III. THE KIVA-3V VALVE MODEL

KIVA-3V can model any number of valves in the cylinder head. Each valve can have its own size and profile, accurate to the fineness of the grid, and its own lift history. The valves may be vertical, with the valve axis parallel to the cylinder axis, or canted at some angle with respect to the cylinder axis. Canting is presently allowed in (x,z) space only, implying that the camshaft(s) are parallel with the y-axis. In logical space, valves can move only in a bottom-top direction. There is currently no provision for horizontal, splayed, or annular valves.

The valve model is an extension of that originally developed by R. P. Hessel,[27–29] in which a valve is treated as a solid object that moves through the mesh using the familiar "snapper" technique already used for piston motion in KIVA-3. Because the valves are modeled exactly, the accuracy of the model is commensurate with that of the rest of KIVA-3. Hessel's approach was to extend subroutine SNAPB to snap the valve upper surfaces in addition to piston faces, and to reassign subroutine SNAPT to snap the lower valve faces. His model considered only vertical valves, as his immediate application was to a heavy-duty diesel engine.

KIVA-3V, however, has two separate new snapper subroutines, SNAPVFCE and SNAPVTOP, tailored specifically for valves, and retains SNAPB and SNAPT in their original roles as piston snappers. SNAPVFCE considers the lower surfaces that face the cylinder, and SNAPVTOP considers the upper surfaces that face the valve ports. To accommodate canted valves, the new subroutines include the x-direction component of motion in addition to the z-direction component. The end result is that the purpose of each of the four snapper subroutines is quite distinct. All previous KIVA-3 capabilities have been retained.

A. Valve Data in File ITAPE17

As in the original KIVA-3, the grid supplied to KIVA-3V as input file ITAPE17 from the grid generator is required to have the piston at its BDC position, and the region array IDREG must be supplied. There are typically three physical regions in a valved IC engine (Fig. 1). As before, IDREG = 1 is assigned to all cells in the cylinder. IDREG = 2 may refer to the intake port(s) and IDREG = 3 to the exhaust port(s), or vice versa. The only possible ambiguity is in the path of valve travel. Here, the cells directly above the valve, i.e., out to the valve diameter, have the IDREG of the port (2 or 3). As the valve opens during the KIVA-3 calculation, the region number 2 or 3 automatically follows downward in the wake of the valve in SNAPVTOP as cells above the valve are activated. As the valve closes, SNAPVFCE assigns the cells below the valve face to region 1, as they become part of the cylinder. Thus, the same physical cells will have different values of IDREG during the run, depending on whether the valve is

