PHYSICAL AND NUMERICAL SIMULATION OF
TURBULENT RECIRCULATING FLOWS IN
MATERIALS PROCESSING OPERATIONS
by
ASHOK MURTHY
B. Tech., Indian Institute of Technology, New Delhi
(1978)
M.Sc.E., University of New Brunswick, Fredericton, Canada
(1981)
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Signature of Author

Department of Materials Science
and Engineering
May 4, 1984
Signature Redacted

Certified by

Julian Szekely /
Thesis Supervisor

Signature Redacted

Accepted by

B. J. Wuensch
Chairman, Department Graduate Committee

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PHYSICAL AND NUMERICAL SIMULATION OF TURBULENT RECIRCULATING FLOWS IN MATERIALS PROCESSING OPERATIONS

by

Ashok Murthy

Submitted to the Department of Materials Science and Engineering on May 4, 1984 in partial fulfillment of the requirements for the Degree of Doctor of Science in Materials Engineering.

ABSTRACT

An experimental technique has been developed to make detailed measurements of flow and turbulence characteristics in a heated melt of molten Wood's Alloy using a completely microcomputer controlled data acquisition and processing environment.

A mathematical model has been developed to represent the flow in the melt starting with calculation of the electromagnetic force field and using the $\kappa-\varepsilon$ model of turbulence.

An alternate turbulence model, the XI model, has been developed as part of this work. The new model is computationally simpler and uses fewer semi-empirical constants than the $\kappa-\varepsilon$ model. Comparison of predictions made using the new model with those made using conventional models and also with the experimental measurements is made. The XI model is shown to predict mean flow and turbulence values very close to those predicted by the $\kappa-\varepsilon$ model. Measured values for mean velocities and turbulent dissipation are shown to be reasonably predicted by both the $\kappa-\varepsilon$ and the XI models.

A parameter, PI, is proposed for evaluation of the onset of turbulence in a melt and as an estimate of the degree of turbulence.

A theory, based on fundamental considerations of turbulence, is proposed for explaining the relationship of vessel mixing times with parameters like stirring power input and vessel size. This theory is shown to agree favourably with both experimental and in-plant measurements as quoted in references.

Thesis Supervisor : Dr. Julian Szekely
Title : Professor of Materials Engineering
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1. INTRODUCTION

In recent years there has been a great increase in the efforts to move towards a reliable description of materials processing operations. This effort is driven, to a large extent, by a desire to automate processes using the now relatively inexpensive computer hardware as "intelligent" controllers. The first step towards computer automation is an accurate mathematical description of the dynamics of the flow and heat and mass transfer characteristics of the system.

This work deals with the physical and numerical modelling of an electromagnetically stirred liquid metal system. The stirring is the result of a force field created by passing a current through the melt between two concentric electrodes, one of which forms the base of the melt while the other dips into the melt from above. This configuration occurs in several processes of industrial importance such as Electro Slag Refining (ESR), Electro Slag Welding (ESW), Submerged Arc Furnace, among others. Many of the problems addressed in this work are, however, more general and consequently many of the results may be applied to a wide range of materials processing operations.

It is felt that the major contributions of this work are:
(1) For the first time, detailed and careful measurements of flow and turbulence parameters have been made in an applied current system using a liquid metal that is solid at room temperature.

(2) A new turbulence model, with an intuitive fundamental basis and a shorter computation time, has been developed and the results compared with existing models and with experiments.

(3) A theory based on fundamental turbulence principles has been developed to explain the dependence of mixing time in metallurgical systems on various operating parameters.

(4) Numerical techniques have been developed to evaluate and correct for the use of thermal anemometers in liquid metals in the presence of magnetic fields and probe surface contamination. A final objective that this work leads to is the implementation of on-line computer based supervisory process control systems which, it is felt, will become increasingly prevalent in the metals processing industry in the years to come.

Regarding the organisation of this thesis, the material has been divided into six chapters. The Literature Survey is presented in Chapter 2 which reviews work on Thermal
Anemometry, particularly in liquid metals and some experimental and mathematical modelling work on electromagnetically agitated systems and on the theory of turbulence.

Chapter 3 describes the experimental setup and some of the considerations involved in making the measurements.

The formulation and implementation of the numerical models is presented in Chapter 4. Three different models have been used to model the turbulent recirculating fluid flow situation. The first model is a widely used version of the two equation model of turbulence called the k-epsilon model. The second is a low Reynolds number version of the same and the third is a new model developed during this work.

In Chapter 5 the experimental measurements and the numerical predictions are compared and discussed.

The concluding remarks and some suggestions for further work in this and in related areas are made in Chapter 6.
2. LITERATURE SURVEY:

In this chapter, literature pertaining to the use of thermal anemometry in liquid metals, to mathematical and physical modelling of electromagnetically driven flows and to turbulent flow phenomena will be reviewed.

2.1 Velocimetry

There are many kinds of techniques available for velocity measurement in fluids\(^{(86)}\). However, the nature of the experiment imposes several constraints on the types of schemes that may realistically be considered to be possible candidates. The fact that the working fluid is an opaque liquid metal rules out optical techniques like Laser Doppler Anemometry. The fact that relatively high frequency turbulence measurements are required rules out the various forms of Pitot Tube based methods.

There is one instrument whose development and application for measuring turbulent flow have far outstripped those of other instruments up to now, namely, the Thermal Anemometer. The hot wire/film anemometer has been very widely used for measuring turbulent air and water flows and is now a well developed technique for such applications. Its use in measuring liquid metal flows is, however, less well developed. Almost universally, the liquid metal has been liquid mercury
at room temperature, with the exception of Murthy and Szekely\(^3\) who used molten Wood's Alloy at 120° C. A large and comprehensive survey of literature pertaining to the use of Thermal Anemometry is presented in \(^{107}\). This listing contains use of the technique both in liquid metals as well as in more conventional fluids. No effort will be made here to review the use of anemometry in conventional fluids. A sampling of the work pertaining to its use in liquid metal flows is presented in an attempt to point out some of the problems encountered and the solutions adopted by the researchers.

An initial problem regarding the use of thermal anemometry in metals was the fact that the fluid is electrically conducting hence the sensor had to be coated with a film that was both electrically insulating as well as thermally conducting. The pioneering work in developing a practical design of such a probe was done by Sajben\(^{12,13}\) who used a lacquer coated hot wire. In his work Sajben pointed out another serious problem with using hot wire probes in mercury namely one of calibration drift. This problem was acknowledged by most of the other workers in the field\(^{1,3,7,9,11-13,15,16,18,38}\). Several techniques were proposed by various researchers to overcome this problem.
(1) The drift was observed to occur when the probe crossed the metal-air interface. So the obvious remedy, and one adopted by many of the workers\(^1,7,12,13,16,38\), was to provide for in-situ calibration in the same vessel where the experiment was to be done, so that the probe never had to be lifted out of the metal pool.

(2) In 1969 Hoff\(^{18}\) suggested, based on his experiments, that coating the hot film probe with a sputtered layer of gold or copper improved its wetting characteristics and hence its drift behaviour. However Hurt and Welty\(^{11}\) pointed out that it was difficult to control the uniformity of thickness of the sputter coating and in general concluded that sputter coating was not worth the effort involved because it did not yield any consistent improvement and in fact was found, in some instances, to reduce the life of the probe.

(3) The third approach has involved a heat transfer analysis of the probe, attempting to compensate the fouling of the probe by taking a reading at zero velocity and then subtracting out the effects of the fouling\(^1,12,13,3\).

Another problem associated with liquid metal anemometry was related to the low Prandtl Number of metals. This in fact spawned two, somewhat related, problems. As Hill\(^{10,14}\)
pointed out, the probe in liquid mercury showed poor directional sensitivity except when the Peclet Numbers were very high. This was due to the fact that the thermal boundary layer became more or less uniform around the probe. This observation implied difficulties in the use of cross wire probes to measure flow direction.

A second problem linked to the thick boundary layer was one of reduced frequency response due to inertia effects. Lim et. al.\(^{6,8}\) suggested theoretically calculated high frequency response limits beyond which use of uncompensated outputs from turbulent liquid metal systems may yield erroneous results.

Use of heated liquid metals that are solid at room temperature holds out the possibility of studying solidification problems as linked to fluid flow. Murthy and Szekely\(^{3}\) used modified hot film probes in molten wood's alloy at 125°C. They too encountered the problem of calibration drift which was tackled by using mathematical transformation techniques mentioned earlier.

While most of the workers have concentrated on the problems of anemometry per se in idealised flow situations,
some have employed the technique as a practical tool to investigate flows of metallurgical interest\(^{(1,16)}\).

Ricou and Vives\(^{(2)}\) have employed a completely different technique using an incorporated magnet probe to measure velocities in melts up to 720\(^{\circ}\) C. This technique is applicable in the absence of external magnetic fields and in general cannot be used for turbulence measurements. Also, this very innovative technique is not yet commercially available.

The question of what effect an external magnetic field would have on the performance of a hot film anemometer probe is a very relevant one and has been examined in greater detail in a subsequent section of this chapter.

2.2 Mathematical and Physical Modelling

In this section work aimed at modelling certain types of electromagnetically driven flows is reviewed. In 1970 Shercliff\(^{(26)}\) studied the case of a point electrode dipping into a semi-infinite pool of inviscid fluid. An analytical solution was developed for this system with a direct current being passed between the point electrode and another electrode set at infinity. Later Souzou and Pickering\(^{(27)}\) extended the analysis for a finite sized current source in a hemispherical
metal pool of finite viscosity. Both these models, though very important from a fundamental standpoint, were rather drastic oversimplifications of the real situation and results could not be extrapolated to metallurgical systems easily. The field was, in a sense, open for the numerical analysts to try and develop a more meaningful description of such systems.

In 1975, Szekely and Asai\textsuperscript{(20,21)} established a fully numerical simulation of the turbulent flow and transport in the liquid phase of a continuous caster.

Later, Szekely and Chang\textsuperscript{(24,25)} established a numerical calculation for turbulent flow in an induction furnace. Their results for mean velocities were compared with laboratory experiments in a Wood's Alloy system\textsuperscript{(23)}. Reasonable agreement (within 30\%) was found for mean velocities. Moore and Hunt\textsuperscript{(19)} studied turbulent flow in an inductively stirred mercury pool and established measured profiles for turbulence and for mean velocities using a drag probe. Trakas et. al.\textsuperscript{(1)} using hot film probes measured spectra in an inductively stirred vessel.

Along somewhat similar lines Szekely and Dilawari\textsuperscript{(22,30,32,33)} and Schwerdtfeger and Kreyenberg\textsuperscript{(29)} made calculations for temperature profiles, heat transfer and
turbulent velocities for the case of the Electro Slag Refining (ESR) system. This was followed up by Choudhary (36) and Choudhary and Szekely (34, 35, 39) who included an automatic calculation of pool profiles in the ESR solidifying ingot on the basis of their heat transfer calculations.

Experimental verification of these calculations has been somewhat less studied. Choudhary (36) reported on comparison of measured pool profiles with his calculations. More recently, Choudhary et. al. (37, 31) reported on comparisons of their calculations with measurements of mean velocity done on the meridional half plane for an applied current mercury system. High speed photography of particle motions on the surface of the mercury yielded somewhat rough measurements of mean velocity. A similar technique was used by Kompan et. al. (40) and by Butsenieks et. al. (43, 41) in a mercury system of related but not identical geometry. Moshnyaga and Sharamkin (42) used pitot tube velocimetry to measure the centerline velocities and pressure field in an electromagnetically stirred vessel. Comparison of measurements with a laminar flow numerical simulation was also reported by Butsenieks et. al. (41).

On a considerably more fundamental level, Alemany et. al. (38) reported on measurement of turbulent MHD flow
spectra in a behind-grid mercury turbulence with an applied magnetic field.

2.3 Turbulence Modelling and Theory

This section relates to the modelling of turbulence phenomena in general. Even though the turbulence model would form an essential component of a mathematical model for the whole process, it has been dealt with separately since many works on turbulence address the idealised problem without much emphasis in the mechanics of the overall flow.

Beek and Miller\(^{(77)}\) extended some preliminary concepts on the effects of turbulent transport on mixing and reaction rates in chemical reactors. Corrsin\(^{(67,68)}\) developed expressions relating mixing time for passive scalar contaminants in a turbulent flow to microscales and thence to the stirring power input to the system for the general case of arbitrary Schmidt Number. Brodkey\(^{(69)}\) applied this analysis to the case of turbulent mixing in a pipe flow and found good agreement between the measured intensity of contaminant segregation and the values predicted using Corrsin's analysis. Brodkey\(^{(70,89)}\) put forward very physical and intuitively appealing description of the mechanism of contaminant dispersion due to turbulence and some calculations for
parameters like mixing time and segregation based on study of the turbulence spectrum.

Numerical calculation of turbulence can be said to be comprised of the following approaches:

a) Ad-Hoc viscosity models
b) One Equation models
c) Two Equation models
d) Stress Transport models
e) Subgrid Scale Closure schemes and Spectral closures

a) and b) are the simplest schemes that are generally considered insufficient to study recirculating flow systems. Two equation models are currently the most popular for recirculating flow situations. These rely on using two parameters to define the state of turbulence in the field. Differential transport equations are written for these two parameters. The choice of parameters for the two equation calculation scheme can yield different models. Of these, the $\kappa - w$ and the $\kappa - \varepsilon$ models have been the most well known though the latter has recently been the more widely used of the two. Spalding\(^{65}\) first used the $\kappa - w$ model to predict concentration fluctuations in an axisymmetric gas jet. Rodi\(^{91}\), Launder and Spalding\(^{84}\) and Rodi and
Spalding(64), among others, described the use of the $\kappa - \epsilon$ model of turbulence in general two-dimensional flow situations. This model was in fact widely used in most of the numerical work on the simulation of metallurgical flow systems as described in a previous section(20-25,29-37,39) and this is among the best documented of all turbulence models.

The stress transport models(74,75) use a higher order closure for the turbulence problem resulting in more differential equations to be solved. These models represent the next level of sophistication of turbulence modelling but are presently not very popular because of their greater demands on computer time and general complexity.

Representing the highest level of numerical attack on the turbulence modelling problem are the Spectral Closure schemes, primarily proposed by Orszag and his associates(63,71,72) and the Subgrid Closure schemes(73,76) which use similar unsteady state schemes but only for flow fluctuations above a certain minimum cutoff eddy size. These methods rely on solving an unsteady form of the Navier-Stokes equations with a very short time step of computation so as to be able to simulate the evolution of the turbulence flow patterns. These techniques are presently used
primarily for meteorological and geophysical flows and represent considerable investment in terms of computer costs.

In 1945, Lotsianskii\(^{(66)}\) evolved the mathematical concept of a "Disturbance Moment", later known as the Lotsianskii Integral or Invariant, which he showed to be a constant in a homogeneous, isotropic flow and determined by the initial disturbance given to the fluid. Proudman and Reid\(^{(61)}\) and Batchelor and Proudman\(^{(62)}\) and Batchelor\(^{(95)}\) showed that the so called invariant could not truly be a constant but rather a slowly varying function over a flow domain. Comte-Bellot et. al.\(^{(80)}\) interpreted this property of slow variance to imply a value that was effectively a constant and applied this invariant to study the behaviour of turbulence decaying behind a grid. They showed that this assumption resulted in very reasonable decay laws for grid turbulence. Hinze\(^{(86)}\) and, to a certain extent, Tennekes and Lumley\(^{(88)}\) used this together with information about other ranges of a 3-D spectrum to patch together a complete picture of the shape of the isotropic spectrum of turbulence.

Part of this present work has been to use an understanding of spectral shapes, based on the Lotsianskii invariant, together with numerical techniques to evolve a new
scheme of calculation which would fit somewhere between a 1-equation and a 2-equation model of turbulence.

Effects of magnetic fields on turbulence and on a related problem, namely hydrodynamic stability, have been widely studied. Since, in this thesis, the magnetic field strength was judged too weak to have much effect on the turbulence, this part of the literature survey is appended for the sake of completeness. References 44-53, 38 represent some of the work related to this topic.

2.4 Heat and Mass Transfer from a Cylinder in MHD flow

Thermal anemometer probes when used in the presence of a magnetic field, either aligned with the probe axis or orthogonal to it, experience a change in heat transfer characteristics (ie. a change in the overall Nusselt Number dependence on flow velocity)\(^{(15,38,99)}\)

Literature surveyed in this section served as a foundation for the numerical calculations that were done in this work to evaluate the influence of a magnetic field on the heat transfer characteristics of a hot wire or hot film probe in a liquid metal flow.
Considerable experimental work has been done in relating the imposition of a magnetic field to the heat transfer from a hot wire/film probe by Lykoudis et. al.\(^{(99)}\) Numerical and analytical type of solutions were explored since such approaches can be extrapolated to different geometries and sizes easily and also gives a more detailed insight into the mechanics of the problem. Regarding numerical solution of the problem, Kalis et. al.\(^{(96)}\) considered the effects of a transverse magnetic field on the pressure profile and drag coefficient around a cylinder but did not consider the closely related problem of heat and mass transfer from the cylinder. In addition, as will be shown later, their use of a rather coarse grid near the surface resulted in a markedly weaker dependence of pressure profiles and drag coefficients on the magnetic field.

The analogous heat transfer problem was tackled by Blum\(^{(97)}\) who used an approximate analytical approach transforming the results obtained for a flat plate boundary layer flow to a circular cylinder.

Chester\(^{(103)}\) approached analytically the problem of the influence of a magnetic field on flow around a sphere but only in the Stokes' flow regime. Soundalgekar et. al.\(^{(98)}\) have done numerical calculations for the case of a transverse
magnetic field on a flat plate boundary layer. The general hydrodynamic problem of the numerical analysis of fluid flow around cylinders (albeit in the absence of magnetic fields) has been extensively studied. References 100-102 are a few of the works in this area. Ishiguro et. al. (104) and Grosh and Cess (105) have reported on experimental measurements of overall heat transfer from a cylinder as related to the flow of liquid metal orthogonal to the cylinder axis. In addition, the books by Hughes and Young (87) and by Roache (85) contain a wealth of valuable information on the subjects of magneto fluid dynamic modelling and numerical fluid dynamics respectively.

The task to be addressed in this work relates to the measurement and numerical representation of an electromagnetically driven turbulent flow. The literature reviewed here provides a basis for setting up and understanding such a system.
3. EXPERIMENTAL MEASUREMENTS

3.1 Introduction

In essence the experiment involved the setting up of a turbulent recirculating flow of liquid metal stirred by passing a direct current through it between two electrodes. The measurements consisted of taking velocity readings at various positions inside the melt and analysing the instantaneous velocity for mean and turbulent components. The anemometer itself, (the principle of operation of which is described in Appendix A) was calibrated using a calibration tow tank. The entire scheme of measurement was completely computer controlled. A brief description of the principal components of this experimental scheme follows. A listing of some of the equipment used in the experimentation, together with the manufacturers' name and location, is given in Appendix D.

3.2 The Main Flow System

The choice of the liquid metal to be used as the principal fluid constituted a major decision and one that had profound effects on the design and selection of equipment. The metal chosen was Wood's Alloy (see Appendix B) Despite the obvious problems associated with operating the vessel and the measurement schemes at higher temperatures, this choice was
made because the use of a metal that was solid at room temperature opened up possibilities of studying solidification linked to fluid flow. This option would clearly not be available if mercury, the generally popular choice, were used. The other advantage was that Wood's Alloy was relatively non-toxic.

The containment vessel consisted principally of a cylindrical copper cylinder (15 cm dia., 10 cm. height) made from 1/16 inch thick copper sheet and brazed together (see Fig. 3.1). The base electrode was made from 1-1/2 inch thick copper plate that was cut and then turned to final shape. The electrode assembly itself was made in two parts, one being the body of the electrode which covered most of the base of the vessel and was fabricated from the plate as described earlier. The electrical connection was made by a threaded pin which could be screwed into the base plate. This pin provided at the other end a connection point which was turned to the specifications required to match the end of the current carrying cable of the welding generator. The inner walls of the vessel were painted over with Epo-tek H-72 epoxy to prevent current passing through the cylinder walls instead of through the melt entirely. On the outer surfaces of the vessel, a tape heater was fixed using ceramic cement. This tape heater was made in two parts—one for the cylindrical
(vertical) walls of the vessel and the other for the base. The electrical power supply for the two heaters was kept under separate control in order to provide greater flexibility in controlling the melt temperature. The side wall heater was controlled by a proportional temperature controller while the base heater was manually set by potentiostat to create approximately isothermal conditions in the melt. Outside the ceramic jacket which held the electrical heaters was a layer of pyrex cotton wool. This entire assembly was placed inside a Plexiglas outer containment vessel which was held by three support rods above a heavy steel base plate. The three supports could be adjusted to keep the vessel and the metal pool horizontal. Holding the bottom of the vessel several inches above the base plate provided enough space beneath for a drain pot.

For periodic maintenance as well as for any future experiments which may need the vessel to be drained (perhaps to study solidification linked to fluid flow) the vessel was provided with a drain point. For this purpose, the bottom electrode was made hollow. Through this hole a slender pushrod was passed. A ceramic plug covered the point where the pushrod emerged from the base plate inside the melt to prevent any possible leakage. Draining could be started by tapping the bottom of the pushrod lightly to dislodge the ceramic plug
which would then float to the top of the metal pool. The inner surface of the base plate was made slightly tapered towards the centrally placed drain hole to assist flow of the metal.

The depth of the metal pool was about 4 cms. The top electrode was 1.5 cms. in diameter and dipped into the melt from the Plexiglas upper plate.

Since the flow and turbulence field would be expected to vary spatially inside the melt, a system of accurate probe positioning was required. The positioning equipment was built on top of the upper plate. It consisted of a motor driven radial traverse. On the slider of the radial traverse was attached a probe holder arm which contained a manually operated axial traverse and a simple theta rotation device about the axis of the probe. Both the axial and radial traverse spindles were provided with 10 turn potentiometers which were connected to a digital display. A program was built in the micro-computer to take keyed-in display voltages and interpret them as \( r, x \) coordinates of the probe tip within it. The probe was never moved to a new location until the location was first plotted out and checked for proximity to walls or any solid object which might break the very fragile probe tip. The same program also provided a grid of potentiometer voltage settings. The operator then simply moved the traverses
(radial and axial) until the approximate voltages appeared on the display.

A sketch of the data flow path for the data relating to the main flow system is given in Fig. 3.2. At the time of the experiment, no attempt was made to analyse or to process the information. The anemometer voltage outputs were continuously recorded on one of the channels of an F.M. tape recorder whose gain factors were set from experience to permit even the highest voltages encountered to be recorded faithfully. The voice memo channel on the recorder was used to make comments about the progress of the experiment and also to note the time of starting and stopping the current and so forth. Time (using a stop watch which was started exactly at the same time the current was switched on) and experiment number was noted on the memo channel at regular intervals to facilitate subsequent playback and analysis. This technique provided a permanent record of the experiment for future analysis and also freed the experimenter from the tasks of operating analysis instrumentation to concentrate on carrying out an experiment which could be potentially dangerous.

The subsequent post-processing of the data took the path as shown in Fig. 3.2. Each tape was played back at least twice, once to get the mean values of voltages for each
experiment and once to do a spectral analysis. The considerations involved in making these two measurements are described in Appendix B. The structure of the micro-computer based data acquisition and information handling scheme is described in Section 3.4.

3.3 Calibration System Design

Fig. 3.3 shows a sketch of the hot film anemometer calibration assembly, which in essence consisted of a shallow, externally heated, horizontal trough, containing molten Wood's Alloy at 120° C. Provision was made to drag a hot film probe, immersed in the metal, parallel with the axis of the trough at a predetermined velocity. This velocity of traverse ranged from about 1 to 10 cm/sec.

This arrangement is quite similar to that used in the calibration of hot film probes in mercury\(^{12-14}\), except for the higher operating temperatures involved.

The trough was made from a semi-cylindrical section of 1-1/2 inch copper pipe brazed to two end plates. The cylindrical section of the trough was heated by a semi-cylindrical resistance heater which had an internal diameter equal to the outer diameter of the pipe. The power to
this heater was regulated by a temperature controller. Temperature measurement for the proportional controller was provided by a thermocouple dipping into the pool of metal. A digital display of the temperature was also provided. Movement of the slider assembly was controlled from a remote switching unit and controller. To allow any initial transients to settle down when the probe first started to move, the measurement was started only after the slider had already moved several centimeters. Data acquisition was started (see Fig.3.4) when the slider tripped on a microswitch and stopped when the microswitch tripped off a fixed distance later. This also enabled a velocity measurement as the computer was programmed to measure the 'ON' time of the microswitch. When sampling was over, the velocity as well as the output voltage was printed out by the micro-computer. The rate of sampling could be set in the program. The logic of the data acquisition software and the information handling schemes are detailed in a subsequent section.

3.4 Microcomputer Usage Scheme

An Apple II Plus microcomputer was used extensively as a laboratory tool. The use of an in-house microcomputer to supervise the entire experimentation scheme held out several advantages, not the least of which were speed, repeatability,
convenient user interfacing, convenient data handling and also the fact that analog signals needed to be digitised before they could be reduced to any usable form. Functionally, the tasks performed by the microcomputer could be classified as:

1. Signal digitisation for both the main system signals and for calibration experiments.
2. Preliminary computations like drift correction, scaling etc.
3. Information handling involving data file handling and creation, mainframe communications etc.
4. Secondary help functions like printing, plotting, interactive human interface, plot digitisation etc.

Many of the program segments performed more than one of the above functions. It was felt that looking at the scheme of microcomputer usage as a step by step sequence performed in a typical experiment would aid in clarifying a somewhat complex chain of interlinked program steps.

Fig. 3.5 shows the Apple II based program files which performed the various operations in a partly sequential manner, while Fig. 3.6 shows the data files that resulted at the end of each segment. A listing of some of the software developed to create this scheme is provided in Appendix E.
These programs are the result of the joint efforts of Mr. T. Kang and this author. The experiments can be divided into three distinct but interlinked data flow paths which are simultaneously processed except at points where data cross linking occurs, in which case a definite priority exists.

