EXPERIMENTAL DETERMINATION OF THE EFFECTIVE TAYLOR DISPERSIVITY IN A FRACTURE

By

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Section 1: **INTRODUCTION**

Reinjection of waste hot water is commonly practiced in most geothermal fields, primarily as a means of disposal. Surface discharge of these waste waters is usually unacceptable due to the resulting thermal and chemical pollution.

Although reinjection can help to maintain reservoir pressure and fluid volume, in some cases a decrease in reservoir productivity has been observed (Horne, 1962). This is caused by rapid flow of the reinjected water through fractures connecting the injector and producers. As a result, the water is not sufficiently heated by the reservoir rock, and a reduction in enthalpy of the produced fluids is seen.

Tracer tests have proven to be valuable to reservoir engineers for the design of a successful reinjection program. By injecting a slug of tracer and studying the discharge of surrounding producing wells, an understanding of the fracture network within a reservoir can be provided.

In order to quantify the results of a tracer test, a model that accurately describes the mechanisms of tracer transport is necessary. One such mechanism, dispersion, is like a smearing out of a tracer concentration due to the velocity gradients over the cross section of flow. If a dispersion coefficient can be determined from tracer test data, the fracture width can be estimated.

The purpose of this project was to design and construct an apparatus to study the dispersion of a chemical tracer in flow through a fracture.
Section 2: LITERATURE SURVEY

The effects of water reinjection in geothermal systems worldwide is discussed in a paper by Horne (1983), which also includes a summary of tracer testing procedures and results.

In order to derive a model to accurately describe the transport of tracer through a fracture, the physics of dispersion must be understood. Taylor (1953) presented a classic study of dispersion in flow through a capillary tube. He showed that convective dispersion combines with transverse molecular diffusion in what we now know as "Taylor Dispersion" (Fig. 1). He showed that the tracer concentration is dispersed symmetrically about a plane that moves with the mean flow velocity. Taylor presents the equation governing the effective longitudinal dispersion:

\[ \eta \frac{\partial^2 C}{\partial z^2} = \frac{\partial C}{\partial t} \]  

(1)

where,

- \( C \) = concentration
- \( z \) = translated distance = \( x - ut \)
- \( x \) = distance
- \( t \) = time
- \( u \) = mean velocity of flow
- \( \eta \) = net longitudinal dispersivity (derived for pipe flow in Taylor's model)

The solutions to eqn (1) for different initial and boundary conditions can be found in Carslaw and Jaeger (1959). For a step input,
found in Carslaw and Jaeger (1959). For a step input,

\[ C = C_* + \frac{1}{2}(C_1 - C_*) \left[ \text{erfc} \left( \frac{x - ut}{\sqrt{2} \eta t} \right) \right] + \text{exp} ^{\frac{ux}{2(\eta t)^{1/2}}} \text{erfc} \left( \frac{x + ut}{\sqrt{2} \eta t} \right) \]  

(2)

where,

- \( C_* \) = base concentration
- \( C_1 \) = injected concentration
- \( C \) = concentration at \( x \)
- \( \text{erfc} \) = complimentary error function

Horne and Rodriguez (1983) used a method similar to Taylor’s to derive an expression for the net longitudinal dispersivity, \( \eta \), for flow in a fracture:

\[ \eta = \frac{2}{105} \frac{b^2 u t}{D} \]  

(3)

where,

- \( b \) = fracture half-width
- \( u \) = mean flow velocity
- \( D \) = coefficient of molecular diffusion

They also showed that, due to the effects of transverse molecular diffusion, any concentration gradients across the fracture would be equalized after a non-dimensional time, \( t_D = 0.5 \) (Fig. 2), where

\[ t_D = \frac{D}{b^2} t \]  

(4)

Fossum and Horne (1982) show how the subroutine VARPRO can be used to determine both linear and non-linear parameters from a set of experimental data. VARPRO uses a non-linear least squares method of curve fitting. Fossum and Horne (1982) matched the calculated response to field data from tracer
Convective dispersion

Taylor dispersion

(convective dispersion + transverse diffusion)

Fig. 1. Dispersion Schematics

Fig. 2. $\delta(t_d)$ vs. $t_d$ (Horne & Rodriguez, 1953)
The present study set out to examine and confirm the applicability of Equation (3), which is only approximate, and to initiate broader investigations into dispersion in fractures. To these ends, an experimental program was undertaken.

The results of several experiments to study dispersion were found in the literature. Bear (1961) performed both one- and two-dimensional studies of dispersion through porous media and produced results which agreed with his theory. Hull and Koslow (1962) present the results of a study of dispersion in a network of channels.
Section 3: DESIGN

The design objectives were aimed at building an apparatus capable of studying dispersion through a fracture in both one- and two-dimensions. The possibility of testing both chemical and fluorescent tracers was another requirement.

1. HELE-SHAW CELL

The size of the model fracture, particularly its aperture, was constrained by the results of Horne and Rodriguez (1983). Any concentration gradient across the width of the fracture will be equalized after a non-dimensional time, $t_D = 0.5$ (Fig. 2). The real time it takes to become equalized is proportional to the square of the fracture half-width:

$$ t = \frac{0.5b^2}{D} \quad (5) $$

Using a diffusion coefficient for potassium iodide ($K_I$) $\approx 2 \times 10^{-3} m^2/sec$ and a fracture half-width of 0.25 mm, the time required is about 16 sec. By using an aperture of 0.54 mm and flowrates of approximately 50 cc/min we could keep the apparatus small enough to fit on a lab bench! The cell is 6 ft long by 1 ft wide. Fig. 3 shows an overall view and Fig. 4 a detail of the design.

The lower plate is 1 in. thick cast aluminum alloy. It is hard anodized to prevent corrosion and provide a tough, non-conductive finish. The upper plate is 1/4 in. float glass and is separated from the aluminum by a gasket made up of three layers of plastic electrical tape. A series of aluminum clamps holds the cell together while four adjustable legs support it horizontally on the lab bench.

2. VALVES

The inlet and outlet ports were implemented by drilling holes 11 in. through the width of the plate. A 0.25 in. slit was then sawed through the surface (Fig. 4) since the pressure drop across the length of the drilled hole is negligible com-
FIG. 4. DETAIL VIEW

FIG. 5. TRACER VALVE
pared with that across the slit, water will flow into the cell at uniform velocity over its width.

An on-off valve (Fig. 5) was designed to allow instantaneous injection of tracer. The valve is activated by hand and can be locked in either on or off position.

3. ELECTRODES

In order to continuously monitor the tracer concentration as it flows through the cell, an array of 96 electrodes was employed. For a KI tracer the conductivity of solution will increase linearly with the log of concentration. Thus we are able to measure the tracer concentration at any electrode location and any chosen time.

The coaxial electrodes were constructed using brass conductive elements and a teflon insulator (Fig. 6). The brass surfaces were electroplated with gold to prevent corrosion and polarization. Each electrode is press fit in to the aluminum plate and mounted flat to within .0015 in. The central electrode is connected to the data aquisition system, and the outer electrode is grounded to the plate.

An instantaneous current is flowed across the electrode while the resulting voltage is measured (requiring less than 0.1 sec.). Voltages can be measured once each second and are stored in a Compaq personal computer. The data is displayed on the screen so it is possible to “watch” the tracer as it flows through the cell. The circuitry and electronics are described in Appendix A, and the computer scanning algorithms are described in Appendix B.

4. CONSTANT FLOWRATE SOURCE

Two constant pressure reservoirs, one for the base concentration and one for the tracer, were constructed (Fig. 7). The flowrate can be adjusted by
changing the height of the center tube.
Section 4: PROCEDURE

I. Solution Preparation

(a) Prepare solutions of desired concentrations using distilled water and iodide standard. A base concentration of 175-200 ppm should be used. Voltage readings from lower concentrations tend to be too unstable for accurate analysis. By injecting ~300 ppm the electrode response remains in the linear portion of the voltage vs. log concentration curve, thus simplifying analysis. Using the 1000 ml volumetric flask, the concentration is:

\[ C(\text{ppm}) = \frac{\text{ liter of iodide standard}}{\text{ liter}} \times 12690 \text{ mg/l} \]

(b) Clean reservoirs and fill with solution.

II. Assembly

(a) Wipe clean the aluminum and glass plates with wet sponge and assemble; clamps should be finger tight.

(b) Flush the Hele-Shaw cell with CO₂ (at p <2 psi or glass may shatter).

(c) Begin flowing water slowly, making sure to clear both the inlet and tracer valve of air, otherwise bubbles will become trapped in the cell. (distilled water was flowed until the cell was void of all air bubbles to save the prepared solutions for test experimental runs.) Pounding on the glass with the butt of your hand, or tapping the glass with the rubber mallet while flowing at high rate can prevent the water front from fingering and forming air pockets.

(d) Now start flowing the solution of base concentration; allow 2 pore volumes (~ 500 cc) to flow before starting to SCAN (see next step).

III. Prepare computer for run
(a) Plug in the multiplexor board power supply (Appendix A describes the design and operation of the multiplexor); turn on printer, then computer.

(b) When "clock" appears (~60 sec) hit <F10>.

(c) Type b:

(d) Remove system diskette from the A drive; replace with a blank diskette.

IV. Ready to run

(a) To begin recording, enter SCAN. Note time. SCAN will measure and store the voltage at each electrode, once per second, and will fill the C (internal) diskette after about 7 min. The voltages will be plotted against the location of each electrode on the screen (they will vary for each electrode since each has different sensitivity). SCAN will stop automatically after 7 min., or sooner if you hit <F1>.

