Navier-Stokes Solutions of the Flowfield in an Internal Combustion Engine

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Theme

THE flowfield inside the cylinder of a reciprocating internal combustion engine is calculated by solving the complete Navier-Stokes equations by use of a time-dependent finite-difference technique. The main problem is to solve these equations, including multicomponent diffusion and finite-rate chemical reactions (for H-C-O-N chemistry), and obtain a complete solution for the velocity, pressure, temperature, and chemical composition of the flowfield throughout the four-stroke cycle of a piston-cylinder arrangement. The effects of turbulence, the ignition process, full droplet breakup, and proper coupling with the intake and exhaust manifolds also should be taken into account. At present, this total problem is a horrendous task, and its exact numercial solution will most likely be an evolutionary process over a long period. However, the present work constitutes one of the first steps in this evolution. Specifically, in the present work the flowfield between the top of the cylinder and the face of the piston is computed as a function of space and time as the piston moves through the conventional 4-stroke cycle, with the inlet and exhaust valves opening and closing appropriately. Combustion is not considered in detail. Solutions are obtained for 2-D geometry (infinite aspect ratio engine) and low Reynolds number. Extensions to 3-D geometry and high Re are discussed in Ref. 1. Another first step recently has been taken by Boni et al.,[2] who have considered just the compression and power stroke, but with detailed combustion.

Contents

Figure 1 illustrates the geometric model of the piston-cylinder arrangement. The flowfield is divided into a 10×9 array of grid points that float with the movement of the piston. The two-dimensional Navier-Stokes equations are solved at these grid points by a modification of the time-dependent finite-difference scheme of MacCormack. Numerical experiments, discussed in Ref. 1, clearly show that the cell Reynolds number must be on the order of unity or less; hence the present results are computationally limited to low Re. The no-slip and constant temperature boundary conditions are applied at the piston and cylinder surfaces; constant manifold pressure and temperature are assumed at the intake and exhaust valves. A detailed discussion and justification of the valve boundary conditions are given in Ref. 1. Typical results are shown in Figs. 2-5, which give the velocity pattern at specific times during the intake, compression, power, and exhaust strokes, respectively. At the top

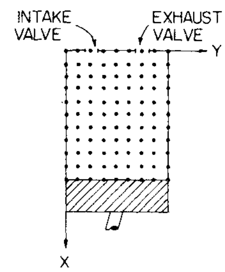

Fig. 1 Model geometry.

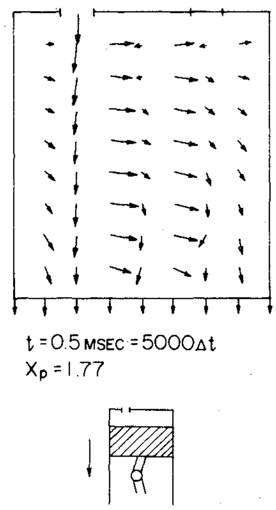

Fig. 2 Velocity distribution on intake stroke: $t = 0.5$ msec $= 5000\Delta t$; $X_p = 1.77$.

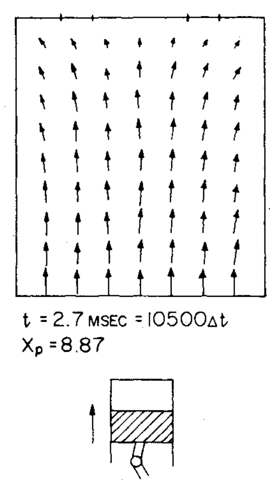

Fig. 3 Velocity distribution on compression stroke: $t = 2.7$ msec $= 10500\Delta t$; $X_p = 8.87$.

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Index categories: Viscous Nonboundary Layer Flows; Airbreathing Propulsion, Subsonic and Supersonic.

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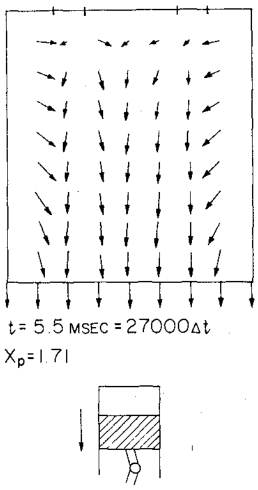

Fig. 4 Velocity distribution on power stroke: $t = 5.5$ msec $= 27000\Delta t$; $X_p = 1.71$.

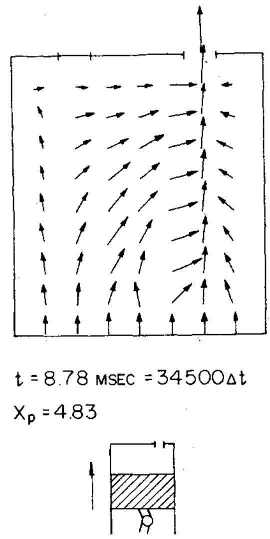

Fig. 5 Velocity distribution on exhaust stroke: $t = 8.78$ msec $= 34500\Delta t$; $X_p = 4.83$.

of the compression stroke, the temperature is increased artificially to simulate combustion. The air is assumed to be calorically perfect. The top of the piston movement is $X_p = 9.0$; the bottom is $X_p = 1.0$. Although the present results are for a very viscous flow (i.e., a thimble-size piston-cylinder at subatmospheric density), the results show a definite flow pattern of some magnitude and complexity inside the cylinder during the complete engine cycle. This flow must have some impact on the real combustion processes; hence the resulting horsepower and emissions from the engine. Results for pressure and temperature distributions are given in Ref. 1.

These distributions are smooth for a low-cell Re, on the order of unity, but have numercially induced wiggles at high-cell Re ≈ 10 or larger. At present, the most severe limitation on obtaining practical viscous flow solutions for typical IC engine operating conditions and sizes is this limitation on cell Reynolds number. Nevertheless, the present results represent a necessary first step towards the eventual practical implementation of Navier-Stokes solutions to IC engine flows.

References

[1] Griffin, M.D., Anderson, J.D., Jr.,and Diwakar, R., "Navier-Stokes Solutions of the Flowfield in an Internal Combustion Engine," AIAA Paper 76-403, 1976.

[2] Boni, A.A., Chapman, M., and Schneyer, G.P., "Computer Simulation of Combustion Processes in a Divided-Chamber Stratified Charge Engine," Presented at the 5th International Colloquim on Gasdynamics of Explosions and Reactive Systems, Bourges, France, 1975; also *Acta Astronautica* Vol. 3, No. 3-4, March-April 1976, pp. 293-307.

[3] MacCormack, R.W., "The Effect of Viscosity in Hypervelocity Impact Cratering," AIAA Paper 69-354, 1969.