Path I- Calibration data flow

The microcomputer is connected real time with the calibration arrangement. The anemometer voltage output is led to channel 1 of the Analog-Digital Converter (ADC) and the microswitch is led to channel 5.

LEVEL 1(P1L1)
The operating environment is provided by routine DATACQ1 (in BASIC) and HOT1.OBJ (in Machine Code). HOT1.OBJ was the machine code routine which did the actual data acquisition and stored the new data into specific memory locations. It was called, as a subroutine, by the control routine, DATACQ1 which served as a user interface to input pertinent parameters (like probe location, current etc.) and to set the operating conditions within which HOT1 must operate.

LEVEL 2(P1L2)
Routine CALFUL1 (in BASIC) reads the specific memory locations where the data has been stored by the Level 1 routines and
computes velocity of probe traverse and average output voltages during the run. These values are then

1. Stored as a disk file under the generic name CALn/m where n represents the probe number and m the calibration number for that particular probe.
2. Output to the terminal for viewing
3. Output to printer for hard copy

The routine returns control to Level 1 (PIL1) for another run.

LEVEL 3 (PIL3)
Routine DRIFT-CALC reads the CALn/m file (once all data points are completed), performs computations to correct the calibration data for drift (described in Section 3.5.3) and stores the corrected values in disk file under the name CALn/m-*

LEVEL 4 (PIL4)
Routine POLYFIT reads the data in data file CALn/m-* and fits a fourth order polynomial through it. The coefficients are then stored under the generic name of CALn/m-*-COEF on disk file. This is the final process step in Path-1 and CALn/m-*-COEF is a data file read by Path2 for processing mean velocities. Thus PIL4 represents an outgoing transfer point.

At this level the calibration curve can be plotted out on the local plotter for viewing, though this is not a necessary step. (See Fig. 5.43)
Path 2—Main Flow System Data Path (Mean Values).

The microcomputer is used in an off-line mode and is used to read data from the taped signals recorded during the experiment.

LEVEL 1 (P2L1)
The environment here is identical to that provided for P1L1. The microswitch is now replaced by a handheld switch for switching on and off the digitisation routine. Operating parameters like rate of sampling or memory allocation may need to be changed according to the needs of the experiment.

LEVEL 2 (P2L2)
Routine SYSFUL1 reads the memory locations for raw data and stores the values of voltages, as well as pertinent data input by the user, in a data file with the generic name SYS-nx where nx stands for the experiment number.

LEVEL 3 (P2L3)
Routine INTERPRET reads the P1L4 data file (CALn/m-**-COEF) as well as the SYS-nx data file and converts the measured voltages to velocities and also obtains the gradient of the calibration curve at that velocity. This information is stored in file set SYSINT-nx. This stage serves as an outgoing transfer point for Path-2.

Path 3—Main Flow System Data Path (Turbulent Values)
LEVEL 1 (P3L1)
The digitisation and spectral analysis is performed off-line from taped recordings using a HP 5423 A Spectrum Analyser. This level results in an output in the form of a spectral plot on paper.

LEVEL 2 (P3L2)
Routine SPECTSV is used to digitise the spectral plot. This is done by mounting the plot on the plotter which is then driven along the curve to be traced, by keyboard control. The coordinates of each point on the curve, along with the necessary data for scaling, are saved in file SPEC-nx.

LEVEL 3 (P3L3)
Routine SPECTAN reads data file SPEC-nx and computes values corresponding to turbulence energy and dissipation by numerical integration. These values are saved in file SPECINT-nx.

LEVEL 4 (P3L4)
Routine COMBINE reads file set SPECINT-nx and also SYSINT-nx (from P2L3) to scale the values of the energies calculated in P3L3 from voltage to velocity based values. The mean velocity (from SYSINT-nx) together with the scaled final values of turbulence energy and dissipation energy along with other pertinent data are stored in data file SYSLAST-nx.
SYSLAST-nx is the final data file which contains only the completely processed experimental results. This file can be either printed locally or transferred to the mainframe computer (IBM-370) using the communication routine T1.

3.5 Hot film anemometry in liquid metals

The use of hot film probes in Wood's Alloy at 120° C posed some definite problems with the sensor itself. Some of the more important problems are described here as well as the steps taken to alleviate them.

The two most important problems were those of probe failure due to the extremely corrosive nature of the heated metal and of the calibration drift with time.

3.5.1 Probe Life

The temperature of the melt was the single most important reason for failure of the probe. A typical probe as supplied by TSI (without modifications) would survive about 5-10 minutes in the melt. Damaged probes were cleaned carefully in an ultrasonic bath (80° C, slightly acidic) and then examined using a Scanning Electron Microscope. Over a period of time two failure mechanisms were identified:
(1) The epoxy coating used to insulate the legs of the probe softened at elevated temperatures and quickly eroded away when subjected to a flow of metal.

(ii) The solder connections at the points where the platinum film was joined to the support legs could not withstand the temperature.

After consultations with TSI, the manufacturers of the anemometry equipment, both the epoxy insulation and the solder used at the joints was changed to higher temperature types. The changes have proved extremely satisfactory and probe life extended to at least 40 hours. Even after that time, probes were discarded due to insufficient sensitivity rather than due to failure. A precaution that has been found quite valuable in this regard has been to examine the probe under an optical microscope and touch up the epoxy coating at points where the coating may appear somewhat thin.

3.5.2 Calibration Drift

Drift in calibration characteristics was found to occur primarily when the probe was introduced into or removed from the melt. This appears to have been the experience of most other workers in this field while working with mercury. Some
researchers (refer to Chapter 2 for details) have circumvented the problem by crossing the liquid metal-air interface only once during an experiment and by providing arrangements to calibrate the probe in-situ. Practical constraints with the present experimentation forbade this, so a technique was developed to correct for calibration drift using heat transfer analysis. The principal assumption of the analysis was that the drift was directly caused by the appearance of a coating of 'fouling' material (perhaps oxide) on the sensor surface, after Sajben\(^ {12, 13} \).

3.5.3 Drift Correction Analysis

The drift correction scheme was based on the fact that as the fouling of the sensor surface changed, this change was reflected in the output voltage produced by the anemometer at zero flow velocity \( (E_0; \text{with only natural convection present}) \). Thus the scheme uses the value of \( E_0 \), the zero-flow voltage, as an indicator that points to the extent of fouling. The entire scheme is computed automatically by the microcomputer and results in a new set of calibration points that are generated by resetting the \( E_0 \) values for each case to a common base value.
The correction analysis involves three levels of correction, in decreasing magnitude of impact.

Heat is generated in the platinum film by resistance heating and conducted through the quartz coating and fouling material and thence convected away by the fluid. The overall heat transfer stages may be visualised by a simple thermal resistance network.

\[
\begin{align*}
T_f & \quad R_i \quad T_s \\
T_s & \quad R_{CN} \quad R_{CV} \\
T_b & \quad R_{CV}
\end{align*}
\]

where:

- \( T_f \) is the film temperature
- \( T_s \) is the surface temperature
- \( T_b \) is the bulk temperature
- \( R_i \) is the thermal resistance of fouling material
- \( R_{CN} \) is the resistance due to natural convection
- \( R_{CV} \) is the resistance due to forced convection
- \( Q \) is the total heat flux rate
- \( R_p \) is the probe resistance
- \( R_3 \) is the bridge resistance in series with the probe
- \( E \) is the voltage output of the anemometer
\[ \Delta T_m = T_f - T_b \]

and \[ \Delta T_{\text{eff}} = T_s - T_b \]

\[ \Phi = \frac{E^2 R_p}{(R_3 + R_p)^2} = E^2 \beta \]

(3.1)

where

\[ \beta = \frac{R_p}{(R_3 + R_p)^2} \]

(3.2)

Consider first the case when there is no flow. Then:

\[ R_{cv} = \infty \]

(3.3)

and

\[ \Phi_0 = E_0 \]

(3.4)

where \( E_0 \) is the voltage output at zero flow velocity.

Now let:

\[ R_{cn} \Delta \eta^{1/4} \Delta T_{\text{eff}} \]

(3.5)

\[ \Phi_0 = \beta E_0 = \frac{\Delta T_{\text{eff}}}{R_{cn}} = \frac{\Delta T_{\text{eff}}}{\eta^{1/4}} \]

(3.6)

or

\[ \beta E_0 = \frac{\Delta T_{\text{eff}}}{\eta} \]

(3.7)

which gives:
\[
\Delta T_{\text{eff}} = \eta \beta E_o \quad (3.8)
\]
and therefore
\[
\Delta T_{\text{eff}} = (\eta \beta E_o)^{0.2} \quad (3.9)
\]
substituting in (3.5) gives
\[
R_{CN} = \eta \beta E_o \quad (3.10)
\]
Now
\[
\frac{\Delta T_m}{\beta E_o} = R_i + R_{CN} \quad (3.11)
\]
or
\[
R_i + \eta \beta E_o = \frac{\Delta T_m}{\beta E_o} \quad (3.12)
\]
introducing the two cases, one the active measurements (superscript (1)) and the other a reference case (superscript (ref)), it may be said that:
\[
\Delta R_i = \Delta \left( \frac{\frac{1}{E_o(I)}}{\frac{1}{E_o(\text{ref})}} \right) = \eta \beta (E_o(I) - E_o(\text{ref})) \quad (3.13)
\]
where
\[
\Delta R_i = R_i^{(1)} - R_i^{(\text{ref})} \quad (3.14)
\]
Now consider the case when the flow velocity is non-zero. Then \(R_{CV}\) is a finite value. \(R_{CV}\) may be written as
\[
R_{CV} = \sqrt{\nu^2} \quad (3.15)
\]
where $\gamma$ is a constant of proportionality. Here

$$\frac{\Delta T_m}{\beta E_v(1)} = R_A + \frac{f_2 \cdot f_{11}}{f_2 + f_{11}} \quad (3.16)$$

and

$$\frac{\Delta T_m}{\beta E_v(\text{ref})} = R_A - \Delta R_A + \frac{f_2 \cdot f_{1,\text{ref}}}{f_2 + f_{1,\text{ref}}} \quad (3.17)$$

where:

$$f_2 \triangleq \gamma^{\frac{3}{4}}$$  

$$f_{11} \triangleq \gamma^{\frac{3}{2}} E_o(1)$$  

$$f_{1,\text{ref}} \triangleq \gamma^{\frac{3}{2}} E_o(\text{ref})$$

subtracting equation 3.16 from 3.17 yields:

$$\frac{1}{E_v(\text{ref})} = \frac{1}{E_v(1)} + \frac{\beta}{\Delta T_m} \left\{ - \Delta R_A + f_2 \left( \frac{f_{1,\text{ref}}}{f_2 + f_{1,\text{ref}}} - \frac{f_{11}}{f_2 + f_{11}} \right) \right\} \quad (3.21)$$

substituting for $\Delta R_A$ from equation 3.13 gives:

$$\frac{1}{E_v(\text{ref})} = \frac{1}{E_v(1)} + \left( \frac{1}{E_v(\text{ref})} - \frac{1}{E_v(1)} \right) + \frac{\beta}{\Delta T_m} \left\{ f_{11} - f_{1,\text{ref}} \right\} + f_2 \left( \frac{f_{1,\text{ref}}}{f_2 + f_{1,\text{ref}}} - \frac{f_{11}}{f_2 + f_{11}} \right) \quad (3.22)$$

Equation 3.22 is used to calculate values for $E_v(\text{ref})$.

The voltages ($E_v(1)$ and $E_v(\text{ref})$) with superscript (1) are the values actually measured during an experiment. $E_v(\text{ref})$ is the artificial value for base voltage (at zero velocity) selected for normalising the calibration curves. (In
this work, $E_0^{\text{ref}}$ has always been kept equal to 15.0 Volts.)

$E_t^{\text{ref}}$ is the set of normalised voltages which when plotted against the velocity provides a minimum drift calibration curve. This calculation is performed automatically by the computer when a new calibration is done. The resulting (normalised) calibration curve is fitted with a fourth order polynomial. This polynomial is used by other calculation stages in voltage to velocity and turbulent parameter conversions. Figs. 5.42 and 5.43 show a typical case of calibration drift before and after correction was applied.

3.6 Effect of Magnetic Fields on Calibration

A question that arose early in the experimental work was that how much does the presence of a magnetic field affect the heat transfer characteristics of the probe. Previous approaches to this problem have included calibrating the probes in the presence of magnetic fields\(^{[38]}\), applying semi-emperical correction factors \(^{[15]}\), or ignoring the effect of the field altogether. To get a better quantitative appreciation of the problem numerical calculations were made to predict the effect of a transverse magnetic field on the flow of a liquid metal past a heated, infinite cylinder (which represents the hot film probe). The geometry of the flow situation is shown in Fig. 5.36. Consider a circular cylinder
of radius 'a' and of infinite extent in the z-direction. The cylinder surface is heated internally to a constant temperature $T_f$. The entire cylinder surface is subjected to a cross flow of a conducting liquid at a velocity $U_0$ normal to its axis and a constant magnetic field of induction $B_0$. The presence of the orthogonal magnetic field alters the velocity profile around the periphery of the cylinder and this in turn influences the heat, mass and momentum transfer characteristics, both local and averaged.

3.6.1 Mathematical Formulation

A mathematical formulation of the problem involves the following:

(1) Momentum balance (Navier Stokes) equations including a source term of electromagnetic origin.

(2) Maxwell's equations for a moving medium.

(3) Energy balance equations

The following assumptions were made:

(1) The fluid is Newtonian

(2) Property values such as viscosity, density, thermal conductivity etc. were assumed to be constant and evaluated at bulk fluid temperature $T_{bulk}$.

(3) The flow is considered stable and laminar

(4) The cylinder is an electrical insulator
The cylinder is infinitely long.

The momentum balance equation including the Lorentz force term may be written as:

$$\mathbf{u} \cdot \nabla \mathbf{u} = \frac{\nabla p}{\rho} + \mu \nabla^2 \mathbf{u} + \mathbf{j} \times \mathbf{B}$$

and the energy transport equation is given by:

$$\mathbf{u} \cdot \nabla T = \kappa \nabla^2 T$$

The effect of the electromagnetic field is introduced into the equation of motion through the \( \mathbf{j} \times \mathbf{B} \) term, which as the vector product of magnetic induction and induced current represents the Lorentz force that acts on the fluid. The Lorentz force may be evaluated with the aid of Maxwell's equations, which may be written as:

$$\mathbf{j} = \sigma (\mathbf{E} + \mathbf{u} \times \mathbf{B}) \quad (3.23)$$

$$\nabla \times \mathbf{B} = \mu_0 \mathbf{j} \quad (3.24)$$

$$\nabla \cdot \mathbf{B} = 0 \quad (3.25)$$

$$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t} \quad (3.26)$$
Expressing the above equations in terms of non-dimensional variables and then rewriting in terms of polar coordinates, yields the following set of equations to be solved:

The momentum balance equation

\[
\frac{\partial}{\partial r} \left( \omega \frac{\partial \psi}{\partial \theta} \right) - \frac{1}{r} \frac{\partial}{\partial \theta} \left( \omega \frac{\partial \psi}{\partial r} \right) = \frac{1}{Re} \left[ \frac{\partial}{\partial r} \left( r \frac{\partial \psi}{\partial r} \right) \right] + \frac{2}{r} \frac{\partial \psi}{\partial \theta^2} + X_m
\]

(3.27)

where:

\[X_m = N \left\{ \sin \theta \frac{\partial \psi}{\partial r} + \cos \theta \frac{\partial \psi}{\partial \theta} \right\} \omega \cos^2 \theta \]

(3.28)

The vorticity - Stream function relationship:

\[
\omega + \frac{1}{r} \frac{\partial}{\partial r} \left( r \frac{\partial \psi}{\partial \theta} \right) + \frac{1}{r^2} \frac{\partial \psi}{\partial \theta^2} = 0
\]

(3.29)

and the energy transport equation:

\[
\frac{1}{r} \frac{\partial}{\partial r} \left( r \frac{\partial T}{\partial \theta} \right) - \frac{1}{r} \frac{\partial}{\partial \theta} \left( r \frac{\partial T}{\partial r} \right) = \frac{1}{Pr}
\]

(3.30)

with the following boundary conditions:

at \( r = \infty \); \( 0 \leq \theta \leq \pi \) \( \psi = 0 \) \( \psi = \rho \sin \theta \) \( T = T_{bulk} \)

at \( \theta = 0, \pi \); \( 1 \leq r \leq \infty \) \( \psi = 0 \), \( \psi = 0 \) \( \frac{\partial T}{\partial \theta} = 0 \)

at \( r = 1 \); \( 0 \leq \theta \leq \pi \) \( T = T_w \)

\( \omega \) being calculated using first order vorticity generation.
In the above set of equations, the principal variables are defined as follows. Stream function \( \psi \) is defined by:

\[
\nabla \times (\nabla \times \psi) = 0
\]

where

\[
\nabla = \frac{\partial}{\partial x} \quad \nabla = \frac{\partial}{\partial y}
\]

Vorticity \( \omega \):

\[
\omega = \nabla \times \nabla
\]

Interaction parameter \( N \):

\[
N = \frac{\Gamma B \rho a}{\mu U_0}
\]

Reynold's Number, \( Re \):

\[
Re = \frac{V_0 a}{\nu}
\]

Peclet Number, \( Pe \):

\[
Pe = \frac{V_0 a}{\lambda}
\]

Dimensionless radial distance by

\[
\gamma = \frac{R}{a}
\]

3.6.2 Results

The results obtained from the above analysis are discussed in Chapter 5 and in Figs. 5.36 through 5.41.
ANEMOMETER PROBE & SKI

ME 12 BASE HEATING CABLE SPIRAL TO ~800 A DC SUPPLY

ANEMOMETER PROBE TRAVERSE

1/2" THREADED STEEL ROD (3 No.5 120° APART.)

CEMENT BONDING FOR HEATING TAPE

CERAMIC DRAIN PLUG

GLASS WOOL INSULATION

0.5 ink ACRYLIC PLATE (10" DIA)

0.5 ink ACRYLIC PLATE (12" x 12")

BASE ELECTRODE (COPPER 1" x 6" DIA)

1/2" WIDE HEATING TAPE

BASE HEATING CABLE SPIRAL

3/8 DRAIN ROD

15/16 COPPER ROD

3/8 DRAIN PIN PUSH UP TO DRAIN

TO GROUND OF DC SUPPLY

STEEL BASE PLATE

EXPERIMENTAL SET UP TO STUDY ELECTROMAGNETICALLY DRIVEN LIQUID METAL FLOW

Fig. 3.1 Experimental Set Up for Main Flow System
Fig. 3.2 Main Flow System Data Processing Path
HOT FILM ANEMOMETER CALIBRATION SYSTEM

Fig. 3.3 Experimental Set Up for Calibration
Fig. 3.4 Calibration System Data Processing
Fig. 3.5
Microcomputer Operating Environment - Program Files

PATH 1
LEVEL 1 DATAACQ1 HOT1.OBJ
LEVEL 2 CALFULL1
LEVEL 3 DRIFT CALC
LEVEL 4 POLYFIT

PATH 2
LEVEL 1 DATAACQ1 HOT1.OBJ
LEVEL 2 SYSFULL1
LEVEL 3 INTERPRET

PATH 3
LEVEL 4 HP 5423A
LEVEL 5 SPECTSV
LEVEL 6 SPECAN
LEVEL 7 COMBINE

DATA FILE: SYSLAST

PROGRAM FILES
Fig. 3.6 Microcomputer Operating Environment - Data Files

**PATH 1**
- LEVEL 1: RAM
- LEVEL 2: CALN/M
- LEVEL 3: CAL/N/M-
- LEVEL 4: CALN/M*-COEF

**PATH 2**
- RAM
- SYS-NX
- SYSINT-NX

**PATH 3**
- PLOT
- SPEC-NX
- SPECINT-NX
- SYSLAST-NX

**DATA FILES**
4. THEORETICAL CONSIDERATIONS

4.1 Introduction

While results from experimental work possess the advantage of being direct measurements of real physical quantities, they are often restricted to the particular geometry and operating conditions of the experiment. It is therefore difficult, if not impossible, to extrapolate to other operating conditions. A mathematical formulation, coupled to a numerical solution scheme, on the other hand can be extended, almost at will, to differing operating conditions and geometries, within the limits of applicability of the model itself. It also lends itself very directly and simply, to the implementation of microprocessor based process control systems. However, a numerical scheme, needs to be evaluated and checked before acceptance and experimentation provides a convenient vehicle for making such a check.

In this chapter, a general mathematical formulation of the overall problem will first be discussed. Following this, the broad techniques used to convert this formulation to a workable numerical scheme are explained. Modelling of the turbulent flow phenomena has occupied a significant part of the effort involved in this thesis and so will be discussed in some depth. Three different numerical schemes are put forward. The first uses the conventional $\kappa - \epsilon$ model of turbulence, the
second uses the Jones and Launder(79) low Reynolds number model. The third scheme uses a new basis for turbulence computation which was developed as part of this work.

4.2 Mathematical formulation of the problem

A mathematical description is sought for the flow phenomena occurring in the Wood's Alloy melt of the geometry and configuration detailed in Chapter 3. A schematic of the flow system is shown in Fig. 4.1

4.2.1 Principal Features and Assumptions

The following are the principal features of the system:

(1) The fluid is Wood's Alloy at 120° C with all the attendant property values which are listed in Appendix B.

(2) The flow is driven by applying a direct current between unequally sized electrodes. This creates a divergent current path in the melt which in turn creates a recirculating flow in the vessel.

(3) The flow is recirculating.

(4) The flow is turbulent.

(5) The fluid is essentially isothermal.
In formulating the model, the following assumptions were made:

(1) Cylindrical symmetry (no rotational flow) resulting from perfectly centered electrodes and vessel.

(2) The top electrode is assumed to be just touching the surface of the melt. (In the experiment, however, the top electrode was adjusted to be dipping into the melt a few millimetres to prevent any possibility of arcing when the current was turned on.

(3) Quasi steady state.

(4) The flow is assumed to be driven by electromagnetic forces alone, i.e. the bouyancy driven component of flow was assumed to be negligibly small.

(5) Electromagnetic damping of the turbulent fluctuations was neglected. Following Alemany et al.\(^{(38)}\), the interaction parameter \(\alpha\), based on the energy containing eddy size was estimated to be approximately

\[
\alpha \approx \frac{\sigma B_0^2 l}{\varphi U} \sim 4 \times 10^{-5}
\]

(4.1)

which is small enough to have a negligible impact on the spectral energy distribution of the turbulence.
(6) The turbulence was assumed to be isotropic to allow the use of simpler models such as the two-equation model of turbulence.

4.2.2 The governing equations

Maxwell's equations

Upon applying the MHD approximation, Maxwell's equations take the following form: *(78)*

Faraday's Law:
\[
\nabla \times \mathbf{E} = - \frac{\partial \mathbf{B}}{\partial t}
\]  

(4.2)

Ampere's Law:
\[
\nabla \times \mathbf{H} = \mathbf{J}
\]  

(4.3)

\[
\nabla \cdot \mathbf{B} = 0
\]  

(4.4)

\[
\nabla \cdot \mathbf{J} = 0
\]  

(4.5)

Furthermore, we have
\[
\mathbf{J} = \sigma (\mathbf{E} + \mathbf{U} \times \mathbf{B})
\]  

(4.6)

and
B = \mathcal{H}_0 H \tag{4.7}

where \( \sigma \) is the electrical conductivity in mho-m, \( \mu_0 \) is the magnetic permeability of free space in Henry/m and \( U \) is the velocity of the fluid in m/s.

Equations 4.2 through 4.5 can be combined\(^{78}\) to give:

\[
\frac{\partial H}{\partial t} = \gamma \nabla H + \nabla \times (U \times H) \tag{4.8}
\]

where

\[
\gamma = \frac{1}{\mu_0} \tag{4.9}
\]

is called the Magnetic Diffusivity. Under conditions of low Magnetic Reynolds' Number, \( \text{Re}_m(= V_0 L \sigma \mu_0) \), this equation can be reduced\(^{32,36}\) to

\[
\frac{\partial H}{\partial t} = \gamma \nabla H \tag{4.10}
\]

or

\[
\sigma \mathcal{H}_0 \frac{\partial H \theta}{\partial t} = \frac{2}{\sigma} \left[ \frac{1}{r} \frac{\partial}{\partial r} (r H \theta) \right] + \frac{2}{\partial x^2} H \theta \tag{4.11}
\]

in cylindrical coordinates with axial symmetry with the electromagnetic body force given by:

\[
\mathbf{F}_{be} = \mathbf{j} \times \mathbf{B} = \mathcal{H}_0 \mathbf{j} \times \mathbf{H} \tag{4.12}
\]

and the current densities being given by:
Using Reynolds' averaging applied to the turbulent fluctuating velocities, the equation of motion (Navier Stokes' equations) may be written as:

$$\rho (\overline{u \cdot v}) \overline{u} = -\nabla p - \nabla \cdot [\tau] + \overline{F_{be}}$$  \hspace{1cm} (4.15)$$

where:

$$\overline{F_{be}} = \overline{A \times B}$$  \hspace{1cm} (4.16)$$

and the mass conservation equation:

$$\nabla \cdot \overline{u} = 0$$  \hspace{1cm} (4.17)$$

Now introducing the vorticity $\omega$

$$\omega = \left[ \frac{\partial u_{y}}{\partial x} - \frac{\partial u_{x}}{\partial y} \right] \theta$$  \hspace{1cm} (4.18)$$

and the stream function, $\psi$

$$\psi = -\frac{1}{\rho} \frac{\partial \overline{u_{y}}}{\partial x}$$  \hspace{1cm} (4.19)$$
the equations 4.15 and 4.17 may be expressed as:

\[
\frac{\partial}{\partial t} \left[ \frac{2}{\partial x} \left( \frac{\partial \omega}{\partial x} \right) - \frac{2}{\partial t} \left( \frac{\partial \omega}{\partial x} \right) \right] - \frac{2}{\partial x} \left[ \frac{\partial}{\partial x} \left( \frac{\partial \omega}{\partial t} \right) \right] + \frac{\partial}{\partial x} \left[ \frac{\partial}{\partial t} \left( \frac{\partial \omega}{\partial t} \right) \right] + \frac{\partial}{\partial x} \left[ \frac{\partial}{\partial t} \left( \frac{\partial \omega}{\partial x} \right) \right]
\]

where

\[
\frac{\partial}{\partial x} \left[ \frac{\partial}{\partial x} \left( \omega \frac{\partial \omega}{\partial t} \right) \right] + \frac{\partial}{\partial t} \left[ \frac{\partial}{\partial t} \left( \omega \frac{\partial \omega}{\partial x} \right) \right] + \frac{\partial}{\partial x} \left[ \frac{\partial}{\partial x} \left( \omega \frac{\partial \omega}{\partial x} \right) \right]
\]

The last term can be shown to take the following form:

\[
\frac{\partial}{\partial x} \left[ \frac{\partial}{\partial x} \left( \omega \frac{\partial \omega}{\partial x} \right) \right] + \frac{\partial}{\partial t} \left[ \frac{\partial}{\partial t} \left( \omega \frac{\partial \omega}{\partial x} \right) \right]
\]

In addition the following relationship exists between \( \omega \) and \( \varphi \):

\[
\omega + \frac{\partial}{\partial x} \left[ \frac{\partial}{\partial x} \left( \frac{\partial \omega}{\partial x} \right) \right] + \frac{\partial}{\partial t} \left[ \frac{\partial}{\partial t} \left( \frac{\partial \omega}{\partial t} \right) \right] = 0
\]

The presence of turbulent fluctuations in the flow affects the above formulation through the value for \( \mu_{\text{eff}} \). Considerations for the introduction of turbulent calculations are detailed in section 4.3.
The presence of turbulence introduces into the stress tensor $\tau$ (in the time averaged flow equations) an additional term ($\rho u'v'$) called the Reynolds' Stress term. Following Boussinesq (74), turbulent or Reynolds' stresses can be computed using the same relationships which exist for viscous stresses in a Newtonian fluid but by replacing molecular viscosity with a scalar turbulent viscosity. This turbulent viscosity may be calculated using one of the several different methods available. The $\kappa - \epsilon$ model of turbulence is a two equation model that has been one of the most popular models for calculations of turbulent recirculating flows. In this section the $\kappa - \epsilon$ model, its low Reynolds' Number version (72) and the basis for a new model, the XI model will be examined.