(b) Allow base concentration to flow for ~1 min. before injecting tracer. To inject, open gate valve, slide tracer valve into position and shut off inlet valve. Record time of injection.

(c) When run is over, enter FIXUP. FIXUP processes the data (~15 min) and stores it in a new file named labfix.dat on the A diskette.

(d) Enter PLOTFIX. This plots the voltage vs. time for each electrode, individually.

(e) Take diskette out and label it; these are your results.

(f) To start a new run, insert a blank disc in the a drive, shut off the tracer, and flow the base concentration (~500 cc). Repeat steps 7-11.

(g) After runs are finished, disassemble and wash down thoroughly. Unplug the multiplexor board, shut off computer and printer.
Section 5: DATA PREPARATION

The processed data (labfix.dat) can be matched to the model given by Equation (2) to provide estimates of the mean speed of flow (u), and the effective dispersivity (η). A FORTRAN program, CURVEFIT, performs this operation, and simultaneously calibrates the measured voltages to concentrations. The program is run as follows:

(a) Copy labfix.dat from drive A to drive C (C must be erased first).

(b) Create a file PAWS on C as follows:

1. \[ N = \text{number of unknowns (12), } \lfloor = 2 (u \text{ and } \eta) , \text{ can be 3 if } t_o \text{ is unknown as well}. \]
2. Initial estimates of u, η; one per line (F10.4).
3. Base concentration \((C_o)\) and injected concentration \((C_i)\); one per line (F10.4).
4. Number of electrodes to be analyzed and electrode numbers (4012); e.g. 080104052122232932 will analyze 8 electrodes - 1,4,5,21,22,23,29 and 32.

(c) Load a blank diskette in drive A.

(d) Type a:

(e) Type b:curvefit

(f) Type c: params <CR>, con <CR>, c:labfix.dat <CR>, prn <CR>.

(g) The program will output a summary of estimated parameters on the printer, and will create output files \((1.dat \text{ through } 32.dat)\) on A. These may be used for plotting. The program takes several hours to run.

(h) On completion, type b:plot, this will plot the results on the screen for a specified range of electrodes.
Section 6: RESULTS

The results of seven one-dimensional experiments are presented in this section. The results from CURVEFIT are displayed in Tables 4-10, and are compared with the dispersivity predicted by Equation (3) in Figures 8-14. Graphs of the data collected from each electrode and the curve that fits it are also presented. Since it was a one-dimensional study, only the central row of 32 electrodes was used.

The actual fracture dimensions are shown in Table 1. Since the glass plate used for the runs was slightly curved, the aperture was measured at the centerline.

<table>
<thead>
<tr>
<th>Aperture</th>
<th>width</th>
<th>length</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0515</td>
<td>24.46</td>
<td>179.1</td>
</tr>
</tbody>
</table>

Table 2 shows the concentrations of the base, ($C_0$), and injected ($C_1$) solutions for each run. The flowrate was measured by recording the time required to fill a 50 ml flask at the outlet. The time of injection, $t_o$, was only recorded for runs 8, 9, and 10.

<table>
<thead>
<tr>
<th>Run</th>
<th>$C_0$ (ppm)</th>
<th>$C_1$ (ppm)</th>
<th>Q (LITRE/SEC)</th>
<th>$t_o$ (SEC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>203</td>
<td>305</td>
<td>0.80</td>
<td>-</td>
</tr>
<tr>
<td>4</td>
<td>203</td>
<td>305</td>
<td>1.25</td>
<td>-</td>
</tr>
<tr>
<td>6</td>
<td>177</td>
<td>305</td>
<td>0.82</td>
<td>-</td>
</tr>
<tr>
<td>7</td>
<td>177</td>
<td>305</td>
<td>1.38</td>
<td>-</td>
</tr>
<tr>
<td>8</td>
<td>177</td>
<td>305</td>
<td>0.66</td>
<td>60</td>
</tr>
<tr>
<td>9</td>
<td>177</td>
<td>305</td>
<td>0.48</td>
<td>42</td>
</tr>
<tr>
<td>10</td>
<td>177</td>
<td>805</td>
<td>0.57</td>
<td>43</td>
</tr>
</tbody>
</table>

The velocities listed in Table 3 are values from CURVEFIT that best match the data (since the fracture cross-section did not have constant aperture, the
flow velocity was not constant over the width of the cell, and \( u = q/A \) may not be accurate). These best-fit values are used in Equation (3) to provide an estimate of the dispersivity \( \langle \eta \rangle \). The estimated times of injection, \( t_s \), used in PARAMS are also listed in Table 3.

<table>
<thead>
<tr>
<th>Run</th>
<th>( u ) (cm/sec)</th>
<th>( \eta ) (cm(^2)/sec)</th>
<th>( t_s ) (sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>0.542</td>
<td>0.210</td>
<td>73.0</td>
</tr>
<tr>
<td>4</td>
<td>0.824</td>
<td>0.486</td>
<td>66.6</td>
</tr>
<tr>
<td>6</td>
<td>0.539</td>
<td>0.208</td>
<td>79.5</td>
</tr>
<tr>
<td>7</td>
<td>0.890</td>
<td>0.567</td>
<td>73.4</td>
</tr>
<tr>
<td>8</td>
<td>0.451</td>
<td>0.146</td>
<td>60.0</td>
</tr>
<tr>
<td>9</td>
<td>0.375</td>
<td>0.101</td>
<td>42.5</td>
</tr>
<tr>
<td>10</td>
<td>0.416</td>
<td>0.124</td>
<td>42.5</td>
</tr>
</tbody>
</table>

The dispersivities predicted by Equation (3) are compared with those estimated by CURVEFIT in Figures 8-14. Only selected electrodes are plotted, as some are inconsistent due to faulty data collection or transmission. Electrodes 1 and 2 were usually inconsistent, probably because the tracer front had not yet become equalized.
### Table 4. RUN 3 Results

<table>
<thead>
<tr>
<th>Electrode</th>
<th>$C_a$ (ppm)</th>
<th>$C_i$ (ppm)</th>
<th>$u$ (cm/sec)</th>
<th>$\eta$ (cm²/sec)</th>
<th>apparent $t_e$ (sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>193.6091</td>
<td>305.1784</td>
<td>0.6992</td>
<td>1.0367</td>
<td>72.9238</td>
</tr>
<tr>
<td>2</td>
<td>201.2811</td>
<td>304.9338</td>
<td>0.6131</td>
<td>0.6220</td>
<td>72.6622</td>
</tr>
<tr>
<td>3</td>
<td>202.9373</td>
<td>305.0957</td>
<td>0.5908</td>
<td>0.4181</td>
<td>72.1451</td>
</tr>
<tr>
<td>4</td>
<td>200.0074</td>
<td>300.0681</td>
<td>0.5835</td>
<td>0.3585</td>
<td>72.6364</td>
</tr>
<tr>
<td>5</td>
<td>200.0959</td>
<td>300.0331</td>
<td>0.6846</td>
<td>0.2718</td>
<td>72.4763</td>
</tr>
<tr>
<td>6</td>
<td>202.9865</td>
<td>305.0680</td>
<td>0.5716</td>
<td>0.3113</td>
<td>72.3291</td>
</tr>
<tr>
<td>7</td>
<td>200.8080</td>
<td>449.3800</td>
<td>0.3034</td>
<td>2.8423</td>
<td>73.1011</td>
</tr>
<tr>
<td>8</td>
<td>199.9427</td>
<td>300.0960</td>
<td>0.5661</td>
<td>0.3005</td>
<td>73.4000</td>
</tr>
<tr>
<td>9</td>
<td>203.0065</td>
<td>305.0846</td>
<td>0.6711</td>
<td>0.2633</td>
<td>72.6024</td>
</tr>
<tr>
<td>10</td>
<td>203.0301</td>
<td>305.0726</td>
<td>0.6663</td>
<td>0.2030</td>
<td>72.8913</td>
</tr>
<tr>
<td>11</td>
<td>203.0107</td>
<td>305.1142</td>
<td>0.6647</td>
<td>0.3166</td>
<td>72.6204</td>
</tr>
<tr>
<td>12</td>
<td>200.0911</td>
<td>300.0483</td>
<td>0.6638</td>
<td>0.2449</td>
<td>73.4000</td>
</tr>
<tr>
<td>13</td>
<td>203.0176</td>
<td>305.1285</td>
<td>0.5593</td>
<td>0.2173</td>
<td>72.4066</td>
</tr>
<tr>
<td>14</td>
<td>203.0000</td>
<td>305.1503</td>
<td>0.5545</td>
<td>0.2358</td>
<td>73.1522</td>
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<tr>
<td>15</td>
<td>203.0166</td>
<td>305.1168</td>
<td>0.5543</td>
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<tr>
<td>16</td>
<td>203.0227</td>
<td>305.1229</td>
<td>0.5513</td>
<td>0.2623</td>
<td>72.9191</td>
</tr>
<tr>
<td>17</td>
<td>203.0147</td>
<td>305.1194</td>
<td>0.5498</td>
<td>0.2511</td>
<td>72.0139</td>
</tr>
<tr>
<td>18</td>
<td>203.0314</td>
<td>305.1045</td>
<td>0.5463</td>
<td>0.2341</td>
<td>72.6125</td>
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<tr>
<td>19</td>
<td>203.0683</td>
<td>305.1092</td>
<td>0.5455</td>
<td>0.2260</td>
<td>72.0204</td>
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<tr>
<td>20</td>
<td>203.0394</td>
<td>305.1175</td>
<td>0.5428</td>
<td>0.2326</td>
<td>72.6915</td>
</tr>
<tr>
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<td>202.9910</td>
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<td>0.5442</td>
<td>0.2481</td>
<td>72.8799</td>
</tr>
<tr>
<td>22</td>
<td>202.8789</td>
<td>305.1857</td>
<td>0.6401</td>
<td>0.2652</td>
<td>72.8374</td>
</tr>
<tr>
<td>23</td>
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<td>305.1272</td>
<td>0.5410</td>
<td>0.2411</td>
<td>72.8148</td>
</tr>
<tr>
<td>24</td>
<td>202.9533</td>
<td>305.2214</td>
<td>0.5405</td>
<td>0.2708</td>
<td>72.2095</td>
</tr>
<tr>
<td>25</td>
<td>203.0517</td>
<td>305.1082</td>
<td>0.5406</td>
<td>0.1829</td>
<td>72.8609</td>
</tr>
<tr>
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<td>305.1186</td>
<td>0.5409</td>
<td>0.2078</td>
<td>72.5939</td>
</tr>
<tr>
<td>27</td>
<td>203.0491</td>
<td>305.1325</td>
<td>0.5416</td>
<td>0.1899</td>
<td>72.5580</td>
</tr>
<tr>
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<td>305.1451</td>
<td>0.5429</td>
<td>0.1909</td>
<td>72.8735</td>
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<tr>
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<td>305.1377</td>
<td>0.5435</td>
<td>0.1865</td>
<td>72.8586</td>
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<tr>
<td>30</td>
<td>203.0372</td>
<td>305.1767</td>
<td>0.5450</td>
<td>0.1787</td>
<td>72.3092</td>
</tr>
<tr>
<td>31</td>
<td>203.0167</td>
<td>305.2894</td>
<td>0.5471</td>
<td>0.2055</td>
<td>72.1761</td>
</tr>
</tbody>
</table>

