

THE USE OF VECTIS IN HONDA'S VTEC LEAN BURN ENGINE DEVELOPMENT

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Abstract

Since the release of the first Honda VTEC-E engine in the 1992 Civic, Honda has continued to actively develop this family of engines. The recently announced 1998 Accord incorporates a 1.8 litre lean-burn VTEC engine. During the development of this engine, Honda analysed and optimised the intake port and piston crown shape using VECTIS in order to improve the lean limit of air-fuel ratio. This paper described the application of VECTIS in the development of this new lean-burn engine.

Background to VECTIS Introduction

In recent years, heightened consumer sensitivity to environmental issues has mandated the development of engines of increasing fuel efficiency and low exhaust emissions, vibration and noise. The achievement of such targets necessitates the use of CAE simulation methods as an integral part of the design process. However, given the increasingly short design and development time for each new engine, considerations of the elapsed time of model generation and solution are of equal importance to the accuracy of the results obtained. Alternatives for the modelling of in-cylinder phenomena include finite volume codes based on structured grids and finite element or finite volume codes using unstructured grids.

Various solution methods have been tested by Honda in this application including direct and indirect solution methods and various pressure-momentum coupling algorithms and turbulence models. However, for the optimisation of in-cylinder flow Honda have concluded that the most appropriate approach is to use an unstructured finite volume grids with the $k-\epsilon$ turbulence model. This is due to the conservative nature of the equations, which is particularly appropriate for internal flows. There are many competing commercially available CFD packages but mesh generation time was a major selection criteria due to the consideration in selecting a package for use by Honda. VECTIS was found to be particularly attractive, enabling meshes to be automatically generated from arbitrary CAD geometry. The user is required only to provide this geometry as a closed, unambiguous surface and to specify the general grid refinement distribution for the model.

Automatic cell refinement and truncation at the boundaries then ensures a grid, which accurately conforms to the CAD geometry. With this combination of finite volume CFD code functionality and advanced automatic mesh generation technology, Honda considers VECTIS to be the most appropriate for engine development.

The Computer System

An IBM-SP platform was selected for the VECTIS installation at Honda R&D. This decision was made because the IBM-SP is central to all computers at Honda. VECTIS is using a network license and would thus allow all workstations to access it. The IBM could also be used with the serial code and the future parallel version of VECTIS. Workstations would be primarily used for the pre and post processing of jobs.

The CAD Interface

VECTIS is intended to accept the definition of the flow domain geometry directly from CAD. As such, only minimal geometry definition capabilities are required within the pre-processor and instead, features are included for the manipulation, merging, adaptation and repair of pre-defined CAD geometry. Honda use CATIA as a company standard for solid, 3D-CAD based design. The part model is defined within CATIA and subsequently converted to STL format for export directly into VECTIS. However, the STL interface of previous versions of CATIA did not provide the necessary quality of STL models. Honda have written a program to generate data directly from the CATIA mock-up solid which then provides a high quality facet model in VECTIS's internal 'triangle file' format. These two interfaces are shown below. The use of the latter route is no longer required.

