, the ingate/runner system can be designed to give directional freezing to or from critical areas.

The conventional method of drawing a layout of the pattern plate to supply to the pattern maker can now be carried out with much more confidence since once the pattern is manufactured it is very often impossible to move the location of the pattern on the plate. The software has also highlighted situations where the design of the component would not produce sound (porosity free) castings and indicates the effects of possible design alterations to improve the situation.

The Lucy foundry in Oxford is a Dismantle foundry producing castings in both flake and nodular iron. In the first six months that Mavis has been operating in the methods department a number of new and problem jobs have been modelled with good results and a few examples are given below.

**Case study 1**

A bearing cover plate in BS 1452 Grade 250 flake graphite iron weighing 2.5kg with three impressions per pattern plate was a new part and the obvious problem was the position of a heavier boss section towards the middle of the thin plate section (Fig 3). The orientation of this boss together with the ingate effect (ie the relatively higher heat input into the mould near the gate) were the main considerations when trying to achieve directional solidification towards the feeder with minimum shrinkage in the boss. Being grey cast iron it was decided to run computer simulations using a shrinkage contraction on freezing of 1%.

Simulation of the part with the boss in different orientations showed that the minimum amount of potential shrinkage occurred with the boss orientated at the bottom of the mould with the hot metal (ingates) introduced towards the top of the component. With this preliminary design in mind the customer was consulted to establish their exact requirements concerning quality, finishing, jiggling and machining.

This allowed the design of the runner system to incorporate a small conner type feeder on the casting that would not interfere with machining or jiggling. The Mavis simulation was then employed to give the size of the feeder needed and most importantly the relative dimensions of the fillet/overlap to obtain the maximum yield from the feeder (Fig 4). This design resulted in the pattern plate sampling correctly first time and allowed the part to be produced with no
fettling. Without the benefit of Mavis this component would most likely have been designed with ingates and hence fettling in the critical jigged location. Details of the component are as follows:

- Casting weight 2.1kg, three per mould = 6.3kg
- Feeder weight 0.15kg at 7% of casting weight, three per mould = 0.45kg
- Runner system 0.79kg at 12.5% of the casting weight
- Pouring bush 2.9kg at 46% of the casting weight
- Total box weight 10.44kg less pouring bush = 7.54kg
- Yield with pouring bush empty 83%
- Yield with pouring bush full 60.3%

**Case study 2**

A hub bearing casting in BS 2789 grade 420/12 ductile iron weighing 1.62kg with four impressions per pattern plate was a new plate with two legs off a central pipe and again the initial problem was orientation of the casting to obtain maximum feeding efficiency and yield while producing a sound casting. Being a ductile iron casting it was decided to run the computer simulations using 3% shrinkage. After trying various orientations on the computer the best design was considered to be with the legs at 45 degrees to the vertical and the casting fed and run through the small box. It was shown from the simulation that a neck could be designed and a feeder head fitted that would result in maximum soundness of the component again with maximum yield and minimum fettling (fig 5). With this information from the computer simulations a right-first-time methodology was achieved incorporating an unusual orientation of the casting and with minimum fettling. Details of the casting are as follows:

- Casting weight 1.62kg, four per mould = 6.48kg
- Feeder weight 0.34kg at 21% of casting weight, four per mould = 1.36kg
- Runner system 1.18kg at 18% of the casting weight
- Pouring bush 2.94kg at 45% of the casting weight
- Total box weight 11.96kg
- Yield with pouring bush empty 72%
- Yield with pouring bush full 54%

**Case study 3**

A 19kg brake position in BS 1452 grade 250 flake graphite iron with one impression in the pattern plate is a medium volume long established part which had previously suffered from low yield and a medium to high scrap rate (fig 6). The casting was modelled to determine the optimum feeder size. At this point it was shown that whilst the feeders were in excess of those theoretically required the casting feeder neck was too small to allow directional freezing towards the feed metal. It was also shown that by introducing hot metal (ingating) at the base of the feeders they could be made to operate more efficiently and hence require less feed metal (fig 7).

The pattern plate was re-engineered using the guidelines shown by Mavis. The results of these modifications are shown below.

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**Fig 5**

**Fig 6**

**Fig 7**

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Case study 4
A 3.09kg piston housing in BS 2789 grade 420/12 ductile iron with four impressions on each pattern plate again was an existing part which had suffered considerable reject rates from the customer due to porosity revealed when the casting was machined on the outside of the centre boss.

Modelling on Mavis showed that it was not possible to manufacture this part on the Dismatic without porosity in the affected area because all effective feed paths have solidified while there is still a significant amount of liquid metal present in the central boss. Lucy Castings managed to demonstrate to the customer that in order to keep feed paths open and allow directional solidification from the central boss to the feeder, the back wall of the casting needed to be thickened up by 4mm (fig. 8). At the same time it was demonstrated that the feeder head volume could be reduced by 25%.

With this information the customer agreed to the modification being carried out even though this would mean extra machining costs. However, the improved casting quality (fig. 9) reduced the machining reject rate from an initial 20% down to 1%. Details of the casting are as follows:

Old casting weight 2.7kg, four per mould = 10.8kg
New casting weight 3.09kg, four per mould = 12.36kg
Old feeder weight 0.75kg four per mould = 3kg
New feeder weight 0.56kg, four per mould = 2.24kg
Old runner and cup 2.46kg
New runner and cup 2.46kg
Old machining scrap rate 21%
New machining scrap rate 1%

This example clearly shows that although extra units costs were incurred the design changes resulted in better economics of production.

The case studies demonstrate that in the first six months that Mavis has been installed at Lucy Castings methoding department very good results have been obtained which easily translate into an economic pay-back period for the initial cost of the software.

Use of the system initially entails the determination of the best computer parameter settings to use (shrinkage, relative mould conductivity, ingate effect etc.) which will most closely imitate actual production conditions. After running simulations design changes can be made on-screen to different castings always remembering that computers only simulate solidification and practical considerations of moulding plant limitations and general foundry rules still apply.

If design modification work is necessary this can first be simulated on the system to check the likely results thus saving expensive machine and pattern shop time which would have otherwise been required to test the benefits of proposed changes. The benefits of Mavis are that right-first-time design is achieved with significantly greater regularity than before, and if changes are required these can be modelled with much less cost than conventional modification and sampling techniques. Yield and runner systems can be optimised and as experience grows it gives the operator a much clearer insight into what is happening as castings solidify in specific moulding media.

The ability to simulate solidification on computer has enabled W. Lucy & Co to consistently design economic methoding systems producing sound, right-first-time castings. Now operators are familiar with the Mavis software a success rate of 95% or more is being achieved.

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![Thermal Contour Plots Show Improved Peeling to the Central Boss of the Modified Component (Bottom) Compared to the Original Design (Top)](image)

![Fig 8](image)

![Fig 9](image)

MODIFIED COMPONENT DESIGN.
DEFECTS DRAWN AWAY FROM
BOSS TO NON CRITICAL AREA.

ORIGINAL COMPONENT DESIGN.
SHINKAGE DEFECTS LOCATED
IN CRITICAL MACHINED AREA.