4.3.1 The $\kappa - \epsilon$ Model

The $\kappa - \epsilon$ model uses two partial differential equations, one for $\kappa$ and the other for $\epsilon$. The $\kappa$ (turbulence energy) equation can be easily derived by multiplying the (instantaneous) Navier Stokes equations by velocity to form the (instantaneous) Energy equation. Subtracting from this the mean energy equation which can be obtained by multiplying the Reynolds averaged Navier-Stokes equation with the mean
(time averaged) velocity. For high Reynolds Numbers, this equation reads \(^{(82)}\)

\[
\frac{1}{\partial t} \frac{\partial \kappa}{\partial x_i} + U_i \frac{\partial \kappa}{\partial x_i} = \frac{2}{\partial x_i} \left[ U_i \left( \frac{u'_i u'_j}{2} + \frac{P}{\rho} \right) \right]
\]

\[- \frac{u'_i u'_i}{\partial x_j} \frac{\partial u_i}{\partial x_j} = \frac{\epsilon}{\nu} \]

where:

Term I is the time rate of change of \( \kappa \)
Term II is the convective transport of \( \kappa \)
Term III is the diffusive transport of \( \kappa \)
Term IV is the generation of turbulence by mean shear (= 'g')
Term V is the dissipation of turbulence.

Terms II and III are of the redistributive type which just change the local values of \( \kappa \). Introducing a gradient transport assumption for the diffusive flux of \( \kappa \), gives the following form of the above equation:

\[
U_i \frac{\partial \kappa}{\partial x_i} = \frac{2}{\partial x_i} \left( \frac{M}{\nu} \frac{\partial \kappa}{\partial x_i} \right) + \frac{M}{\rho} \left( \frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i} \right) \frac{\partial u_i}{\partial x_j} - \frac{\epsilon}{\nu}
\]

This equation alone cannot be solved because \( \epsilon \) is an unknown variable. This in a sense represents the point of departure for the 1-equation, the 2-equation and the spectral models.
The $\kappa - \epsilon$ model resolves the problem by postulating another transport partial differential equation for $\epsilon$ of the form:

$$\frac{\partial \epsilon}{\partial t} + U_i \frac{\partial \epsilon}{\partial x_i} = \frac{\partial}{\partial x_i} \left( \frac{\mu}{\sigma_t} \frac{\partial \epsilon}{\partial x_i} \right) + C_1 \frac{\epsilon}{\kappa} g - C_2 \frac{\epsilon^2}{\kappa}$$

(4.27)

where

$\sigma_\epsilon$ is the 'Prandtl Number' for $\epsilon$ transport

$g$ is the generation of turbulence energy

$C_1$, $C_2$ and $\sigma_{\epsilon}$ are constants which were introduced when the exact form of the $\epsilon$ transport equation (79) is reduced to the gradient transport form given above. Constant $C_2$ is determined from experiments on the decay of behind grid turbulence while constant $C_1$ is determined from near wall boundary layer flows.

The following are the values suggested (82, 84) for the constants in the $\kappa - \epsilon$ model.

$$C_1 = 1.144 \quad \sigma_\kappa = 1.0$$

$$C_2 = 1.92 \quad \sigma_\epsilon = 1.3$$

The $\kappa - \epsilon$ model in the form described above has been applied successfully to many two dimensional wall boundary layers, duct flows, free shear flows and recirculating flows. A useful account of many interesting applications is given by Rodi (91) and by Launder and Spalding (84).
4.3.2 The Low Reynolds Number Model

This model due to Jones and Launder (72) is an extension of the $\kappa - \epsilon$ model which was developed primarily to handle near-wall boundary layer flows for computations inside the viscous sublayer. An explanation of the principal basis of this model may be found in reference (72).

4.4 Turbulence Modelling - The XI Model

The XI model is a 1-equation turbulence model which possesses the capability to produce results very similar to, often almost exactly the same as the $\kappa - \epsilon$ model of turbulence. The technique, in essence, is to eliminate the dissipation energy transport equation altogether and to calculate the local dissipation energy directly from the local kinetic energy at that grid point. This is achieved by utilising certain information about the behaviour of idealised, decaying, isotropic turbulence and extending this to the case of a forced stationary flow. (It is shown later that this is not as strong an assumption as it may seem.) In more physical terms, the technique results in defining a certain quantity (XI) associated with large scale (low wavenumber) eddies which is:
(1) assumed to remain constant over the whole flow field.
(2) determined by the characteristic dimension of the system and by the amount of stirring power supplied to stir the flow system.

In a sense, this implies that the large scale eddies (the so called 'permanant scales') are determined by the dimensions of the flow system to a greater extent than the energy containing scales are, (the latter association being made in the case of conventional 1-equation models.)

4.4.1 Theoretical basis for the model

In 1945, Lotsianskii\(^{(66)}\) proved that in decaying, isotropic turbulence, a certain functional, the 'Disturbance moment', (later called the 'Lotsianskii Invariant or Integral') should be a constant over the whole flow field and determined by the amount of disturbance supplied to the flow. The functional, defined as

\[
I_L = \frac{\kappa}{3\pi} \int_0^\infty f(\gamma) \, d\gamma
\]  

(4.28)

was later shown by Proudman and Reid\(^{(54)}\) and by Batchelor and Proudman\(^{(56)}\) to be not truly a constant but rather a slowly varying function over the flow domain. Comte-Bellot and
Corrsin(80) showed that, except under certain conditions of transient flow, the assumption of the constancy of 'I_L' was reasonable for grid turbulence and indeed produced good results for the decay of behind-grid turbulence.

Using the Lotsianskii integral as determining the low wavenumber end of the spectrum gives a relationship of the form

\[ E(k) = I_L k^4 \]  
(4.29)

for the spectral power density distribution in that region(77). The spectral shape at higher wavenumber range (in the inertial subrange) has been shown(77, 79) to be of the form

\[ E(k) \propto \epsilon^{2/3} k^{-5/3} \]  
(4.30)

with the two curves connected by a smooth curve, the Von-Karman patch(77) given by

\[ E(k) = E(k_e) \frac{17/6}{\left[1 + (k/k_e)^2\right]^{17/6}} \left(\frac{k}{k_e}\right)^4 \]  
(4.31)

Simple algebraic manipulations of these three expressions yields the location of the energy containing scale, \( k_e \), as

\[ k_e = \left(\frac{1}{I_L}\right)^{3/17} \epsilon^{2/17} \]  
(4.32)

\[ E(k_e) = 2^{17/6} I_L k_e^4 \]  
(4.33)
It has also been shown\(^{77,79}\) that integrating the spectral curve

\[ \chi = \int_0^\infty E(k) \, dk \]  

yields an expression of the form

\[ E(k_e) = \frac{0.2U'}{k_e} \land 0.133 \frac{\chi}{k_e} \]  

(4.35)

Substituting for \(E(k_e)\) from eqn.(4.33) gives

\[ \chi = \frac{2}{0.133} I_L \quad \varepsilon \]  

(4.36)

Substituting for \(k_e\) from eqn.(4.32) gives

\[ \chi \geq I_L \quad \varepsilon \]  

(4.37)

or

\[ \varepsilon \geq \frac{2}{3} \chi \]  

(4.38)

where

\[ \frac{2}{3} \leq \left( \frac{I_L}{\varepsilon} \right) \]  

(4.39)

Equation 4.38 has the capability to yield a point value for dissipation energy, provided that the value of \(\varepsilon\) is known. Notice here that the assumption of the Lotsianskii 'disturbance moment' \(I_L\) being a constant is not such a strong assumption since it appears as \(\chi\) which is \(I_L\) raised to the
power of $-0.118$ or, at worst, as $\xi^{1.7}$ which is $I_L$ raised to the power of $-0.200$.)

The characteristic length scale associated with the large scale ('permanent') eddies is given by Hinze\(77\) as

$$
\left( \frac{I_L}{\mu_t/\rho} \right)^{1/3} \sim L_p
$$

(4.40)

Now postulating that the largest eddy sizes are constrained by the vessel dimensions and so equating $L_p$ to the characteristic vessel dimension, $L_v$, yields an expression of the form

$$
\frac{I_L}{\nu^2} \sim L_v^3
$$

(4.41)

$$
I_L \sim \nu^2 L_v^3
$$

(4.42)

$$
\frac{\xi}{2} \sim \left( \frac{\nu^2}{L_v^3} \right)^{-0.118}
$$

(4.43)

The characteristic kinematic eddy viscosity can be determined once each iteration cycle by

$$
\eta_p = \nu_p \int \int \int [S_{ij}]^2 dV_0
$$

(4.44)

or

$$
\nu_p \sim \frac{\eta_p}{\int \int \int [S_{ij}]^2 dV_0}
$$

(4.45)

where $\eta$ is the efficiency of turbulence generation\(60-63\).

(Also refer to Section 4.6)
Notice that in the process of eliminating the transport equation for $\varepsilon$, the constants $C_1$, $C_2$ and $C_3$ have also been eliminated. Indeed, in this model, the only constant remaining is $C_d$ which is left equal to 0.09 as in the $\kappa-\varepsilon$ model (in addition to the Prandtl number for kinetic energy, $\sigma_k$ which is generally accepted to be approximately unity.

4.5 Boundary Conditions

Boundary conditions for the three different schemes are substantially the same. For the spectral model, however, no boundary conditions for dissipation energy ($\varepsilon$) are required since there is no differential equation for this variable.

4.5.1 Boundary conditions for magnetic field calculations

The mathematical statement of the boundary conditions used with the differential equations in the preceding sections is given below. A more detailed explanation of the considerations underlying these statements may be found in references (36) and (78).

(1) Upper Electrode Axial Surface

at $x=0$, $0 \leq r \leq R_e$

$$\frac{\partial H_\theta}{\partial x} = 0 \quad \{ f_r = 0 \}$$

(2) Free Surface of Melt
at \( x=0, \) \( R_e \leq r \leq R_m \)
\[
\frac{1}{2\pi r} \int x = \frac{1}{r} \frac{\partial}{\partial r} \left( r \frac{\partial H_\theta}{\partial r} \right) = 0 ^{3}
\]

(3) Bottom electrode Surface
at \( x=X(5), 0 \leq r \leq R_m \)
\[
\frac{\partial H_\theta}{\partial x} = 0 \quad \left\{ \begin{array}{c}
J_r = 0
\end{array} \right\}
\]

(4) Cylindrical wall of Vessel
at \( r=R_m, 0 \leq x \leq X(5) \)
\[
H_\theta = \frac{I}{2\pi r R_m}
\]

(5) Centerline of Vessel
at \( r=0, 0 \leq x \leq X(5) \)
\[
H_\theta = 0 \quad \text{or} \quad \frac{\partial}{\partial r} \left( \frac{H_\theta}{r} \right) = 0
\]

4.5.2 Boundary Conditions for Flow Equations

Boundary conditions are required for mean velocities and also for turbulence parameters. The conditions for the mean values should be stated in terms of the primary variables, Vorticity \((\omega)\) and Stream Function \((\psi)\). The conditions for turbulence parameters are given in terms of expressions for kinetic energy \((\kappa)\) and (except in the case of the spectral model) dissipation energy \((\epsilon)\). Only the final form of the
boundary conditions are given here. A more detailed explanation may be found in references (36,74-76)

1. Centerline of Vessel
   at \( r=0, \ X(1) \leq x \leq X(5) \)
   \[
   \gamma = \frac{\partial \alpha}{\partial r} = \frac{\partial E}{\partial r} = 0
   \]
   \[
   \left( \frac{\omega}{r} \right)_0 = \frac{8}{9} \left[ \frac{(\gamma_0 - \gamma_1)}{r_2^2} + \frac{\gamma_1 - \gamma_0}{r_1^2} \right] \bigg/ \left( r_2^2 - r_1^2 \right)
   \]
   Where suffixes 0,1,2 denote the points on the centerline axis and the adjacent grid nodes in the \( r \)-direction respectively.

2. Free Surface of Melt
   at \( x=X(1), \ R_e \leq r \leq R_m \)
   \[
   \gamma = \frac{\omega}{r} = \frac{\partial \alpha}{\partial x} = \frac{\partial E}{\partial x} = 0
   \]

3. Top Electrode Axial Surface
   at \( x=X(1), \ 0 \leq r \leq R_e \)
   \[
   \gamma = 0 \quad , \quad \alpha = E = 0
   \]
   \[
   \left( \frac{\omega}{r} \right)_0 = \frac{3(\gamma_0 - \gamma_1)}{r_2^2 (x_1 - x_0)^2} - \frac{1}{2} \left( \frac{\omega}{r} \right)_{r_1}
   \]
   Where suffixes 0 and 1 refer to a grid node on the boundary and to the adjacent node in the \( x \)-direction respectively.

4. Bottom Electrode Axial Surface
   at \( x=X(5), \ 0 \leq r \leq R_m \)
   \[
   \gamma = 0 \quad , \quad \alpha = E = 0
   \]
   \[
   \left( \frac{\omega}{r} \right)_0 = \frac{3(\gamma_0 - \gamma_1)}{r_1^2 (x_1 - x_0)^2} - \frac{1}{2} \left( \frac{\omega}{r} \right)_{r_1}
   \]
The suffixes have the same meaning as in B.C. 4 above

\[(5) \quad \text{Cylindrical Wall}\]

at \(r=R_m, \ x(1) \leq x \leq x(5)\)

\[\eta = \xi = 0\]

\[\left( \frac{\omega}{r} \right)_0 = \frac{3}{p} \frac{\eta_0 - \eta_1}{(r_1 - r_0)^2 r_0 r_1} - \frac{1}{2} \left( \frac{\omega}{r} \right)_1\]

Where suffixes 0 and 1 refer to a grid point on the boundary and to the adjacent node in the \(r\)-direction respectively.

4.6 Numerical Solution Scheme

The derivation of the finite difference discretization equations and the treatment of wall and neighbor nodes follows the techniques laid down in references (74) and (36) and will not be discussed here. The program itself is based, in part, on the work of Dr. M. K. Choudhary\(^{(36)}\).

Treatment of boundary conditions for the turbulent parameters needs special care. As detailed by Pun and Spalding\(^{(82)}\), a pseudo boundary condition is set up for the wall neighbor nodes. A source term for the kinetic energy equation is specified as:

\[S_K = \tau_w \frac{\partial u}{\partial \eta} - C_d \frac{p \kappa^2}{\tau_w} \frac{\partial u}{\partial \eta} \quad (4.46)\]
at the neighbor node while the dissipation energy is calculated from:
\[
\varepsilon = C_d \frac{2/4}{3/2} \frac{n}{(0.41 \delta)}
\]  
(4.47)

The three models all share a large part of the program, hence it was found convenient to build the entire system as a single program set ('EMFLOW') and allow choice of the required options by reading a controlling data file. The computational steps followed under the influence of different control options is shown in Fig. 4.2. The algorithmic path taken within the program can be seen to be arranged in a cascade or 'waterfall' fashion allowing the user to exit computations at any of the levels. A flow chart of the steps followed by the program when Routing I (the Spectral model) is chosen (by setting NFIELD, NFLOW, NTURB, NSCHEM = 1 and LREYN, NCHECK = 0) is shown in Fig. 4.3. A similar flow chart for the steps entailed in choosing Routing II (the $\kappa - \epsilon$ model) is shown in Fig. 4.4. It may be noted here that the XI model has only one partial differential equation to solve while the $\kappa - \epsilon$ model has two. The extra step in the XI model of computing $\ell$ needs only the solution of an algebraic equation and that too only in an integral sense for the entire control volume.
A complete source code listing of all these routines is also provided for reference in Appendix F.

Provision is made for the program to auto-check whether the flow will indeed be turbulent or laminar by evaluating a Performance Index of Stirring (PI). This is believed to be a far more reliable estimate of the degree of turbulence than afforded by a simple estimation of overall Reynolds Number. The basis for the calculation of PI is described in Section 4.7.

4.7 Some Useful Integral System Parameters

The objective of this section is to extend concepts of turbulence theory to compute some overall system parameters which may be beneficial in attempting to answer practical questions such as;

(1) Is the flow going to be laminar or turbulent? What is the degree of turbulence?
(2) How long is it likely to take for an added contaminant to become homogeneously distributed in the melt?

4.7.1 A Performance Index for Stirring
To sustain turbulence in a flow system, it is necessary to have a steady flow of energy through the turbulent energy cascade. In an overall sense, (integrating over the contents of the whole vessel) the total rate of generation of turbulence should equal the total rate of dissipation of turbulence.

\[ G = \Phi \]  

(4.48)

It is, however, not necessary for the entire stirring power supplied to the system by the external agency (Electromagnetic force field, Gas injection or other as the case may be) to appear as turbulence\(^{(54,67-70)}\). Corrsin\(^{(67,68)}\) based on Laufer's\(^{(54)}\) measurements and later Brodkey\(^{(69,70,89)}\) have postulated the existence of a factor of efficiency \(\gamma\) governing the generation of turbulence. Thus it may be said that:

\[ \gamma P = G = \Phi \]  

(4.49)

The local generation term \(g_{ij}\) can be expressed as:

\[ g_{ij}(r,x) = 2\mu_t \left[ \left( \frac{\partial U_x}{\partial x} \right)^2 + \left( \frac{\partial U_y}{\partial y} \right)^2 + \left( \frac{U_r}{r} \right)^2 + \frac{1}{2} \left( \frac{\partial U_x}{\partial x} + \frac{\partial U_y}{\partial y} \right)^2 \right] \]  

(4.50)

evaluated at location \((r,x)\).

Integrating this over the whole volume gives:

\[ G = \iiint_{\text{Vol}} g_{ij}(r,x) \ dV \text{ol} \]  

(4.51)
Taking a characteristic value for $\mu_t$ as a constant over the whole flow field, the expression for the total generation, $G$ may be written as:

$$G = 2\mu_t \int \int \left[ \frac{\partial u_x^2}{\partial x} + \frac{\partial u_y^2}{\partial y} + \frac{1}{2} \left( \frac{\partial u_x}{\partial x} + \frac{\partial u_x}{\partial y} \right)^2 \right] dV_0$$

$$P.I. = \frac{M_t}{\mu} = \frac{\gamma \rho}{\nu} \left[ \int \int \left[ \frac{\partial u_x^2}{\partial x} + \frac{\partial u_y^2}{\partial y} + \frac{1}{2} \left( \frac{\partial u_x}{\partial x} + \frac{\partial u_x}{\partial y} \right)^2 \right] dV_0 \right]$$

### 4.7.2 Mixing Time Analysis

Following the analysis adopted by Corrsin\(^{(6)}\), it may be shown that the time constant of mixing can be given by:

$$\tau = \frac{\rho^2}{12 \rho_c} \approx \frac{\lambda^2}{6 \nu}$$

Using Taylor, the dissipation rate $\phi$ may be expressed by

$$\phi \approx \frac{10}{3} \nu \frac{\bar{u}^2}{\lambda^2} = \gamma \frac{P}{M}$$

using values averaged over the whole melt of mass $M$ Kg.

In isotropic turbulence at large Reynolds Numbers, Von Karman and Howarth deduced an approximate relation between dissipative scale $\lambda$ and integral scale $L$

$$\frac{\lambda}{L} \sim \frac{1}{R_\lambda}$$

Using the constancy factor proposed by Corrsin we may rewrite the above relation as
\[
\frac{A}{L} = \frac{A}{R_\lambda} 
\]

(4.56)

\[
R_\lambda = \frac{u'^2}{\nu} = \frac{q/\sqrt{3}}{\nu} 
\]

(4.57)

\[
q = \sqrt{\frac{3}{\lambda^2}} A L \nu 
\]

(4.58)

Substituting this in eqn.(4.53) gives:

\[
\bar{\zeta} \approx \left\{ \frac{A^2}{21.6\eta} \frac{M L^2}{P} \right\}^{\frac{1}{3}} 
\]

(4.59)

Where \( A \approx 20 \) (approx.) as measured from behind grid turbulence measurements. Expanding eqn.(4.59) gives

\[
\bar{\zeta} \approx \left( \frac{A^2}{21.6\eta} \right)^{\frac{1}{3}} \left( L^2 \frac{M}{P} \right)^{0.333} 
\]

(4.60)

Defining 'mixing time' \( (t_m) \) as the time required for concentration fluctuations to be within 5% variation from the mean, gives

\[
t_m \approx 3 \tau \]

So

\[
t_m \approx 3 \left( \frac{A^2}{21.6\eta} \right)^{\frac{1}{3}} \left( L^2 \frac{M}{P} \right)^{0.333} 
\]

(4.62)

If the same equation were written using power in Watts/Ton of melt \( (P_t) \), the expression for \( t_m \) would read:

\[
t_m \approx \frac{80}{\sigma^{\frac{1}{3}}} \left( L^2 / P_t \right)^{0.333} 
\]

(4.63)
Sano and Mori\(^{58}\) have found that measurements of \(t_{\text{min}}\) in various configurations and sizes of gas injected systems can be well correlated by an expression of the form:

\[
\frac{t_{\text{m}}}{t} = 100 \left\{ \frac{D^2}{H} \right\}^{0.337} / P_t
\]  

(4.64)

Fig. 5.33 taken from Sano and Mori\(^{58}\) shows this correlation, together with the experimental results of various researchers working with gas injected systems. 'A' represents the correlation stated above. Lines B1 and B2 represent the experimental results of Haida et al.\(^{57}\) for a water model without and with slag respectively. Lines C1 and C2 represent the experimental results of Hsiao et al.\(^{56}\) for 60 ton and 6 ton gas injected ladles while line D represents the results of Lehrer\(^{55}\) for a water model of a gas sparged system.

( Note here that the analysis of Sano and Mori is not being used but rather the fact that measurements quoted therein can be correlated by the expression above. The original analysis of Sano and Mori considered the time of mixing as determined by the circulation time for the mean flow in the vessel. However, as Nakanishi et al.\(^{59}\) have pointed out, mixing time in metallurgical melts appears to be dominated by diffusion (and eddy diffusion) rather than by bulk circulation time in the melt. This appears to be reasonable considering the high
Schmidt Numbers encountered in metallurgical flow systems. It should also be pointed out at this stage that the turbulence analysis followed in this work is quite general in nature and is not restricted in any way to gas injected systems. The value of turbulence efficiency would, of course, be expected to be different in different classes of systems.

In keeping with the rather gross approximations made in this analysis, it may be written that:

\[ L = D = H = L_v \]

in which case eqn.(4.63) becomes

\[ t_m \geq \frac{80}{\eta^{\frac{1}{3}}} \left\{ \frac{L_v^2}{P_t} \right\}^{0.333} \]

(4.66)

and eqn.(4.64) becomes:

\[ t_m \geq 100 \left\{ \frac{L_v^2}{P_t} \right\}^{0.337} \]

(4.67)

Equating the two gives:

\[ \eta = (0.80)^3 = 0.51 \]

(4.68)

Somewhat surprisingly, this value of \( \eta \) for turbulence generation in gas injected ladles is found to match exactly with the value of 0.50 found by Laufer for pipe flow
turbulence generation and suggested by Corrsin as a first guess value for $\eta$.

This value of efficiency has been calculated for the case of gas injected ladle metallurgical systems. It is expected that the efficiency of turbulence generation would be different for different classes of systems. However in the absence of data of this sort for different systems of metallurgical interest, it is recommended that $\eta = 0.50$ be used as a first guess until a better estimate is forthcoming.

Nakanishi et. al. (59) have noted in their work that the data they reviewed (see Fig.5.32) does not appear to demonstrate any dependance on the linear size of the particular equipment that was studied. Indeed at first glance this would appear to be true from Fig.5.32. However a closer look at the derived dependance of mixing time on linear size (Eq.4.66) indicated a relationship of the form

$$ t_m \propto L_v^{2/3} \quad (4.69) $$

Now, in the data surveyed by Nakanishi et. al. the largest vessel is a 200 ton unit while the smallest is a 65 kg water model. This implies that the ratio:

$$ \frac{\text{max. vol. of vessel}}{\text{min. vol. of vessel}} $$
is in the region of 340. Very roughly, this would indicate a ratio of characteristic linear dimensions to be around \((340)^{1/3} = 7\).