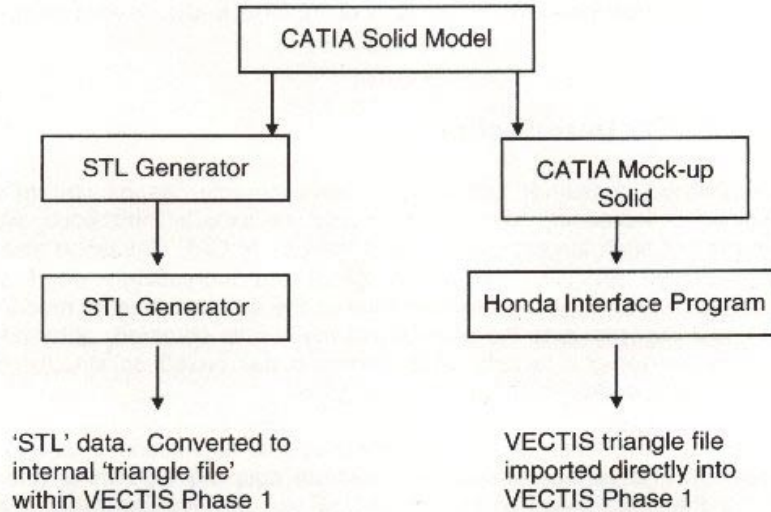


Table 1. Alternative interfaces for CAD data used by Honda

Steady Flow Calculation

The basis of the analysis work described in this paper was the new 1998 model year engine for the Honda Accord. The specification of this engine is as shown in Table 1. While maintaining high output and torque of previous production, the objective of this engine design was to improve fuel economy. As a first step in the analysis of the new design, a steady flow calculation was executed in order to gain an understanding of the basic in-cylinder flow characteristics generated by the port.

Maximum Valve Lift	9 mm
Cylinder Bore	85 mm
Connecting Rod Length	148.25 mm
Crank Radius	40.75 mm

Table 2. Engine parameters

Model Geometry

Figure 1 shows the geometry of the intake ports in the form of STL data generated by the CATIA CAD system. One of the most significant innovations of this design is the bypass route provided between the primary and secondary intake ports. This enhances the swirl generation capability of the previous VTEC engine. At low load conditions one valve is partially opening thus forcing flow through the bypass route. See figure 2. In order to examine the impact of this new feature, a steady flow calculation was carried out with the valve for the secondary port in the closed position. The model used for this purpose is shown in Figure 3.

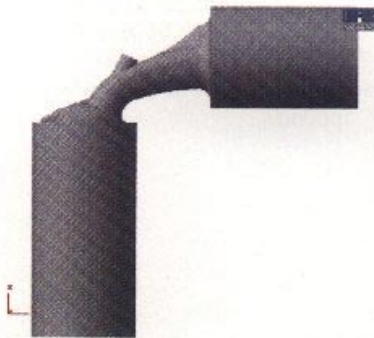


Figure 1. Overall view

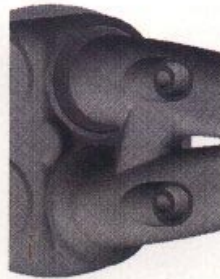


Figure 2. Bypass route



Figure 3. Secondary port closed

Mesh Generation

By careful use of the mesh refinement blocks, it was possible to include significant grid refinement in the critical valve-valve seat region while maintaining the overall mesh size within the practical limits of the computer. The mesh produced is shown in Figure 4, comprising approximately

300,000 cells. All the pre processing was performed on local workstation (SGI and IBM), the mesh was created and 'linked' for the main solver which would be running on the IBM SP platform.

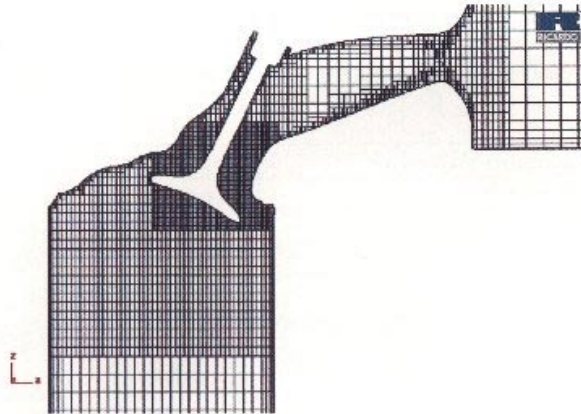


Figure 4. Showing mesh detail around valve

Boundary Conditions

Pressure boundary conditions were used for the steady flow calculation. The input condition to the port was specified as 100,000Pa and the output of the cylinder was specified as 94,000Pa, giving a total pressure differential across the flow domain of 6,000Pa. This condition was selected as being the same as used for standard experimental flow bench testing. The port wall temperature was specified at 20 deg C with an appropriate wall roughness being applied.

Results of Steady Flow Analysis

The predicted flow distribution is shown in Figure 5 in the form of velocity vectors. In addition the resulting swirling flow generated by the bypass passage can be seen in figure 6, which is showing the inplane velocity. The detail of velocity vectors at the valve opening are shown in Figure 7. The effect of the bypass can be seen in the promotion of the flow on the cylinder side of the valve. This phenomenon is critical to the achievement of the lean burn target for this engine.

