APPENDIX B - INSTRUMENT TRAVERSE MECHANISM

The qualification of the wind tunnel and plate system for the particle drag reduction experiment required sampling of air velocity and turbulence over a large volume of the wind tunnel test section, spanning the width, height, and length. A traversing mechanism was engineered to move sensors around a large part of the required volume without sizable distortion of the air flow. While gross traversing along the length and width of the test section was certainly simple enough, the measurement of extremely thin laminar boundary layers in the vertical direction, in a mechanism with two other axis of motion, provided a unique challenge. In fact, the major instrumentation companies did not provide such mechanisms from stock, and even their single axis traverse machinery was prohibitively expensive.

Boundary layer measurements on the plate required a resolution at least a twentieth of the displacement thickness of the boundary layer. The laminar boundary layer near the front of the test plate provided the critical condition, requiring a resolution of at least one thousandth of an inch under normal test flow conditions. It was judged that a precision of plus or minus ten per cent of this resolution would provide adequate estimates of the boundary layer wall friction and integral properties. In order to provide capability for future experiments, the overall vertical reach had to be within two inches of the test section ceiling, or 30 inches above the floor. The lower boundary was not as critical. Since the traverse across the width of the tunnel was provided by a cantilever arm, somewhat less strong than the upright supports, its length was designed for reaching across the test plate. The horizontal crossarm extended 16 and one-half inches from the centerline of the upright supports. Movement along the length of the test section was provided by a track laid on the test section floor, which allowed the entire traverse mechanism to roll up and down the tunnel. A general view of the traverse mechanism is shown in Figure 60. Although these basic traverse mechnism requirements

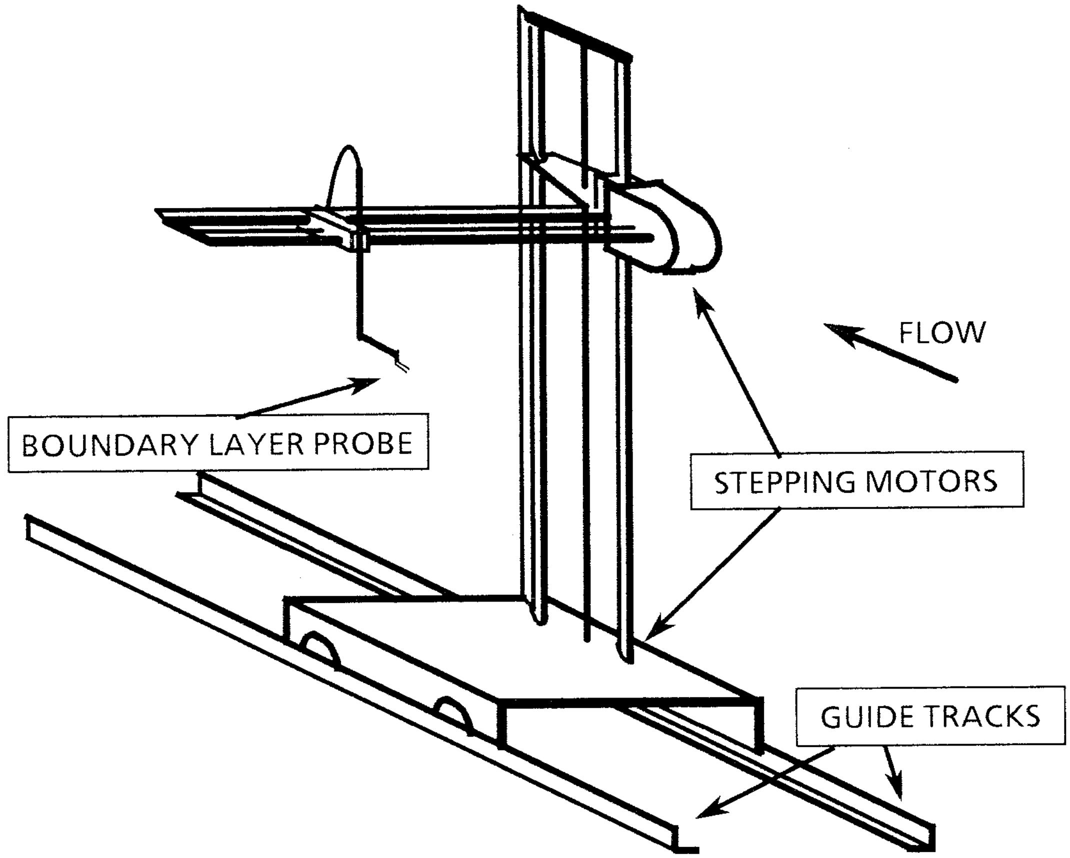

Figure 60. - Traverse general layout

are very stringent, it is to be noted that this equipment also had to operate reliably and accurately in a vibrating wind tunnel, in an airstream carrying abrasive particles, and in environmental extremes of humidity and temperature (from zero degrees to over one hundred-twenty degrees Fahrenheit).