Now in eq. (4.69), \(L_v\), the characteristic vessel dimension appears to the power of 0.66. This would mean that introducing into Fig. 5.32 a linear scale dependency as indicated by eqs. 4.66 and 4.67 would imply a change in Y-axis location of the data points by a factor of \((7)^{2/3} = 3.6\) or, on the Log scale used in Fig. 5.32, a maximum difference of 0.5 units. This change is clearly of the same magnitude as the half decade variability of the data points themselves. It may therefore be inferred that an expression for mixing time such as the one given by eq. 4.66 does not necessarily contradict the findings of Nakanishi et. al. Indeed, the additional parameters of efficiency and linear vessel size may prove to be one of the reasons contributing to the spread in data points.
Fig. 4.1 Schematic of Flow System to be Modelled
Fig. 4.2 Schematic of 3-D Turbulence Energy Spectrum

\[ E(k) \propto \frac{(k/k_e)^4}{[1 + (k/k_e)^2]^{17/6}} \]
Fig. 4.3 Option Control in Computer Program

NULL → M.FIELD → LAMINAR

K-EPSON MODEL

LOW-\textit{Re}_e MODEL

XMODEL

KEY

LREYN

NSCHEM

NTURB

NFIELD

NLOW

NFIELD
Fig. 4.4 Flow Chart of Calculations using XI Model (1 eqn. model)
GUESS VECTORS FOR $\omega$, $\psi$, $\chi$, $\varepsilon$

1. UPDATE $\omega$ FIELD

2. UPDATE $\psi$ FIELD

UPDATE VELOCITY FIELD

UPDATE EDDY VISCOSITY FIELD

3. UPDATE $K$ ENERGY FIELD

4. UPDATE $\varepsilon$ FIELD

CONVERGED?

NO → YES → EXIT

Fig. 4.5 Flow Chart of Calculations using $k$-$\varepsilon$ Model (2-eqn. model)
5 RESULTS AND DISCUSSION

In this chapter, results of experimental measurements and numerical computation will be compared and discussed. In addition the behaviour of the calculated values for certain practically relevant parameters like Performance Index (P.I. for short) and Mixing Time ($t_m$) and finally the results of analyses pertaining to the use of thermal anemometry in liquid metal and also in the presence of magnetic fields will be presented. Throughout this chapter, Models I, II and III refer to the $k-\varepsilon$ model, the Low Reynolds Number model and the XI model respectively.

5.1 Main Flow System - Measurements and Computations

Fig. 5.1 shows computed current density ($J$) vector plot. Two facts stand out here: (1) Most of the current passes through in a region relatively close to the smaller electrode. This means that insulation of the wall of the vessel should not play too important a role as the leakage wall current may, quite reasonably, be expected to be small. (2) The current divergence is the strongest in the immediate neighborhood of the small electrode. Hence this region is crucial in driving the overall flow.

Fig. 5.2 shows a computed velocity vector plot. The formation of one circulation loop is clearly seen. The arrows denote the velocity vector at the center of the arrow. The broken arrows, however, indicate only the local flow direction, the magnitude being greater than the maximum for
the plot (3.0 cm/sec). Fig. 5.3 through 5.9 show the distribution of the local velocity across the radius at various depths. The absolute magnitude velocity was chosen as a basis for presentation since the hot film probe in the experiment actually measured the absolute resultant velocity. The good agreement of the experimentally measured velocities with the computed values is evident. Also to be noticed is the fact that all three models (I- $\kappa - \epsilon$, II- Low Reynolds Number version of $\kappa - \epsilon$, and III- XI model) predict exactly the same distribution except at the centerline. This extremely close correspondence between the calculations is partly because the flow is largely convection driven and partly because the turbulent viscosity predictions also match very closely (see Fig. 5.24). Fig. 5.8 clearly shows up the location of the eye of the vortex at about 5 cms radius. Notice also that the dip in the velocity near the vortical region is also reflected in the experimental measurements.

Fig. 5.35 shows a typical experimentally measured spectrum of turbulence with the various pertinent operating conditions and directly computed parameters noted on it.

Scalar valued overall Dissipation Energy is plotted along the radial direction at different depths in Fig. 5.10 through 5.16. Once again two facts are to be noticed here: (1) The XI model, even though it is a one equation model (see description in chapter 4) and therefore not containing
any of the constants involved in the $\epsilon$ transport equation, comes remarkably close to the predictions using the $\kappa - \epsilon$ model of turbulence. The Jones and Launder Low Reynolds Number model, however, also predicts approximately the same as the other two models being only marginally different from the $\kappa - \epsilon$ model. (2) All three models seem to predict the experimentally observed values of dissipation energy reasonably well in general. The agreement gets progressively worse as one approaches the depth at which the vortical point is located and gets better the farther away one is from the vortex.

Figures 5.17 through 5.23 show the variation of local RMS turbulence velocity in the form of radial scans at various depths from the melt surface. Once again the new XI model predicts values of the RMS fluctuations very close to those predicted by the $\kappa - \epsilon$ model. Comparison with experimentally measured values is however less encouraging. In general the numerical calculations overpredict the values of the fluctuating velocity. This may seem somewhat surprising, in view of the fact values of dissipation energy were really quite well represented by the computations. One possible reason for this apparently paradoxical behaviour may be related to the fact that the major contribution to the total dissipation energy comes from a range of frequencies towards the higher frequency end of the spectrum while the major
contribution to the value of \( \kappa \) comes from frequencies in the lower ranges, particularly in the vicinity of the spectral density peak. Now the spectrum analysis equipment used in this experimentation (as in most cases) uses an AC coupled mode with a lower frequency cut off at 0.1 Hz (which is used by the system to distinguish the fluctuating from the mean component). This low frequency truncation would result in lower values for experimentally measured \( \kappa \) but would not affect the value for \( \epsilon \). Also, the higher wavenumber region of the spectrum has been shown to be closer to isotropy than the low wavenumber regions. Since the dissipation energy is a high wavenumber phenomenon it is less likely to be affected by the assumption of isotropy than the kinetic energy and RMS fluctuation, which have a major contribution from the low wavenumber range of the spectrum. It would, however, seem hard to attribute the discrepancy entirely to these effects and it is likely that there is a combination of factors at play here.

Fig. 5.24 is a representative plot of the variation of effective viscosity across the radius. As may be expected, the three models predict almost the same values of turbulence enhanced viscosity, though the XI model shows a peak at the centerline while the \( \kappa - \epsilon \) model shows a peak somewhat away from the centerline. The wall neighbor node has exactly the same value with all three models since it is controlled
largely by the 'Wall Function' calculation scheme which is common to all three models.

The concept of the efficiency of turbulence generation plays a central role in the formulation of the XI model. On the basis of the considerations discussed in Chapter 4, a value of $\gamma = 0.5$ was used in all the preceding calculations. Fig. 5.25 and Fig. 5.26 show the effect of varying the value of $\gamma$ on the $\epsilon$ and RMS fluctuating velocity profiles across the radius of the melt. Decreasing the value of $\gamma$ lowers the calculated value of both the Kinetic and Dissipation energies all over the field, or in general, decreases the degree of turbulence in the melt.

Figures 5.27, 5.28 and 5.29 show contour plots for Kinetic Energy, Dissipation Energy and Effective Viscosity from calculations using the XI model. These plots present the same information as in the radial plots in a more compact fashion and are included here mostly to provide a 'bird's eye view' of the system.

5.2 Performance Index Computations

Fig. 5.30 shows sample voltage outputs from the anemometer when different currents are passed through the melt. The 100 Amp. trace could be said to be laminar or at least substantially so. The 250 Amp. trace shows up what is probably the onset of turbulence and is what may be
characterised as 'weakly turbulent'. The 500 Amp. setting appears definitely turbulent. The transition from laminar to turbulent flow occurs somewhere between 100 A and 250 A possibly close to the 250 A end. Even a qualitative understanding of the onset of turbulence can be important because, as will be discussed later in this chapter, the rate of turbulence dissipation can be an important parameter in determining mixing, homogenisation and even reaction rates in the melt. Use of vessel Reynolds Number to predict the onset of turbulence may be misleading. For example, Reynolds Numbers based on the depth of melt and centerline velocity for the 100, 250 and 500 A cases are:

\[ R_{100} = 2090 \quad R_{250} = 5570 \quad R_{500} = 11,146 \]

It would be difficult, if not impossible, to judge the onset of turbulence without apriori knowledge of the dynamics of the specific flow configuration (an example would be the transition point for pipe flow which is placed around \( 2300 = Re_b \).) This would be particularly difficult for the more complex case of a recirculating flow system.

The whole concept of Performance Index (P.I.) fits in here. The value of PI is an immediate intuitive estimate of the 'degree of turbulence' in the whole flow field and reflects the ratio of Turbulent viscosity to Molecular Viscosity in an integral sense. Hence a value of PI=0 would indicate an ideally laminar flow situation. Intuitively, it
may be said that any flow with a value of PI greater than 10 can be considered turbulent. The values of PI for the three current settings are:

\[ \text{PI}_{100} = 5.5 \quad \text{PI}_{250} = 12.2 \quad \text{PI}_{500} = 23 \]

Looking at these figures one can place the transition to turbulence as somewhere between 100 A and 250 A, possibly closer to 250 A. This is similar to what may be deduced by examining the traces in Fig. 5.30.

Fig. 5.31 shows a plot of the variation of PI with current. Such a plot could prove useful in predicting the degree of turbulence in a melt as the operating parameter (current) is changed.

5.3 Mixing Time Computations

Fig. 5.32 is the plot due to Nakanishi and Szekely \(^{(59)}\), relating mixing time to specific power supplied to the melt (Total power/ mass of the melt) for various metallurgical systems and is excerpted from Reference (60). This represents the first attempt to relate metallurgical system mixer performance to turbulence parameters and is placed here in context of what is to follow. Fig. 5.32 is taken from Sano and Mori\(^{(58)}\). Using a value of turbulence efficiency \(\tau\) as 0.5 and using eq.4.63 to calculate mixing time, values of \(t_m\) calculated for the experimental setup of this work (with currents = 100, 250, 500 and 2500 Amperes) have also been
indicated on the figure with stars. Line A represents the correlation stated in equation 4.64. Lines B1 and B2 represent the experimental results of Haida et. al.\textsuperscript{(57)} for a water model without and with slag respectively. Lines C1 and C2 represent the experimental results of Hsiao et. al.\textsuperscript{(56)} for 60 ton and 6 ton gas injected ladles while line D represents the results of Lehrer\textsuperscript{(55)} for a water model of a gas sparged system.

Fig. 5.34 shows the variation of overall mixing time for the current stirred melt used in this work, computed using the XI model with $\gamma = 0.5$. Thus the melt could be expected to be 95% mixed in 24 seconds with a 500 Ampere current while it would take 120 seconds with a 100 A current and 4.8 seconds with a 2500 A current. Such a plot could be used in industrial practice to determine how long a blow or current stirring should be applied in order to get good mixing in the melt.

5.4 M.H.D. Flow around a cylinder

Figs. 5.36 through 5.41 relate to the behaviour of a heated cylinder subjected to a cross flow of metal and a magnetic field on the orthogonal axes. Fig. 5.36 shows the schematic of the flow situation. Figs. 5.37 and 5.38 are presented to serve as a check on the computational technique used in this work. Fig. 5.37 shows a comparison of calculated
value of Drag Coefficient at zero magnetic field with corresponding values found by other workers. Fig. 5.38 compares the calculated values of Nusselt Number with the measurements of Ishiguro et. al.\(^{95}\) and the older computations of Grosh and Cess\(^{96}\). The good agreement in both figures is evident.

Fig. 5.39 shows the computed variation of overall Nusselt Number with Magnetic Interaction (N). It is clear that even substantial levels of magnetic interaction would affect the heat transfer rate only marginally.

Fig. 5.40 shows, in a similar fashion, the corresponding variation of overall Sherwood Number for mass transfer from the cylinder. This shows a considerably stronger dependance on the magnetic interaction, the strongest dependency being demonstrated by the drag coefficient on magnetic interaction (Fig. 5.41). This last result would indicate the need for caution when interpreting results obtained by using drag probes to measure flow fields in the presence of magnetic fields. Also shown in this last figure are the results of Kalis et. al.\(^ {87}\). The discrepancy between the two has been shown to be probably due to the use of a rather coarse computational grid near the cylinder wall.

5.5 Calibration Drift Correction
Figs. 5.42 and 5.43 relate to typical results obtained from the calibration drift correction routine described in Chapter 4. Fig. 5.42 shows a typical calibration drift if plotted using as-measured values of voltage increment against flow velocity. Fig. 5.43 shows the same basic data but after the voltages have been adjusted to correct for drift. The improved reproducibility of the corrected calibration is evident.

5.6 Summary

To summarise, it may be said that the $k-\epsilon$ model as well as the XI model predict mean flow quite well and turbulence dissipation rates only reasonably well but RMS fluctuating velocities are not as well predicted. The MHD flow analysis, though restricted to orthogonal fields, indicates negligible effects of magnetic fields on anemometer behaviour in fields of the range found in this work. The PI criterion has been shown to predict the onset of turbulence reasonably well, though somewhat constrained in its use by the need to specify a value for $\eta$. The calibration drift correction scheme has been shown to improve the reproducibility of calibration curves considerably. The theory proposed for turbulent mixing in metallurgical melts appears to correlate experimental and plant scale data reasonably well.
Fig. 5.1
Computed Current Density Vector Plot

CURRENT DENSITY FIELD

99 KA/M²
Fig. 5.2
Computed Velocity Vector Plot

VELOCITY FIELD

R

Z

D

3 CM/S

4.00

7.50
Fig. 5.3  Magnitude of Velocity, Radial Scan - Depth = 0.7 cms
Fig. 5.4  Magnitude of Velocity, Radial Scan - Depth = 1.05

CMs
Fig. 5.5 Magnitude of Velocity, Radial Scan - Depth = 1.44 cms
Fig. 5.6  Magnitude of Velocity, Radial Scan - Depth = 1.79 cms
Fig. 5.7  Magnitude of Velocity, Radial Scan - Depth = 2.14 cms
Fig. 5.8  Magnitude of velocity, Radial Scan - Depth = 2.5 cms
Fig. 5.9 Magnitude of velocity, Radial Scan - Depth = 2.85 cms
Fig. 5.10 Turbulence Dissipation Energy (W/Kg.s) Depth = 0.70 cms
**EXPERIMENTS**  
○ MODEL I  
△ MODEL II  
★ MODEL III

Fig. 5.11  Turbulence Dissipation Energy (W/Kg.s) Depth = 1.05 cms
Fig. 5.12 Turbulence Dissipation Energy (W/Kg.s) Depth = 1.44 cms
**Fig. 5.13** Turbulence Dissipation Energy (W/Kg.s) Depth = 1.79 cms
Fig. 5.14 Turbulence Dissipation Energy (W/Kg.s) Depth = 2.14 cms
Fig. 5.15 Turbulence Dissipation Energy (W/Kg.s) Depth = 2.50 cms
Fig. 5.16 Turbulence Dissipation Energy (W/Kg.s) Depth = 2.85 cms
Fig. 5.17  R.M.S. Turbulent Velocity (M/sec) Depth = 0.70 cms
EXPERIMENTS

MODEL I

MODEL II

MODEL III

Fig. 5.18 R.M.S. Turbulent Velocity (M/sec) Depth = 1.05 cms
Fig. 5.19 R.M.S. Turbulent Velocity (M/sec) Depth = 1.44 cms
Fig. 5.20  R.M.S. Turbulent Velocity (M/sec) Depth = 1.79 cms
Fig. 5.21  R.M.S. Turbulent Velocity (M/sec) Depth = 2.14 cms
Fig. 5.22 R.M.S. Turbulent Velocity (M/sec) Depth = 2.50 cms
Fig. 5.23 R.M.S. Turbulent Velocity (M/sec) Depth = 2.85 cms
Fig. 5.24 Effective Viscosity (Kg/m-sec) Depth = 1.44 cms
Fig. 5.25  Effect of Varying $\eta$ on D.Energy Profile, Depth = 1.44 cms
Fig. 5.26 Effect of Varying $\nu$ on Fluc. Velocity, Depth = 1.44 cms
FIG. 5.27 Contour Plot of Fluctuation Velocity Distribution in Melt
Fig. 5.28 Contour Plot of Dissipation Energy Distribution in Melt
Fig. 5.29
Contour Plot of Effective Viscosity Distribution in Melt

EFFECTIVE VISCOSITY*1E3
Fig. 5.30 Typical Anemometer Voltage outputs with computed values of $P_i$.
Fig. 5.31 Variation of Computed value of PI with current passed through melt.
Fig. 5.32 Variation of Mixing Time with Stirring Power density in the melt (Ref. 59)
Fig. 5.33 Variation of Mixing Time with \((P/D^2/H)\) in the melt (Ref. 58)
Fig. 5.34 Computed Variation of Mixing Time with Current passed through melt
Kinetic Energy = 5.36E-5 Watt/m²
Dissipation Energy = 1.8E-4 Watt/m²
Mean velocity = 2.5 cm/s
R = 1.53 cm z = 2.46 cm
Current = 500 A
MAGNETIC FIELD

CYLINDER HEATED FROM WITHIN WALL TEMPERATURE

$B_0$

$T_{\text{bulk}}$

$T_w$

$U_0$

Flow Of Conducting Liquid
Comparison of calculated Drag Coefficients at Red = 40

<table>
<thead>
<tr>
<th>Source</th>
<th>$C_D$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kawaguti</td>
<td>1.618</td>
</tr>
<tr>
<td>Apelt</td>
<td>1.469</td>
</tr>
<tr>
<td>Kalis, Tsinober et al.</td>
<td>1.645</td>
</tr>
<tr>
<td>This study</td>
<td>1.616</td>
</tr>
</tbody>
</table>

Fig. 5.37  Comparison of Drag Computed Drag Coefficient at Mag.Field = 0
Fig. 5.38 Comparison of Averaged Nusselt Number with experiments
Variation Of Averaged Nusselt Number With Magnetic Interaction

\[ RE_{d} = 65.6 \]
\[ Pr = 0.023 \]

Fig. 5.39 Computed Variation of Averaged Nusselt Number with Magnetic Interaction Parameter
Fig. 5.40 Computed Variation of Averaged Sherwood Number with Magnetic Interaction Parameter

Variation Of Averaged Sherwood Number With Magnetic Interaction

$R_e_d = 65.6$

$Sc = 100$
Overall Drag Coefficient As Function Of Magnetic Interaction

- This Study
- Kalis, Tsinober et al.
- Coarse Grid Simulations

Fig. 5.41 Computed Variation of Drag Coefficient with Magnetic Interaction Parameter
Fig. 5.42 Example of Calibration Curve for Hot Film Anemometer - before correction analyses.
Fig. 5.43 Example of same calibration curve - after correction analysis.

CORRECTED CALIBRATION

(2) - JUNE/7/83

(5) - JUNE/27/83
6. CONCLUSIONS AND RECOMMENDATIONS

In this chapter some concluding remarks on the principal contributions and findings of this work are presented. Suggestions for further work along the lines of this investigation are also made.

6.1 Conclusions

Enumerated here are some of the contributions made by this work to the study of recirculating liquid metal flows in materials processing operations.

1) An experimental technique has been developed to make detailed measurements of flow and turbulence characteristics in a heated melt of liquid metal. The technique features modified probes for use in high temperature (upto 150°C) liquid metal melts, automatic calibration drift correction and a completely microcomputer controlled data acquisition and processing environment.

2) A mathematical model has been developed to represent the flow in the melt starting with calculation of the electromagnetic force field driving the flow and using the conventional $\kappa - \epsilon$ model to represent the turbulence.
3) An alternative turbulence model has been proposed. This model, called the XI model, has been entirely developed as part of this work and has the following features:

(a) It is a computationally simple model that uses 1 transport equation to represent the turbulence as opposed to 2 transport equations for the $\kappa - \epsilon$ model.

(b) It eliminates the need for most of the semi-empirical constants used by the $\kappa - \epsilon$ model.

(c) It is intuitively appealing as it uses simple concepts like specific power input to the system and characteristic vessel size as important parameters to characterise the state of turbulence.

4) Comparison of predictions using the conventional models as well as the new XI model show that:

(a) The XI model calculation of mean flow as well as turbulence parameters is very close to those predicted by the $\kappa - \epsilon$ model.

(b) Use of the Low Reynolds Number model does not result in any substantially different predictions.

(c) All three models predict the mean velocity and dissipation energy measured in the melt reasonably well. Turbulence intensity is, however, less well represented by all three models.
5) A parameter, called the 'Performance Index', (PI for short), is proposed. It is shown that this parameter can be used as a criterion for predicting the onset of turbulence in the recirculating flow in a melt more reliably than afforded by the use of a simple Reynolds Number evaluation.

6) Consideration of a 'Turbulence Efficiency' factor (η) is proposed as an important criterion in determining the performance of a metallurgical agitation system. A calculation, made to evaluate this efficiency factor for gas stirred melts, shows η = 0.5 in such systems. It is expected that this value of η will be different in different classes of systems.

7) A theory is proposed for explaining the variation of mixing times in metallurgical system reactors with different levels of power input and vessel size. The predicted variation using this theory is shown to match very well with the experimentally observed relationship. The fundamental basis of this theory, it is felt, permits its use in a wide variety of metallurgical systems to evaluate mixing or reaction times.

6.2 Suggestions for further work
This section presents some thoughts on how certain aspects of the work presented in this thesis may be extended to further enhance our knowledge of mixing in metallurgical systems.

1) It is felt that pulsating the applied current passing through the melt with a variable frequency presents possibilities for an interesting investigation into the turbulence, and thence, mixer performance of metallurgical reactors. If the frequency of pulsation is adjusted to be inside the spectral range of turbulence frequencies, alteration of the spectral shape and consequently, of the turbulence parameters, may result. Also, an oscillating force field may be expected to result in a (possibly) enhanced turbulence efficiency factor, $\eta$. This would have a direct effect on the turbulence levels and mixing times for the system. This line of investigation is presently being pursued as continuing graduate research work.

2) The XI model may be used for other turbulent recirculating flow problems and the results compared with similar computations using the $\kappa-\epsilon$ model and experimental results, if available.
3) Values for turbulence efficiency need to be evaluated for different classes of metallurgical systems like the applied current configuration (e.g., Electro Slag Refining) or the inductively stirred system (e.g., Induction Furnace). This could be conveniently done using the same technique that was used for gas injected systems in this work, i.e., by utilising information about the overall mixing time for the system.
APPENDIX A

Thermal Anemometry Theory

The detecting element of a thermal anemometer consists of a very fine short metal wire (or film) which is heated by an electric current. The sensor is cooled by the flowing liquid, causing the heat transfer rate from the wire/film to increase. Typical sensors, of the hot wire and hot film type, are shown below:

Fig. A.1

Fig. A.2
A very important part of the hot wire/film anemometer is the control circuit. There are two basic types of measurement schemes possible:

(1) The Constant Current Anemometer and
(2) The Constant Temperature Anemometer.

The constant current type of anemometer operates by taking the voltage signal caused by wire resistance changes and compensates for frequency lag with a non-linear amplifier. The constant temperature control scheme, while certainly not a recent innovation, has gained rapidly in acceptance during the last few years. It operates by utilising feedback controlled bridge circuit to maintain the sensor at constant temperature. The figure below depicts a constant temperature system.

