thermodynamic effects, the pressure ratio effect, drive current effect and supply pressure effect, and is illustrated in figure

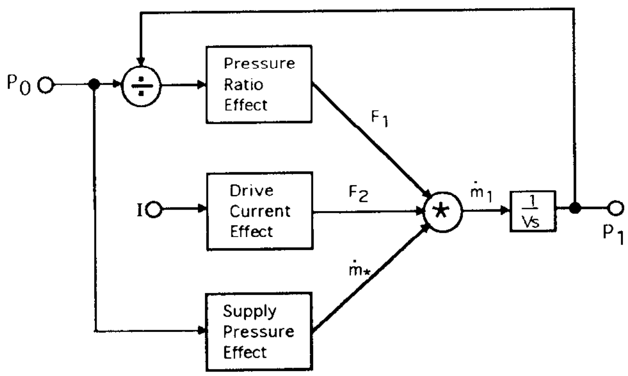

Figure 3. System Thermodynamic Effects

3. F1 and F2 are expressed as limiting ratios, and $\dot m_*$ is the flow rate uninhibited by F1 or F2. Fliegner's formula [2] is used to calculate $\dot m_*$:

$$\dot m_* = 0.532 C P_0 \frac{A}{\sqrt{T_0}}, \qquad (3)$$

where C is the empirically determined coefficient of discharge through the servo,
A is the area of the flow through the servo,
T_0 is the temperature of the air at the source.

From [2], the pressure ratio effect, F1, is expressed as

$$F1 = \frac{\dot m}{\dot m_*}, \qquad (4)$$

where

$$\dot m = 2.05 C A P_1 \sqrt{\left(\frac{1}{T_0}\right)\left(\frac{P_0}{P_1}\right)^{0.283}\left[\left(\frac{P_0}{P_1}\right)^{0.283} - 1\right]}. \qquad (5)$$

The drive current effect, F2, is the primary means by which the controller regulates the mass flow rate into the orifice, and relates current applied to the servo with flow rate. This limiting effect is expressed by the ratio

$$F2 = \frac{\dot m}{7} \text{ liters per minute}, \qquad (6)$$

where $\dot m$ for the specific servo used is shown by figure 4 [3]. Note that it is dependent upon whether vacuum or pressure is being applied.

In addition to the above thermodynamic effects, the system is also subject to transducer noise in the form of jitter. The period jitter for the pressure transducer, operating at a frequency of 5 kHz, was empirically determined to be 0.72 nS [4]. From this, the corresponding pressure jitter was calculated to be 0.00089 inHg. The pressure jitter calculation, in addition to being dependent upon period jitter, is also dependent upon temperature. Not only is pressure jitter dependent upon temperature, but it was found that a 50° C increase in temperature resulted in a 50% increase in period jitter [4].

From all of the above details, the reader can see that developing a conventional controller which takes these things into account can be a pretty hairy business! The PID developer had to account for the inherent fluid flow non-linearities, variations in temperature, noise, different sizes of

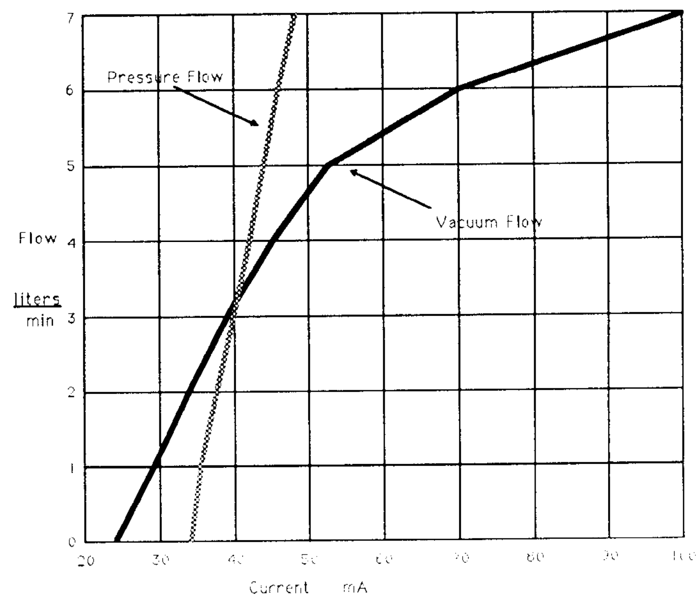

Figure 4. Servo Valve Flow Characteristics

control volumes, and even leakages in the pneumatic system. The fuzzy controller, however, as we shall later see, was developed with complete ignorance of these physical phenomena.

Control System Structure

The functional diagram shown in figure 5 illustrates the high level strategy to achieve and maintain a desired altitude. First, the current pressure in the controlled volume is sampled and used by software to calculate two different pressure rate demands, for ramp and steady-state. The ramp calculation is performed by using pressure-altitude look-up tables [5], and is pertinent when the system is slewing from one altitude to another. Next, the sampled pressure is subtracted from the target pressure to calculate the steady-state rate demand,