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Engine design using state-of-the-art tools

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Engine
design

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ENGINE DESIGN USING STATE-OF-THE-ART TOOLS ILLUSTRATED BY THE L21/31 CYLINDER CRANKCASE

Methods for an efficient shortening of the development times

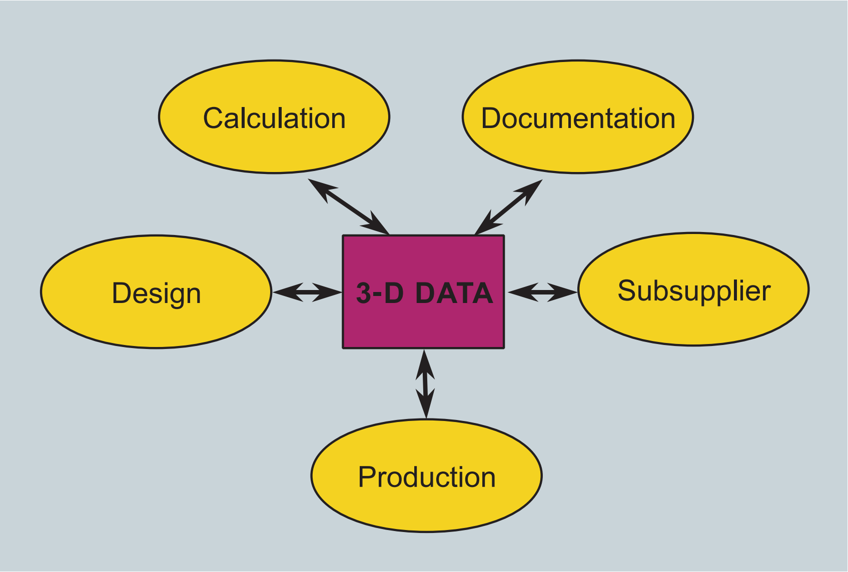
The market anticipates from engine developers products which ensure high reliability over many years of economical operation despite a low purchase price. In addition, more and more ecological and environment-relevant aspects come to the fore. Continuously shorter development times are available to the offer in order to comply with these demands.

When developing new engines, we fulfil these requirements by using modern data processing systems both in the R&D and in the production range. In connection with simultaneous engineering methods, which are characterised by overlapping work sequences and a close cooperation between the various expert departments, a continuous process from the idea to the complete component can be realised.

Key advantages this method offers are:

- ❐ improvement of process and product quality
- ❐ shortening of product development times, and
- ❐ improved staff motivation.

Here at MAN B&W data based on the 3-D CAD program PRO/ENGINEER are used as the basis for the subsequent processes (Fig. **1**).



1 Universal use of the 3-D data.

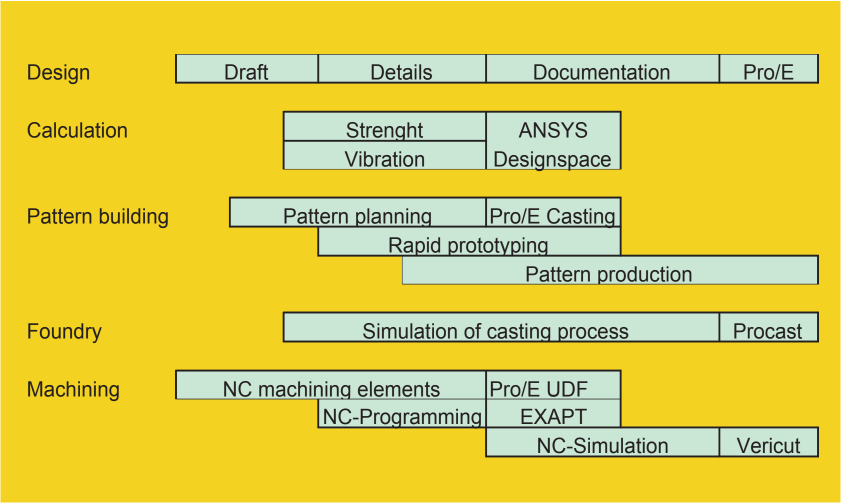
It is the intention of this paper to illustrate these processes and the resultant benefits by taking the development of the L21/31 cylinder crankcase as an example (Fig. **2**).