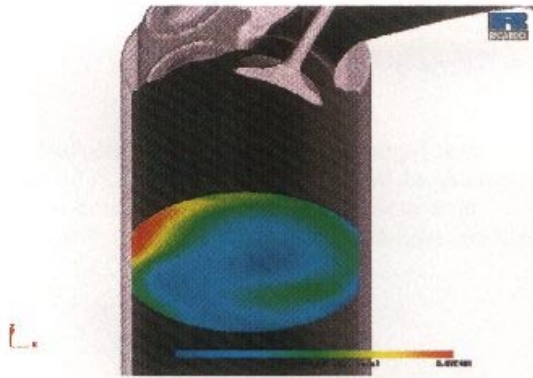


Figure 5. Velocity scalar showing swirling flow

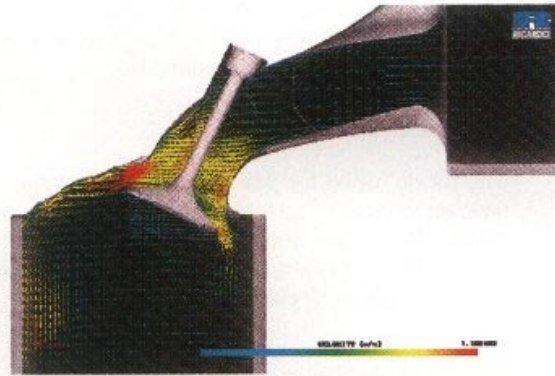


Figure 6. Flow around the active valve

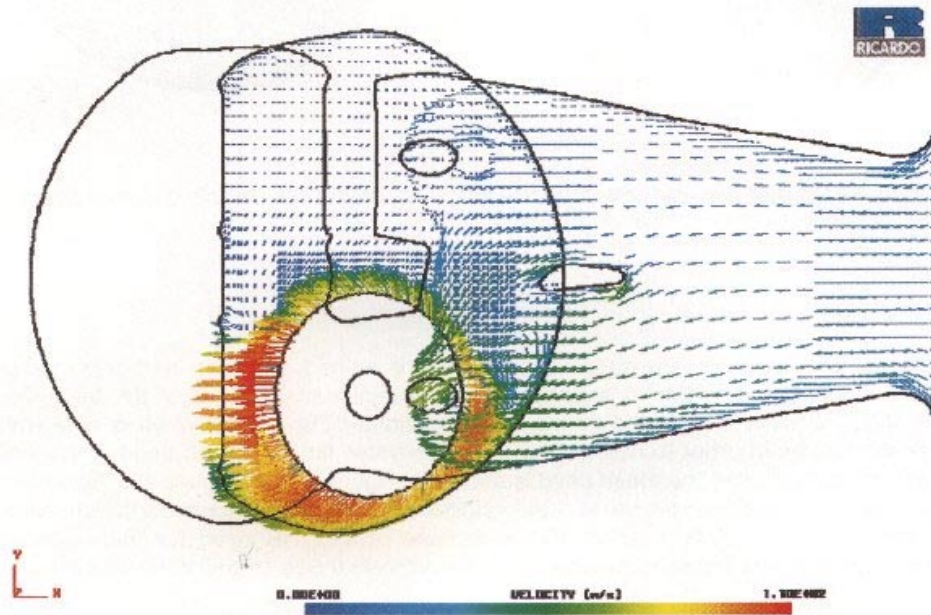


Figure 7 Bypass flow

Unsteady Flow Calculation

Having visualised the swirl generation effect of the new port design in the steady flow calculation, the next step was to evaluate the design of piston crown shape. This was only possible by performing a full three-dimensional moving valve and piston calculation. A full model of the port and piston crown where assembled.

Model Geometry

The model used for the unsteady calculation is shown in Figure 8 and 9. For this calculation the flow rig chamber has been removed and the geometry of the piston crown added. The piston crown has three geometrical features. Feature 'A' is a slotted channel, which promotes swirl around the periphery of the cylinder, to promote local swirl the 'dish' B was added. The raised bank C helps to direct the flow into the 'dish'.