![Graph](image-url)  
**Fig. 8.** Comparison of estimated and calculated dispersivity. Run 3.
### Table 6. RUN 4 Results

<table>
<thead>
<tr>
<th>Electrode</th>
<th>$C_0$ (ppm)</th>
<th>$C_1$ (ppm)</th>
<th>$u$ (cm/sec)</th>
<th>$\eta$ (cm²/sec)</th>
<th>Apparent $t_o$ (sec)</th>
</tr>
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**Fig. 9.** Comparison of estimated and calculated dispersivity. Run 4.
Run 4 - electrode 25

Run 4 - electrode 26

Run 4 - electrode 27

Run 4 - electrode 28

Run 4 - electrode 29

Run 4 - electrode 30

Run 4 - electrode 31

Run 4 - electrode 32

Concentration (ppm)

Time (secs)

200 250 300 350
Table 6. **RUN 5 Results**

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**Fig. 10.** Comparison of estimated and calculated dispersivity. Run 5.
### Table 7. RUN 7 Results

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![Graph](image)

**Fig. 11.** Comparison of estimated and calculated dispersivity. Run 7.
Table 8. RUN 8 Results

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![Graph](image-url)

**Fig. 12.** Comparison of estimated and calculated dispersivity. Run 8.
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**Fig. 13.** Comparison of estimated and calculated dispersivity. Run 9.
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run9 - electrode 2

run9 - electrode 3

run9 - electrode 4

run9 - electrode 5

run9 - electrode 6

run9 - electrode 7

run9 - electrode 8

Concentration (ppm)

Time (secs)
## Table 10. RUN 10 Results

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Fig. 14. Comparison of estimated and calculated dispersivity. Run 10.
Section 7: CONCLUSIONS

The approximation for Taylor Dispersion, Equation (3), is sufficiently accurate to be used in a fracture flow model for tracer test analysis.

The slight decline of dispersivity with distance suggests that further studies may find a stricter criterium for the non-dimensional time before tracer front equalization.
Section 8: REFERENCES


12. VARPRO, Computer Science Dept., Stanford University.
APPENDIX A: MULTIPLEXER BOARD

The multiplexer board contains circuitry which switches through the electrode array, allowing instantaneous voltage measurement at each location. Its design is described by the flow diagram of Fig. A.1.1.

The circuitry is capable of testing 128 electrodes, divided into 8 groups of 16. The computer selects a bank of 16 electrodes and the voltage across each is measured individually using a resistance bridge. The signal is amplified, converted to digital logic, and stored in OUTPUT.DAT for later processing.

Fig. A.1.1. Multiplexer Board Design
APPENDIX B: COMPUTER SCANNING ALGORITHMS

Figure B.1.1 shows a flow diagram describing the computer scanning algorithms used for data acquisition, transmission, curve fitting and plotting.

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<td><em>labfix.dat</em></td>
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<td><em>PLOTFIT</em></td>
<td>outputs to screen</td>
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<td><em>hit shift-PrtSc to send to printer</em></td>
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<td><em>labfix.dat</em></td>
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<td>outputs to screen</td>
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Fig. B. 1.1. Computer Scanning Algorithms
Appendix C: COMPUTER PROGRAMS AND SUBROUTINES

Directory of Lab Control Diskette

Volume in drive B has no label
Directory of B:

<table>
<thead>
<tr>
<th>File</th>
<th>Type</th>
<th>Size</th>
<th>Date</th>
<th>Time</th>
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<td>BAS</td>
<td>3153</td>
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<td>BAS</td>
<td>4779</td>
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<td>10:15a</td>
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<td>11:01p</td>
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23 File(s)  4096 bytes free
SCAN