Steps involved in producing a preliminary design

Design and concept definition in the design department

When designing a cylinder crankcase (Fig. **3**) a distinction has to be made between the many possibilities open to the design engineer at the detailed

2 Simultaneous Engineering process of a casting product.



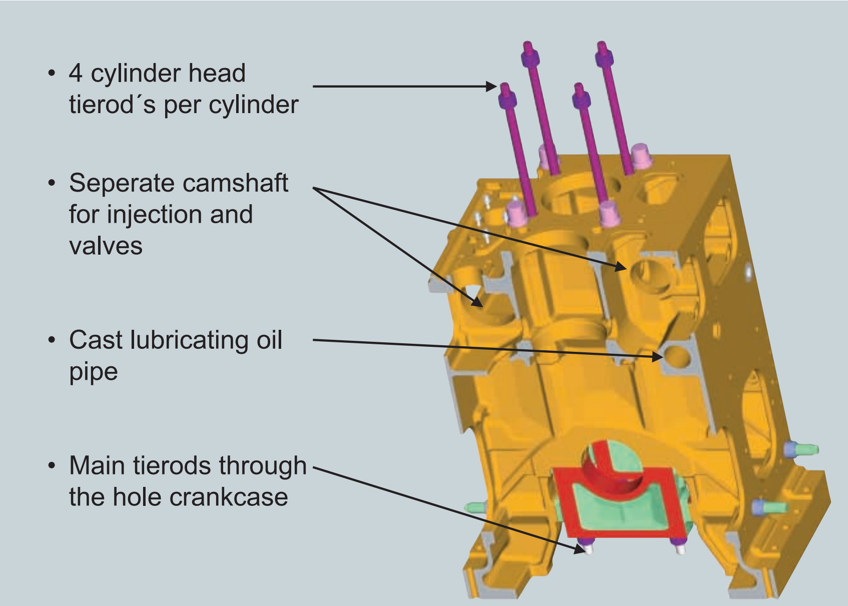
level, which allow a considerable amount of freedom, and the fact that the basic design principles have already been fairly clearly outlined [KOEH-98].

The L21/31 is the latest member of an engine family comprising the L16/24, L21/31 and L27/38 engines. The fact that the engine is a member of a family meant that an array of pre-defined, tried-and-trusted design constraints would have to be adhered to from the outset. Furthermore, a number of key design parameters were already known, and the designers would be able to draw on them when producing the preliminary design.

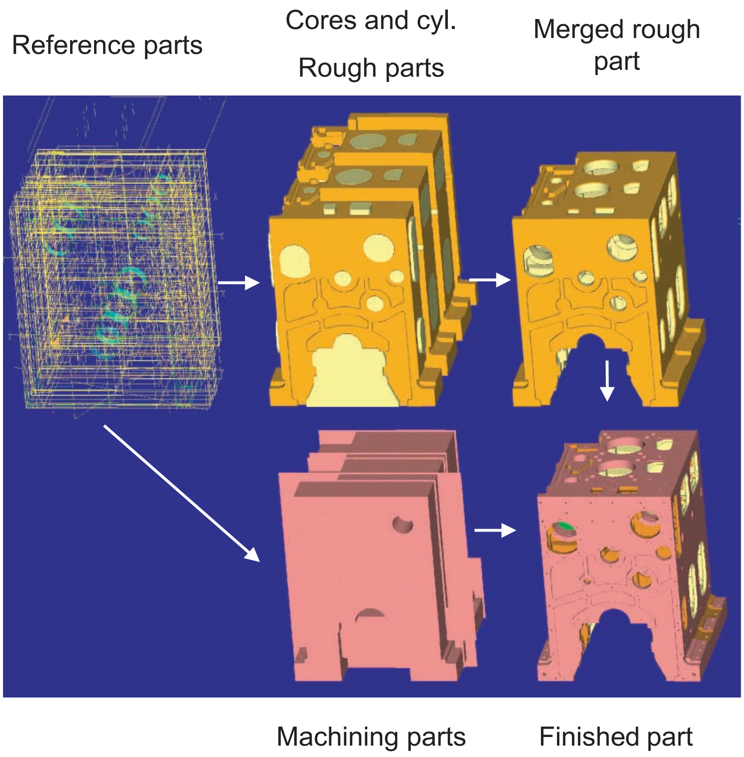
In considering the options still open to the designer at the start of the design process a distinction has to be made between peripheral subassemblies for which no preliminary designs have been drafted and subassemblies whose dimensions have not yet been definitively laid down. From these known parameters and possible freedoms it is the designer's job to come up with a preliminary cylinder crankcase design which is as compact as possible.

Generating the preliminary design as 3-D CAD model

Using the parameters thus obtained the preliminary design is prepared in the PRO/Engineer 3-D CAD system. If the expected final geometry of the cylinder crankcase is already broadly known at the outset, the designer can begin giving thought to the model structure before modelling begins, making subsequent documentation and improvements to the production engine easier.
Here the following considerations are important. The models must be