As the velocity past the sensor increases the sensor will tend to cool with a resulting decrease in the resistance. This
resistance decrease will cause the voltage to decrease changing the input to the amplifier. The phase of the amplifier is such that this decrease in voltage will cause an increase in the output of the amplifier to increase the current through the sensor. If the amplifier has a sufficient gain, it will tend to keep its inputs very close to the balanced condition. Therefore any change in the sensor resistance will be immediately corrected by an increase or decrease in the current through the sensor. The output of the constant temperature system is the voltage output of the amplifier which in turn is the voltage required to drive the necessary current through the sensor. Since with feedback control the resistances in the bridge are constant, the voltage across the bridge is directly proportional to the current through the sensor and power is equal to current squared times the probe resistance. Therefore, the square of the voltage measured on top of the bridge is directly proportional to the instantaneous heat transfer between the sensor and environment.
APPENDIX B

Calculation of $x$ and $e$ from the Spectrum

A typical frequency domain spectrum is shown in Fig. 5.35 and represents a plot of $E(n)$ versus $n$, where $n$ is the frequency in Hertz. From this spectrum, the values of the Kinetic Energy of Turbulence, $x$, and the Dissipation Rate of Turbulence, $e$, are calculated using the following relationships:

$$x = \frac{3}{2} \left( GD \times GF \right)^2 \times \int_{0}^{\infty} E(n) \, dn$$

and

$$e = \frac{60 \pi^2 \nu}{U^2} \left( GD \times GF \right)^2 \times \int_{0}^{\infty} \frac{E(n)}{n^2} \, dn$$

where GD is the gradient of the calibration curve at the operating point specified by the mean velocity in M/sec/Volt and GF is the gain factor set on the analog data recorder input amplifiers. The other symbols have their usual meanings.
APPENDIX C

Properties of Wood's Alloy

COMPOSITION:

Bismuth 4 parts
Lead 2 part
Cadmium 1 part
Tin 1 part

PHYSICAL(87) :

Freezing Range 69 - 72 °C
Density 8.4x10³ Kg/m³
Electrical Conductivity 0.99x10⁶ mho/m
Molecular Viscosity 2.29x10⁻³ N/s/m²
Appendix D

Equipment Specifications:

Microcomputer and Peripherals:
* Apple II Plus, 48 K RAM, MOSTEK 6502 Processor, 2 disk drives, BASIC and ASSEMBLER support
* AI13 12 Bit A/D Converter, 16 Channel, 20 μs conversion time, (Interactive Structures, Bala Cynwyd, Pennsylvania)
* PL12 Flat Bed Plotter, 7" x 10" (also from Interactive Structures)
* Micromodem II, 300 Baud, Direct Connect Modem (Hayes Microcomputer Products, Norcross, Georgia)
* MPI - 88G Dot Matrix Printer (Microperipherals Inc., Salt Lake City, Utah)
* 'The Clock', Real time clock with 1msec BCD bits (Mountain Computer Inc., Santa Cruz, California)

DC Current Generator:
Gold Star 600SS, Rated 600 Amps at 60% Duty Cycle with remote contactor control. (Miller Electric Mfg. Co., Appleton, Wisconsin)

Spectrum Analysis:
* HP 5423 A Structural Dynamics Analyser
* HP 54470 B Digital Filter
* HP 54410 B A/D Converter
* HP 9872 S Flat Bed Plotter

(All from Hewlett Packard Co., Palo Alto, California)

THERMAL ANEMOMETRY:

* (2) Series 1050 Constant Temperature
* (2) Series 1057 Signal Conditioner
* Series 1051 Monitor and Power Supply
* 1212-60 Hg. Probes

(All from Thermo Systems Inc., St. Paul, Minnesota)

ANALOG DATA RECORDING:

Teac R 61 FM Data Recorder, 4 Channel, Single Speed, Variable Gain (TEAC Corporation, Tokyo, Japan)
APPENDIX E

Microcomputer Program Listings
FILE: DATAQC1 BAS A1 VM/SP CONVERSATIONAL MONITOR SYSTEM PAGE 001

100 TEXT: HOME: FLASH: HTAB 10: PRINT "RAW DATA ACQ": NORMAL
200 DIM A$(9),B(9),C(9),A(9)
220 GOSUB 9700: REM HIMEM SETTING
290 K = 0
300 ARYSZ = 36609 + K:STALC = 36611 + K:ACTSTL = 36613 + K
310 ENLOC = 36615 + K:MULTSZ = 36617 + K:MLPNM = 36619 + K
320 SLPNM = 36621 + K:INERVL = 36623 + K:NMCHN = 36624 + K
325 GSTAL = 36625 + K:GNCD = 36646 + K:TYPE = 36651 + K
330 MXCLN = 36655 + K:TIMEIN = 36656 + K:L2AP = 36662 + K
340 R1EF = 36668 + K:R2EF = 36669 + K:SEXCLN = 36671 + K
350 LIAP = 36672 + K:SITAL = 36678 + K:CLSYS = 36730 + K
360 GIR = 36698 + K:XPNO = 36702 + K:XCRD = 36704 + K
370 YCRD = 36706 + K:ZCRD = 36708 + K:RTN = 36710 + K
380 XDTE = 36732 + K:PARA = 36608 + K:HOTI = 36736 + K
390 CURR = 36712 + K:TEMP = 36714 + K:SVLTG = 36718
500 D$ = CHR$(4):R$ = CHR$(13):H = 256
1000 PRINT R$;D$;"BLOAD DAPARA,D1"
1010 IF AN$ = "Y" THEN POGUE 34, Z1: HOME: GOSUB 2000: REM VAR INPUT
1030 MEXCLN = 36655 + K:TIMEIN = 36656 + K:L2AP = 36662 + K
1040 PRINT: INPUT "NEED TO CHANGE VARIABLES? Y/N";AN$
1050 IF AN$ = "Y" THEN GOSUB 4000: GOTO 1030
1060 PRINT D$;"BLOAD HOTI.OBJO,D1"
1070 POKE 34, PEEK (37) - 1: HOME: INPUT "WHICH ROUTINE (MULT/SNGL) ";OP$
1080 POKE CHOICE, ASC (LEFT$ (OP$, i)) + 128: POKE TYPE, ASC (LEFT$ (OP$, 1)) + 128
1085 IF LEFT$ (OP$, 1) > "S" THEN GOTO 1100
1100 POKE 36769, 23: POKE 36888, 0: POKE 36961, 34. POKE 36989, 234
1100 PRINT R$;D$;"RUN SAVDAT1,D1"
1120 CALL HDT1: REM MAIN DATA ACQ ROUT
1125 POKE 36789, 128: POKE 36888, 17: POKE 36961, 44: POKE 36989, 96
1130 PRINT R$;D$;"RUN SAVDAT1,D1"
1140 PRINT R$;D$;"RUN SAVDAT1,D1"
1150 INVERSE: PRINT "VARIABLE INPUT MODE": NORMAL: POKE 34, PEEK (37)
1190 INPUT "NO. OF CHANNELS FOR SAMPLING=";C%: POKE NMCHN,C%
1200 FOR I = 1 TO C%
1205 PRINT I:"CHN <GNCD, NO.> W/COMMA="; VTAB PEEK (37): HTAB 33: INPUT D%, E%
1210 E% = E% + D% * 16: POKE GNCD + 5 - I, E%
1240 NEXT I
1260 FOR J = 1 TO 5: POKE GNCD + 5 - J, E%: NEXT J
1270 PRINT "VARIABLE INPUT: PRINT "INPUT 4-HEX DIGITS PRECEDED BY \"$\" SIGN": NORMAL
1280 PRINT "DATA STACK SIZE=";A$(0)
1290 INPUT "ACT. START LOC. OF D-STACK=";A$(2)
1300 INPUT "START LOCATION OF D-STACK=";A$(1)
2120 INPUT "MAX. END LOC. OF D-STACK = ";A$(3)
2130 INPUT "DATA SIZE OF MULT-ROUT = ";A$(4)
2140 INPUT "LOOP NO. OF MULT-ROUT = ";A$(5)
2150 INPUT "LOOP NO. OF SNGL-ROUT = ";A$(6)
2160 INPUT "LOOP NO. FOR INTERVAL = ";A$(7)
2170 FOR J = 0 TO 7
2180 A$ = A$(J): GOSUB 9800
2190 POKE ARYSZ - 1 + 2 * J,D: POKE ARYSZ + 2 * J,C
2200 NEXT J
2210 RETURN
3000 PRINT "A: NO. OF CHANNELS FOR SMPG ="; TAB(32); PEEK(NMCHN)
3010 FOR I = 1 TO PEEK(NMCHN)
3020 D% = INT (PEEK(GNCD + 5 - I) / 16): E% = PEEK(GNCD + 5 - I) - D% * 16
3030 PRINT "A:";I; "-CHN GNCD ="; TAB(16); D%; TAB(21); I; "-CHN NO. ="; TAB(36); E%
3040 NEXT I
3050 E% = PEEK(GNCD + 5 - I)
3060 PRINT "A: M/SW GNCD ="; TAB(16); "O"; TAB(21); "M/SW CHN NO ="; TAB(36); E%; PRINT
3070 FOR J = 0 TO 7
3080 D = PEEK(ARYSZ - 1 + 2 * J): C = PEEK(ARYSZ + 2 * J): GOSUB 9900
3090 A$(J) = A$
3100 NEXT J
3110 PRINT "1: DATA ARYSZ ="; TAB(15); A$(0); TAB(21); "2: START LOC ="; TAB(34); A$(1)
3120 PRINT "3: ACT. ST. LOC ="; TAB(15); A$(2); TAB(21); "4: END LOC ="; TAB(34); A$(3)
3130 PRINT "5: MULT DAT. SZ ="; TAB(15); A$(4); TAB(21); "6: L. NO. MULT ="; TAB(34); A$(5)
3140 PRINT "7: L. NO. SNGL ="; TAB(15); A$(6); TAB(21); "8: L. NO. INTRL ="; TAB(34); A$(7); PRINT
3150 INVERSE: PRINT "SEE IF HIMEM =< ACTSTL, STALOC = ACTSTL - 1"
3160 HTAB 7: PRINT "MULTSZ = $1000, ARYSZ = $FF00-ACTSTL"
3170 HTAB 7: PRINT "ARYSZ > (4 )NMCHN + LN(MULT/SNGL)"; NORMAL
3180 RETURN: END
4000 Z2 = PEEK(37) - 1: POKE 34, Z2: HOME
4010 INPUT "TYPE ALPHA/NO./CTRL-S TO BE CHANGED = "; C$
4020 IF LEFT$(C$, 1) = CHR$(19) THEN GOTO 4180
4030 IF ASC (C$) = < 57 THEN GOTO 4150
4040 INPUT "NO. OF CHANNELS FOR SAMPLING = "; C$
4050 POKE NMCHN,C$
4060 FOR I = 1 TO C$
4070 PRINT I; "-CHN <GNCD, NO.> W/COMMA = "; VTAB PEEK(37): HTAB 33: INPUT D%, E%
4080 E% = E% + D% * 16: POKE GNCD + 5 - I, E%
4090 NEXT I
4100 INPUT "MAIN SWITCH CHANNEL NUMBER = "; E%
4110 FOR J = 1 TO 5
4120 POKE GNCD + 5 - J, E%
4130 NEXT J
4140 GOTO 4170
4150 INPUT "THEN VALUE(4-HEX DIG.W/'$')= ? "; A$
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GOSUB 9800: J = VAL (C$) - 1: POKE ARYSZ - 1 + 2 * J, D: POKE ARYSZ + 2 * J, C

GOTO 4010

RETURN: END

9700 C = PEEK (116): D = PEEK (115): GOSUB 9900

9710 VTAB 3: PRINT "PRESENT HIMEM ="; TAB(33); A$

9720 VTAB 4: HTAB 32: PRINT "=": D + C * 256: ZI = PEEK (37)

9730 VTAB 5: PRINT "WANT TO CHANGE HIMEM Y/N?": VTAB 5: HTAB 32: GET A$

9740 IF A$ > "Y" THEN GOTO 9780

9750 VTAB 5: HTAB 1: PRINT "INPUT NEW HIMEM "

9755 VTAB 5: HTAB 17: INVERSE: PRINT "(4-HEX:$XXXX)=": NORMAL: VTAB 5: HTAB 32: INPUT A$

9760 GOSUB 9800: B = C * 256 + D: VTAB 6: HTAB 32: PRINT "="; B

9770 HIMEM: B: ZI = PEEK (37)

9780 POKE 34, ZI: HOME: RETURN: END

9800 FOR I = 2 TO 5

9810 A(I) = ASC (MID$(A$, I, 1))

9820 IF A(I) < 57 THEN A(I) = A(I) - 48: GOTO 9840

9830 A(I) = A(I) - 55

9840 NEXT I

9850 C = A(2) * 16 + A(3): D = A(4) * 16 + A(5)

9860 RETURN: END

9900 A(I) = INT (C / 16): A(2) = C - A(1) * 16: A(3) = INT (D / 16): A(4) = D - A(3) * 16: A$ = "$"

9910 FOR I = 1 TO 4

9920 IF A(I) < 10 THEN A$ = A$ + STR$(A(I)): GOTO 9940

9930 A(I) = A(I) + 55: A$ = A$ + CHR$(A(I))

9940 NEXT I

9950 RETURN: END
100   TEXT : HOME : FLASH : HTAB 7: PRINT "FULL CONV OF CAL-DATA": NORMAL
200   DIM A(9),B(9),C(19),D(9),E(9),G(9),GA(9)
210   GOSUB 9700: REM HIMEM SETTING
290   K = 0
300   ARYSZ = 36609 + K:SALOC = 36611 + K:ACTSTL = 36613 + K
310   ENLOC = 36615 + K:MULTSZ = 36617 + K:MLPNN = 36619 + K
320   SLPNM = 36621 + K:INERV1 = 36623 + K:NMCHN = 36624 + K
325   GSTAL = 36625 + K:SCD = 36646 + TYPE = 36651 + K
330   MXCLN = 36655 + K:TIMEIN = 36656 + K:2AP = 36662 + K
340   I1EF = 36668 + K:R2EF = 36669 + K:SEXCLN = 36671 + K
350   L1AP = 36672 + K:STAL = 36678 + K:CSLVS = 36730 + K
360   G1R = 36698 + K:XPND = 36702 + K:XC RD = 36704 + K
370   YCRD = 36706 + K:ZCRD = 36708 + K:RTN = 36710 + K
380   CRR = 36712 + K:TEM = 36714 + K:CHR = 36716 + K:SVTG = 36718
390   XCRD = 36732 + K:PARA = 36608 + K:HT1 = 36736 + K
500   D$ = CHR$(4):R$ = CHR$(13):H = 256
1000  POKE 34,71: HOME : PRINT : INPUT "DRIVE NO. ":D
1010  POKE 34,2: HOME : PRINT R$:D$:"CATALOG,D":D% 
1020  INPUT "DATA ACQ TYPE =? (M/S) ":TY$
1030  INPUT "EXP. NO. = ":XP 
1040  FS = "C" + STR$(XP) + "-" + TY$:G$ = FS + "-TS"
1050  PRINT R$:D$:"BLOAD ":FS;" ;D":D% : HOME : Vtab 2: INVERSE : PRINT F$;" ,D;D%: NORMAL : POKE 34,3
1060  NC = PEEK (NMCHN):A% = 4:NP = 7
1070  GOSUB 6000: REM GAIN CODE:CALC:(D(I)),(GA(I))
1080  IF TY$ > "S" THEN GOTO 1100
1090  GOSUB 3000: GOTO 1100: REM SNGL CONV
1100  GOSUB 2000: REM MULTI CONV
1110  GOSUB 4000
1120  INPUT "WANT TO CONV TS ? (Y/N) ":ANS$
1130  IF LEFT$(ANS$,1) > "Y" THEN GOTO 1150
1140  PRINT R$:D$:"BLOAD ":G$;" ;D":D% : Vtab 2: INVERSE : PRINT G$;" ,D;D%: NORMAL : POKE 34,3: GOSUB 4500
1150  PRINT R$:D$:"RUN MENU,D$
1160  END
2000  DS = PEEK (MULTSZ) * 4 + PEEK (MULTSZ - 1):DAS=DS:DS=DS
2100  NBD = PEEK (SEXCLN) * 4 + PEEK (SEXCLN - 1):NAD = PEEK (MEXCLN) * 4 + PEEK (MEXCLN - 1)
2200  FOR I = 0 TO NC - 1
2300  A(I) = 0:B(I) = 0
2400  FOR K = 0 TO 4
2500  B(I) = B(I) + PEEK (STAL + 5 + I + K) * (H * K) / (DAS * NBD)
2600  A(I) = A(I) + PEEK (GSTAL + 5 + I + K) * (H * K) / (DAS * NAD)
2700  NEXT K
2900  B(I) = D(I) * B(I) / 4095 / GA(I):A(I) = D(I) * A(I) / 4095 / GA(I)
2910  NEXT I
2100  MSB = INT (PEEK (2AP + 5) / 16):MTB = PEEK (2AP + 5) - MSB + 16
2110  TBM = PEEK (2AP + 2) * 16 + PEEK (2AP + 5) - MSB + 16
2120  TBM = PEEK (2AP + 4) / 10 + MSB / 100 + MTB / 1000
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2120 MSA = INT ( PEEK (L1AP + 5) / 16):MTA = PEEK (L1AP + 5) - MSA * 16
2130 TAM = PEEK (L1AP + 2) * 16 + PEEK (L1AP + 3) + PEEK (L1AP + 4) / 10 + MSA / 100 + MTA / 1000
2140 RETURN : END
3000 DBS = PEEK (MULTSZ) * H + PEEK (MULTSZ - 1):DAS = PEEK (SEXCLN) * H + PEEK (SEXCLN - 1)
3005 NBD = PEEK (SEXCLN) * H + PEEK (SEXCLN - 1):NAD = PEEK (SLPNM) * H + PEEK (SLPNM - 1)
3010 FOR I = 0 TO NC - 1
3020 A(I) = O:B(I) = O
3030 FOR K = 0 TO 4
3040 B(I) = B(I) + PEEK (GSTAL + 5 * I + K) * (H ^ K) / (DBS * NBD)
3050 A(I) = A(I) + PEEK (S1TAL + 5 * I + K) * (H ^ K) / (DAS * NAD)
3060 NEXT K
3070 B(I) = D(I) * B(I) / 4095 / GA(I):A(I) = D(I) * A(I) / 4095 / GA(I)
3080 NEXT I
3090 MSB = INT ( PEEK (L1AP + 5) / 16):MTB = PEEK (L1AP + 5) - MSB * 16
3100 TBM = PEEK (L1AP + 2) * 16 + PEEK (L1AP + 3) + PEEK (L1AP + 4) / 10 + MSB / 100 + MTA / 1000
3110 MSA = INT ( PEEK (L2AP + 5) / 16):MTA = PEEK (L2AP + 5) - MSA * 16
3120 TAM = PEEK (L2AP + 2) * 16 + PEEK (L2AP + 3) + PEEK (L2AP + 4) / 10 + MSA / 100 + MTA / 1000
3130 RETURN : END
4000 POKE 34,3: HOME
4010 INPUT " WANT TO PRINT OUT? (Y/N)":AN$: IF LEFT$ (AN$,1) = < "Y" THEN HOME : GOTO 4030
4020 PRINT R$:D$:"PR#1": POKE 1401,80: HOME
4030 FOR I = 0 TO NP - 1:print "FILE: " ;C(5) = C(5) / 100
4040 A$ = STR$(C(O))
4050 FOR J = 0 TO NP - 1:J: PRINT "(XCD + 1) * H + PEEK (XCRD + 1) * J : NEXT J
4060 C(O) = C(O) / 1E3:C(6) = C(6) / 100
4065 TV = C(O) / TAM
4070 FOR I = 1 TO 39: PRINT "*": NEXT I: PRINT : PRINT
4080 PRINT "FILE NAME & EXP NO = " ;TAB(20):F$:TAB(41);"EXPERIMENT DATE = ":LEFT$ (A$,4);"/" ;MID$ (A$,5,2);"/" ;RIGHT$ (A$,2)
4090 PRINT "CURR = " ;C(4); " AMP": TAB( 21); "$O/H R= ";C(6)
4110 PRINT "TR = " ;C(O); CM": TAB( 21); TV= ";TV=":CM/SEC
4120 FOR J = 0 TO NC - 1
4120 PRINT "GNCD:CH-":J + 1;"= " ;G(J): TAB( 21); "REC GN:CH-":J + 1;"= " ;GA(J): TAB( 41); "SVLTG:CH-":J + 1;"= " ;E(J); " VOLT"
4140 PRINT "BASE VLTV: CH-":J + 1;"= " ;B(J); " VOLT" ;TAB( 41)
4150 PRINT "ACTIVE VLTV: CH-":J + 1;"= " ;A(J); " VOLT"
4160 NEXT J
4170 PRINT "TOT SAMP TIM: BAS=" ;TBM; " SEC": TAB( 41)
4180 PRINT "TOT DAT PTS: BAS=" ;DBS; " NBD=" ;NBD
4190 PRINT "TOT SAMP TIM: ACT=" ;MTA; " SEC": TAB( 41)
4200 PRINT "TOT DAT PTS: ACT=" ;DAS; " NAD=" ;NAD
4210 PRINT : FOR I = 1 TO 39: PRINT "*": NEXT I: PRINT
4220 PRINT R$:D$:"PR#0"
4230 RETURN : END
4500 POKE 34, PEEK (37): HOME : INPUT " WANT TO PRINT-OUT TS? (Y/N)":AN$: IF LEFT$ (AN$,1) = < "Y" THEN GOTO 4520
4510 PRINT R$:D$:"PR#1": POKE 1401,80
4520 HOME :SP = PEEK (ACTSTL) * H + PEEK (ACTSTL - 1)
4530 FOR J = 0 TO NAD - 1
4540 PT = SP + J + A% = NC
4550 FOR I = 0 TO NC - 1
4560 B(I) = 0:PR = PT + I * A%
4570 FOR K = 0 TO A% - 1
4580 B(I) = B(I) + PEEK (PR + K) * (H^K) / DAS: NEXT K
4590 B(I) = B(I) * D(I) / 4095 / GA(I)
4600 NEXT I
4610 PRINT R$;J + 1":";
4620 FOR I = 0 TO NC - 1
4630 TP = I * 18 + 7:TP = TP - INT (TP / 40) * 40: IF PEEK (36) = > TP THEN TP = TP + 40
4640 PRINT TAB( TP);"C":I + 1;"";B(I);
4650 NEXT I:
4660 PRINT R$;D$;"PR#0": RETURN:
4670 END
4680 FOR I = 0 TO NC - 1
4690 G(I) = INT (PEEK (GNCD + 4 - I) / 16):C(I) = PEEK (GNCD + 4 - I) - G(I) * 16:D(I) = G(I)
4700 IF D(I) > = 4 THEN D(I) = D(I) - 4
4710 B% = INT (D(I) / 2 + 0.5):C% = D(I) - INT (D(I) / 2) * 2
4720 D(I) = 5 * (((2 ^ C%) / (10 ^ B%))
4730 GA(I) = PEEK (GIR + I) / 100
4740 E(I) = PEEK (SVLTG + 2 * I) * H + PEEK (SVLTG + 2 * I + 1):E(I) = E(I) / 1E3
4750 NEXT I
4760 RETURN : END
9700 C = PEEK (116):D = PEEK (115): GOSUB 9900
9710 VTAB 3: PRINT "PRESENT HIMEM": TAB( 33):A$
9720 VTAB 4: HTAB 32: PRINT "":D + C * 256:Z1 = PEEK (37)
9730 VTAB 5: PRINT "WANT TO CHANGE HIMEM Y/N?": VTAB 5: HTAB 32: GET AN$
9740 IF AN$ < < "Y" THEN GOTO 9780
9750 VTAB 5: HTAB 1: PRINT "INPUT NEW HIMEM "
9760 VTAB 5: HTAB 17: INVERSE : PRINT "(4-HEX;$XXXX)=": NORMAL : VTAB 5: HTAB 32: INPUT A$
9770 GOSUB 9900: B = C * 256 + D: VTAB 6: HTAB 32: PRINT "":B
9780 POKE 34,Z1: HOME : RETURN : END
9800 FOR I = 2 TO 5
9810 A(I) = ASC ( MIDS (A$,I,1))
9820 IF A(I) < < 57 THEN A(I) = A(I) - 48: GOTO 9840
9830 A(I) = A(I) - 55
9840 NEXT I
9850 C = A(2) * 16 + A(3):D = A(4) * 16 + A(5)
9860 RETURN : END
9890 A(I) = INT (C / 16):A(2) = C - A(1) * 16:A(3) = INT (D / 16):A(4) = D - A(3) * 16:A$ = "$"
9910 FOR I = 1 TO 4
9920 IF A(I) < 10 THEN A$ = A$ + STR$ (A(I)): GOTO 9940
9930 A(I) = A(I) + 55:A$ = A$ + CHR$ (A(I))
9940 NEXT I
9950 RETURN : END
100 TEXT: HOME: FLASH: HTAB 7: PRINT "POLY-FITTING OF CAL-CURVE": NORMAL
110 HIMEM: 36864: REM 36864+$9000
120 POKE 34,3: HOME
200 DIM X(100),Y(100),W(100),CY(100),E(100),A(10,11),XN(100)
300 D$: CHR$(4):R$: CHR$(13)
500 REM PROGRAM FOR POLYNOMIAL FITTING TO A SET OF DATA
510 REM BY LEAST-SQUARE-METHOD
520 GOSUB 4000: REM FILE READING SUBR
530 GOSUB 4500: REM ORIG. COEFF. MATRIX MAKING SUBR
540 PRINT "***ORIGINAL SQUARE COEFFICIENT MATRIX***": PRINT : GOSUB 2500: REM MATRIX PRINTING SUBR
550 GOSUB 1000: REM L/U DECOMPOSITION
560 PRINT "***L/U DECOMPOSED MATRIX***": PRINT : GOSUB 2500
570 REM RESET THE RHS INTO C (COEFF)--DO THIS FOR EACH DEGREE
580 FOR I = (MS + 1) TO SF
590 FOR J = 1 TO I: C(J) = A(J,TF): NEXT J
610 GOSUB 2000: REM SOLUTION SUBROUTINE
620 PRINT "***FINAL RESULT: COEFFICIENTS***": PRINT
630 GOSUB 2700: REM COEFF PRINTING SUBR
640 GOSUB 5000: REM REFERENCE OUTPUT SUBR
650 GOSUB 5500: REM COEFF-FILE SAVE
660 NEXT I: REM TRY NEXT DEGREE OF POLYNOMIAL
670 PRINT R$:D$:"RUN MENU.D1"
680 END
1000 REM THIS SUBR FORMS L/U EQUIVALENT OF SQ COEFF MATRIX A
1010 REM THE L/U MATRIX, IN COMPACT FORM, IS RETURNED IN A
1020 FOR I = 1 TO SF
1030 FOR J = 2 TO SF
1040 SUM = 0
1050 IF J > I THEN GOTO 1110
1060 FOR K = 1 TO J - 1: SUM = SUM + A(I,K) * A(K,J): NEXT K
1070 A(I,J) = A(I,J) - SUM
1080 GOTO 1170
1110 IF (I - 1) = 0 THEN GOTO 1150
1120 FOR K = 1 TO I - 1: SUM = SUM + A(I,K) * A(K,J): NEXT K
1130 REM TEST FOR SMALL VALUE ON DIAGONAL
1150 IF ABS (A(I,I) < 1.0E - 10) THEN GOTO 1200
1160 A(I,J) = (A(I,J) - SUM) / A(I,I)
1170 NEXT J
1175 NEXT I
1180 RETURN : END
1200 PRINT "REDUCTION NOT COMPLETED, DUE TO SMALL VALUE IN DIVISOR IN ROW--"; I: RETURN
1210 END
2000 REM THIS SUBR FINDS SOLUTION TO A SET OF I-LINERAR EQUATION
2010 REM THAT CORRESPONDS TO THE RHS VECTOR C.
2020 REM A-MATRIX = L/U DECOMPOSITION EQUIV TO ORIG COEFF MATRIX
2030 REM BY L/U REDUCTION PROCEDURE. SOLUTION VECTOR IS RETURNED IN C VECTOR
2040 REM NOW, DO THE REDUCTION STEP
2050 C(1) = C(1) / A(1,1)
2060 FOR J = 2 TO I
2070 SUM = 0
2080 FOR K = 1 TO J - 1: SUM = SUM + A(J,K) * C(K): NEXT K
2090 C(J) = (C(J) - SUM) / A(J,J)
2100 NEXT J
2102 PRINT : PRINT "***FINALLY DECOMPOSED LAST COLUMN OF L/U MATRIX***": PRINT
2104 GOSUB 2700
2110 REM NOW, DO BACK SUBSTITUTION, AND DIAGONAL ELEMENTS OF U-MATRIX ARE ALL 1S.
2120 FOR J = 2 TO I
2130 SUM = 0
2140 FOR K = (I - J + 2) TO I: SUM = SUM + A(I - J + 1,K) * C(K): NEXT K
2150 C(I - J + 1) = C(I - J + 1) - SUM
2155 NEXT J
2160 RETURN
2170 END
2500 REM (N X N+1) MATRIX PRINTING SUBR
2510 FOR I = 1 TO SF
2520 PRINT "<";I;">-TH ROW ELEMENTS"
2530 FOR J = 1 TO TF
2532 TB = 20 * (J - 1) + 1: TB = TB - INT (TB / 40) * 40
2534 IF PEEK (36) = > TB THEN TB = TB + 40
2540 PRINT TAB( TB);"(";J;") ";A(I,J);
2550 NEXT J
2560 PRINT ; NEXT I
2570 RETURN
2580 END
2700 REM COEFF PRINTING SUBR
2710 FOR J = 1 TO I: TB = 20 * (J - 1) + 1: TB = TB - INT (TB / 40) * 40
2720 IF PEEK (36) = > TB THEN TB = TB + 40
2730 PRINT TAB( TB);"(";J;") ";C(J): NEXT J: PRINT
2740 RETURN
2750 END
4000 REM FILE READING SUBROUTINE
4010 INPUT "REF'NED CAL-ASSY F.N. = ":F$
4020 PRINT R$;D$;"OPEN ";F$,".D2"
4040 INPUT R$;D$;"READ ";F$
4045 INPUT EO,SZ
4050 FOR I = 1 TO SZ
4060 INPUT X(I),Y(I)
4065 W(I) = 1
4070 NEXT I
4080 PRINT RS;D$;"CLOSE ":F$
4090 N = SZ: PRINT "+NO. OF POINTS: N = ":N
4095 IX = EO
4098 FOR I = 1 TO N:X(I) = X(I) - IX: NEXT I
4100 PRINT: INPUT "+STARTING, FINAL DEG OF POLYNOM-APPROX:(DEG. LE. N-1 & .LE. 9) =? ";MS,MF
4105 SF = MF + 1:TF = MF + 2
4120 RETURN: END
4500 REM ORIGINAL COEFFICIENT MATRIX MAKING SUBR(N ROWS,N+1 COL)
4510 REM ARRAY XN HOLDS POWER OF THE EACH X VALUE
4520 FOR I = 1 TO N:XN(I) = 1: NEXT I
4530 REM COMPUTE 1ST / N+1ST COLUMN OF A.
4540 REM I MOVES DOWN THE ROWS. J SUMS OVER THE N VALUES
4550 FOR I = 1 TO SF
4560 A(I,1) = 0:A(TF) = 0
4570 FOR J = 1 TO N
4580 A(I,1) = A(I,1) + XN(J) * W(J)
4590 A(I,TF) = A(I,TF) + Y(J) * XN(J) * W(J)
4600 XN(J) = XN(J) * X(J)
4610 NEXT J
4620 NEXT I
4630 REM COMPUTE THE LAST ROW OF A. I (COLUMN #). J SUMS OVER N VALUES
4640 FOR I = 2 TO SF
4650 A(SF,I) = 0
4660 FOR J = 1 TO N
4670 A(SF,I) = A(SF,I) + XN(J) * W(J)
4680 XN(J) = XN(J) * X(J)
4690 NEXT J
4700 NEXT I
4710 REM FILL THE REST OF A. I-ROW,J MOVES ACROSS THE COLUMNS
4720 FOR J = 2 TO SF
4730 FOR I = 1 TO MF
4740 A(I,J) = A(I + 1,J - 1)
4750 NEXT I
4760 NEXT J
4770 RETURN: END
5000 REM REFERENCE OUTPUT SUBROUTINE
5010 VAR = 0:ESQ = 0
5020 FOR J = 1 TO N
5030 CY(J) = 0
5040 FOR K = 2 TO I:CY(J) = (CY(J) + C(I-K+2)) * X(J): NEXT K
5050 CY(J) = CY(J) + C(I):ER = Y(J) - CY(J)
5055 IF Y(J) = 0 THEN E(J) = 999999999: GOTO 5060
5058 E(J) = ER * 100 / Y(J)
5060 ESQ = ESQ + ER ^ 2
5070 NEXT J
VAR = ESQ / (N - 1)

