for this system it was found that the flow rate and changes in flow rate for changes in the servo position are dependent on whether pressure or vacuum is applied. The servo requires larger changes in current applied to achieve a given amount of flow for vacuum than for pressure. Therefore, it was necessary to develop two mbf sets for the servo delta, one to be used when pressure is applied, and one to be used when vacuum is applied.

After using the above criteria for modifying the fuzzy controller, the testing and tuning cycle was repeated until the desired system performance was reached. The final tuned membership functions can be seen in figure 11.

Fuzzy Controller Performance

The performance of the fuzzy controller of the static pressure channel in comparison with the PID controller can be analyzed by considering its trajectory error, steady-state error, response time and response to noisy inputs. These items are discussed in the following paragraphs.

Trajectory Error - The trajectory error, associated with slewing to a target altitude, is the difference between the target slew rate and the actual slew rate. For the last developed version of the fuzzy controller, using a target slew rate of 5000 ft/min (climbing), the average trajectory error for the fuzzy controller was 59.11 ft/min, while the average for the PID was 58.47 ft/min, a difference of only 7.68 inches per minute! It is expected that further straightforward refinements could reduce the trajectory error even more. The slew trajectories for this 5000 ft/min climb are shown in figures 12 and 13. Figure 14 shows the sample slew distribution for this run (the sample rate was 1 Hz).

Steady-State Error - The steady-state error is important after the system reaches the target altitude and settles into the steady-state region, which has been defined as ±100 feet from the target. This error is the difference between the target altitude and the actual altitude. For the last developed version of the fuzzy controller, the steady-state error was about the same as with the PID (averaging less than 1 ft, well within the allowable error of ±3 ft), as can be seen in the test profiles in figures 15 and 16.

Response Time - The response time of the fuzzy controller was faster than that of the PID, partially due to the heavy filtering used with the PID. The response time is affected by the control surface of the fuzzy control (back in figure 10). Each point on this surface is the output activation level (axis z), given the input (x, y). A faster response time can be shown as having a greater slope on the surface.

Noise - As describe previously, the transducers are subject to jitter. Additionally, it was discovered during development that the test set hardware internally generated large amounts

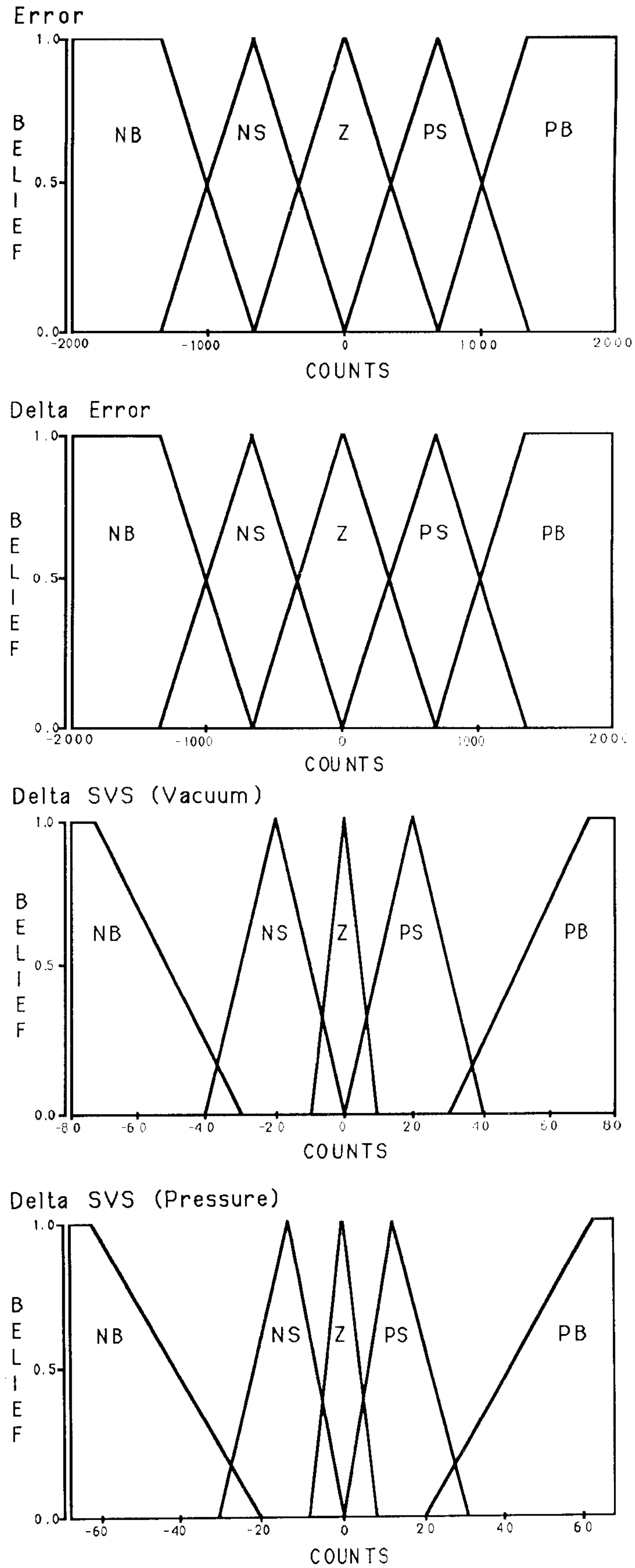

Figure 11. Final Tuned Fuzzy Membership Functions