10 DEF FNRCNV(X)=X+6*INT(X/10)
20 HRS=0
30 MIN=0
40 SEC=0
50 OUT &H719,23
60 OUT &H718,3
70 OUT &H718,129
80 OUT &H719,1
90 OUT &H716,57
100 OUT &H718,31
110 OUT &H718,0
120 OUT &H718, FNRCNV(SEC)
130 OUT &H719,2
140 OUT &H716,57
150 OUT &H718,16
160 OUT &H718,FNRCNV(MIN)
170 OUT &H718, FNRCNV(HRS)
180 OUT &H715,71
190 OUT &H719,9
200 OUT &H718,0
210 OUT &H718,0
220 OUT &H719,10
230 OUT &H718,0
240 OUT &H718,0
250 OUT &H719,59
260 DIM ELECVOLT(100), YFOLD(100), XFOLD(100)
270 FOR NUM=1 TO 100
280 XFOLD(NUM)=(NUM-1)*19+15: YFOLD(NUM)=130
290 NEXT NUM
300 SIGMAX=2!
310 ON KEY(1) GOSUB 1090
320 KEY OFF
330 OPEN "c:output.dat" FOR OUTPUT AS #1
335 SCAN=0
340 SCREEN 2
350 CLS
360 PRINTCOL=1
370 TIME$=TIME$
380 OLDTIME$=TIME$
390 THS=0
400 NUMCYCLE=0
410 ADHIGH=0
420 ADBLOW=0
430 ADDRESS=&H710
440 OUT &H71F, &HBO
450 OUT &H714, 128
460 VOLTAGE=1
470 VOLTS=5
480 DECIMAL=.204.7*VOLTS
490 DECIMAL=INT(DECIMAL): DAHIGH=INT(DECIMAL/256): DALOW=DECIMAL-256*DAHIGH
500 FOR CYCLE=1 TO 2
510 REM alternate voltage
520 REM IF CYCLE=1 THEN DAHIGH=&H7: DALOW=&HFF ELSE DAHIGH=&H8: DALOW=0
530 OUT &H711,DAHIGH
540 OUT &H710,DALOW
550 FOR CIRCUIT=1 TO 2
560 OUT &H71D,CIRCUIT
570 PRINTCOL=1+(CIRCUIT-1)*20
580 FOR ELECTRODE=0 TO 15
590 OUT &H710,ELECTRODE
600 OUT &H716,0
610 IF ELECTRODE=0 THEN GOTO 720
620 ADSIG=256*ADHIGH+DALOW
630 IF ADSIG>32767 THEN ADSIG=ADSIG-65536!
640 ADVOLT=VOLTAGE*ADSIG/204.8
650 ELECNUM=Circuit-1,16+ELECTRODE
660 ELECVOLT(ELECNUM)=ADVOLT
670 PRINT #1, USING "&. ####. ####. ####":OLDTIME$,THS,ELECNUM,ADVOLT
700 REM LOCATE ELECTRODE,PRINTCOL
710 REM PRINT USING "&. ####. ####. ####":OLDTIME$,THS,(CIRCUIT-1)*16+ELECTRODE
720 IF INF(&H714)<128 THEN GOTO 720
730 ADVLOW=INF(&H715)
740 ADHIGH=INF(&H716)
750 NEXT ELECTRODE
760 ADSIG=256*ADHIGH+DALOW
770 IF ADSIG>32767 THEN ADSIG=ADSIG-65536!
780 ADVOLT=VOLTAGE*ADSIG/204.8
790 ELECNUM=Circuit-1,16+16
800 ELECVOLT(ELECNUM)=ADVOLT
810 PRINT #1, USING "&. ####. ####. ####":OLDTIME$,THS,ELECNUM,ADVOLT
820 OLDTIME$=T $ME$
830 OUT &H719,163
840 OUT &H713,17
850 THS=INF(&H718)
860 THS=THS-6*INT(THS/16)
870 NEXT CIRCUIT
880 NUMCYCLE=NUMCYCLE+1
890 OLDTIME$=T $ME$
900 KEY(1) ON
910 MIN=1:MAX=32:YBASE=130
920 FOR NUM=1 TO 32
930 SIGNAL=ELECVOLT(NUM)
940 YP=YBASE-60*SIGNAL/SIGMAX
950 XP=(NUM-MIN)*19+15
960 IF NUM<MAX THEN LINE(XPOLD(NUM),YPOLD(NUM))-(XPOLD(NUM+1),YPOLD(NUM+1)),0
970 IF NUM>MIN THEN LINE(XPOLD(NUM),YPOLD(NUM))-(XPOLD(NUM-1),YPOLD(NUM-1)),1
COMMON /A/VOLT(32,500)
INTEGER ELEC,ELECN,HR,MIN,SEC,THS,RECNO
DIMENSION TIME(500),CTBL(20),VTBL(20,32)
CALBRT=0
IF (CALBRT.EQ.0) GO TO 200
C Next section skipped if no calibration desired
OPEN (3,FILE='cal.dat',STATUS='OLD',ACCESS='SEQUENTIAL')
READ (3,103) NFTS
103 FORMAT(12)
DO 10 ELEC=1,32
DO 11 N=1,NFTS
READ(3,102) NDUMMY,VTBL(N,ELEC)
102 FORMAT (14,11X,F6.4)
CTBL(N)=NDUMMY
11 CONTINUE
10 CONTINUE
END FILE 3
OPEN (1,FILE='c:output.dat',STATUS='old',ACCESS='direct',
& rec=24,form='formatted')
READ (1,100,REC=1) HR,MIN,SEC,THS,ELEC,SIG
100 FORMAT (I2,1X,I2,1X,I2,2X,I2,2X,I2,2X,F6.4)
TZERO=3600.*HR+60.*MIN+SEC
DO 1 ELEC=1,32
RECNO=ELEC
1=1
READ (1,100,REC=RECNO,END=2) HR,MIN,SEC,THS,ELECN,SIG
IF (ELEC.EQ.1) TIME(I)=3600.*HR+60.*MIN+SEC-TZERO
IF (CALBR. NE. 0) CONCN=CONVRT(SIG,NPTS,ELEC,CTBL,VTBL(1,ELEC))
VOLT(ELEC,I)=SIG
WRITE (*,'(f7.1,1x,f10.4)') time(I),conc
I=I+1
RECNO=RECNO+32
GO TO 3
2 CONTINUE
WRITE (*,'(14)') ELEC
1 CONTINUE
END FILE 1
OPEN (2,FILE='a:labfix.dat',status='new',access='sequential')
DO 4 ELEC=1,32
DO 5 I=1,1
WRITE (*,'(101)') TIME(I),VOLT(ELEC,I)
5 CONTINUE
4 CONTINUE
END FILE 2
STOP
END
FUNCTION CONVRT(SIG,NPTS,ELEC,CTBL,V)
DIMENSION CTBL(20),V(20)
NPTS=NPTS-1
IF (SIG.GT.V(I)) GO TO 1
DO 2 I=1,NPTS1
IF (SIG.GT.V(I+1)) GO TO 3
2 CONTINUE
SLOPE=(V(NPTS)-V(NPTS-1))/(CTBL(NPTS)-CTBL(NPTS-1))
CONVRT=CTBL(NPTS)+SLOPE*(V(NPTS)-SIG)
RETURN
3 SLOPE=(CTBL(I+1)-CTBL(I))/(V(I+1)-V(I))
CONVRT=CTBL(I+1)+SLOPE*(SIG-V(I+1))
RETURN
1 SLOPE=(CTBL(2)-CTBL(1))/(V(2)-V(1))
CONVRT=CTBL(1)+SLOPE*(SIG-V(1))
RETURN
END
10 DIM X(500), Y(500)
11 DIM FILE$(32)
12 DATA "1","2","3","4","5","6","7","8","9","10","11","12","13","14","15","16"
13 FOR ELEC%=1 TO 32
14 READ FILE$(ELEC%)
15 NEXT ELEC%
20 INPUT "Experiment number"; NUMEXP$
30 INPUT "Range of electrodes"; MINELEC%, MAXELEC%
40 FOR ELEC%=MINELEC% TO MAXELEC%
50 FILE$=#FILE$(ELEC%)+".dat"
60 TITLE= "Run - " + NUMEXP$;" ; Electrode " + FILE$(ELEC%)
70 OPEN FILE$ FOR INPUT AS 1
80 INPUT #1, NUMPTS
90 XLOG%=0
100 YLOG%=0
110 PT%=0
120 FOR N=1 TO NUMPTS
130 IF EOF(1) THEN GOTO 180
140 INPUT #1, X(N), Y(N)
150 IF XLOG% THEN X(N)=LOG(X(N))/LOG(10!)
160 IF YLOG% THEN Y(N)=LOG(Y(N))/LOG(10!)
170 NEXT N
180 PRINT "number of data points is ", N
190 Ni=N-1
200 YMIN=150!
210 YMAX=320!
220 XMAX=X(N-5)
230 XMIN=X(1)
240 IF XLOG% THEN XMAXA=10!^XMAX; XMINA=10!^XMIN ELSE XMAXA=XMAX; XMINA=XMIN
250 IF YLOG% THEN YMAXA=10!^YMAX; YMINA=10!^YMIN ELSE YMAXA=YMAX; YMINA=YMIN
260 PRINT "minimum & maximum x value", XMINA, XMAXA
270 PRINT "minimum & maximum y value", YMINA, YMAXA
280 XSCRA=9!
290 YSCRA=6!
300 XSCR=XSCRA-.5
310 YSCR=YSCRA-.5
320 PRINT "screen size is", XSCR, "wide, by", YSCR, "high"
330 XDIV=50!
340 YDIV=50!
350 IF XLOG% THEN XDIV=LOG(XDIV)/LOG(10!)
360 IF YLOG% THEN YDIV=LOG(YDIV)/LOG(10!)
370 DEF FNX(P)=INT((P/XSCRA)*639!)
380 DEF FNY(P)=199-INT((P/YSCRA)*199!)
390 WID=XMAX-XMIN
400 WID=YMAX-YMIN
410 SCREEN 2,0,0
420 KEY OFF
430 CLS
440 KEY OFF
450 KPASS=1
510 LINE (FNIX(1!), FNIY(1!))-(FNIX(1!), FNIY(YSCR))
520 LINE (FNIX(1!), FNIY(1!))-(FNIX(XSCR), FNIY(1!))
525 LOCATE 1,20,0 : PRINT TITLE$
530 NX=INT(XWID/XDIV)
540 NY=INT(YWID/YDIV)
550 FOR I=0 TO NX
560 PSET (FNIX(1!+I*(XSCR-1!)*XDIV/XWID),FNIY(1!))
570 LINE -STEP(0,.199-FNIY(.125))
580 NEXT
590 FOR I=0 TO NY
600 PSET (FNIX(1!),FNIY(1!+I*(YSCR-1!)*YDIV/YWID))
610 LINE -STEP(-FNIX(.125),0)
620 NEXT
630 FOR I=0 TO NX
640 XVAL=XMIN+I*XDIV
650 XPOS=((XVAL-XMIN)/XWID)*(XSCR-1!)+.85
660 IX=INT(80*XPOS/XSCRA)+1
670 IY=25-INT(12.5/YSCRA)
680 IF IX>80 OR IX<1 OR IY>25 OR IY<1 GOTO 720
690 LOCATE IY,IX
700 IF XLOG% THEN XVAL=10!*XVAL
710 PRINT XVAL
720 NEXT
730 FOR I=0 TO NY
740 YVAL=YMIN+I*YDIV
750 YPOS=((YVAL-YMIN)/YWID)*(YSCR-1!)+1!
760 IX=25-INT(25*YPOS/YSCRA)
770 IX=INT(.4*80)/XSCRA
780 IF YMAX>1000 THEN IX=IX-1
790 IF YMAX>10000 THEN IX=IX-1
800 IF IX>80 OR IX<1 OR IY>25 OR IY<1 GOTO 840
810 LOCATE IY,IX
820 IF YLOG% THEN YVAL=10!*YVAL
830 PRINT YVAL
840 NEXT
850 LOCATE 1,1
860 IF KPASS=0 THEN KPASS=1: OUT &H3DD,&H20: GOTO 510
880 KPASS=0
890 XP=FNIX(1!+(XSCR-1!)*(X(1)-XMIN)/XWID): YP=FNIY(1!+(YSCR-1!)*(Y(1)-YMIN)/YD)
900 IF PT% THEN CIRCLE (XP,YP),FNIX(.03): PAINT(XP,YP) ELSE PSET(XP,YP)
910 FOR I=2 TO N
920 XP=FNIX(1!+(XSCR-1!)*(X(I)-XMIN)/XWID): YP=FNIY(1!+(YSCR-1!)*(Y(I)-YMIN)/YD)
930 IF PT% THEN CIRCLE (XP,YP),FNIX(.03): PAINT (XP,YP) ELSE LINE -(XP,YP)
940 NEXT
950 IF KPASS>0 THEN GOTO 1060
960 KPASS=1
970 BEEP
980 PT%=1
1000 INPUT #1,NUMPTS
1010 FOR N=1 TO NUMPTS
1020 IF EOF(1) GOTO 890
1030 INPUT #1,X(N),Y(N)
1040 NEXT N
1050 GOTO 890
1060 BEEP
1070 CLOSE 1
1080 NEXT ELECT
1090 SCREEN 0,0,0
1100 SYSTEM
20 DIM X(1000), Y(1000)
25 INPUT "ymin,ymax,ydiv"; YMIN, YMAX, YDIV
30 CHOICE=0
35 OPEN "a:labfix.dat" FOR INPUT AS 1
40 I=0
45 XOLD=-1
50 IF EOF(1) THEN GOTO 120
60 INPUT #1, X(I), Y(I)
90 IF X(I)<XOLD THEN GOTO 120
95 XOLD=X(I)
96 I=I+1
100 IF EOF(1) THEN GOTO 120
110 GOTO 50
120 N=I-1
125 CHOICE=CHOICE+1
126 PTZ=0
140 XMAX=X(N)
150 XMIN=0
160 XSCRA=7!
170 YSCRA=6!
180 XSCR=XSCRA-.5
190 YSCR=YSCRA-.5
200 XDIV=60
220 IF XLOG% THEN XDIV=LOG(XDIV)/LOG(10!)
230 IF YLOG% THEN YDIV=LOG(YDIV)/LOG(10!)
240 DEF FNIX(F)=INT((F/XSCRA)*639!)
250 DEF FNIY(P)=199-INT((P/YSCRA)*199!)
260 XWID=XMAX-XMIN
270 YWID=YMAX-YMIN
280 SCREEN 2,0,0
290 KEY OFF
300 CLS
310 C..S
320 KEY OFF
325 LOCATE 1,40,0 : PRINT "electrode",CHOICE
330 KPASS=1
340 LINE (FNIX(1!),FNIY(1!))- (FNIX(1!),FNIY(YSCR))
350 LINE (FNIX(1!),FNIY(1!))- (FNIX(XSCR),FNIY(1!))
360 NX=INT(XWID/XDIV)
370 NY=INT(YWID/YDIV)
380 FOR I=0 TO NX
390 FSET (FNIX(1!+I*(XSCR-1!)*XDIV/XWID),FNIY(1!))
400 LINE -STEP(0,199-FNIY(.125))
410 NEXT I
420 FOR I=0 TO NY
430 FSET (FNIX(1!),FNIY(1!+I*(YSCR-1!)*YDIV/YWID))
440 LINE -STEP(-FNIX(.125),0)
450 NEXT I
460 FOR I=0 TO NX
470 XVAL=XMIN+I*XDIV
480 XPOS=((XVAL-XMIN)/XWID)*(XSCR-1!)+.85
490 IX=INT(80!*XPOS/XSCR)+1
500 IY=25-INT(12.5/YSCR)
510 IF IX>80 OR IX<1 OR IY>25 OR IY<1 GOTO 550
520 LOCATE IY,IX
540 PRINT XVAL
550 NEXT I
560 FOR I=0 TO NY
570 YVAL=YMIN+I*YDIV
580 YPOS=((YVAL-YMIN)/YWID)*(YSCR-1!)+1!
590 IY=25-INT(25*YPOS/YSCR)
600 IX=INT(.6*80!/XSCR)-2
610 IF IX>80 OR IX<1 OR IY>25 OR IY<1 GOTO 650
620 LOCATE IY,IX
640 PRINT YVAL
650 NEXT I
660 LOCATE 1,1
670 XP=FNIX(1!+(XSCR-1!)*((X(1)-XMIN)/XWID)): YP=FNIX(1!+(YSCR-1!)*((Y(1)-YMIN)/YD))
680 IF PT% THEN CIRCLE (XP,YP),FNIX(.03): PAINT(XP,YP) ELSE PSET(XP,YP)
690 FOR I=2 TO N
700 XP=FNIX(1!+(XSCR-1!)*((X(I)-XMIN)/XWID)): YP=FNIX(1!+(YSCR-1!)*((Y(I)-YMIN)/YD))
710 IF PT% THEN CIRCLE (XP,YP),FNIX(.03): PAINT (XP,YP) ELSE LINE -(XP,YP)
720 NEXT I
730 BEEP
735 IF CHOICE < 32 THEN GOTO 40
3000 CLOSE 1: STOP
**CURVEFIT**

```fortran
C **************************************************************************
C PROGRAM BEGINS - Gilardi experiment analysis
C **************************************************************************
C **************************************************************************
C IMPLICIT REAL*8(A-B,D-H,0-Z)
C
SET DIMENSIONS FOR VARFRO. BE CAREFUL WHEN SETTING THE DIMENSIONS FOR THE INCIDENCE MATRIX INC. SEE NOTE.
C
DIMENSION Y(500), T(500), ALF(3), BETA(2), W(500), A(500), B(500), C(500), D(500), E(500), F(500), G(500), H(500), INC(12,8), NELTRY(32), NGO(32)
COMMON XPOS, TZERO
COMMON /DUMMY/C(500,6)
EXTERNAL ADA
CHARACTER*6 CFILE(32)
PATA CFILE/'1.dat','2.dat','3.dat','4.dat','5.dat',
@ '6.dat','7.dat','8.dat','9.dat',
@ '10.dat','11.dat','12.dat','13.dat','14.dat','15.dat',
@ '16.dat','17.dat','18.dat','19.dat',
@ '20.dat','21.dat','22.dat','23.dat','24.dat','25.dat',
@ '26.dat','27.dat','28.dat','29.dat',
@ '30.dat','31.dat','32.dat'/

SET PARAMETERS FOR VARFRO.

FLOD=0
NL = 100
LPRINT=10

READ DATA SEQUENTIAL ORDERING AND PROPER FORMATTING ARE IMPORTANT.

NL IS THE NUMBER OF NONLINEAR PARAMETERS

READ (5,311) NL
311 FORMAT (I11)
WRITE(6,12) NL
12 FORMAT (1H0,10X,'NUMBER OF NONLINEAR PARAMETERS:/',I3)

L IS THE NUMBER OF LINEAR PARAMETERS

L=2
```
ESTIMATES OF THE NONLINEAR PARAMETERS