3 Predefined design-features for cylinder crankcase L21/31.



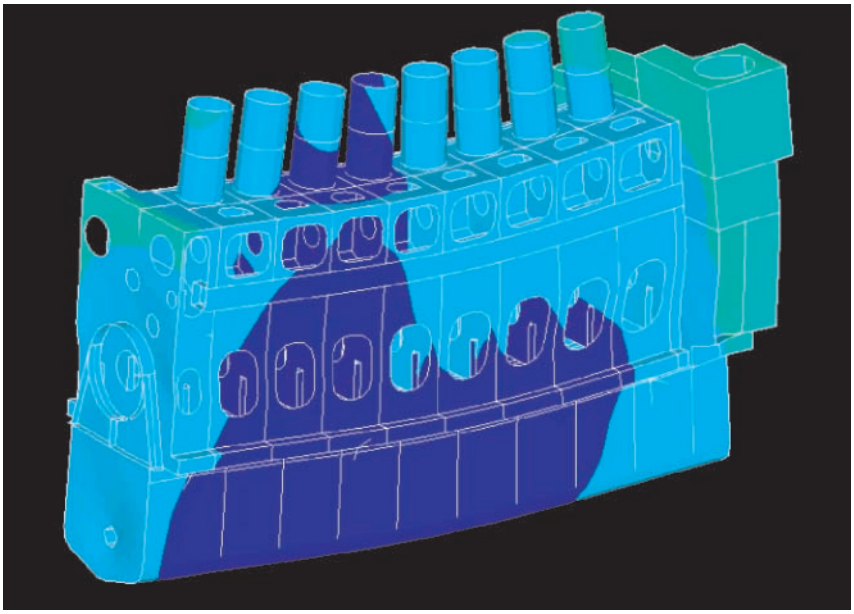
4 Modelling strategy for the 3-D CAD cylinder crankcase.

☐ well defined
☐ easily changeable and stable
☐ usable for FEM calculations, i.e. simplifications must be possible,
☐ suitable for subsequent processes, such as producing mould patterns.

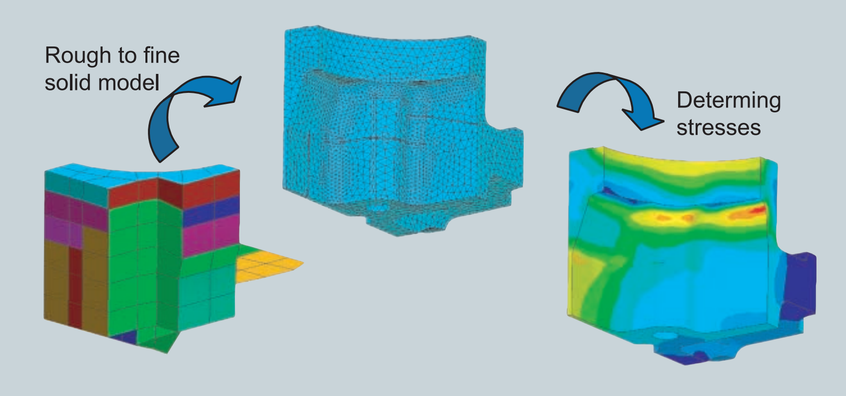
Model performance should not be lost at high degrees of detail and the generation and maintenance of other cylinder numbers should be quick and simple.

In our cylinder crankcase example the following characteristics have proved to be advantageous:

☐ Modelling was performed in cylinder sections with a patterned structure. This means that the cylinder numbers of production documentation can be generated very quickly from a prototype frame. Designers mainly work with manageable patterns with few design elements.
☐ Cavities were modelled as cores. This method makes rounding easier since the designer can see the areas requiring rounding from the outside. The models can easily be used for actual coring.
☐ For processing a number of surface models were produced and, if possible, built up as cylinder parts. For irregular patterns an additional machining part was produced over the entire length of the crankcase (Fig. **4**).



5 Shell structure for vibration simulation L21/31.



6 Sub-model for stress calculation cylinder liner seat.

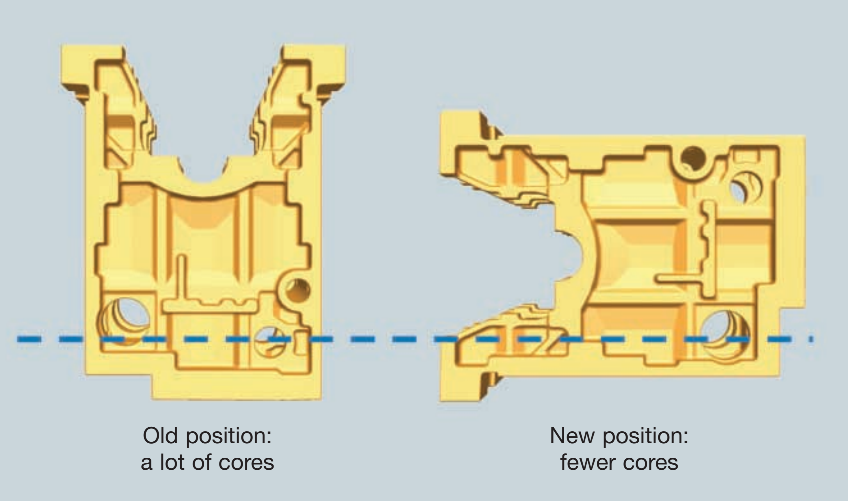
Use of the 3-D data for design, calculation and simulation