PRINT : PRINT "SUM OF ERROR SQ'ED = ";ESQ; SPC( 5);"VARIANCE OF FITTING = ";VAR; PRINT

PRINT "NO. "; TAB( 10);"X"; TAB( 19);"Y"; TAB( 30);"CY"; TAB( 45);"ERROR, %"

FOR ZZ=1 TO 79:PRINT "-";:NEXT ZZ:PRINT

FOR J = 1 TO N
   J$ = STR$(J)
   IF INT(J / 10) = 0 THEN J$ = " " + J$
   PRINT J$; TAB( 5);X(J); TAB( 18);Y(J); TAB( 26);CY(J); TAB( 49);E(J)
   NEXT J

RETURN : END

INPUT "CAL-COEFF FILE NAME = ";G$

PRINT R$;D$;"OPEN ";G$",".D2"

PRINT R$;D$;"DELETE ";G$

PRINT R$;D$;"OPEN ";G$

PRINT R$;D$;"WRITE ";G$

PRINT C(1);",";C(2);",";C(3);",";C(4);",";C(5)

PRINT EO

PRINT R$;D$;"CLOSE ";G$

RETURN : END
*THIS ASSEMBLY ROUTINE CONSISTS OF TWO MAIN PARTS (GETMULT, GETSNGL), PREPARATION STEP AND OTHER SUBROUTINES.

**ZERO PAGE VARIABLES**

- ZLOCEQU $06: * ZERO LOCATION PTR, DUMMY, =1B, ASM
- ZPAGEEQU $07: * PAGE COUNTER (DATA ARRAY), =1B, ASM
- XSAXVEQU $08: * X REGISTER SAVE1, =1B, ASM
- XSAXVEQU $09: * X REGISTER SAVE2, =1B, ASM
- ZNMCHNEQU $19: * NO. OF CHANNELS, =1B, ASM
- CHN1VEQU $1A: * 1ST CHAN VLTG(L), 3B>, ASM
- CHN2VEQU $1D: * 2ND CHAN VLTG(L), 3B>, ASM
- ZLPNUMEQU $1F: * LOOPING NO. (H), <2B, ASM
- ZGNCEQU $EB: * GAINCODE (G5, G4, G3, G2, G1), 5B>, ASM
- YSAVEQU $F9: * Y REGISTER SAVE1, =1B, ASM
- CHN3VEQU $FA: * 3RD CHAN VLTG(L), 3B>, ASM
- CHN4VEQU $FD: * 4TH CHAN VLTG(L), 3B>, ASM

**DATA ARRAY SIZE (H), <2B, BASIC**

- ARYSZEQU $8F01
- STALDCEQU $8F03: **START LOC. OF D. ARY(H), ACT. LOC-1**
- ACTSTLEQU $8F05: **ACT. START LOC OF D. ARY(H), <2B, BAS**
- ENDLCEQU $8F07: **END LOCATION OF DAT ARY(H), <2B, ASM**
- MULTSEQU $8F09: **SIZE OF MULT DATA(H), <2B, BASIC**
- LNMULTEQU $8F08: **LOOPING NO. OF MULT(H), <2B, BASIC**
- LNSNGLEQU $8F0D: **LOOPING NO. OF SNGL(H), <2B, BASIC**
- INTVL EQU $8F0F: **LP NO. OF INTERVAL DELAY(H), <2B**
- NMCHNEQU $8F10: **NO. OF CHANNELS, =1B, BASIC**
- GTOT1EQU $8F11: * GRAND TOTAL1(L), 5B>, ASM
- GTOT2EQU $8F16: * GRAND TOTAL2(L), 5B>, ASM
- GTOT3EQU $8F1B: * GRAND TOTAL3(L), 5B>, ASM
- GTOT4EQU $8F20: * GRAND TOTAL4(L), 5B>, ASM
- NMCHNEQU $8F25: **CHOICE DISPLAY, =1B, ASM**
- GNCDEQU $8F26: **GAINCODE, (G5, G4, G3, G2, G1), 5B>, BASIC**
- REFTIME1EQU $8F3C: *REF. TIME1, =1B, ASM
- REFTIME2EQU $8F3D: *REF. TIME2, =1B, ASM
- DLN1EQU $8F2C: * DISP. L. N. (1, 2 * NMCHN FOR S, M)
- DLN2EQU $8F2D: * DISP. L. N. (2, 4 FOR S, M), =1B, ASM
- EXCMLEQU $8F2F: * EXEC' TED LP. NO. OF MULT
- EXCSLEQU $8F3F: * EXEC' TED LP. NO. OF SNGL
- LAPTIME2EQU $8F36: * LAP TIME, 6B>, ASM
FILE: H01

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08F30: TIMEIN EQU $8F30 * TIME INITIAL,6B>,ASM
08F40: LAPT1M EQU $8F40 * LAP TIME,6B>,ASM
08F46: STOT1 EQU $8F46 *STOTAL1(L),5B>,ASM
08F4B: STOT2 EQU $8F4B *STOTAL2(L),5B>,ASM
08F50: STOT3 EQU $8F50 *STOTAL3(L),5B>,ASM
08F55: STOT4 EQU $8F55 *STOTAL4(L),5B>,ASM
08F80: ORIGIN EQU $8F80 * ORIGIN OF THIS BINARY FILE

OOOO: *OTHER PAGE VARIABLES

COCO:

55 CLOCK EQU $COCO *CLOCK, 5B>, ASM
CODO:

56 AI13 EQU $CODO *ANAL/DIG CONV, 3B>, ASM

OOOO:

88 *******************PREPARATION SECTION

66 ********************

----- NEXT OBJECT FILE NAME IS H01.OBJO

88B0: ORG ORIGIN
88F80:A9 00 63 LDA #$00 *ZLOC=$00
88F82:85 06 64 STA ZLOC
88F84:20 16 92 65 JSR PARYCLR *G/S-TOT & EXC(M/S)LN CLEAR
88F87:20 50 92 66 JSR TCARYCL *INIT/LAP TIME CHNV CLR
88F8A:AD 10 8F 67 LDA NMCHN *ZNMCHN=NMCHN CLR
88F8D:85 19 68 STA ZNMCHN
88F90:20 7C 92 70 JSR SCRNCLR
88F92:A9 01 71 LDA #$01 *VTAB=01
88F94:85 22 72 STA $22
88F96:AD 25 8F 73 LDA CHOICE *OPTION(MULT OR SNGL)
88F99:C9 03 74 CMP #S'
88F9B:F0 03 75 BEO SKIP77
88F9D:AC 8F 76 JMP BSVLTG
88FA0:4C 78 90 77 SKIP77 JMP GETSNGL

77 ********************

88FA3: MULTIPLE DATA PICKING ROUTINE

88FA3: BASE VOLTAGE MEASURE ROUTINE
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8FA3:A2 00 85 BSVLTG LDX #$00 *CAPTION 1 DISP & CHOICE
8FA5:20 84 92 86 JSR HDLNCHD

8FAB:A2 05 88 LDX #$05 *ZGNCD=GNCD
8FAA:BD 25 8F LOOP72 LDA GNC1,X
8FAD:95 EA 90 STA ZGNC1,X
8FAF:CA 91 DEX
8FB0:DO F8 92 BNE LOOP72

8FB2:20 30 92 94 JSR DARYCLR *DATA ARRAY CLEAR
8FB5:20 F3 94 JSR PTRSET

8FB8:AO 00 97 LDY #$00 *LNMULT
8FBA:20 8E 92 98 JSR LPLMTST *LOOPING LIMIT SET

8FBD:20 65 92 100 JSR MSWAIT *MAIN SW(0/5V) WAITING & BELL

8FC0:20 D4 92 102 JSR INITIM *INITIAL TIME SET SUBR

8FC3:20 01 91 104 LOOP70 JSR MULTDAT
8FC6:20 9D 92 105 JSR STOPTM
8FC9:20 1F 93 106 JSR STORE *STORE DATA INTO DATA ARRAY

8FCC:AD 25 8F 108 LDA CHOICE
8FCF:C9 D9 109 CMP #/'Y'
8FD1:DO O3 110 BNE EXIT74
8FD3:20 OE 94 111 JSR DISP L

8FD6:20 6E 92 113 EXIT74 JSR MSWCHK *MAIN SW CHECK STEP
8FD9:FO 08 114 BEQ EXIT75

8FDB:CE 116 DEC ZLPNUM-1 *LOOPING TIME COUNT
8FDD:DO E4 117 BNE LOOP70
8FDF:CF 118 DEC ZLPNUM
8FE1:10 EO 119 BPL LOOP70

8FE3:20 9D 92 121 EXIT75 JSR STOPTM
8FE6:20 FE 94 122 JSR BELL
8FE9:20 C8 92 123 JSR LAPTMV

8FEC:20 7C 92 125 JSR SCRNLCL *CAPTION-4 DISPLAY
8FEF:A2 22 126 LDX #$22
8FF1:20 13 93 127 JSR CAPTDISP
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8FF4:A0 00 129 LDY #$00 *LNMULT
8FF6:A2 10 130 LDX #$10 *EXCSLN
8FF8:20 5E 94 131 JSR EXLPNM *EXEC’TED LP NO CALC
8FFB:A0 34 133 LDY #$34 *EXCSLN
8FFD:A2 35 134 LDX #$35 *STOT
8FFF:B6 09 135 STX XSAV2
9001:20 7A 94 136 JSR MULTADD
9004:20 C6 93 138 JSR ARYDISP
9007:A2 35 140 LDX #$35 *STOT
9009:20 EE 93 141 JSR GOTLAPT *STOT &LAPTIME & BELL
900C:EA EA EA 142 DFB $EA,$EA,$EA
900F: 144 *ACTIVE VOLTAGE MEASURE ROUTINE
900F:A2 11 146 GETMULT LDX #$11 *CAPTION 3 DISP & CHOICE
9011:20 84 92 147 JSR HDLNCHO
9014:A2 05 149 LDX #$05 *ZGNCD=GNCD
9016:BD 25 8F 150 LOOP12 LDA GCND-1,X
9019:95 EA 151 STA ZGNCD-1,X
901B:CA 152 DEX
901C:DO F8 153 BNE LOOP12
901E:20 30 92 155 JSR DARYCLR *DATA ARRAY CLEAR
9021:20 F3 94 156 JSR PTRSET
9024:A0 00 158 LDY #$00 *LNMULT
9026:20 8E 92 159 JSR LPLMTST *LOOPING LIMIT SET SUBR
9029:20 65 92 161 JSR MSWAIT *MAIN SW(0/5V) WAITING & BELL
902C:20 D4 92 163 JSR INITIM *INITIAL TIME SET SUBR
902F:20 01 91 165 LOOP20 JSR MULTDAT *MULTIPLE DATA SAMPLING SUBR
9032:20 9D 92 167 JSR STOPTM *LAP TIME SETTING SUBR
9035:20 1F 93 169 JSR STORE *STORE DATA INTO DATA ARRAY
9038:AD 25 8F 171 LDA CHOICE
9038:C9 D9 172 CMP #'Y'
903D:DO 03 173 BNE EXIT14
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903F:20 OE 94 174 JSR DISPLAY  *DISPLAY DATA ON SCRNR

9042:20 6E 92 177 EXIT14 JSR MSWCHK  *MAIN SW CHECK STEP
9045:FO 08 178 BEQ EXIT15

9047:CE 180 DEC ZLPNUM-1  *LOOPING TIME COUNT
9049:DD E4 181 BNE LOOP20
904B:CF 182 DEC ZLPNUM
904E:10 EO 183 BPL LOOP20

904F:20 9D 92 185 EXIT15 JSR STOPTM  *LAP TIME SETTING SUBR
9052:20 FE 94 186 JSR BELL

9055:20 7C 92 188 JSR SCRNCLR  *CLEAR SCRNR
9058:A2 2C 189 LDX #$2C  *CAPTION-5 DISPLAY
905A:20 13 93 190 JSR CAPTDISP

905D:A0 00 192 LDY #$00  *LMULT
905F:A2 00 193 LDX #$00  *EXCLMN
9061:20 5E 94 194 JSR EXLPNM  *EXEC'TED LP NO CALC

9064:A0 24 196 LDY #$24  *EXCLMN
9066:A2 00 197 LDX #$00  *GTOT
9068:86 09 198 STX XSAV2
906A:20 7A 94 199 JSR MULTADD  *MULT DATA ADD SUBR
906D:20 C6 93 201 JSR ARYDISP

9070:A2 00 203 LDX #$00  *GTOT
9072:20 EE 93 204 JSR GTOTLAPT  *GTOT & LAPTME & BELL
9075:60 205 RTS
9076:EA EA 206 DFB $EA,$EA

208 **********************************************
209 *SINGLE DATA PICKING ROUTINE*
210 **********************************************

9078: A2 36 212 GETSNGL LDX #$36  *CAPTION-6 DISPLAY & CHOICE
9079:20 84 92 213 JSR HDLNCHO
JSR DARYCLR  *DATA ARRAY CLEAR SUBR

LDX ZNMCHN  *ZGNCD=GNCD,DIFFERENT SEQ FROM MULT
LDY #$04
LDA GNCD,Y
STA ZGNCD.X
DEY
DEX
BPL LOOP32

LDY #$00  *LNMULT
JSR LPLMTST  *LOOPING LIMIT SET SUBR

JSR MSWAIT  *MAIN SW(0/5V) WAITING & BELL
JSR INITIM  *INITIAL TIME SETTING SUBR
AND #$FO  *4LSB-MASKING OF CLOCK+3
STA REFTIM2  *1-15 SEC

JSR PTRSET

LDX LNSNGL  *CHN4V+2=LNSNGL(H)
STX CHN4V+2
LDX LNSNGL-1  *CHN4V+1=LNSNGL(L)
BNE SKIP31
DEC CHN4V+2

SKIP31  *XSAV2=INTVL(H)
JSR SNGLDAT
LDA CHOICE
CMP '#Y'
BNE EXIT33
JSR LNDISP  *EXEC'TED LP NO DISP
JSR TMSTEP2  *TIME STEP CHECK SUBR
JSR MSWCHK  *MAIN SW VLTG CHK SUBR
BEQ EXIT22
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90CD: C6 CE 259 DEC ZLPNUM-1
90CF: D0 CC 260 BNE LOOP41
90D1: C6 CF 261 DEC ZLPNUM
90D3: 10 CB 262 BPL LOOP41

90D5: 20 9D 92 264 EXIT22 JSR STOPTM *LAPTIME SETTING
90DB: 20 C8 92 266 JSR LAPTMV

90DC: 20 7C 92 268 JSR SCRNCLR
90DE: A2 47 269 LDX #$47 *CAPTION-7 DISPLAY LOOP
90E0: 20 13 93 270 JSR CAPTDISP

90E2: A0 O2 272 LDY #$00 *LMULT
90E3: A2 10 273 LDX #$10 *EXCSLN
90E4: 20 5E 94 274 JSR EXLPNM *EXEC'TED LOOPI NG NO CALC

90E6: A0 O2 276 LDY #$02 *LSNGL
90E7: A2 35 277 LDX #$35 *STOT
90F1: 86 09 278 STX XSAV2
90F3: 20 7A 94 279 JSR MULTADD *STOT ADD SUBR

90F6: 20 C6 93 281 JSR ARYDISP *ARRAY DISPLAY SUBR

90F9: A2 35 283 LDX #$35 *STOT
90FB: 20 EE 93 284 JSR GTOTLAPT *STOT & LAP TIME DISP & BELL

90FE: 60 286 RTS
90FF: EA EA 287 DFB $EA,$EA

289 ***********************************************************************
290 *OTHER SUBROUTINES AND CONSTANTS
291 ***********************************************************************

293 *MULTIPLE DATA GETTING SUBROUTINE

9101: AE 08 8F 295 MULTDAT LDX MULTSZ +XSAV2= MULTSZ(H)
9104: B6 09 296 STX XSAV2
9106: AE 08 8F 297 LDX MULTSZ-1 +XSAV1=MULTSZ(L)
9109: DO 02 298 BNE SKIP15
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9106:CB 09  299  DEC  XSAV2
9100:BE 08  300  SKIP15  STX  XSAV1

910F:AB  EF  302  LDA  ZGNCD+4  *1ST CHN SMPG PREP
9111:BD  DO  CO  303  STA  AI13

9114:A9  EE  305  LDA  #$00  *CHN VLTG CLEAR LOOP
9116:AE  EE  306  LDY  #$06
9118:95  19  307  LOOP17  STA  CHN1V-1,X
911A:95  F9  308  STA  CHN3V-1,X
911C:CA  309  DEX
911D:DE  F9  310  BNE  LOOP17

911F:AB  19  312  LOOP18  LDX  ZNMCHN
9121:AB  EF  313  LDA  ZGNCD+4  *1ST CHN ACT SMPG & ADD
9123:BD  DO  CO  314  STA  AI13
9126:20  OA  95  315  JSR  DELAY13
9129:18  316  CLC  *1ST CHN SMPG & ADD
912A:AC  D1  CO  317  LDY  AI13+1
912D:BD  DO  CO  318  LDA  AI13
9130:DE  1A  319  ADC  CHN1V
9132:85  1A  320  STA  CHN1V
9134:AB  EE  321  LDA  ZGNCD+3  *2ND CHN SMPG PREPARATION
9136:BD  DO  CO  322  STA  AI13  *
9139:9B  323  TYA
913A:29  OF  324  AND  #$0F
913C:65  1B  325  ADC  CHN1V+1
913E:85  1B  326  STA  CHN1V+1
9140:99  02  327  BCC  SKIP16
9142:EE  1C  328  INC  CHN1V+2
9144:CA  329  SKIP16  DEX
9145:EA  330  NOP
9146:FO  6C  331  BEQ  NEXT11

9148:AB  EE  333  LDA  ZGNCD+3  *2ND CHN ACT SMPG
914A:BD  DO  CO  334  STA  AI13
914D:20  OA  95  335  JSR  DELAY13
9150:1B  336  CLC  *2ND CHN SMPG & ADD
9151:AC  D1  CO  337  LDY  AI13+1
9154:BD  DO  CO  338  LDA  AI13
9157:65  1D  339  ADC  CHN2V
9159:85  1D  340  STA  CHN2V
915B:AB  ED  341  LDA  ZGNCD+2  *3RD CHN SMPG PREP
915D:8D  DO  CO  342  STA  AI13  *
9160:98  343  TYA
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9161:29 OF 344 AND #$0F
9163:65 1E 345 ADC CHN2V+1
9165:85 1E 346 STA CHN2V+1
9167:90 O2 347 BCC SKIP17
9169:E6 1F 348 INC CHN2V+2
916B:CA 349 SKIP17 DEX
916C:EA 350 NOP
916D:FO 45 351 BEQ NEXT11

916F:A5 ED 353 LDA ZGNCD+2 *3RD CHN ACT SMPG
9171:BD DO CO 354 STA AI13
9174:20 OA 95 355 JSR DELAY13
9177:18 356 CLC *3RD CHN SMPG & ADD
9178:AC D1 CO 357 LDY AI13+1
917B:AD DO CO 358 LDA AI13
917E:65 FA 359 ADC CHN3V
9180:BE FA 360 STA CHN3V
9182:A5 EC 361 LDA ZGNCD+1 *4TH CHN SMPG PREP
9184:BD DO CO 362 STA AI13 *
9187:9B 363 TYA
9188:2F OF 364 AND #$0F
918A:65 FB 365 ADC CHN3V+1
918C:85 FB 366 STA CHN3V+1
918E:00 O2 367 BCC SKIP18
9190:E6 FC 368 INC CHN3V+2
9192:CA 369 SKIP18 DEX
9193:EA 370 NOP
9194:FO 1E 371 BEQ NEXT11

9196:A5 EC 373 LDA ZGNCD+1 *4TH CHN ACT SMPG
9198:BD DO CO 374 STA AI13
919B:20 OA 95 375 JSR DELAY13
919E:18 376 CLC *4TH CHN SMPG & ADD
919F:AC D1 CO 377 LDY AI13+1
91A2:AD DO CO 378 LDA AI13
91A5:65 FD 379 ADC CHN4V
91A7:85 FD 380 STA CHN4V
91AA:9B 381 TYA
91AC:65 FE 383 ADC CHN4V+1
91AE:85 FE 384 STA CHN4V+1
91B0:90 O2 385 BCC NEXT11
91B2:66 FF 386 INC CHN4V+2

91B4:A5 EF 388 NEXT11 LDA ZGNCD+4 *1ST CHN SMPG PREP
FILE: HOT1

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91B6:8D DO CO 389 STA AI13 *
91B9:A5 06 390 LDA ZLOC +5 CYCLES DELAY
91BB:EA 391 NOP

91BC:C6 08 393 DEC XSAV1
91BE:00 09 395 DEC XSAV2

91C2:10 01 396 BPL SKIP29
91C4:60 397 RTS
91C5:4C 1F 91 39B SKIP29 JMP LOOP18

91C8: 400 *SINGLE DATA GETTING SUBROUTINE

91C8: A6 19 402 SNGLDAT LDX ZNMCHN *X=ZNCH
91CA: B5 0D 403 LOOP33 LDA ZGNCD,X +EACH CHN SMPG PREP
91CC: 8D DO CO 404 STA AI13
91CF: 20 07 95 405 JSR DELAY19