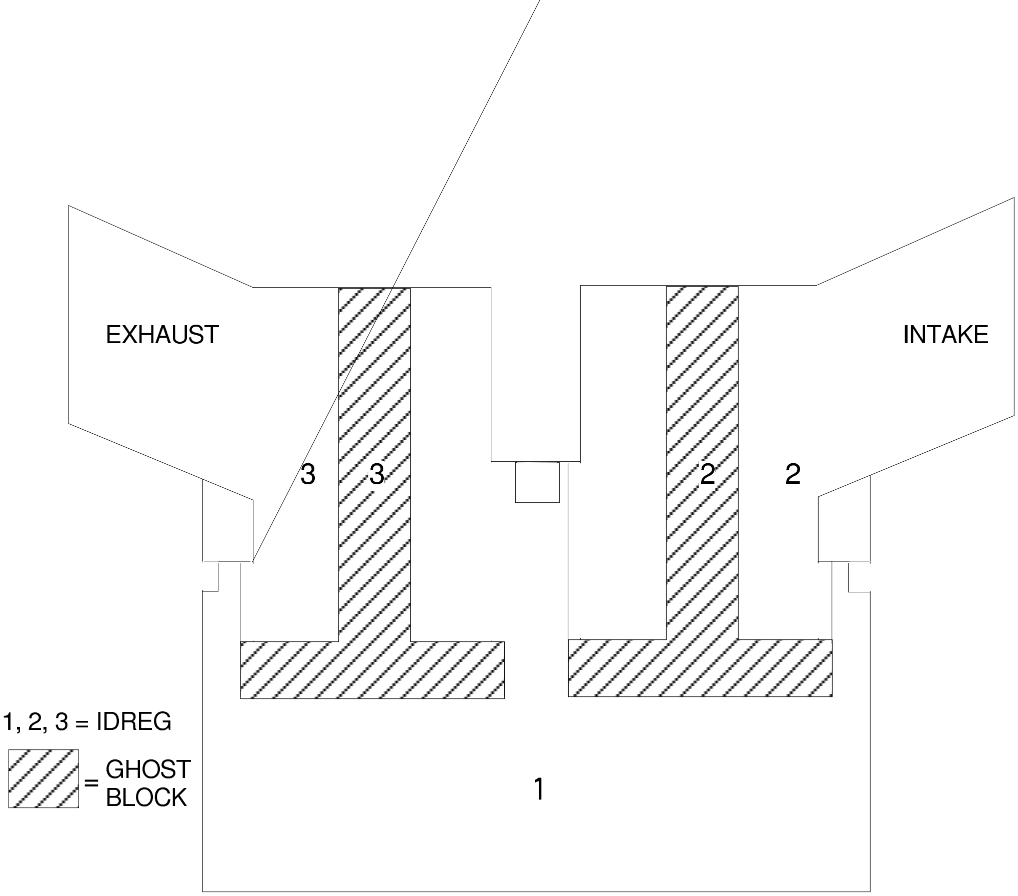

Fig. 1. The three physical regions in a KIVA-3V grid for a typical valved IC engine.

currently above or below them. Cells in a valve recess or pocket always have IDREG = 1.

A new vertex flag array, IDFACE, must also be supplied by the grid generator as part of the ITAPE17 data file. *The addition of IDFACE is the only change to the ITAPE17 file.* In the original KIVA-3, there were only two possible moving surfaces: the piston and the optional upper piston. The program was able to use z-coordinates and vertex and flag information to identify moving surfaces, without requiring additional input data. The implementation of valves and their associated multiple moving surfaces requires additional information to identify *which* moving surface a vertex or cell face is identified with. By the new definition, a lower piston is always moving surface 0, and all vertices on the piston face have a flag IDFACE = 0. Vertices on the upper piston face in an opposed-piston geometry have vertex flags IDFACE = 1.

Although both the lower and upper surface of a valve move with the same velocity, each surface is identified separately because each moving surface is treated as a separate entity by the valve snappers. Because an upper piston is not an option in a valved geometry, the value IDFACE = 1 is available. The vertices of bottom surfaces of valves (i.e., the valve face) always have *odd* values for IDFACE (1, 3, ...), and the top valve surfaces and stems always have *even* values for IDFACE (2, 4, ...). By this definition, any moving surface, be it piston or valve, that has fluid above it has an even IDFACE. Conversely, if fluid lies below the face, the IDFACE is odd. All the remaining vertices in the grid, which are not associated with any moving surface, are assigned IDFACE = –1.

B. Valve Data in File ITAPE5

- NVALVES is the number of valves,

  and for *each* valve:

- VLIFTMIN, the minimum lift in cm, below which the valve is closed;
- SKIRTTH, the thickness of the vertical edge of the valve, in cm ;
- TMOVE, the valve temperature in Kelvins. (Because a temperature for each valve can now be specified, the previous TVALVE line in earlier ITAPE5 files has been deleted);
- VTILTXZ, the valve cant angle from cylinder axis, in degrees: + , -, or 0.0;
- NLIFT, the number of lift entries for the valve on file ITAPE18.

C. Valve Lift Data: File ITAPE18

Input data file ITAPE18 (free format) is a table of crank angles (integers) and corresponding valve lifts in cm (real numbers). The table must provide the lift information for one complete engine cycle: 0^{o} to 720^{o} for a 4-stroke engine, or 0^{o} to 360^{o} for a 2-stroke engine. KIVA-3V determines the length of an engine cycle from the new input quantity REVREP (revolutions between repetion), which should be specified as 2.0 for a 4-stroke engine, or 1.0 for a 2-stroke engine. All crank angles for which the lift is zero may be excluded from ITAPE18, which minimizes the length of the file. In addition, the crank angle increment from one line to the next is not required to be uniform throughout the file. The history for each valve appears in succession, with NLIFT lines per valve.

D. Valve Movement

Each cycle, subroutine VALVE interpolates the lifts and velocities of the valves at the current crank angle from the data on ITAPE18. If the current crank angle lies outside the table range, the subroutine will use the appropriate equivalent crank angle inside the table range, permitting multiple engine cycles to be calculated. In physical space, the vertices that lie on a valve surface move as a unit each cycle in subroutine REZONE, using the current valve velocity components (UMOVE, WMOVE). Vertices on the valve stem are assigned the valve velocity, which allows the proper wall stress to be calculated and spray particles on the stem to be moved. To preserve the original zoning in the port, these vertices are never actually moved in subroutine REZONE.