As can be seen in the general layout, vertical traverse travel is supported by two case-hardened one-inch diameter precision steel shafts. The horizontal travel is supported by similar one-half inch diameter shafts. Precision Thomson Industries linear ball bearings were used for the vertical carriage and for the probe mount carrier. Power and control is provided by two KA82944-M1 stepper motors from North American Philips Controls Corporation. These motors provided 36 inch-ounce holding torque and a stepping resolution of 7.5 degrees. Power transmission from the motors is provided through one-quarter inch steel screw shafts with twenty threads per inch. These were directly driven by the stepper motors and supported by custom bearing assemblies of extremely low backlash. The shafts drove the carriage assemblies via custom machined precision brass nut plates.

Altogether, the sophisticated mechanical design of the traverse is complemented by the electronics required to drive the stepper motors and provide traverse positioning information. The stepper motors provide the ability to control the traverse in an open loop manner. The desired number of steps is commanded through the traverse control console, which in turn sends signals to the stepper motor driver transistors mounted on the traverse itself. The controls layout on the face of the console is shown in Figure 61.

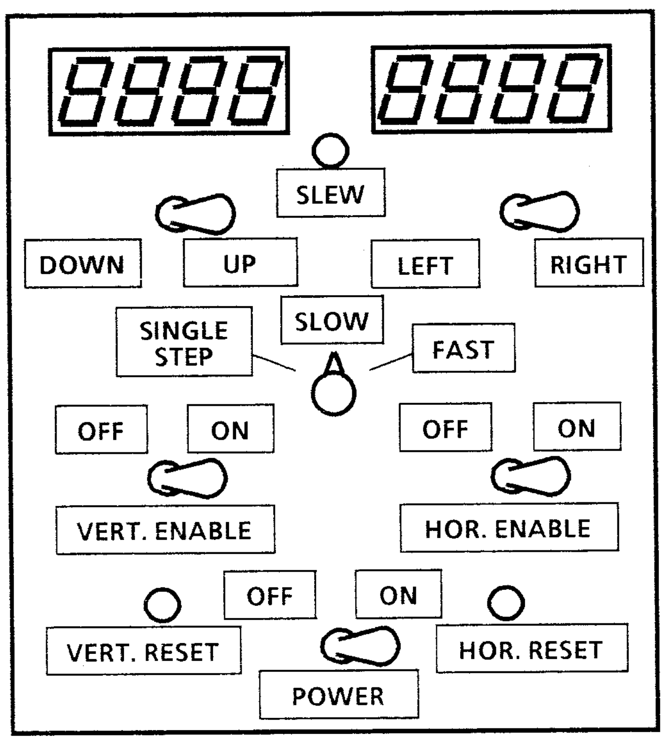

Figure 61 - Traverse console controls

The state of electronics at the time of the traverse was designed required assembly of the console from medium-scale integration transistor-transistor logic (TTL) circuits. The console was designed to provide drive signals to move the stepper motors in either direction at selectable rates, and to count the number of steps and transfer the count to multiplexed light emitting diode displays. A functional diagram of the traverse control is shown in Figure 62. The ciruitry design used 27 integrated circuit packages, 31 transistors, and approximately 80 other discrete parts. All of this circuitry required a five volt requlated power supply at four amps, while the motors required 12 volts at two amps.