91D0: B5 EB 407 LDA ZGNCD,X *EACH CHN ACT SMPG
91D4: 80 DO CO 408 STA AI13
91D7: C8 409 INY *10 CYCLE DELAY & ARRAY PTR UPDATE
91DA: F0 04 410 BEQ SKIP32 *
91DC: DO 02 412 BNE SKIP33 *
91DE: E6 07 413 SKIP32 INC ZPAGE *
91E0: 18 414 SKIP33 CLC * 9 CYCLES DELAY & H-BY SAVE
91E1: A0 D1 CO 415 LDA AI13+1 *
91E4: 48 416 PHA *

91E5: AD DO CO 418 LDA AI13 *8LSB ADD
91E8: 71 06 419 ADC (ZLOC).Y
91EA: 91 06 420 STA (ZLOC).Y
91EC: C8 421 INY
91ED: 68 422 PLA *4MSB ADD
91EE: 29 0F 423 AND #$OF
91F0: 71 06 424 ADC (ZLOC).Y
91F2: 91 06 425 STA (ZLOC).Y
91F4: C8 426 INY
91F5: A9 00 427 LDA #$00
91F7: 71 06 428 ADC (ZLOC).Y
429 STA (ZLOC),Y  
430 INY  
432 DEX  
433 BNE LOOP33  
435 SEC *INTERVAL DELAY(MIN 15 MICRO-SEC)  
436 LDA XSAV2 *INT  
437 LDX XSAV1 *INT  
438 BEQ SKIP34 *INT  
439 LOOP34 DEX *INT  
440 BNE LOOP34 *INT  
441 SBC #$01 *INT  
442 BPL LOOP34 *INT  
444 DEC CHN4V+1 *LOOPING TIME COUNT  
445 BNE SNGLDAT  
446 DEC CHN4V+2  
447 BPL SNGLDAT  
448 RTS  
450 *ARRAY CLEAR SUBROUTINE  
452 PARYCLR LDA #$00  
453 LDY #$14 *GTOT VAR CLEAR  
454 LOOP16 STA GTOT1-1,Y  
455 STA STOT1-1,Y  
456 DEY  
457 BNE LOOP16  
459 STA EXCMLN-1 *EXC(M/S)LN CLEAR  
460 STA EXCMLN  
461 STA EXCSLN-1  
462 STA EXCSLN  
463 RTS  
465 DARYCLR JSR PTRSET  
467 LDX ARYSZ *XSAV1=ARYSZ(H)  
468 STX XSAV1  
469 LDX ARYSZ-1 *X=ARYSZ(L)
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923B: DO 02 470  BNE SKIP11
923C: C6 08 471  DEC XSAV1

923F: A9 00 473  SKIP11 LDA #$00
9240: C8 474  LOOP14 INY +DATA ARRAY CLEAR
9241: C8 474  LOOP14 LDA #$00
9242: DO 02 475  BNE SKIP12
9244: E6 07 476  INC ZPAGE
9245: 91 06 477  SKIP12 STA (ZLOC),Y
9248: CA 478  DEX
9249: DO F6 479  BNE LOOP14
924B: C6 08 480  DEC XSAV1
924D: 10 F2 481  BPL LOOP14
924F: 60 482  RTS

9250: A9 00 484  TCARYCL LDA #$00
9252: A2 06 485  LDX #$06 +CLOCK VAR CLEAR
9254: 9D 2F 8F 486  LOOP15 STA TIMEIN-1,X
9257: 9D 3F 8F 487  STA LAPTIM1-1,X
925A: 9D 35 8F 488  STA LAPTIM2-1,X
925D: 95 19 489  STA CHN1V-1,X *CHN VLTG CLEAR
925F: 95 F9 490  STA CHN3V-1,X
9261: CA 491  DEX
9262: DO FO 492  BNE LOOP15
9264: 60 493  RTS

9265:    495  *MAIN SW WAITING SUBROUTINE

9265: 20 6E 92 497  MSWAIT JSR MSWCHK
9268: FO FB 498  BEQ MSWAIT
926A: 20 9E 94 499  JSR BELL
926D: 60 500  RTS

926E:    502  *MAIN SW CHECKING SUBR

926E: A5 EB 504  MSWCHK LDA ZGNCD
9270: 8D DO CO 505  STA AI13
9273: 20 9B 95 506  VSR DELAY0
9276: AD D1 CO 507  LDA AI13+1
9279: 29 OF 508  AND #$0F
927B: 60 509  RTS

927C:    511  *SCREEN CLEAR SUBROUTINE
927C. A9 00 513 SCRNC LR LDA #$00
927E. 85 22 514 STA $22
9280. 20 58 FC 515 JSR $FC58
9283. 60 516 RTS

9284:
518 *HEADLINE DISP & CHOICE SUBR

9284: 20 13 93 520 HDLNCHO JSR CAPTDISP
9287: 20 35 FD 521 JSR $FD35 *GET A KEY FROM KEYPAD
928A. 8D 25 8F 522 STA CHOICE
928D. 60 523 RTS

928E:
525 *INITIAL LOOPING LMT SET SUBR

928E. B9 OB 8F 527 LPLMTST LDA LNMULT,Y *ZLPNUM=(LNMULT,Y)(H)
9291. B5 CF 528 STA ZLPNUM
9293. B9 OA 8F 529 LDA LNMULT-1,Y *ZLPNUM-1=(LNMULT-1,Y)(L)
9296. D0 02 530 BNE SKIP14
9298. C6 CF 531 DEC ZLPNUM *DECREASE ZLPNUM BY 1
929A. B5 CE 532 SKIP14 STA ZLPNUM-1
929C. 60 533 RTS

929D:
535 *ELAPSED TIME CALCULATION SUBR

929D. AE C4 CO 537 STOPTM LDX CLOCK+4 *10 TO 1 MIL-SEC (BCD FORMAT)
92A0. AD C3 CO 538 LDA CLOCK+3 *2^3-2^0 SEC & 100 MIL-SEC (BCD)
92A3. AC C2 CO 539 LDY CLOCK+2 *2^11-2^4 SEC
92A6. 8E 45 8F 540 STX LAPTIMI+5 *LAPTIMI+5=10 TO 1 MIL-SEC (BCD FMT)
92A9. D8 542 CLD
92AA. AA 543 TAX
92AB. 29 OF 544 AND #$OF
92AD. 8D 44 8F 545 STA LAPTIM1+4 *LAPTIM1+4=100 MIL-SEC (BCD FMT)
92B0. 8A 547 TXA
92B1. 29 FO 548 AND #$FO
92B3. 38 549 SEC
92B4. ED 33 8F 550 SBC TIMEIN+3
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92B7:08 551 PHP *P-REGISTER SAVE
92B8:4A 552 LSR A *DIVIDE A-REG BY 16
92B9:4A 553 LSR A
92BA:4A 554 LSR A
92BB:4A 555 LSR A
92BC:8D 43 8F 556 STA LAPT1+3 *LAPT1+3=2^3--2^0 SEC
92BF:98 558 TYA
92C0:28 559 PLP *P-REGISTER RESTORE
92C1:ED 32 8F 560 SBC TIMEIN+2
92C4:8D 42 8F 561 STA LAPT1+2 *LAPT1+2=2^11--2^4 SEC
92C7:60 562 RTS

92C8: 564 *LAPTIME MOVE SUBR
92CA:BD 3F 8F 566 LAPTMV LDX #$06
92CD:9D 35 8F 567 LOOP71 LDA LAPT1-1,X
92D0:CA 569 DEX
92D1:DD 570 BNE LOOP71
92D3:60 571 RTS

92D4: 573 *INITIAL TIME SET SUBROUTINE
92D6:AD C6 CO 575 INITIM LDA CLOCK+6 *CLOCK STOP
92D7:AD C5 CO 576 LDA CLOCK+5 *CLOCK RESTART
92D9:AD C3 CO 578 LDA CLOCK+3 *2^3--2^0 SEC READ
92DA:AE C2 CO 579 LDX CLOCK+2 *2^11--2^4 SEC READ
92EC:8D 33 8F 580 STA TIMEIN+3
92ED:8E 32 8F 581 STX TIMEIN+2
92E6:60 582 RTS

92E7: 584 *TIME STEP CHECK SUBR:500 MIL-SEC
92E8:18 586 TMSTP1 CLC
92E9:F8 587 SED *SET DECIMAL FLAG
92EB:AD 3C 8F 588 LDA RETTIM1 *REFTIM1=REFTIM1+INTERVAL
92EC:69 05 589 ADC #$05 *INTERVAL=500 MIL-SEC
92EE:29 0F 590 AND #$0F
92F0:8D 3C 8F 591 STA RETTIM1
92F3:D8 592 CLD
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92F4: AD C3 CO 593 LOOP19 LDA CLOCK+3 *2^3--2^0 & 100 MIL-SEC (BCD) READ
92F7: 29 0F 594 AND #$0F
92F9: CD 3C 8F 595 CMP REFTIM1
92FC: D0 F6 596 BNE LOOP19
92FE: 60 597 RTS

92FF: 18 599 TMSTEP2 CLC *TIME STEP=1 SEC
9300: AD 3D 8F 600 LDA REFTIM2
9303: 69 10 601 ADC #$10
9305: BD 3D 8F 602 STA REFTIM2
9308: AD C3 CO 603 LOOP51 LDA CLOCK+3 *SEC & 100 MIL-SEC
930B: 29 F0 604 AND #$FO
930D: CD 3D 8F 605 CMP REFTIM2
9310: D0 F6 606 BNE LOOP51
9312: 60 607 RTS

9313: 609 611 CAPTDISP LDA CAPTN1,X
9316: BD OC 95 612 BEQ RETURN
931A: 20 ED FD 613 JSR $FDED
931E: EE 614 INX
931C: D0 F6 615 BNE CAPTDISP
931E: 60 616 RETURN RTS

931F: 618 *MULTIPLE DATA STORE SUBROUTINE

931F: A4 F9 620 STORE LDY YSAV1 *Y=YSAV1
9321: A6 19 621 LDX ZNMCHN *XSAV1=ZNMCHN
9323: 86 08 622 STX XSAV1
9325: A2 00 624 LDX #$00 *CHN1V SAVE
9327: 20 42 93 625 JSR CHNVST0
932A: F0 13 626 BEQ NEXT12
932C: A2 03 627 LDX #$03 *CHN2V SAVE
932E: 20 42 93 628 JSR CHNVST0
9331: F0 OC 629 BEQ NEXT12
9333: A2 EO 630 LDX #$EO *CHN3V STORE
9335: 20 42 93 631 JSR CHNVST0
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9338:FO 05 632 BEQ NEXT12
933A:A2 E3 633 LDY #$E3 +CHN4V STORE
933C:20 42 93 634 JSR CHNVSTO
933F:84 F9 636 NEXT12 STY YSAV1
9341:60 637 RTS

9342:C8 639 CHNVSTO INY
9343:D0 02 640 BNE SKIP19
9345:E6 07 641 INC ZPAGE
9347:B5 1A 642 JSR CHNVSTO
9349:91 06 643 STA (ZLOC),Y
934B:C8 644 INY
934C:B5 1B 645 LDA CHNV+1,X
934E:91 06 646 STA (ZLOC),Y
9350:C8 647 INY
9351:B5 1C 648 LDA CHNV+2,X
9353:91 06 649 STA (ZLOC),Y
9355:C8 650 INY
9356:06 08 651 DEC XSAV1
9358:60 652 RTS

9359: 654 +DIRECT ADDITION OF CHNV INTO G/S-TOT

9359:A6 19 656 ADDTN LDX ZNMCHN
935B:86 08 657 STX XSAV1
935D:A6 09 659 LDX XSAV2 +GTO1=$00 (XSAV2) STO1=$35
935F:A0 00 660 LDY #$00 +CHN4V ADDITION
9361:20 89 93 661 JSR CHNVADD
9364:FO 1C 662 BEQ NEXT13
9366:20 83 93 664 JSR INCX5
9369:A0 03 665 LDY #$03 +CHN2V ADDITION
936B:20 89 93 666 JSR CHNVADD
936E:FO 12 667 BEQ NEXT13
9370:20 83 93 669 JSR INCX5
9373:A0 E0 670 LDY #$E0 +CHN3V ADDITION
9375:20 89 93 671 JSR CHNVADD
9378:FO 08 672 BEQ NEXT13
937A:20 83 93 674 JSR INCX5
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937D:  AO  E3  675  LDY  #$E3  +CHN4V ADDITION
937F:  20  89  93  676  JSR  CHNVADD

9382:  60  678  NEXT13  RTS

9383:  18  680  INCX5  CLC
9384:  8A  681  TXA
9385:  69  05  682  ADC  #$05
9387:  AA  683  TAX
9388:  60  684  RTS

9389:  18  686  CHNVADD  CLC
938A:  89  1A  00  687  LDA  CHN1V,Y
938D:  7D  11  8F  688  ADC  GTOT1,X
9390:  9D  11  8F  689  STA  GTOT1,X
9393:  89  1B  00  690  LDA  CHN1V+1,Y
9396:  7D  12  8F  691  ADC  GTOT1+1,X
9399:  9D  12  8F  692  STA  GTOT1+1,X
939C:  89  1C  00  693  LDA  CHN1V+2,Y
939F:  7D  13  8F  694  ADC  GTOT1+2,X
93A2:  9D  13  8F  695  STA  GTOT1+2,X
93A5:  90  08  696  BCC  SKIP23
93A7:  FE  14  8F  697  INC  GTOT1+3,X
93AA:  DD  03  698  BNE  SKIP23
93AC:  FE  15  8F  699  INC  GTOT1+4,X
93AF:  C6  08  700  DEC  XSAV1
93B1:  60  701  RTS

93B2:  703  *LOOPING NUMBER DISPLAY SUBR

93B2:  20  58  FC  705  LDNDSP  JSR  $FC58
93B5:  E6  FC  706  INC  CHN3V+2
93B7:  D0  02  707  BNE  SKIP42
93B9:  E6  FD  708  INC  CHN4V
93BB:  A5  FD  709  SKIP24  LDA  CHN4V  +H-BYTE
93BD:  20  DA  FD  710  JSR  $FDDA
93C0:  A5  FC  711  LDA  CHN3V+2  +L-BYTE
93C2:  20  DA  FD  712  JSR  $FDDA
93C5:  60  713  RTS
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93C6: 715 *ARRAY DISPLAY SUBROUTINE
93C6:A2 09 717 ARYDISP LDX #$09  *CAPTION 2 DISPLAY
93C8:20 13 93 718 JSR CAPTDISP
93CB:20 F3 94 719 JSR PTRSET
93CE:A5 19 721 LDA ZNMCHN
93D0:8D 2C 8F 722 STA DLN1
93D2:09 04 723 LDA #$04
93D5:8D 2D 8F 724 STA DLN2
93D8:A9 02 725 LDA #$02  *VTAB=02
93DA:85 22 726 STA #$22
93DF:C9 09 729 CMP #'Y'
93E1:DO 06 730 BNE SKIP51
93E3:20 C3 94 731 JSR MEMDISP
93E6:4C DC 93 732 JMP DISPASK
93E9:A9 00 734 SKIP51 LDA #$00  *VTAB=00
93EB:85 22 735 STA #$22
93ED:60 736 RTS

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93EE: 738 *GTOT/STOT & TOTAL LAPTIME DISP & BELL
93EE:A4 19 740 GTOTLAPT LDY ZNMCHN
93F0:84 09 741 STY XSAV2
93F2:A0 05 742 LOOP28 LDY #$05
93F4:BD 11 8F 743 LOOP27 LDA GTOT1,X
93F7:20 DA FD 744 JSR $FDDA
93FA:EB 745 INX
93FB:88 746 DEY
93FC:00 F6 747 BNE LOOP27
93FE:A9 8D 748 LDA #$8D
9400:20 ED FD 749 JSR $FDED
9403:C6 09 750 DEC XSAV2
9405:00 EB 751 BNE LOOP28
9407:20 2A 94 753 JSR LAPTDISP
940A:20 FE 94 754 JSR BELL
940D:60 755 RTS
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940E: 757 *CHN VLTG & LAP TIME DISPLAY SUBROUTINE

940E:A4 19 759 DISPLY LDY ZMCHN

9410:A2 00 761 LDX #$00 *CHN1V DISP
9412:20 48 94 762 JSR CHNVDISP
9415:FO 13 763 BEQ LAPTDISP
9417:A2 03 764 LDX #$03 *CHN2V DISP
9419:20 48 94 765 JSR CHNVDISP
941C:FO 0C 766 BEQ LAPTDISP
941E:A2 E0 767 LDX #$EO *CHN3V DISP
9420:20 48 94 768 JSR CHNVDISP
9423:FO 05 769 BEQ LAPTDISP
9425:A2 E3 770 LDX #$E3 *CHN4V DISP
9427:20 48 94 771 JSR CHNVDISP

942A:AD 42 8F 773 LAPTDISP LDA LAPTIM1+2 2^11--2^4 SEC
942D:20 DA FD 774 JSR $FDDA
9430:AD 43 8F 775 LDA LAPTIM1+3 2^3--0 SEC
9433:20 DA FD 776 JSR $FDDA
9436:AD 44 8F 777 LDA LAPTIM1+4 *100 MIL SEC
9439:20 DA FD 778 JSR $FDDA
943C:AD 45 8F 779 LDA LAPTIM1+5 *10--1 MIL SEC
943F:20 DA FD 780 JSR $FDDA
-9442:A9 8D 781 LDA #$BD
9444:20 ED FD 782 JSR $FDDE
9447:60 783 RTS

9448:85 1C 785 CHNVDISP LDA CHN1V+2,X
944A:20 DA FD 786 JSR $FDDA
944D:85 1B 787 LDA CHN1V+1,X
944F:20 DA FD 788 JSR $FDDA
9452:85 1A 789 LDA CHN1V,X
9454:20 DA FD 790 JSR $FDDA
9457:A9 AO 791 LDA #$AO
9459:20 ED FD 792 JSR $FDDE
945C:88 793 DEY
945D:60 794 RTS
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**945E:** 796 *FINAL EXEC'TED LOOP NO CALC

**945E:A5 CF 798 EXLPNM**

LDA ZLPNUM

BPL SKIP91 *IF ZLPNUM(H) => $00 THEN BR

**9460:10 04 799 BPL**

INC ZLPNUM

**9464:10 02 801 BPL**

SKIP98 *UNCOND BR(NOW ZLPNUM(H) => $00)

**9466:C6 CE 802 SKIP91**

DEC ZLPNUM-1

**9468:38 803 SKIP98**

SEC

**9469:B9 0A 8F 804**

LDA LNMULT-1,Y

**946C:E5 CE 805**

SBC ZLPNUM-1

**946E:9D 2E 8F 806**

STA EXCMLN-1,X

**9471:B9 0B 8F 807**

LDA LNMULT,Y

**9474:E5 CF 808**

SBC ZLPNUM

**9476:9D 2F 8F 809**

STA EXCMLN,X

**9479:60 810**

RTS

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**947A:** 812 *MULT/SNGL DATA ADD SUBROUTINE

**947A:20 8E 92 814 MULTADD JSR**

LPLMTST *ZLPNUM=EXCMLN OR LNSNGL

**947C:20 F3 94 815 JSR**

PTRSET

9480:A6 09 817 LOOP98

LDX XSAV2

9482:A5 19 818

LDA ZNMCHN

9484:85 08 819

STA XSAV1

9486:C8 820 LOOP99

INY

**9487:D0 02 821 JSR**

BNE SKIP97

**9489:E6 07 822 JSR**

INC ZPAGE

948B:18 823 SKIP97

CLC

948C:B1 06 824

LDA (ZLOC),Y *1ST BYTE

948E:7D 11 8F 825 ADC GTOT1,X

9491:9D 11 8F 826 STA GTOT1,X

9494:C8 827 INY

**9495:B1 0B 828 LDA**

(ZLOC),Y *2ND BYTE

9497:7D 12 8F 829 ADC GTOT1+1,X

949A:9D 12 8F 830 STA GTOT1+1,X

949D:C8 831 INY

949E:B1 0B 832 LDA (ZLOC),Y *3RD BYTE

94A0:7D 13 8F 833 ADC GTOT1+2,X

94A3:9D 13 8F 834 STA GTOT1+2,X

94A6:C8 835 INY

**94A7:90 08 836 JSR**

BCC SKIP95

**94A9:FE 14 8F 837 JSR**

INC GTOT1+3,X

**94AC:00 03 838 JSR**

BNE SKIP95

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INC GTOT1+4,X
839

SKP95 TXA
840

CLC
841

ADC #$05
842

TAX
843

DEC XSAV1
844

BNE LOOP99
845

BNE LOOP98
848

DE ZLPNUM
849

LOOP24
850

BNE LOOP25
851

RTS
852

*DATA ARRAY DISPLAY SUBROUTINE: 20 LINES AT A TIME
853

*TO CONTINUE TO DISPLAY, TYPE "Y"
854

855

MEMDISP LDY YSAV1
856

LDA #$14 *XSAV1=20
857

STA XSAV1
858

LDX DLN1 *XSAV2=DLN1
859

LOOP25
860

STX XSAV2
861

LDX DLN2 *X=DLN2
862

463

564

655

766

877

988

A99

B00

C11

D22

E33

F44

056

157

258

359

460

561

662

763

864

965

066

167

268

369

470

571

672

773

874

975

076

177

278

379

480

581

682

783

884

985

086

187

288

389

490

591

692

793

894

995

*XSAV1=20

*XSAV2=DLN1

*X=DLN2

SKP26

INC ZPAGE

SKP26

LDA (ZLOC),Y

JSR $FDDA

DEX

BNE LOOP23

LDA #$10

JSR $FDED

DEC DLN2

BNE LOOP24

LDA #$8D

JSR $FDED

DEC DLN1

BNE LOOP25

LDA #$80

JSR $FDED

DEC XSAV2

BNE LOOP24

LDA #$8D

JSR $FDED

DEC XSAV1

BNE LOOP25
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94FO: 84 F9 880 STY YSAV1
94F2: 60 881 RTS

94F3: 883  *POINTER SET SUBROUTINE
94F3: AC O3 8F 885 PTRSET LDY STALOC +2PAGE=STALOC(H)
94F6: 84 O7 886 STY ZPAGE
94F8: AC O2 8F 887 LDY STALOC-1 +YSAV1=STALOC(L)
94FB: 84 F9 888 STY YSAV1
94FD: 60 889 RTS

94FE: 891  *RING-BELL SUBROUTINE
94FE: A9 87 893 BELL LDA #$97
9500: 20 ED FD 894 JSR $FDED
9503: 20 ED FD 895 JSR $FDED
9506: 60 896 RTS

9507: 898  *TIME DELAY SUBROUTINE
9507: A5 O6 900 DELAY19 LDA ZLOC
9509: EA 901 NOP
950A: EA 902 DELAY13 NOP
950B: 60 903 DELAYO RTS

950C: 905  *DATA AND CONSTANTS
950C: C2 C1 D3 907 CAPTN1 ASC 'BASE ' +F-D:$4F,F-N;$4E
950F: C5 AO
9511: 4F 4E AO 908 DFB $4F,$4E,$AO,$BA
9514: BA
9515: C4 BF AO 909 CAPTN2 ASC 'D? Y/N'
9518: D9 AF CE
951B: BD OO 910 DFB $BD,$00
951D: C1 C3 D4 911 CAPTN3 ASC 'ACTV '
9520: D6 AO
9522: 4F 4E AO 912 DFB $4F,$4E,$AO,$BA
9525: BA
9526: C4 BF AO 913 ASC 'D? Y/N'
9529: D9 AF CE
952C: BD OO 914 DFB $BD,$00
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952E:C2 C1 D3  915 CAPTN4  ASC 'BASE ' +F-F;$46
9531:C5 AO  9533:4F 46 46  916  DFB $4F,$46,$46,$8D,$00
9536:BD OO  9538:C1 C3 D4  917 CAPTN5  ASC 'ACTV ' 
953B:D6 AO  953D:4F 46 46  918  DFB $4F,$46,$46,$8D,$00
9540:BD OO  9542:D3 CE C7  919 CAPTN6  ASC 'SNGL '
9545:CC AO  9547:4F 4E AO  920  DFB $4F,$4E,$AO,$BA
954A:BA
954B:C4 BF AO  921  ASC 'D? Y/N'
954E:D9 AF CE  9551:8D OO  922  DFB $8D,$00
9553:D3 CE C7  923 CAPTN7  ASC 'SNGL '
9556:CC AO  9558:4F 46 46  924  DFB $4F,$46,$46,$8D,$00
955B:BD OO  
955D:  925 *PROGRAMMED BY TAEWOOK KANG, MAY 5, 1983
955D:  926 *REVISED BY TAEWOOK KANG, AUG. 23, 1983
955D:  927 *RECONSTRUCTED BY TAEWOOK KANG, SEPT. 1, 1983
955D:  928 *REMODIFIED FOR HOT W/F ANNEMO BY TAEWOOK KANG, FEB. 20, 1984

*** SUCCESSFUL ASSEMBLY: NO ERRORS

?8F05 ACTSTL 9359 ADDTN
CODO AI13 93C6 ARYDISP
8F01 ARYSZ 94FE BELL
8FA3 BSVLGT 9313 CAPTDISP
950C CAPTN1 9515 CAPTN2
7951D CAPTN3 7952E CAPTN4
7953B CAPTN5 79542 CAPTN6
79553 CAPTN7 1A CHN1V
1D CHN2V FA CHN3V
FD CHN4V 9389 CHNVADD
9448 CHNVDISP 9342 CHNVSTO
8F2B CHOICE COCO CLOCK
9230 DARYCLR 950B DELAYO
950A DELAY13 9507 DELAY19
93DC DISPASK 940E DISPLY
8F2C DLN1 8F20 DLN2
89F07 ENLOC 8F2F EXCLMN
8F3F EXCLS1N 9042 EXIT14
904F EXIT15 90D5 EXIT22
VM/SP CONVERSATIONAL MONITOR SYSTEM