POSO=9.8425
READ (5,310) VELOC,DIFFS,TZERO,DC0,DC1
READ (5,312) NTRIES, (NELTRY(K),K=1,NTRIES)
FORMAT (F10.4)
DO 314 K=1,32
NGO(K)=1.
DO 313 K=1,NTRIES
NGO(NELTRY(K))=0.
WRITE (6,20) VELOC,DIFFS,TZERO
FORMAT (/,'Mean Velocity(cm/sec) Diffusivity (cm2/sec). 
# ' Time zero (sec)',/,(5X,F9.5,18X,F13.3,10X,F10.3))

LPF2=L+NL+2

N IS THE NUMBER OF OBSERVATIONS
IV IS THE NUMBER OF INDEPENDENT VARIABLES T

IV=1

T IS THE INDEPENDENT VARIABLE
Y IS THE N-VECTOR OF OBSERVATIONS

WRITE (7,323)
FORMAT(2X,'Elec Co Cinj Velocity ', 1', Disp To',/,' ppm ppm ',' cm/sec cm2/sec sec')
DO 200 NELEC=1,32
N=0
TOLD=0.
203 N=N+1
READ (4,301,END=202) T(N),Y(N)
FORMAT (2F10.4)
IF (TOLD.GT.T(N)) GO TO 202
TOLD=T(N)
GO TO 203
202 N=N-5
IF (NGO(NELEC).GT.0) GO TO 200
WRITE (6,320) NELEC
FORMAT (/,'Electrode number ',I3, '***************')
XPOS=POSO+5.08*(NELEC-1)
ALF(1)=VELOC
ALF(2)=DIFFS
ALF(3)=TZERO
W(N) ARE THE WEIGHTING PARAMETERS

DO 1 I=1,N
1  W(I)=1.0

IMINF=IDINT(TZERO-XPOS/VELOC)-100
IMIN=IDINT(TZERO)
IF (IMIN.LT.IMINF) IMIN=IMINF
IF (IMIN.NT.N-200) IMIN=N-200
N=N-IMIN
DO 201 I=1,N
T(I)=T(IMIN+I)
Y(I)=Y(IMIN+I)
WRITE (6,*) T(I),Y(I)
CONTINUE

CALL VARPRO(L,NL,N,NMAX,LFP2,IV,T,Y,W,ADA,A,
*IFPRINT,ALF,BETA,IERR,10)

VO=BETA(1)
VL=BETA(1)+2.*BETA(2)
BFAR=(VL-VO)/DLOG(DC0/DC1)
APAR=VL+BFAR*DLOG(DC1)
DO 211 I=1,N
211 Y(I)=DEXP((AFAR-Y(I))/BFAR)
CALL VARPRO(L,NL,N,NMAX,LFP2,IV,T,Y,W,ADA,A,
*IFPRINT,ALF,BETA,IERR,100)

LP1=L+1
CALL ADA (LP1,NL,N,NMAX,LFP2,IV,A,INC,T,ALF,1)
DO 8 I=1,N
C(I,LP1)=0.
DO 9 J=1,L
C(I,J)=BETA(J)*A(I,J)
9  C(I,LP1)=C(I,LP1)+C(I,J)
8 CONTINUE
OPEN (1,FILE=CFILE(NELEC),STATUS='NEW',ACCESS='SEQUENTIAL')
WRITE (1,305) N
DO 205 I=1,N
205 WRITE (1,14) T(I),Y(I)
WRITE (1,305) N
DO 206 I=1,N
206 WRITE (1,14) T(I),C(I,LP1)
14 FORMAT (1X,8F10.4)
305 FORMAT (I6)

END FILE 1
DCMID=BETA(1)+BETA(2)
DO 400 I=1,N
IF (C(I,LP1).GT.SNGL(DCMID)) GO TO 401
TMID=T(I)
400 CONTINUE
401 TOCALC=TMID-XPOS/ALF(1)
WRITE (7,302) NELEC,BETA(1),BETA(1)+2.*BETA(2),ALF(1),ALF(2)
TOCALC
302 FORMAT (2X,14,5F12.4)
200 CONTINUE
STOP
END
SUBROUTINE ADA (LP, NL, N, NMAX, LFP2, IV, A, INC, T, ALF, ISEL)
IMPLICIT REAL*8(A-H,O-Z)
DIMENSION ALF(NL), A(NMAX, LFP2), T(NMAX), INC(12,8)
COMMON XPOS, TZERO

PI = 4.*ATAN(1.)
TPI = 2./DSQRT(PI)
L = LP - 1
IF (NL .LT. 3) ALF(3) = TZERO

THE INCIDENCE MATRIX INC(NL, L+1) IS FORMED BY SETTING
INC(K, J) = 1 IF THE NONLINEAR PARAMETER ALF(K) APPEARS
IN THE J-TH FUNCTION PHI(J). (THE PROGRAM SETS ALL OTHER
INC(K, J) TO ZERO.)