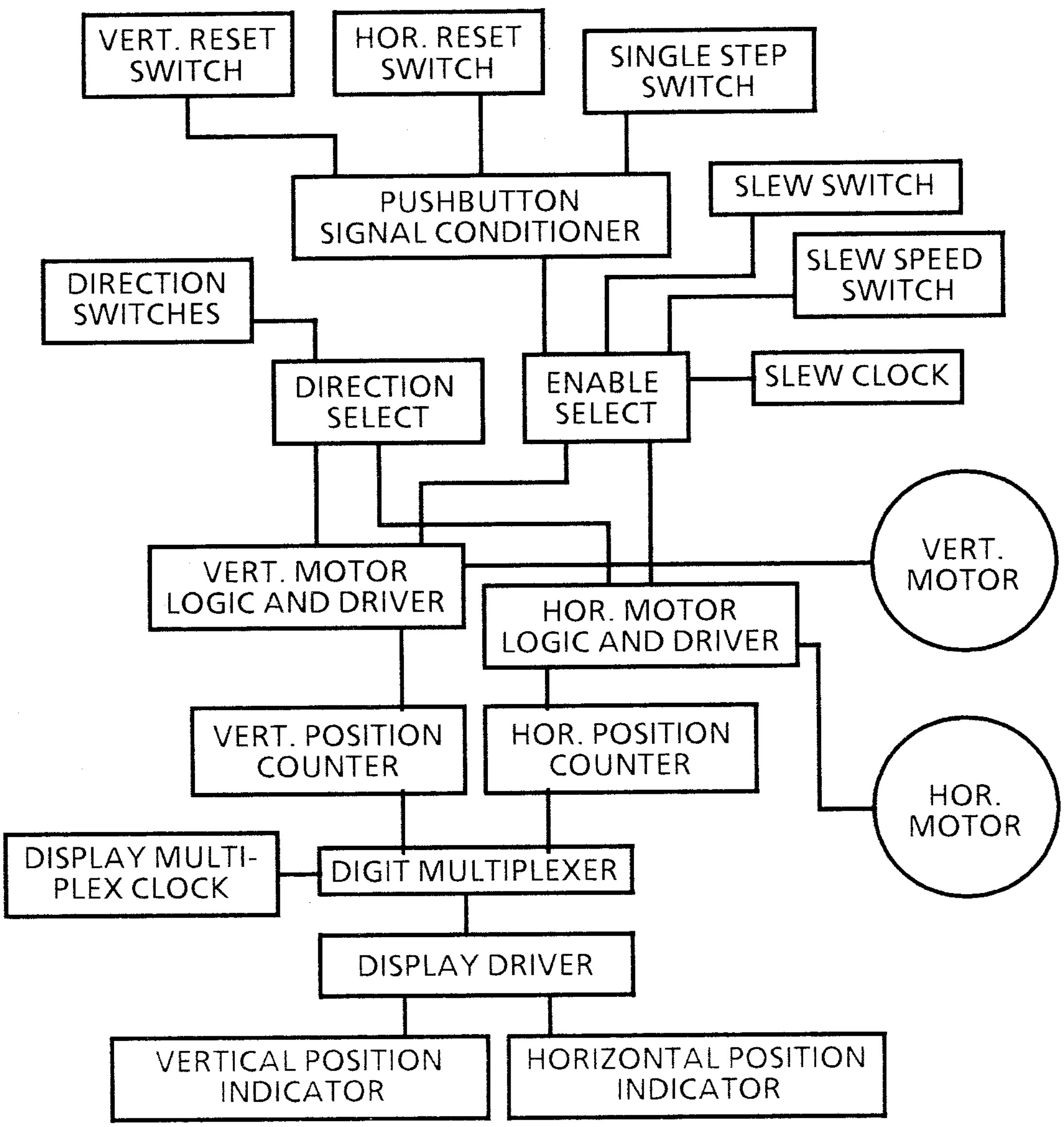

Figure 62 - Functional diagram of traverse control

Thanks to the use of TTL circuitry, it is possible to interface a computer to the traverse mechanism.

Accuracy tests were performed on the traverse mechanism in horizontal and vertical displacements. A dial displacement indicator was used that was accurate to 1×10^{-4} inches. Typical data from the tests are shown in Table IV and Table V. Maximum error found was 1.5×10^{-2} inches for horizontal movement, and 5×10^{-5} inches for vertical movement. Since the statistical analysis indicates greater precision than the dial indicator provides, it is assumed that the accuracy is at least as good as the dial indicator, or 1×10^{-4} inches. It can be seen that the traverse mechanism is very accurate in vertical displacement, and has fair accuracy in horizontal displacement, when traversing in a single direction. The tests also determined the amount of backlash in the system. Backlash in horizontal movement was found to be about 1.5×10^{-2} inches, and vertical backlash was found to be about 5×10^{-4} inches.