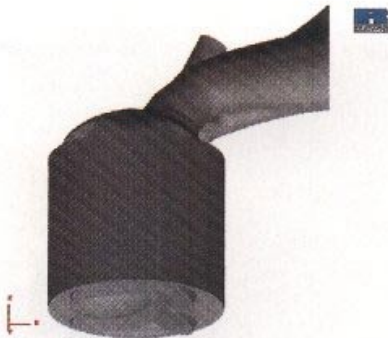


Figure 8. Ports, cylinder and piston geometry

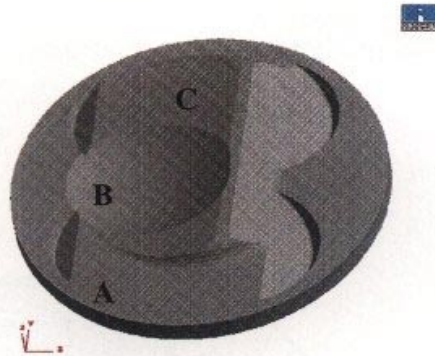


Figure 9. Details of piston shape

Mesh Generation

The unsteady flow calculation required use of a more refined grid than had been used for the steady flow calculation in order to accommodate the minimum valve lift of the secondary valve when the VTEC system is activated at low load conditions. The maximum lift is only 1mm and a fine mesh is required in order to resolve the flow. The valve timing and lift used in this calculation are shown in Figure 10 and the mesh used is shown in Figure 11 and Figure 12. As a result of the complex shape of the piston crown and the additional refinement added the mesh comprised a total of approximately 400,000 cells. In the release of VECTIS used for this calculation, the calculation was re-zoned between meshes at approximately 0.5 to 1mm increments of valve lift.

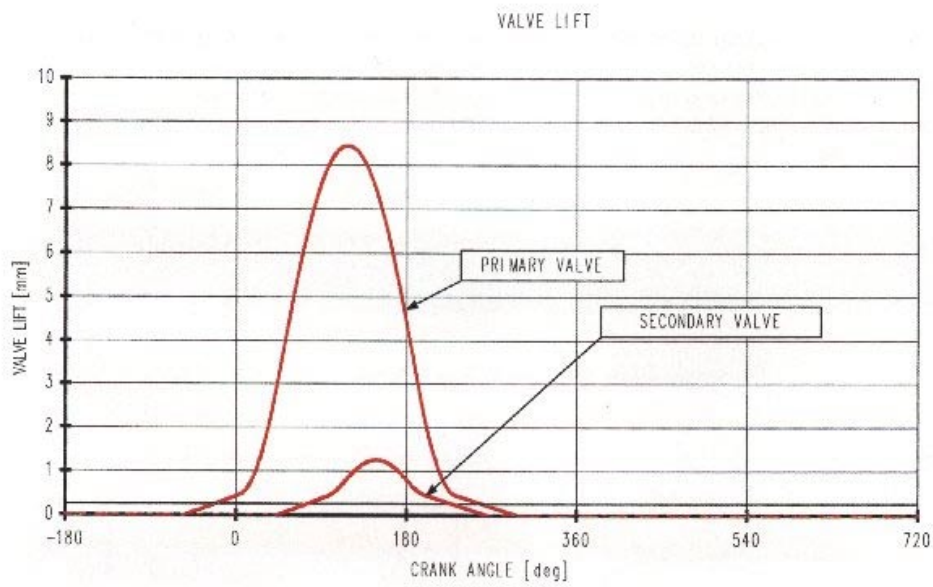


Figure 10 Valve lift curves

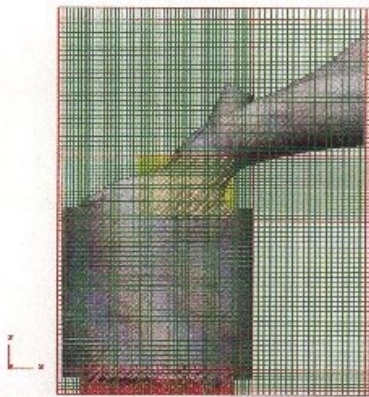


Figure 11 Mesh details

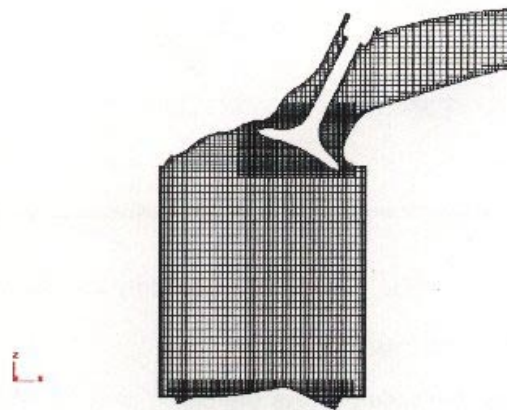


Figure 12 Mesh details around valve and piston

In future it is hoped that by using the new Boundary motion feature fewer meshes will be required.