Vibration analysis

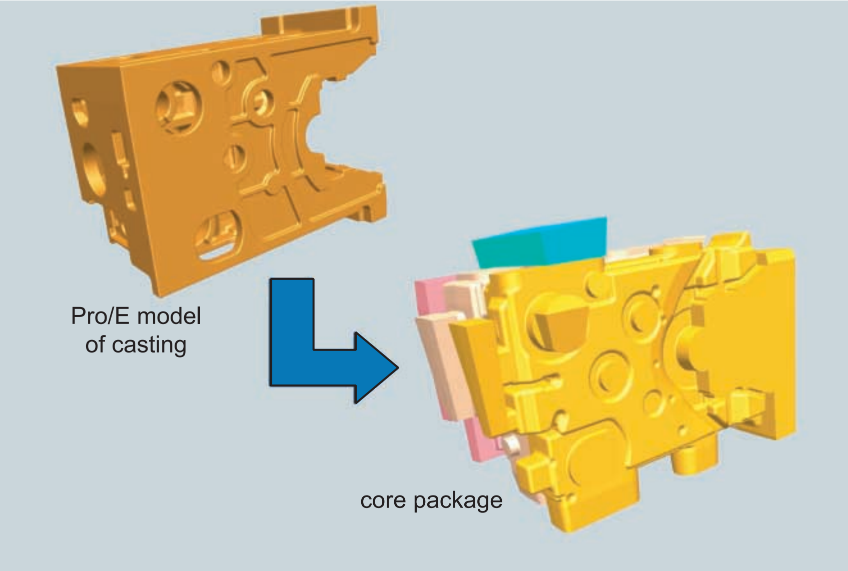
At a very early developmental stage the vibration simulation can be used to provide information about the material to be used and the resultant wall thicknesses, foot geometry and necessary stiffenings in the window area.

This usually involves deriving a shell structure of the 3-D engine design in order to keep the model size at an efficient level for the simulation. As a solid model the CAD model is already too complex at the design stage to be able to retroactively produce an automatic shell structure; features are however already contained in various FEM programs that can simplify the derivation process (Fig. **5**).

We calculated flexible mountings for the 6L, 7L, 8L and 9L cylinder variants. With the aid of these models we were able, in addition to performing the basic calculations, to carry out investigations of variants as well. We also used sub-models to check for areas that might be regarded as critical (Fig. **6**).



7 Casting positions.



8 Pro/E model core structure.

The vibration calculation produced a required outer wall thickness of 16 mm. Since additional rigidity is required for resilient mountings, it was decided to opt for a stiffer oil sump for this particular application.

The foot geometry defined in the preliminary design was confirmed as being sufficiently stiff. It was decided that stiffening of the rear side of the widow was not necessary.

Static calculation on a crankcase section

For the static calculation of the component a simplified two-cylinder model was prepared in order to save on computer resources. Unnecessary external roundings were suppressed wherever possible since they do not play a major role in static calculations. Having first consulted the designer, the calculator left curves recognised as critical in the model in order to avoid errors occasioned by singularities.

The model was produced parametrically to the original model, i.e. alterations in the design were incorporated into the calculation model by regenerating the calculation model. A section was taken from the cylinder crankcase from centre-window to centre-window and examined with the three critical load scenarios:

❒ cylinder crankcase in pre-loaded state
❒ cylinder crankcase subjected to mass force
❒ cylinder crankcase subjected to firing force.

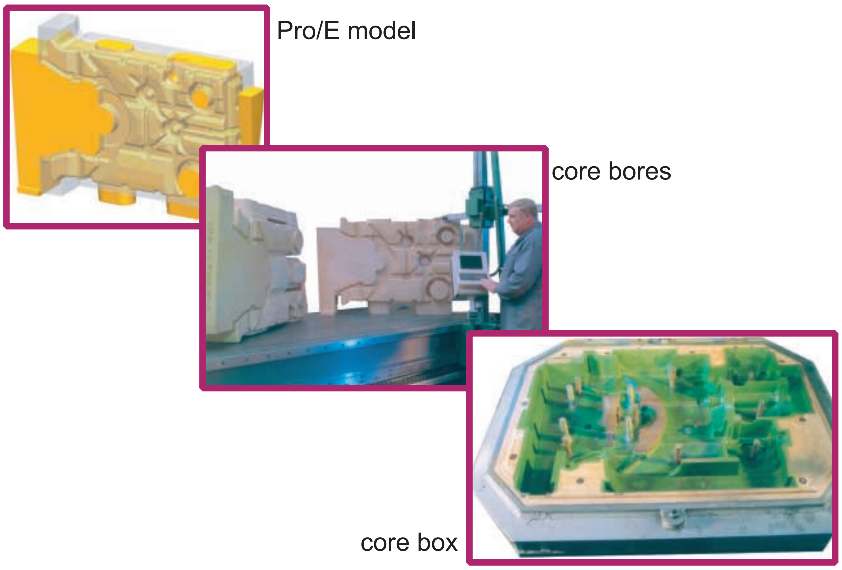
The results of the simulation were used to implement improvements in way of the collar bush. Critical areas caused by core supports were stress-optimised. In addition, the calculations indicated that EN-GJS-400 was the only material that should be used for the frame of the L21/31 and not grey cast iron.