IF (ISEL .EQ. 2) GO TO 90
IF (ISEL .EQ. 3) GO TO 165

INC(1, 1) = 0
INC(2, 1) = 0
INC(1, 2) = 1
INC(2, 2) = 1
IF (NL .EQ. 3) INC(3, 2) = 1

THE VECTOR-SAMPLED FUNCTIONS PHI(J) ARE STORED IN
THE FIRST N ROWS AND FIRST L COLUMNS OF THE MATRIX
B(I, J). B(I, J) CONTAINS PHI(J, ALF; T(I), I, ... N;
J = 1, L. THE CONSTANT FUNCTIONS PHI WHICH DO NOT
DEFEND UPON ANY NONLINEAR PARAMETERS ALF MUST
APPEAR FIRST.
DO 81 I=1,N
    IF (ISEL.EQ.1) A(I,1)=1.0
    A(I,2)=0.
    TTI=T(1)-ALF(3)
    IF (TTI.LE.0.) GO TO 81
    TFUNC=DSORT(ALF(2)*TTI)
    A(I,2)=DERFC((XPSS-ALF(1)*TTI)/(2.*TFUNC))
    IF (XPSS*ALF(1)/ALF(2).GT.20.) A(I,2)=A(I,2)+DEXP(ALF(1)*XPSS/ALF(2))*DERFC((XPSS*ALF(1)*TTI)/(2.*TFUNC))
    CONTINUE

81 CONTINUE

IF (ISEL.EQ.2) GO TO 200

DO 170 I=1,N
    A(I,4)=0.
    A(I,5)=0.
    A(I,6)=0.
    TTI=T(1)-ALF(3)
    IF (TTI.LE.0.) GO TO 170
    E1=DEXP(-((XPSS-ALF(1)*TTI)**2)/(4.*ALF(2)*TTI))
    E2=DEXP(-((XPSS+ALF(1)*TTI)**2)/(4.*ALF(2)*TTI))
    E3=0.
    IF (ALF(1)*XPSS/ALF(2).LT.20.) E3=DEXP(ALF(1)*XPSS/ALF(2))
    ERF1=DERFC((XPSS+ALF(1)*TTI)/(2.*DSORT(ALF(2)*TTI)))
    FUNC=2.*DSORT(TTI*ALF(2)**3)
    A(I,4)=-TPI*E1*(-TTI/(2.*DSORT(ALF(2)*TTI)))
    IF (E3.GT.0.) A(I,4)=A(I,4)+(XPSS/ALF(2))*E3*ERF1+E3*(-TPI*E2)*TTI/(2.*DSORT(ALF(2)*TTI))
    A(I,5)=TPI*E1*(XPSS-ALF(1)*TTI)/FUNC
    IF (E3.GT.0.) A(I,5)=A(I,5)-E3*ERF1*ALF(1)*XPSS/ALF(2)**2+E3*TPI*E2*(XPSS+ALF(1)*TTI)/FUNC
    IF (NL.LT.3) GO TO 170
    A(I,6)=-TPI*E1*(XPSS/(2.*DSORT(ALF(2)*TTI**3)))+ALF(1)/FUNC
    IF (E3.GT.0.) A(I,6)=A(I,6)+E3*(-TPI*E2)*((XPSS/(2.*DSORT(ALF(1)*TTI**3)))-ALF(1)/FUNC)
    CONTINUE
FUNCTION DERFC(Y)
DOUBLE PRECISION
DIMENSION *
DOUBLE PRECISION
INTEGER *
DATA * * * *
DATA st * *
DATA * *
DATA * *
DATA * *
DATA 9 * *
DATA * *
DATA DFlTA

DERFC,Y
P(5), Q(4), P1(9), Q1(8), P2(6), Q2(5)
P, Q, P1, Q1, P2, Q2, XMIN, XLARGE, SQRP1, X,
RES, XSQ, XNUM, XDEN, XI, XBIG
ISW, I

! P(1)/113.8641541510502D0/,
! P(2)/377.4852376853020D0/,
! P(3)/3209.377589138469D0/,
! P(4)/.1857777061846032D0/,
! P(5)/3.161123743870566D0/
! Q(1)/244.0246379344442D0/,
! Q(2)/1282.616526077372D0/
! Q(3)/2844.236833439171D0/
! Q(4)/23.6012905234412D0/
! P1(1)/8.883149794386376D0/,
! P1(2)/66.11919063714163D0/,
! P1(3)/298.6351381974001D0/
! P1(4)/881.952212417691D0/
! P1(5)/1712.047612634071D0/
! P1(6)/2051.078377826071D0/
! P1(7)/1230.339354797997D0/
! P1(8)/2.15311534744038D-8/
! P1(9)/5.641884969886701D0/
! Q1(1)/117.6939508913125D0/
! Q1(2)/537.1811018620099D0/
! Q1(3)/1621.389574566690D0/
! Q1(4)/3290.799235733460D0/
! Q1(5)/4362.619090143247D0/
! Q1(6)/3439.367674143722D0/
! Q1(7)/1230.339354803749D0/
! Q1(8)/15.7449261107083D0/
! P2(1)/-3.6034489994980440D-01/,
! P2(2)/-1.557817261112292D-01/,
! P2(3)/-1.6083785148742280D-02/,
! P2(4)/-6.5874916152983780D-04/,
! P2(5)/-1.631538713730210D-02/,
! P2(6)/-3.053266349612323D-01/
! Q2(1)/1.872952849923460D0/,
! Q2(2)/5.279051029514284D-01/,
! Q2(3)/6.0518341312441320D-02/,
! Q2(4)/2.335204976268692D-03/,
! Q2(5)/2.568520192289822D0/
! XMIN/1.00D-10/, XLARGE/6.375D0/
! XBIG/13.3D0/
! SQRP1/.5641895835477563D0/
X = Y
ISW = 1
IF (X.GE.0.0DO) GO TO 5
ISW = -1
X = -X
5 IF (X.LT.477DO) GO TO 10
IF (X.LE.4.0DO) GO TO 30
IF (ISW.6T.0) GO TO 40
IF (X.LT.XLARGE) GO TO 45
RES = 2.0D0
GO TO 70
10 IF (X.LT.XMIN) GO TO 20
XSQ = X*X
XNUM = F(4)*XSQ+F(5)
XDEN = XSQ+Q(4)
DO 15 I = 1,3
   XNUM = XNUM*XSQ+P(I)
   XUEN = XDEN*XSQ+Q(I)
15 CONTINUE
RES = X*XNUM/XDEN
GO TO 25
20 RES = X*P(3)/Q(3)
25 IF (ISW.EQ.-1) RES = -RES
RES = 1.0D0-RES
GO TO 70
30 XSQ = X*X
XNUM = P1(B)*X+P1(9)
XDEN = X+Q1(B)
DO 35 I = 1,7
   XNUM = XNUM*X+P1(I)
   XDEN = XDEN*X+Q1(I)
35 CONTINUE
RES = XNUM/XDEN
GO TO 60
40 IF (X.GT.XBIG) GO TO 65
45 XSQ = X*X
XI = 1.0D0/XSQ
XNUM = P2(5)*XI+P2(6)
XDEN = XI+Q2(5)
DO 50 I = 1,4
   XNUM = XNUM*XI+P2(I)
   XDEN = XDEN*XI+Q2(I)
50 CONTINUE
RES = (ERFPI+XI*XNUM/XDEN)/X
60 RES = RES*DEXP(-XSQ)
IF (ISW.EQ.-1) RES = 2.0D0-RES
GO TO 70
65 RES = 0.0D0
70 DERFC = RES
RETURN
END
SUBROUTINE VARPRO (L, NL, N, NMAX, LFP2, IV, T, Y, W, ADA, A, X IPRINT, ALF, BETA, IERR, ITMAX)
DOUBLE PRECISION A(NMAX, LFP2), BETA(L), ALF(NL), T(NMAX, IV), 2 W(N), Y(N), ACUM,EPS1, GNSTEP, NU, FRJRES, R, RNEW, XNORM,
2 AS,BS,S
INTEGER B1, OUTPUT
LOGICAL SKIF
EXTERNAL ADA
DATA EPS1 /1.D-6/, OUTFUT /6/
IEHR = 1
ITER = 0
LP1 = L + 1
B1 = L + 2
LNL2 = L + NL + 2
NLFl = NL + 1
SKIP = .FALSE.
MODIT = IFRINT
IF (IPRINT .LE. 0) MODIT = ITMAX + 2
NU = 0.
NU = 1.
5 CALL DFA (L, NL, N, NMAX, LFP2, IV, T, Y, W, ALF, ADA, IERR,  
I IFRINT, A, BETA, A(1, LP1), R)
GNSTEF = 1.0
ITERIN = 0
IF (ITER .LT. 0) GO TO 10
IF (NL .EQ. 0) GO TO 90
IF (IERH .NE. 1) GO TO 99
IF (IPRINT .LE. 0) GO TO 1C)
WRITE (OUTPUT, 207) ITERIN, R
WRITE (OUTFUT, 207) NU
10 CALL ORFAC1(NLF1, NMAX, N, L, IFRINT, A(1, B1), FRJRES, IERR)
IF (IERR .LT. 0) GO TO 99
IERR = 2
IF (NU .EQ. 0.) GO TO 30
25 CALL ORFAC2(NLF1, NMAX, N, NU, A(1, B1))
30 CALL BACSUE (NMAX, NL, A(1, B1), A(1, LNL2))
DO 35 K = 1, NL
A(K, B1) = ALF(K) + A(K, LNL2)
35 CALL DFA (L, NL, N, NMAX, LFP2, IV, T, Y, W, A(1, B1), ADA,  
X IERR, IPRINT, A, BETA, A(1, LP1), RNEW)
IF (IERR .NE. 2) GO TO 99
ITER = ITER + 1
ITERIN = ITERIN + 1
SKIF = MOD(ITER, MODIT) .NE. 0
IF (SKIF) GO TO 45
WRITE (OUTPUT, 203) ITER
WRITE (OUTPUT, 216) (A(K, B1), K = 1, NL)
WRITE (OUTFUT, 207) ITEKIN, RNEW
45 IF (ITER .LT. ITMAX) GO TO 50
IERR = -1
CALL VARERR (IPRINT, IERR, 1)
GO TO 95
50 IF (RNEW - R .LT. EPS1*(R + 1.D0)) GO TO 75
IF (NU .NE. 0.) GO TO 60
GNSTEP = 0.5*GNSTEP
IF (GNSTEP .LT. EPS1) GO TO 95
DO 55 K = 1, NL
\begin{verbatim}
55 \text{A}(K, B1) = \text{ALF}(K) + \text{GNSTEP} \times \text{A}(K, LNL2)