Table V - Horizontal Traverse Sample Data

- Probe Carrier at 9.375 Inch Height and 12 Inch Horizontal Displacement From Left Limit (At Start of Test)
- Dial indicator reading is inches $\times 10^{-3}$
- Traverse reading is in counts, each count translates to a single 7.5 degree motor step
- Positive displacement towards the right, or outward from the vertical supports

COUNTS	INDICATOR	COUNTS	INDICATOR	COUNTS	INDICATOR
0	0	37	38.3	25	34.4
1	0.7	38	39.7	24	33.3
2	1.2	39	40.9	23	32.3
3	2.0	40	42.0	22	31.3
4	2.7	41	42.9	21	30.4
5	3.2	42	43.8	20	29.8
6	3.9	43	45.1	19	29.1
7	4.2	44	46.2	18	28.6
8	5.1	45	47.2	17	28.2
9	6.0	46	48.2	16	27.8
10	7.1	47	49.1	15	27.4
11	7.9	48	50.0	14	26.9
12	8.8	49	50.7	13	26.1
13	9.5	50	51.5	12	25.0
14	10.3	49	51.5	11	24.1
15	11.5	48	51.3	10	23.1
16	12.6	47	51.3	9	22.2
17	13.9	46	51.3	8	21.3
18	15.0	45	51.3	7	20.2
19	16.1	43	51.5	6	19.2
20	17.2	42	51.5	5	18.3
21	18.6	41	51.5	4	17.2
22	19.8	40	51.5	3	16.4
23	21.1	39	51.5	2	15.2
24	22.2	38	51.0	1	14.3

Table V - Horizontal Traverse Sample Data (Cont'd)

COUNTS	INDICATOR	COUNTS	INDICATOR	COUNTS	INDICATOR
25	23.2	37	50.0	0	12.9
26	24.3	36	49.1	-1	10.7
27	25.4	35	48.1	-2	10.2
28	26.5	34	47.2	-3	8.9
29	27.3	33	46.3	-4	7.6
30	28.3	32	45.2	-5	6.3
31	29.5	31	43.8	-6	5.4
32	31.2	30	42.0	-7	4.5
33	32.8	29	40.6	-8	3.3
34	34.1	28	38.9	-9	2.3
35	35.6	27	37.2	-10	1.0
36	37.0	26	35.8	-11	-0.1

Table VI - Vertical Traverse Sample Data

- Probe Carrier at 12 Inch Height and 6.5 Inch Horizontal Displacement From Left Limit (At Start of Test)
- Dial indicator reading is inches $\times 10^{-3}$
- Traverse reading is in counts, each count translates to a single 7.5 degree motor step
- Positive indicated displacement downwards

COUNTS	INDICATOR	COUNTS	INDICATOR	COUNTS	INDICATOR
0	0	9966	35.3	9968	33.8
9999	1.2	9965	36.5	9969	32.7
9998	2.1	9964	37.6	9970	31.6
9997	3.1	9963	38.7	9971	30.5
9996	4.2	9962	39.8	9972	29.3
9995	5.2	9961	41.0	9973	28.3
9994	6.3	9960	42.1	9974	27.2
9993	7.3	9959	43.2	9975	26.2
9992	8.4	9958	44.2	9976	25.2
9991	9.5	9957	45.2	9977	24.2
9990	10.6	9956	46.3	9978	23.2
9989	11.6	9955	47.3	9979	22.1
9988	12.6	9954	48.4	9980	21.1
9987	13.7	9953	49.4	9981	20.0
9986	14.7	9952	50.4	9982	19.1
9985	15.7	9951	51.6	9983	18.0
9984	16.8	9950	52.4	9984	17.0
9983	17.8	9951	51.8	9985	15.9
9982	18.8	9952	50.8	9986	14.9
9981	19.8	9953	49.8	9987	13.9
9980	20.8	9954	48.7	9988	12.8
9979	21.8	9955	47.7	9989	11.8
9978	22.9	9956	46.6	9990	10.7
9977	23.9	9957	45.4	9991	9.7
9976	25.0	9958	44.5	9992	8.7
9975	26.0	9959	43.5	9993	7.6

Table VI - Vertical Traverse Sample Data (Cont'd)

COUNTS	INDICATOR	COUNTS	INDICATOR	COUNTS	INDICATOR
9974	26.9	9960	42.4	9994	6.6
9973	27.9	9961	41.3	9995	5.5
9972	28.9	9962	40.2	9996	4.3
9971	30.0	9963	39.2	9997	3.2
9970	31.1	9964	38.1	9998	2.2
9969	32.2	9965	37.0	9999	1.3
9968	33.2	9966	35.9	0	0.3
9967	34.3	9967	34.8	-1	-0.7