Using the models in production

Cooperation between the design department and the foundry

At the same time as the simulations were being carried out the first foundry decisions were taken.

The production costs of the blanks are considerably influenced by the casting position of the parts as it determines the number of the cores which is required for mould manufacture. Since the start-up of the new



9 From 3-D model to sand core.

10 Core making.

type series, all cylinder crankcases are cast lying on their sides (Fig. **7**), which permits reducing the cores for the 8L 21/31 cylinder crankcase to only 13.

Pattern- and mould-making

The main work in the foundry on the Pro/E model involves designing the pattern. Owing to the associativity of the Pro/E models this work is performed simultaneously with the other work on the raw casting model, the geometry of the raw casting always serving as the reference. All the required cores with their core prints and the geometry of the model are derived from it.

13 cores are
putting in the mould

Closing of the mould
after only 4 hours

11 Coring up the mould.

A 3-D model of the core structure from the 1L21/31 cylinder crankcase is sufficient for virtual check of the mould-making method (Fig. **8**).

This is then followed by production of the physical foundry pattern. This involves a combination of manual and machine production in order to keep costs to a minimum. All free-form surfaces are milled directly on CNC machines using the relevant 3-D geometry data. Time is saved by checking the dimensions directly against the Pro/E model with the aid of the computer. This procedure produces significantly more accurate patterns, as well as considerably reducing pattern production times (Fig. **9**).

For filling and curing, all cores are made on high-performance core shooters (Fig. **10**). Not only does this significantly reduce the number of individual cores, the foundry is also able to complete the orders in an extremely short time (Fig. **11**).

12 Casting the mould.

Computation of mould filling

Pouring the real cored-up sand mould takes approx. 40 seconds (Fig. **12**). In order to minimise the risk involved in the first casting, the entire gating and feeder system was checked using FEM simulations prior to use whilst the design process was in progress.

The goal when designing a casting system for EN-GJS-400 is to achieve calm, turbulence-free mould filling with as small as possible a free melt surface. The air attack face should be minimised because this material may react with oxygen during casting, which could result in undesired slags in the casting.

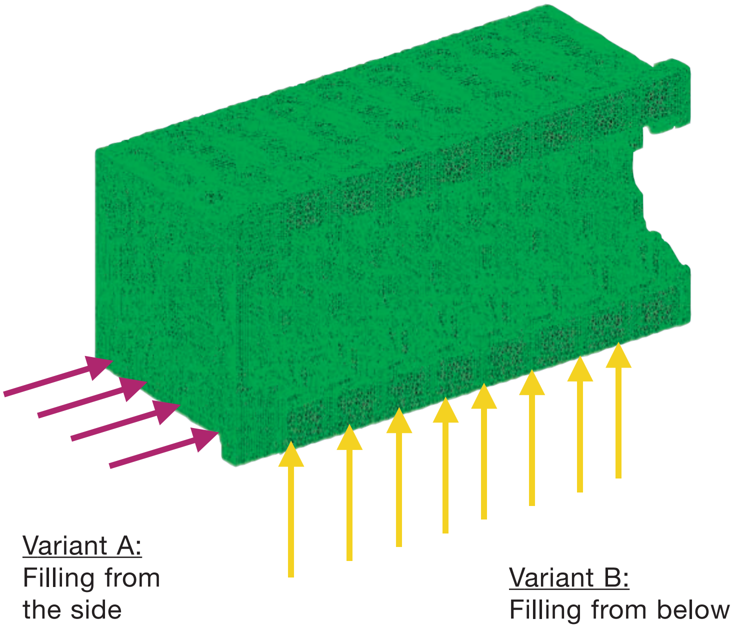
In this case we had a choice of gating systems (Fig. **13**):

☐ variant A: a front-end position of the ingates: less-elaborate or

☐ variant B: a position of the ingates below the casting: more costly than variant A.

Qualitative comparison of these variants is possible by conducting FEM simulations of the mould-filling process. The results can be seen in Figures **14** and **15**.

As can clearly be seen, when gating from below (Fig. **15**) the gate has a much smaller free melt surface when filling commences than when gating from the side (Fig. **14**). Afterwards the size of the free melt surfaces is similar. For the first casting variant B was therefore chosen.