GO TO 40
56 NU = 1.5*NU
60 IF (.NOT. SKIP) WRITE (OUTPUT, 206) NU
   IF (NU .LE. 100.) GO TO 65
   IERR = -2
   CALL VARERR (IFRINT, IERR, 1)
   GO TO 95
65 DO 70 K = 1, NL
    KSUB = LP1 + K
   DO 70 J = K, NLP1
      JSUB = LP1 + J
   70 A(K, JSUB) = A(ISUB, KSUB)
   GO TO 25
75 R = RNEW
   DO 80 K = 1, NL
    ALF(K) = A(K, B1) - \text{ALPHA} 
   ACUM = \text{GNSTEP} \times \text{XNORM}(NL, A(1, LNL2)) / \text{XNORM}(NL, ALF)
   80 IF (ITERIN .EQ. 1) NU = 0.5*NU
   IF (SKIP) GO TO 85
   WRITE (OUTPUT, 200) NU
   WRITE (OUTPUT, 208) ACUM
85 IERR = 3
   IF (FRJRES .GT. EPS1*\text{R} + i.DO) GO TO 5
   IERRH = ITER
   95 IF (NL .GT. 0) CALL DPA(L, NL, N, NMAX, LFP2, IV, T, Y, W, ALF, X ADA, 4, IFRINT, A, BETA, A(1, LP1), R)
   CALL POSTFR(L, NL, N, NMAX, LNL2, EPS1, R, IFRINT, ALF, W, A, X A(1, LP1), BETA, IERR)
   RETURN
200 FORMAT (9H \text{NU} =, E15.7)
203 FORMAT (12H \text{ITERATION}, 14, 24H \text{NONLINEAR: PARAMETERS})
206 FORMAT (25H \text{STEP RETRACTED}, \text{NU} =, E15.7)
207 FORMAT (1H0, I5, 20H \text{NORM OF RESIDUAL} =, E15.7)
208 FORMAT (34H \text{NORM(DELTA-ALF) / NDRM(ALF)} =, E12.3)
216 FORMAT (1H0, 7E15.7)
END
SUBROUTINE ORFAC1(NLP1, NMAX, N, L, IFRINT, B, FRJRES, IERR)
DOUBLE PRECISION ACUM, ALFHA, B(NMAX, NLP1), BETA, DSIGN, FRJRES, X U, \text{XNORM, AS,B,S}
C
NL = NLP1 - 1
NL23 = 2*N + 3
LP1 = L + 1
DO 30 K = 1, NL
  LPK = L + K
  ALPH = DSIGN(XNORM(N+1-LPK, B(LP1, K)), B(LP1, K))
  U = B(LP1, K) + ALPH
  B(LP1, K) = U
  BETA = ALPH * U
  IF (ALPH .NE. 0.0) GO TO 13
  IERR = -8
  CALL VARERR (IFRINT, IERR, LP1 + K)
\end{verbatim}
SUBROUTINE DPFI(L, NL, N, NMAX, LFF2, IV, T, Y, W, ALF, FiDFi, ISEL, DOUBLE PRECISION A(NMAX, LFPZ), ALF(NL), T(NMAX, IV), W(N), Y(N), X NORM, AS, BS, S)

X IPRINT, A, U, H, HNORM)
X ACUM, ALPHA, BETA, DSIGN, NU, U, X NORM, AS, BS, S

INTEGER FIRSTC, FIRSTR, INC(12, 8)

EXTERNAL ADA
IF (ISEL .NE. 1) GO TO 3
   LF1 = L + 1
   LNL2 = L + 2 + NL
   LP2 = L + 2
   LPP1 = LPP2 - 1
   FIRSTC = 1
   LASTC = LPP1
   FIRSTR = LP1
   CALL INITIAL(L, NL, N, NMAX, LPP2, IV, T, W, ALF, ADA, ISEL, X, IFPRINT, A, INC, NCON, NCONF1, PHILP1, NOWATE)
   IF (ISEL .NE. 1) GO TO 99
   GO TO 30
3 CALL ADA (LP1,NL,N,NMAX,LPP2,IV,A,INC,T,ALF,MINO(ISEL,3))
   IF (ISEL .EQ. 2) GO TO 6
   FIRSTC = LP2
   LASTC = LPP1
   FIRSTR = (4 - ISEL)*L + 1
   GO TO 50
6 FIRSTC = NCONF1
   LASTC = LP1
   IF (NCON .EQ. 0) GO TO 30
   IF (A(I, NCONF) .EQ. SAVE) GO TO 30
   ISEL = -7
   CALL VARERR (IFPRINT, ISEL, NCONF)
   GO TO 99
30 IF (PHILP1) GO TO 40
   DO 35 I = 1, N
35   R(I) = Y(I)
   GO TO 50
40   DO 45 I = 1, N
45   R(I) = Y(I) - R(I)
50 IF (NOWATE) GO TO 58
   DO 55 I = 1, N
55   ACUM = W(I)
   DO 55 J = FIRSTC, LASTC
58   ACUM = ACUM + A(I, J) * ACUM
58 IF (L .EQ. 0) GO TO 75
   DO 70 K = 1, L
70   KP1 = K + 1
   IF (ISEL .GE. 3 .OR. (ISEL .EQ. 2 .AND. K .LT. NCONF1)) GO TO 66
   ALPHA = DSIGN(XNORM(N+1-K, A(K, K)), A(K, K))
   U(K) = A(K, K) + ALPHA
   A(K, K) = -ALPHA
   FIRSTC = KP1
   IF (ALPHA .NE. 0.0) GO TO 66
   ISEL = -8
   CALL VARERR (IFPRINT, ISEL, K)
   GO TO 99
66   BETA = -A(K, K) * U(K)
   DO 70 J = FIRSTC, LASTC
   ACUM = U(K)*A(K, J)
   DO 68 I = KP1, N
68   ACUM = ACUM + A(I, K)*A(I, J)
   ACUM = ACUM / BETA
   A(K, J) = A(K, J) - U(K)*ACUM
   DO 70 I = KP1, N
A(I, J) = A(I, J) - A(I, K) * ACUM

IF (ISEL .GE. 3) GO TO 85
RNURM = XNORM(N-L, R(LP'1))
IF (ISEL .EQ. 2) GO TO 99
IF (NCON .GT. 0) SAVE = A(I, NCON)

CALL BACSUE (NMAX, L, A, R)
DO 95 I = FIRSTR, N
IF (L .EQ. NCON) GO TO 95
M = LP1
DO 90 K = 1, NL
ACUM = 0.
DO 88 J = NCON1, L
IF (INC(K, J) .EQ. 0) GO TO 88
M = M + 1
ACUM = ACUM + A(I, M) * R(J)
88 CONTINUE
KSUB = LP1 + K
IF (INC(K, LP1) .EQ. 0) GO TO 90
M = M + 1
ACUM = ACUM + A(I, M)
90 A(I, KSUB) = ACUM
95 A(I, LNL2) = R(I)
99 RETURN
END

SUBROUTINE INIT(L, NL, N, NMAX, LPF2, IV, T, W, ALF, ADA, ISEL, X IPHINT, A, INC, NCON, NCONP1, PHILP1, NOWATE)
DOUBLE PRECISION A(NMAX, LPF2), ALF(NL), T(NMAX, IV), W(N)
INTEGER OUTFUT, F, INC(l2, E3)
EXTERNAL ADA