Boundary Conditions

Time dependent inlet boundary conditions were derived from a one dimensional intake and exhaust system simulation model. This one dimensional wave action code was developed internally by Honda and allows boundary conditions to be extracted for 3D simulation in VECTIS. The boundary condition data used for this calculation is shown in Figure 13 and represents operation at 1600rev/min.

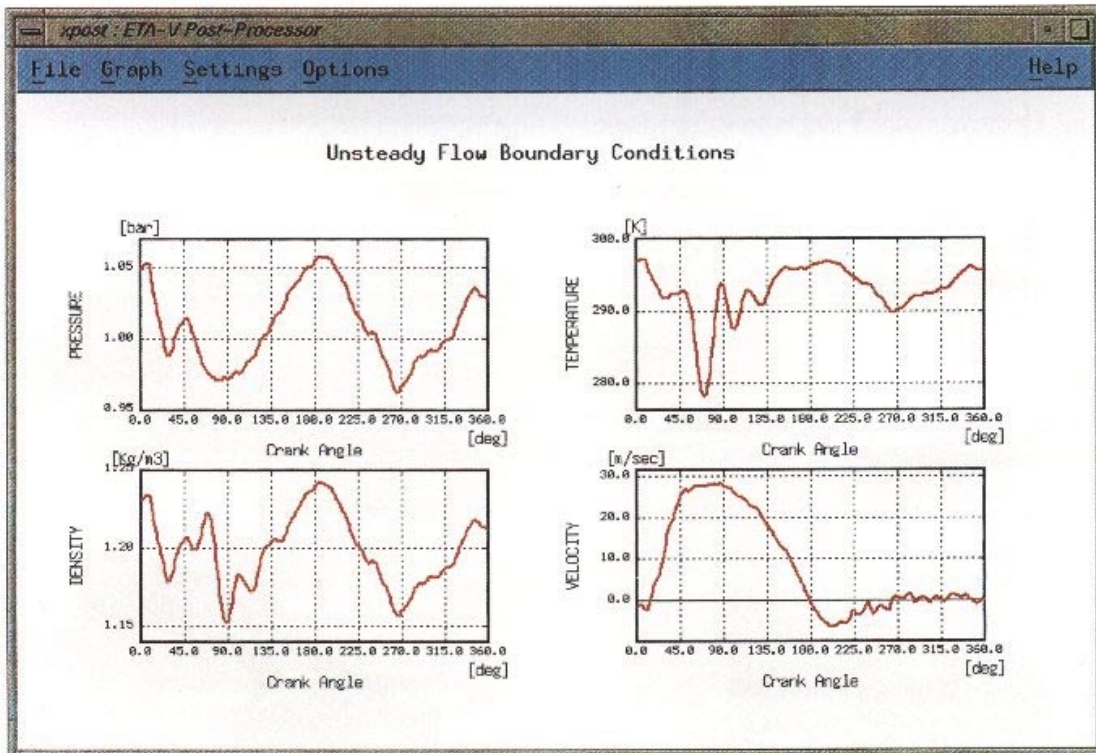


Figure 13 Boundary conditions from Honda's 1D code.

Results of Unsteady Calculation

The flow distribution across the piston crown is shown in the velocity vector plots Figure 14 and 15, respectively for 40 degrees and 100 degrees ATDC. Figure 14 clearly shows that the geometry of feature 'A' promotes a similar flow structure to that observed in the steady flow calculation. However, it is also seen that this flow conflicts with the raised bank (feature 'C') in Figure 15 and that the tumble motion, which is promoted in the region of feature 'B', occurs at approximately BDC. Figures 16 and 17 show the detailed flow interactions with the piston. The desired flow structure had thus been created for this engine design. These results were confirmed in subsequent engine tests, which verified that the target lean limit for air-fuel ratio had been achieved.