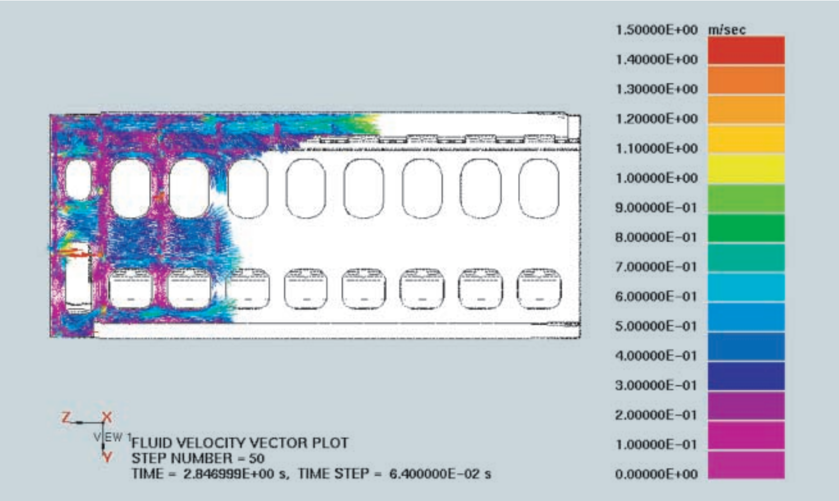


13 Calculation of filling.

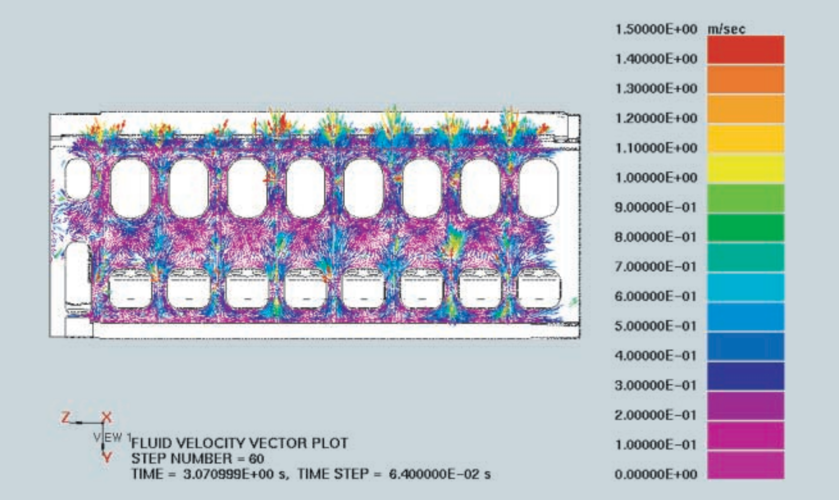
Solidification simulation

The solidification simulation is used to design the cooling and feeding system for the casting. This involves calculating the temperature distribution and the solidification process of the component over time (Fig. **16**). An unfavourable solidification process with resulting micro porosities is counteracted by changes in the cooling and feeding system.

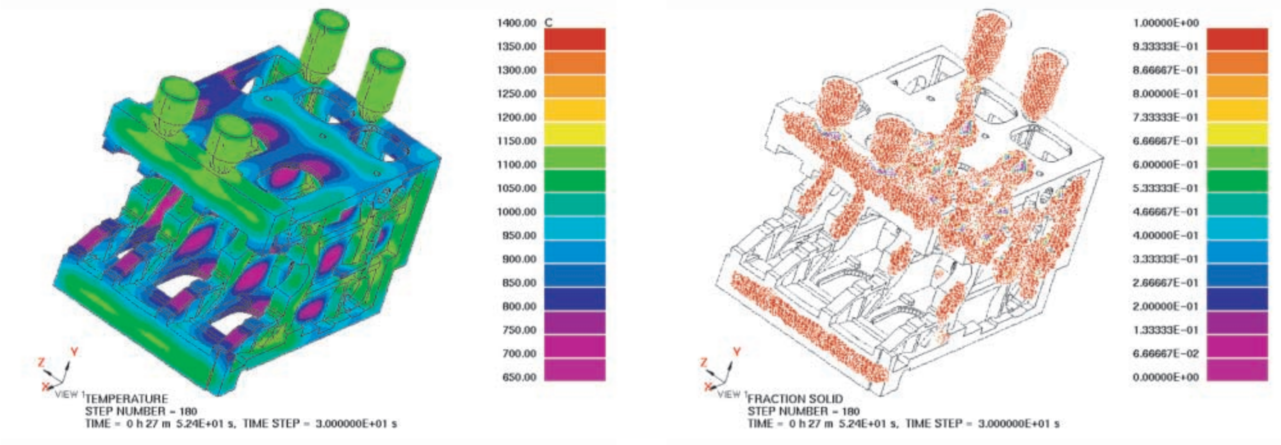
The simulation calculations carried out were an extremely valuable help in order to obtain a low-cost and fault free first cast of the cylinder crankcase.