IF (L .GE. 0 .AND. NL .GE. 0 .AND. L+NL .LT. N .AND. LNL2 .LE. X LPP2 .AND. 2*NL + 3 .LE. NMAX .AND. N .LE. NMAX .AND. X IV .GT. 0 .AND. .NOT. (NL .EQ. 0 .AND. L .EQ. 0)) GO TO 1
ISEL = -4
CALL VARERR (IFRINT, ISEL, 1)
GO TO 99
1 IF (L .EQ. 0 .OH. NL .EQ. 0) GO TO 3
DO 2 J = 1, LP1
2 INC(K, J) = 0
3 CALL ADA (LP1, NL, N, NMAX, LPF2, IV, A, INC, T, ALF, ISEL)
NOWATE = .TRUE.
DO 9 I = 1, N
NOWATE = NOWATE .AND. (W(I) .EQ. 1.0)
IF (W(I) .GE. 0.) GO TO 9
ISEL = -6
CALL VARERR (IFRINT, ISEL, 1)
GO TO 99
9 W(I) = DSQRT(W(I))
NCON = L
NCONP1 = LP1
PHILP1 = L .EQ. 0
IF (PHILP1 .OR. NL .EQ. 0) GO TO 99
P = ∅
DO 11 J = 1, LP1
  IF (P.EQ. ∅) NCONPI = J
DO 11 K = 1, NL
  INCJ = INC(K, J)
  IF (INCJ .NE. 0) NCONPl = J
  IF (INCJ .NE. 1) GO TO 15
CONTINUE
NCON = NCONPI - 1
IF (IFRINT .GE. 0) WRITE (OUTPUT, 210) NCON
IF (L+P+2 .EQ. LPP2) GO TO 20
ISEL = -5
CALL VARERR (IFRINT, ISEL, I)
GO TO 99
DO 25 K = 1, NL
  IF (INC(K, LP1) .EQ. 1) FHILPI = .TRUE.
99 RETURN
210 FORMAT (33H0 NUMBER OF CONSTANT FUNCTIONS =, I4 )
END
SUBROUTINE BACSUB (NMAX, N, A, X)
  DOUBLE PRECISION A(NMAX, N), X(N), ACUM, AS, BS, S
  X(N) = X(N)
  A(N, rd)
  IF (N .EQ. 1) GO TO 30
  NF1 = N + 1
  DO 20 IBACC = 2, N
    I = NF1 - IBACK
    IF (I .EQ. 1) X(I) = GCUM / A(I, I)
    ACUM = X(I)
    DO 10 J = IP1, N
      ACUM = ACUM - A(I, J)*X(J)
    10 RETURN
  END
SUBROUTINE POSTFR (L, NL, N, NMAX, LNL2, EPS, RNORM, IPRINT, ALF, X, W, R, U, IERR)
  DOUBLE PRECISION A(NMAX, LNL2), ALF(NL), R(N), U(L), W(N), ACUM, X, EPS, FRJKES, RNORM, SAVE, DABS, AS, BS, S
  INTEGER OUTPUT
  DATA OUTPlJT /6/
  LF1 = L + 1
  LFNL = LNLZ - 2
  LNL1 = LPNL + 1
  DO 10 I = 1, N
    W(I) = W(I)**2
    IF (L .ELI Q) GO TO 30
    DO 25 KBACK = 1, L
      K = LP1 - KBACK
      KP1 = K + 1
      ACUM = 0.
      DO 20 I = KP1, N
        ACUM = ACUM + A(I, K) * R(I)
        SAVE = R(K)
        R(K) = ACUM / A(K, K)
        ACUM = -ACUM / (U(K) * A(K, K))
        UK(K) = SAVE
    20 RETURN
  END
\[ R(I) = R(I) - A(I, K) \cdot ACUM \]

\[ ACUM = 0. \]

DO 35 I = 1, N

ACUM = ACUM + R(I)

SAVE = ACUM / N

IF (NL .EQ. 0) GO TO 45

CALL ORFAC1(NL+1, NMAX, N, I, IFRINT, A(1, L+2), FRJRES, 4)

DO 40 I = 1, N

A(I, LNL2) = R(I)

DO 40 K = LP1, LNL1

A(I, K) = A(I, K+1)

A(1, LNL2) = HNOKM

ACUM = RNORM*RNORM/(N - L - NL)

A(2, LNL2) = ACUM

CALL COV(NMAX, LFNL, ACUM, A)

IF (IFRINT .LT. 0) GO TO 99

WRITE (OUTPUT, 209)

IF (L .GT. 0) WRITE (OUTPUT, 210) (U(J), J = 1, L)

IF (NL .GT. 0) WRITE (OUTPUT, 211) (ALF(K), K = 1, NL)

WRITE (OUTPUT, 214) RNORM, SAVE, ACUM

WRITE (OUTPUT, 209)

RETURN

FOMAT (1H0, 50(1H'))

FORMAT (20H0 LINEAR PARAMETERS // (7E15.7))

FORMAT (25H0 NONLINEAR PARAMETERS // (7E15.7))

FORMAT (21H0 NORM OF RESIDUAL =, E15.7, 33H EXPECTED ERROR OF OBSERVATIONS =, E15.7, / 39H ESTIMATED VARIANCE OF OBSERVATIONS = X E15.7 )

FORMAT (95H WARNING -- EXPECTED ERROR OF OBSERVATIONS IS NOT ZERO. COVARIANCE MATRIX MAY BE MEANINGLESS. /)

END

SUBROUTINE COV(NMAX, N, SIGMA2, A)

DOUBLE PRECISION A(NMAX, N), SUM, SIGMA2, AS, BS, S

DO 10 J = 1, N

A(J, J) = 1./A(J, J)

IF (N .EQ. 1) GO TO 70

NM1 = N - 1

DO 60 I = 1, NM1

IF1 = I + 1

DO 60 J = IF1, N

JM1 = J - 1

SUM = 0.

DO 50 M = I, JM1

SUM = SUM + A(I, M) * A(J, M)

60 A(I, J) = -SUM * A(J, J)

70 DO 90 I = 1, N

SUM = 0.

DO 80 M = J, N

SUM = SUM + A(I, M) * A(J, M)

80 A(I, J) = SUM

90 RETURN

END
SUEROUTINE VARERR (IFRINT, IERR, K)
DOUBLE PRECISION AS, BS, S
INTEGER ERRNO, OUTPUT
DATA OUTPUT /6/
IF (IFRINT .LT. 0) GO TO 99
ERRNO = IABS(IERR)
GO TO (1, 2, 99, 4, 5, 6, 7, 8), ERRNO
1 WRITE (OUTPUT, 101)
GO TO 99
2 WRITE (OUTPUT, 102)
GO TO 99
4 WRITE (OUTPUT, 104)
GO TO 99
5 WRITE (OUTPUT, 105)
GO TO 99
6 WRITE (OUTPUT, 106) K
GO TO 99
7 WRITE (OUTPUT, 107) K
GO TO 99
8 WRITE (OUTPUT, 108) K
99 RETURN
101 FORMAT (46HO PROBLEM TERMINATED FOR EXCESSIVE ITERATIONS //)
102 FORMAT (49HO PROBLEM TERMINATED BECAUSE OF ILL-CONDITIONING //)
104 FORMAT (/, 50H INPUT ERROR IN PARAMETER L, NL, N, LFF2, OR NMAX. //)
105 FORMAT (68HO ERROR -- INC MATRIX IMPROPERLY SPECIFIED, OR DISAGRE
XES WITH LFF2. //)
106 FORMAT (19HO ERROR -- WEIGHT, I4, I4H IS NEGATIVE //)
107 FORMAT (28HO ERROR -- CONSTANT COLUMN, I3, 37H MUST BE COMPUTED
XONLY WHEN ISEL = 1. //)
108 FORMAT (33HO CATASTROPHIC FAILURE -- COLUMN, I4, 28H IS ZERO, SIF
XE DOCUMENTATION. //)
END
DOUBLE PRECISION FUNCTION XNORM(N, X)
DOUBLE PRECISION X(N), RMAX, SUM, TERM, DABS, DSRHT
FIND LARGEST (IN ABSOLUTE VALUE) ELEMENT
RMAX = 0.
DO 10 I = 1, N
   IF (DABS(X(I)) .GT. RMAX) RMAX = DABS(X(I))
10 CONTINUE
SUM = 0.
IF (RMAX .EQ. 0.) GO TO 30
DO 20 I = 1, N
   TERM = 0.
   IF (RMAX + DABS(X(I)) .NE. RMAX) TERM = X(I)/RMAX
   SUM = SUM + TERM*TERM
20 XNORM = RMAX*DSQRT(SUM)
99 RETURN
END
APPENDIX E: ELECTRODE MOUNTING PROCEDURE

1. Drill .250 in. hole in plate.

2. Measure electrode O.D. with micrometer.

3. Using hand reamer with block to keep it aligned, ream hole so that the electrode can be press fit (if the fit is too tight, the electrode will deform and be wasted).

4. Clean electrode and hole with acetone.

5. Using the silver disc on the top of the electrode and the rubber hammer, tap the electrode part way into the plate.

6. Apply a bead of loctite cement around the electrode O.D.,

7. Tap electrode until it is flush with plate (+ .0015 in.). A dial indicator can be used to check this tolerance.

8. Wipe clean with acetone.
APPENDIX F: MATERIALS SUPPLIERS

The cast aluminum plate was purchased from Castle Metals, San Francisco, 321-2500.

The plate was anodized at Sanford Metal Processing, Menlo Park, 327-5172.

The float glass was purchased at Acme Glass, Palo Alto, 321-7781.

If a thicker pyrex glass is desired, try Heussner Optics, Santa Clara, 988-4214.

The brass parts used to construct the electrodes were purchased at Don's Hobby shop, Menlo Park, 322-7176.

The electrodes were gold plated at Hansen Labs, on campus.