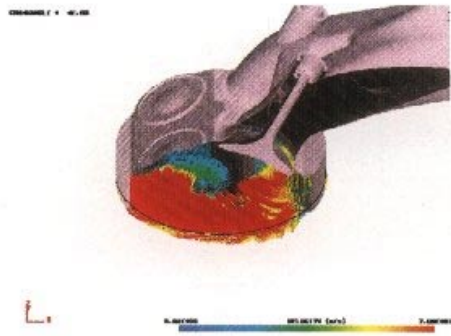


Figure 14 Flow at 40 deg ATDC

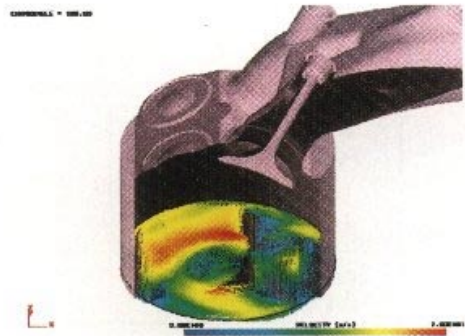


Figure 15 Flow at 100 deg ATDC

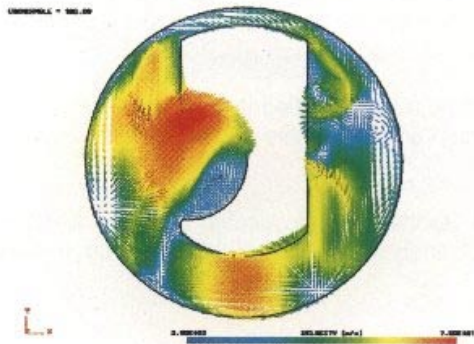


Figure 16 Flow structure in 'dish'

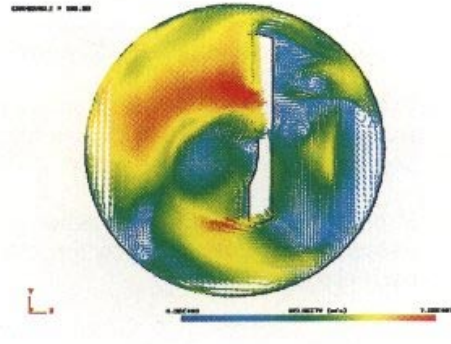


Figure 17 Flow structure around piston top

Summary of Calculations

The following table provides a summary of the two calculations described in this paper:

	Time Required for Each Process	
	Steady Flow Calculation	Unsteady Calculation
Mesh Generation (VECTIS Phase 2)	2 hours	20 hours
Mesh Linking (VECTIS Phase 4)	0.5 hours	1 hour
Solution of equations (VECTIS Phase 5)	2 days	14 days

Table 3. Summary of calculations

The processing time for mesh generation and solution in the unsteady analyses are clearly areas requiring improvement. However, it is Honda's opinion that the former will be addressed by the boundary motion enhancements in VECTIS 3.3, and the latter will be addressed by the parallel release. Tests have already been carried out using a beta version of parallel VECTIS based on the steady flow calculation.

Conclusions

From the work described in this paper, the following conclusions are drawn:

- 1) Using the port and combustion chamber shape defined in CATIA, it has been possible to easily complete both the steady and unsteady in-cylinder CFD calculations required for the design of the lean burn, VTEC engine for the 1998 Accord.
- 2) The desired operating flow structure was obtained by understanding the influence of the port shape from the results of the steady flow calculation and using this information to derive an acceptable design for the piston crown.
- 3) In order to increase the utilisation of VECTIS in Honda's engine design activities it will be necessary to further reduce the elapsed time of analysis. This will be achieved through parallelisation.

Further Applications of VECTIS at Honda

The calculations described in this paper are just the first VECTIS applications to be implemented by Honda. Already applications such as water-jacket flow simulations, catalyst optimisation and spray modelling are being examined. Given experiences to date, it is Honda's opinion that the capabilities of VECTIS will continue develop and keep pace with the future requirements of engine design.