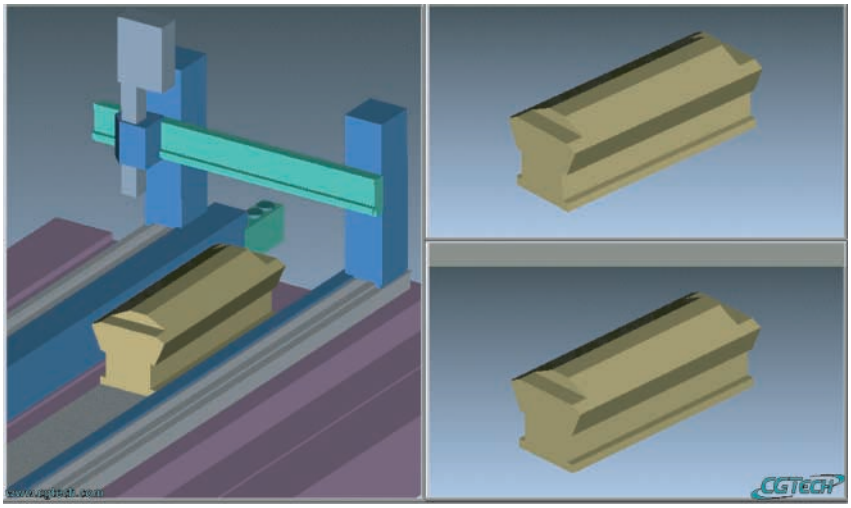
14 Variant A: mould filling from the side.



15 Variant B: mould filling from below.



16 FEM simulation of cooling and solidification process.



17 Simulation of tool paths in machining centres.

Machining

3-D models are being used for machining for

❒ jig design
❒ programming 3-D co-ordinate measuring machines
❒ NC programming of machining centres
❒ checking of collisions of the machining process.

By the simulation of tool paths in machining centres a control and optimisation of the program processes is possible without the need to carry out costly running-in trials of the program on the machine tool. Once the machine kinematics, the tool data, the milling and boring program and the component's 3-D data have been loaded the NC program is run as a dynamically calculated film. Machining elements generated at the component are visualised, as are any collisions between the machine and the component (Fig. **17**).

Simulation of assembly procedures

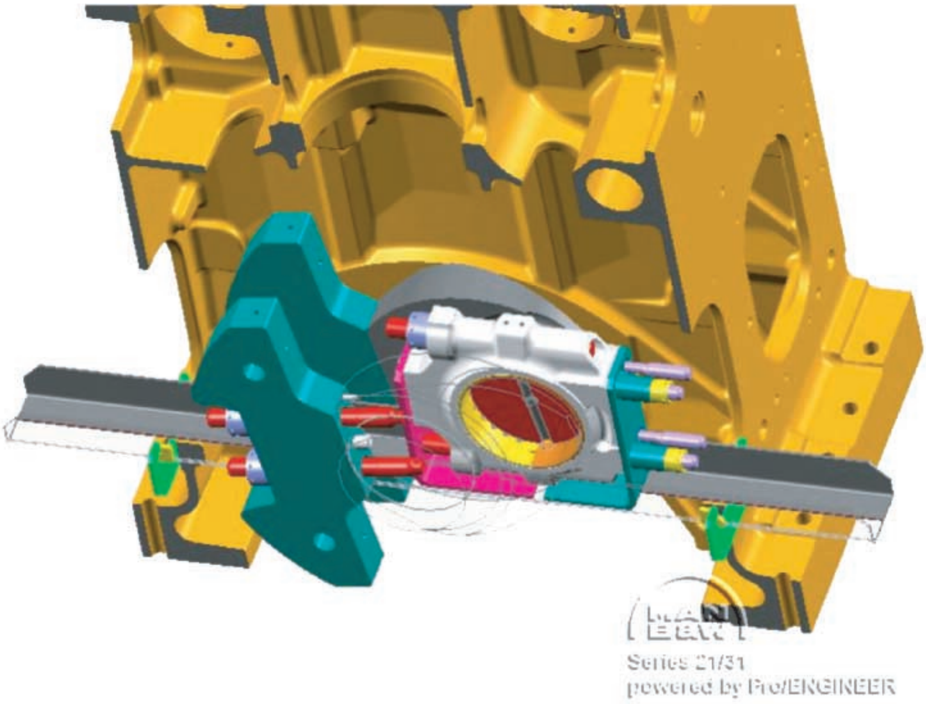
At present assembly procedures and maintenance work are depicted using drawings derived from the 3-D data. In the future it may be possible to simulate these processes as an assembly film (Fig. **18**). This will raise their information content significantly. The cost of producing these films will be about the same as the cost of producing drawings.

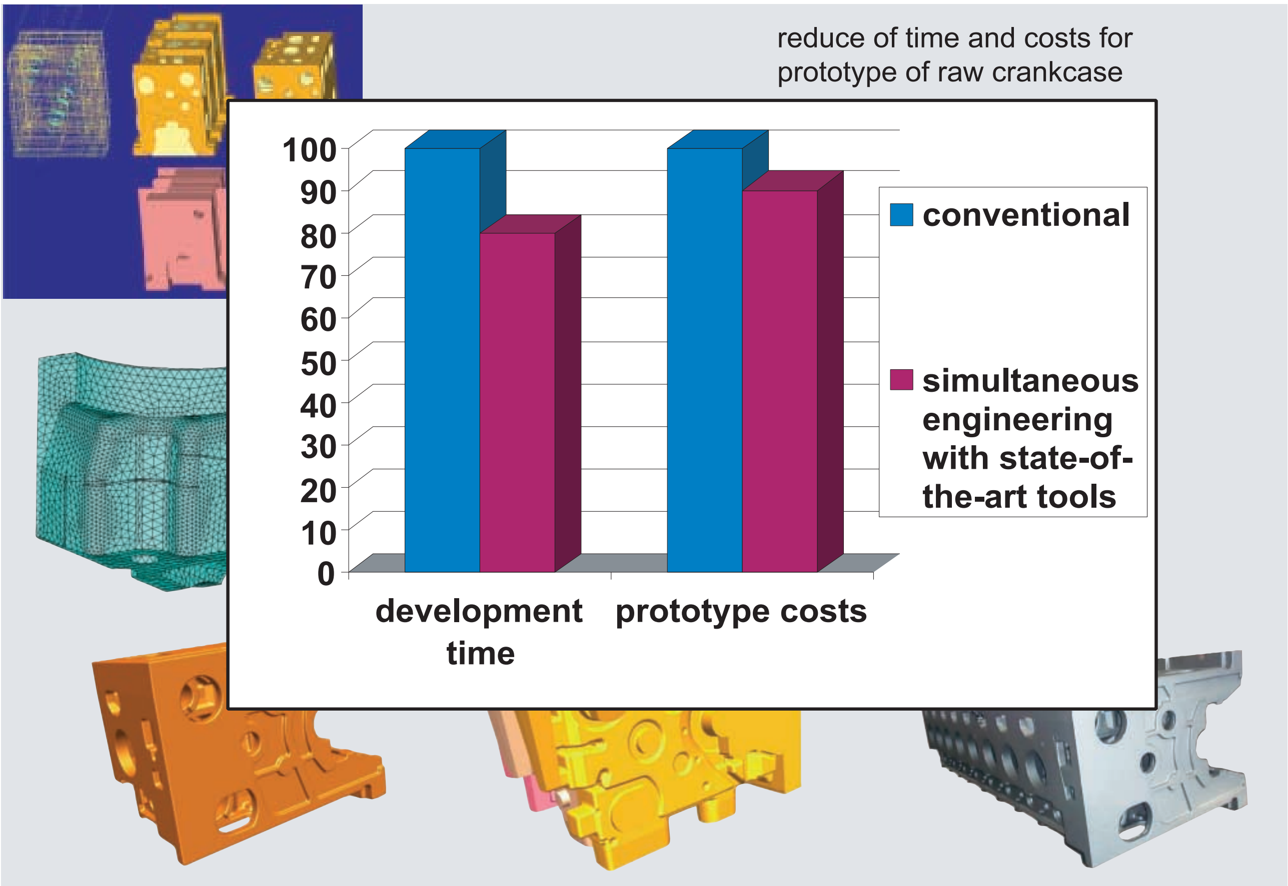
What concrete benefits did state-of-the-art tools bring to the L21/31 cylinder crankcase project?

The main advantage in the case of the L21/31 project proved to be a significant reduction in development time to generation of the cylinder crankcase prototype and hence to availability of the engine prototypes (Fig. **19**).

Additional, secondary benefits compared with conventional methods were:

18 Simulation of fitting and removing of a conrod bearing.





19 Results of L21/31 cylinder crankcase prototype project.

- With the extended simulation possibilities, strength-related changes were not necessary for production documentation.
- The missing cylinder numbers 6L/7L and 9L for the production documentation were obtained in less than one week's design work. Alterations were passed on to all variants automatically.
- The quality of the documentation was improved by each design engineer having the current crankcase design as boundary geometry during the development phase.
- With the 3-D data the precise weight calculations could be carried out easily. Combined with simulation calculation, a weight optimisation could be carried out without significant risk.
- The development of the rough cylinder crankcase prototype was possible without fully documented drawings.

In future, it will be possible to generate other frame-sizes from the models of the 21/31 cylinder crankcase by a simple process of scaling. The association of the data makes it possible to scale all subsequent 3-D models (such as foundry patterns) as well. This will further shorten development times.

Literature

[KOEH-98] Köhler, Eduard: "Verbrennungsmotoren: Motormechanik, Berechnung und Auslegung des Hubkolbenmotors". ISBN 3-528-03108-5, Wiesbaden Vieweg-Verlag (http://www.vieweg.de)