90C5 EXIT33 8FD6 EXIT74
8FE3 EXIT75 945E EXLPNM
900F GETMULT 9078 GETSNGL
8F26 GCND 8F11 GTOT1
?8F16 GTOT2 8F1B GTOT3
?8F20 GTOT4 93EE GTOTLAPT
9284 HDLNCH0 93B3 INCX5
92D4 INITIM 8F0F INTVL
942A LAPTDISP 8F40 LAPTIM1
8F36 LAPTM2 92C8 LAPTMV
93B2 LNDISP 8FOB LNMULT
8F0D LNSNGL 9016 LOOP12
92A1 LOOP14 9254 LOOP15
921A LOOP16 9118 LOOP17
911F LOOP18 92F4 LOOP19
902F LOOP20 94D1 LOOP23
94CE LOOP24 94C9 LOOP25
93F4 LOOP27 93F2 LOOP28
90B4 LOOP32 91CA LOOP33
9006 LOOP34 909D LOOP41
9308 LOOP51 8FC3 LOOP70
92CA LOOP71 8FAA LOOP72
9480 LOOP98 9486 LOOP99
928E LPLMTST 94C3 MEMDISP
9265 MSWAIT 926E MSCHK
947A MULTADD 9101 MULTDAT
8F09 MULTZ 9184 NEXT11
933F NEXT12 9382 NEXT13
8F10 NMCHN 8F80 ORIGIN
9216 PARYCLR 94F3 PRSET
8F3C REFTIM1 8F3D REFTIM2
931E RETURN 927C SGRNCLR
923F SKIP11 9246 SKIP12
929A SKIP14 910D SKIP15
9144 SKIP16 916B SKIP17
9192 SKIP18 9347 SKIP19
93AF SKIP23 9466 SKIP26
91C5 SKIP29 9OAC SKIP31
91DE SKIP32 91E0 SKIP33
9209 SKIP34 93B3 SKIP42
9369 SKIP51 8FAO SKIP77
9456 SKIP91 94B1 SKIP95
948B SKIP97 9468 SKIP98
91CB SNGLDAT 8F03 STALOC
929D STOPM 931F STORE
FILE: HDT1  ASSM  D1  VM/SP CONVERSATIONAL MONITOR SYSTEM  PAGE 025

192 8F46 STOT1  ?8F4B STOT2
?8F50 STOT3  ?8F55 STOT4
9250 TCARYCL  8F30 TIMEIN
?92E7 TMSTEP1  92FF TMSTEP2
08 XSAV1  09 XSAV2
F9 YSAV1  EB ZGNC
06 ZLOC  CF ZLPNUM
19 ZNMCHN  07 ZPAGE
06 ZLOC  07 ZPAGE
08 XSAV1  09 XSAV2
19 ZNMCHN  1A CHN1V
1D CHN2V  CF ZLPNUM
EB ZGNC  F9 YSAV1
FA CHN3V  FD CHN4V
8F01 ARYSZ  8F03 STALOC
?8F05 ACTSTL  ?8F07 ENDCALL
8F09 MULTSZ  8F0B LNMULT
8F0D LNSNGL  8F0F INTVL
8F10 NMCHN  8F11 GTOT1
?8F16 GTOT2  ?8F1B GTOT3
?8F20 GTOT4  8F25 CHOICE
8F26 GNCD  8F2C DLN1
8F2D DLN2  8F2F EXCMLN
8F30 TIMEIN  8F36 LAPTIM2
8F3C REFTIM1  8F3D REFTIM2
8F3F EXCSLN  8F40 LAPTIM1
8F46 STOT1  ?8F4B STOT2
?8F50 STOT3  ?8F55 STOT4
8FA3 BSVLG  8FAA LOOP72
8FC3 LOOP70  8FDB EXIT74
8FE3 EXIT75  ?900F GETMULT
9016 LOOP12  902F LOOP20
9042 EXIT14  904F EXIT15
9078 GETSNGL  9084 LOOP32
909D LOOP41  90AC SKIP31
90C5 EXIT33  90DB EXIT22
9101 MULTDAT  910D SKIP15
9118 LOOP17  911F LOOP18
9144 SKIP16  916B SKIP17
9192 SKIP18  91B4 NEXT11
91C5 SKIP29  91C8 SNGLDAT
91CA LOOP33  91DE SKIP32
91E0 SKIP33  9206 LOOP34
9209  SKIP34  9216  PARYCLR
921A  LOOP16  9230  DARYCLR
923F  SKIP11  9241  LOOP14
924E  SKIP12  9250  TCARYCL
9254  LOOP15  9265  MSWAIT
926E  MSWCHK  927C  SCRNCRL
9284  HDLNCHD  928E  LPLMTST
929A  SKIP14  929D  STOPTM
92C8  LAPTMV  92CA  LOOP71
92D4  INITIM  ?92E7  TMSTEP1
92F4  LOOP19  92FF  TMSTEP2
9308  LOOP51  9313  CAPTDISP
931E  RETURN  931F  STORE
933F  NEXT12  9342  CHNVSCTO
9347  SKIP19  ?9359  ADDTN
9382  NEXT13  9383  INCX5
9389  CHNVADD  93AF  SKIP23
93B2  LNDISP  93BB  SKIP42
93C6  ARVDISP  93DC  DISPASK
93E9  SKIP51  93EE  GTOCTAPT
93F2  LOOP28  93F4  LOOP27
940E  DISPLAY  942A  LAPTDISP
9448  CHNVDISP  945E  EXLPNM
9466  SKIP91  9468  SKIP98
947A  MULTADD  9480  LOOP98
9486  LOOP99  948B  SKIP97
94B1  SKIP95  94C3  MEMDISP
94C9  LOOP25  94CE  LOOP24
94D1  LOOP23  94D6  SKIP26
94F3  PTRSET  94FE  BELL
9507  DELAY19  950A  DELAY13
950B  DELAYO  950C  CAPTN1
?9515  CAPTN2  ?951D  CAPTN3
?952E  CAPTN4  ?9538  CAPTN5
?9542  CAPTN6  ?9553  CAPTN7
COCO CLOC  CODO AI13
FILE: SYSFUL1  BAS  A1
VM/SP CONVERSATIONAL MONITOR SYSTEM

100 TEXT: HOME: FLASH: HTAB 7: PRINT "FULL CONV OF SYS-DATA": NORMAL
200 DIM A(9), B(9), C(19), D(9), E(9), G(9), GA(9)
210 GOSUB 9700: REM HIMEM SETTING
290 K = 0
300 ARYSZ = 36609 + K: STALOC = 36611 + K: ACTSTL = 36613 + K
310 ENLOC = 36615 + K: MULTSZ = 36617 + K: MLPNM = 36619 + K
320 SLPNM = 36621 + K: INERV = 36623 + K: NMCHN = 36624 + K
325 GSTAL = 36625 + K: GCND = 36646 + K: TYPE = 36651 + K
330 MEXCLN = 36655 + K: TIMEIN = 36656 + K: L2AP = 36662 + K
340 R1EF = 36668 + K: R2EF = 36669 + K: SEXCLN = 36671 + K
350 L1AP = 36672 + K: S1TAL = 36678 + K: CLSYS = 36698 + K
360 GIR = 36699 + K: XPND = 36702 + K: XCRD = 36704 + K
370 YCRD = 36706 + K: X: TEMP = 36714 + K: OHR = 36716 + K: SVLTG = 36718
380 XDTE = 36732 + K: PARA = 36608 + K: HOTI = 36736 + K
390 XDTE = 36732 + K: PARA = 36608 + K: HOTI = 36736 + K
500 D$ = CHR$(4): R$ = CHR$(13): H = 256
100 POKE 34, Z1: HOME: PRINT "DRIVE NO.?": D$
1010 POKE 34, 2: HOME: PRINT R$; D$; "CATALOG,D": D$
1020 INPUT "DATA ACQ TYPE =? (M/S)": TY$
1030 INPUT "EXP. NO. =": XP
1040 F$ = "S-" + STR$(XP) + "-" + TY$: G$ = F$ + "-TS"
1050 PRINT R$; D$; "BLOAD " + F$;",D": HOME: VTAB 2: INVERSE: PRINT F$;",D": D$: NORMAL: POKE 34, 3
1060 NC = PEEK(NMCHN): A% = 4: NP
1070 GOSUB 6000: REM GAIN CODE CALC; (D(I)), (GA(I))
1080 IF TY$ < "S" THEN GOTO 1100
1090 GOSUB 3000: GOTO 1110: REM SNGL CONV
1100 GOSUB 2000: REM MULT CONV
1110 GOSUB 4000
1120 INPUT "WANT TO CONV TS ? (Y/N)"; AN$
1130 IF LEFT$(AN$, 1) > "Y" THEN GOTO 1150
1140 PRINT R$; D$; "BLOAD "; G$;",D": HOME: VTAB 2: INVERSE: PRINT G$;",D": D$: NORMAL: POKE 34, 3: GOSUB 4500
1150 PRINT R$; D$; "RUN MENU,D1"
1160 END
2000 DS = PEEK(MULTSZ) * H + PEEK(MULTSZ - 1) : DAS = DS: DBS = DS
2010 NBD = PEEK(SEXCLN) * H + PEEK(SEXCLN - 1) : NAD = PEEK(MEXCLN) * H + PEEK(MEXCLN - 1)
2020 FOR I = 0 TO NC - 1
2030 A(I) = 0: B(I) = 0
2040 FOR K = 0 TO 4
2050 B(I) = B(I) + PEEK(S1TAL + 5 * I + K) * (H ^ K) / (DBS * NBD)
2060 A(I) = A(I) + PEEK(GSTAL + 5 * I + K) * (H ^ K) / (DAS * NAD)
2070 NEXT K
2080 B(I) = D(I) - B(I) / 4095 + GA(I): A(I) = D(I) - A(I) / 4095 / GA(I)
2090 NEXT I
2100 MSB = INT(PEEK(L2AP + 5) / 16): MTB = PEEK(L2AP + 5) - MSB * 16
2110 TBM = PEEK(L2AP + 2) * 16 + PEEK(L2AP + 3) + PEEK(L2AP + 4) / 10 + MSB / 100 + MTB / 1000
FILE: SYSFUL1 BAS A1 VM/SP CONVERSATIONAL MONITOR SYSTEM

4520 FOR I = 0 TO NC - 1
4530 A(I) = 0: B(I) = 0
4540 FOR K = 0 TO 4
4550 B(I) = B(I) + PEEK (GSTAL + 5 * I + K) + (H ^ K) / (DBS * NBD)
4560 A(I) = A(I) + PEEK (G(1) + 5 + I + K) + (H ^ K) / (DAS * NAD)
4570 NEXT K
4580 NEXT I
4590 MSA = INT ( PEEK (L1AP + 5) / 16): MTA = PEEK (L1AP + 5) - MSA * 16
4600 TAM = PEEK (L1AP + 2) * 16 + PEEK (L1AP + 3) + PEEK (L1AP + 4) / 10 + MSA / 100 + MTA / 1000
4610 POKE 1401, 80: HOME
4620 INPUT 3130
4630 3120 MSA
4640 3110
4650 3100 NEXT I
4660 3090 MSA = INT ( PEEK (L2AP + 5) / 16): MTA = PEEK (L2AP + 5) - MSA * 16
4670 3110 TAM = PEEK (L2AP + 2) * 16 + PEEK (L2AP + 4) / 10 + MSA / 100 + MTA / 1000
4680 3120 RETURN : END
4690 FILE: SYSFUL1 BAS A1 VM/SP CONVERSATIONAL MONITOR SYSTEM
4540 PT = SP + J * A% * NC
4550 FOR I = 0 TO NC - 1
4560 B(I) = 0: PR = PT + I * A%
4570 FOR K = 0 TO A% - 1
4580 B(I) = B(I) + PEEK (PR + K) * (H ^ K) / DAS: NEXT K
4590 B(I) = B(I) * D(I) / 4095 / GA(I)
4600 NEXT I
4610 PRINT R$;J + 1;":"
4620 FOR I = 0 TO NC - 1
4630 TP = I * 18 + 7: TP = TP - INT (TP / 40) * 40: IF PEEK (36) = > TP THEN TP = TP + 40
4640 PRINT TAB( TP);"C";I + 1;"=";B(I);
4650 NEXT I;
4660 FOR I = 0 TO NC - 1
6010 G(I) = INT (PEEK (GNCD + 4 - I) / 16): C(I) = PEEK (GNCD + 4 - I) - G(I) * 16: D(I) = G(I)
6020 IF D(I) > = 4 THEN D(I) = D(I) - 4
6030 B% = INT (D(I) / 2 + 0.5): C% = D(I) - INT (D(I) / 2) * 2
6040 D(I) = 5 * ((2 ^ C%) / (10 ^ B%))
6045 GA(I) = PEEK (G1R + I) / 100
6048 E(I) = PEEK (SVLTG + 2 + I) * H + PEEK (SVLTG + 2 + I + 1): E(I) = E(I) / 1E3
6050 NEXT I
6060 RETURN : END
9700 C = PEEK (116): D = PEEK (115): GOSUB 9900
9710 VTAB 3: PRINT "PRESENT HIMEM=": TAB(33): A$
9720 VTAB 4: HTAB 32: PRINT ":": D + C * 256: Z1 = PEEK (37)
9730 VTAB 5: PRINT "WANT TO CHANGE HIMEM Y/N?": VTAB 5: HTAB 32: GET AN$
9740 IF AN$ > < "Y" THEN GOTO 9780
9750 VTAB 5: HTAB 1: PRINT "INPUT NEW HIMEM "
9755 VTAB 5: HTAB 17: INVERSE : PRINT "(4-HEX;$XXXX)=": NORMAL : VTAB 5: HTAB 32: INPUT A$
9760 GOSUB 9800: B = C * 256 + D: VTAB 6: HTAB 32: PRINT ":": B
9770 HIMEM: B: Z1 = PEEK (37)
9780 POKE 34, Z1: HOME : RETURN : END
9800 FOR I = 2 TO 5
9810 A(I) = ASC (MID$ (A$, I, 1))
9820 IF A(I) = < 57 THEN A(I) = A(I) - 48: GOTO 9840
9830 A(I) = A(I) - 55
9840 NEXT I
9850 C = A(2) * 16 + A(3): D = A(4) * 16 + A(5)
9860 RETURN : END
9900 A(I) = INT (C / 16): A(2) = C - A(1) * 16: A(3) = INT (D / 16): A(4) = D - A(3) * 16: A$ = "$$
9910 FOR I = 1 TO 4
9920 IF A(I) < 10 THEN A$ = A$ + STR$ (A(I)): GOTO 9940
9930 A(I) = A(I) + 55: A$ = A$ + CHR$ (A(I))
9940 NEXT I
9950 RETURN : END
100 TEXT : HOME : FLASH : HTAB 7: PRINT "VOLTAGE--VELOCITY CONV": NORMAL
110 HIMEM: 36864: REM 36864=$9000
200 DIM A(9),B(9),C(19),D(9),E(9),GA(9)
205 DIM BV(255),AV(255),XR(255),YH(255),ZA(255),DAS(255),NAD(255),TAM(255),RG(255),VE(255),GT(255)
500 D$ = CHR$ (4):R$ = CHR$ (13)
1000 VTAB 3: INPUT "ENTER NATURAL CONV CONST = ";NT
1010 INPUT "ENTER FORCED CONV CONST = ";ZT
1020 GOSUB 4000: REM CAL-COEFF READING
1030 GOSUB 5000: REM OLD SYSASSY READING
1050 FOR I = 0 TO SZ - 1
1060 GOSUB 3000
1065 VE(I) = V2:GT(I) = GD
1070 GOSUB 2000: PRINT
1075 K = I
1080 INPUT "CONTINUE? (Y/N) ":AN$: IF LEFT$(AN$,1) > < "Y" THEN GOTO 1100
1090 NEXT I
1100 GOSUB 5500
1110 PRINT R$;D$;"RUN MENU,D1"
1120 END
2000 POKE 34,2: HOME : FOR J = 1 TO 39: PRINT ":"; NEXT J: PRINT
2010 PRINT "EXP NO= ":I + NO; TAB(16);"COEFF FN= ":CF$: TAB(41);"BV= ";BV(I);" V": TAB(21);"AV= ";AV(I);" V"
2020 PRINT "X/R= ";XR(I);" CM"; TAB(21);"Y/O= ";YH(I);" CM"; TAB(41);"Z= ";ZA(I);" CM"; TAB(21);"REC GN= ";RG(I)
2030 PRINT "TOT DAT PTS= ";DAS(I);" *= ";NAD(I);" = ";DAS(I) + NAD(I); TAB(41);"TOT MEAS TM= ";TAM(I);" SEC"
2050 PRINT "MEAN VELOCITY= ";VE(I);" CM/SEC"; TAB(41);"GRADIENT= ";GT(I);" (CM/SEC)/VOLT"
2060 FOR J = 1 TO 39: PRINT "**": NEXT J: PRINT
2070 RETURN : END
3000 V1 = 1.39
3010 AL = .0016
3020 OH = .20
3030 DT = OH / AL
3040 RP = 5.01 * (1 + OH) - 0.2
3050 BT = RP / (10 + RP) ^ 2
3060 SN = (NT ^ .8) * (BT ^ (- .2)) * EO ^ (-.4)
3070 DR = DT / BT * (1 / BV(I) ^ 2 - 1 / EO ^ 2)
3080 SO = (NT ^ .8) * (BT ^ (- .2)) * BV(I) ^ (-.4)
3090 SC = SO - SN
3100 TC = SN / (ZT + V1 ^ (-.4) + SN) - SO / (ZT + V1 ^ (-.4) + SO)
3110 TS = TC * ZT + V1 ^ (-.4)
3120 DC = DR - SC - TS
3130 VG = 1 / AV(I) ^ 2 - BT * DC / DT
3140 VT = (1 / VG) ^ .5
3150 VN = VT - EO
3160 V2 = C(0) + C(1) * VN + C(2) + VN ^ 2 + C(3) * VN ^ 3 + C(4) * VN ^ 4
3170 ER = (V2 - V1) / V1:ER = ER * 100
3180 EL = 1
IF ABS(ER) > EL THEN V1 = V2
IF ABS(ER) > EL THEN GOTO 3100
GD = C(1) + 2 * C(2) + VN + 3 * C(3) + VN^2 + 4 * C(4) + VN^3
RETURN

INPUT "COEFF FILE NAME = "; CF$;
PRINT R$; D$: "OPEN "; CF$; ";,D2"
PRINT R$; D$: "READ "; CF$;
INPUT C(0), C(1), C(2), C(3), C(4)
INPUT EO
PRINT R$; D$: "CLOSE "; CF$;
RETURN

INPUT "SYS-ASSY FILE NAME = "; F$;
PRINT R$; D$: "OPEN "; F$; ";,D2"
PRINT R$; D$: "READ "; F$;
INPUT SZ, NO, N9
FOR I = 0 TO SZ - 1
INPUT BV(I), AV(I), XR(I), YH(I), ZA(I), DAS(I), NAD(I), TAM(I), RG(I)
PRINT R$; D$: "CLOSE "; F$;
RETURN

INPUT "REFINED SYS-ASSY FILE NAME= "; G$;
SZ = K + 1
PRINT R$; D$: "OPEN "; G$; ";,D2"
PRINT R$; D$: "DELETE "; G$;
PRINT R$; D$: "OPEN "; G$;
PRINT R$; D$: "WRITE "; G$;
PRINT SZ; ";:NO:": ";NO + SZ - 1:":; CF$;
FOR I = 0 TO SZ - 1
PRINT VE(I); ";:GT(I):": ";XR(I):": ";YH(I):": ";ZA(I):": ";DAS(I):": ";NAD(I):": ";TAM(I):": ";RG(I)
NEXT I
PRINT R$; D$: "CLOSE "; G$;
RETURN

HOME : HTAB 5: INVERSE : PRINT "AUTOCORRELATION ENTRY MODE": NORMAL
VTAB 7
PRINT ";:TIME": ";TC(1): PRINT TAB( 5); "AUTOCORR": ";AC(1)
PRINT ";:TIME": ";TC(2): PRINT TAB( 5); "AUTOCORR": ";AC(2)
PRINT ";:TIME": ";TC(3): PRINT TAB( 5); "RECORDER SCALE FACTOR": ";SF
VTAB 5: PRINT "H FOR HELP"
NORMAL : PRINT
PRINT TAB( 5); "X FOR NO CHANGE"
VTAB 18
HTAB 10: PRINT "WHICH? ": GET A$
VTAB 20
IF A$ = "1" THEN INPUT "1)...TIME,AUTOCORR= ";TC(1),AC(1)
IF A$ = "1" THEN GOTO 6000
IF A$ = "2" THEN INPUT "2)...TIME,AUTOCORR= ";TC(2),AC(2)
IF A$ = "2" THEN GOTO 6000
IF A$ = "3" THEN INPUT "SCALE FACTOR= ";SF
IF A$ = "3" THEN GOTO 6000
IF A$ = "X" THEN RETURN
IF A$ = "X" THEN RETURN
IF A$ = "H" THEN GOSUB 7500
IF A$ = "H" THEN GOTO 6000
RETURN:
END
REM ...
PRINT OUT SECTION FOR SPECTRAL CHARACTERISTICS
PRINT
PRINT "MICROSCALE= ";LM(2);"CMS"
PRINT
PRINT "FLUC.VELOCITY,FROM AUTOCORR= ";TV(2);"CM/S"
PRINT
PRINT "DISSIPATION ENERGY= ";EP(1);"WATTS"
PRINT
PRINT "KINETIC ENERGY= ";KE(1);"WATTS"
FOR I = 1 TO 35: PRINT ": NEXT I: PRINT
RETURN:
END
REM .. AUTOCORR READ OUT HELP SEGMENT
HOME
INPUT "MIN. ON TIME SCALE? ";XL(1)
INPUT "MAX. ON TIME SCALE? ";XL(2)
INPUT "SPAN IN CMS? ";XL(3)
INPUT "DIST.YOU WISH TO INTERPRET? ";XL(4)
INVERSE: PRINT "END OF TIME-AXIS INPUT": NORMAL
INPUT "MIN. ON AUTOCORR SCALE? ";YL(1)
INPUT "MAX. ON AUTOCORR SCALE? ";YL(2)
INPUT "SPAN IN CMS? ";YL(3)
INPUT "DIST.YOU WISH TO INTERPRET? ";YL(4)
INVERSE: PRINT "END OF INPUT": NORMAL
XL(5) = (XL(2) - XL(1)) * XL(4) / XL(3)
YL(5) = (YL(2) - YL(1)) * YL(4) / YL(3)
7640 TC(1) = 0: TC(2) = XL(5)
7650 AC(2) = YL(5) + YL(1)
7660 RETURN : END
THIS ROUTINE CONTROLS THE PLOTTER AND WRITES COORDINATE DATA TO DISK

TEXT: HOME: FLASH: HTAB 7: PRINT "SPECTRUM CO-OR SAVE": NORMAL

HIMEM: 36864: REM 36864=$9000

DIM SV%(1,1023),KL(255),ED(255),DD(255)

PTRED = 36992:CNTRL = 25

D$ = CHR$ (4):R$ = CHR$ (13):YS = 10.6

PRINT R$;D$;"BLOAD PLTRED1.OBJO,D1"

POKE 34,2: HOME: VTAB 3

PRINT "1.INSERT PLOT ON PLOTTER"

PRINT "2.LOCATE THE PEN AT ORIGIN"

PRINT "4.(I,J,K,M)=CTRL KEY FOR FAST PEN MOVE"

PRINT "5.(J)=STORE CO-OR INTO MEMORY"

PRINT "6.<CR>=END KEY FOR CO-OR READING"

PRINT "1,10 HZ MK MUST BE READING #1 & #2": NORMAL

PRINT "PRESS ANY KEY TO START": GET AN$:

CALL PTRED

TP = PEEK (CNTRL) + PEEK (CNTRL + 1) * 256

NP = TP - 2

PRINT TAB(2);NP:" DATA POINTS ARE TAKEN"

GOSUB 5000

INPUT "WANT TO CONTINUE? (Y/N) ";AN$:

IF LEFT$ (AN$,1) > "N" THEN GOTO 1100

PRINT R$;D$;"RUN MENU,D1"

END

CALL PTRED

INPUT "WANT TO PRINT OUT? (Y/N) ";AN$:

IF LEFT$ (AN$,1) = "N" THEN GOTO 2030

PRINT R$;D$;"PR#0"

RETURN:

END

INTEGRATING..."

XO% = SV%(0,0):X1% = SV%(0,1)

FOR I = 2 TO TP - 1

KL(I - 1) = (SV%(1,1) - XO%) / (X1% - XO%) / (YS * 78.74)

ED(I - 1) = EO + SV%(1,I) * (EO - EO) / (YS * 78.74)

DD(I - 1) = 20 * KL(I) + ED(I)

NEXT I

INTEGRATE FOR KE AND EP

INTEGRATION USES TRAPEZOIDAL RULE
3080 KE = 0.0
3090 EP = 0.0
3100 FOR I = 1 TO NP - 1
3110 DK = 10^KL(I+1) - 10^KL(I)
3120 EM = (10^ED(I+1)/10) + 10^ED(I)/10)/2
3130 DM = (10^DD(I+1)/10) + 10^DD(I)/10)/2
3140 KE = KE + EM * DK
3150 EP = EP + DM * DK
3160 NEXT I
3170 RETURN ; END
5000 REM SAVE COORDINATE SET TO DISK
5030 INPUT "ENTER MIN., MAX ON DB SCALE ";EO,E2
5040 INPUT "EXPERIMENT # = ";F$
5050 F$ = "SPEC-" + F$
5060 YS = 5.5
5070 PRINT R$;D$;"OPEN ";F$;",".D2"
5075 PRINT R$;D$;"DELETE ";F$;
5080 PRINT R$;D$;"OPEN ";F$
5085 PRINT R$;D$;"WRITE ";F$
5090 PRINT NP
5100 PRINT EO;",";E2
5110 FOR I = 0 TO TP - 1
5120 PRINT SV%(0,I);",";SV%(1,I)
5130 NEXT I
5140 PRINT R$;D$;"CLOSE ";F$
5150 HOME : PRINT F$;",".D2 SAVE COMPLETED"
5160 RETURN ; END
100 TEXT : HOME : FLASH : HTAB 7: PRINT "SPECTRUM ANALYSIS": NORMAL
110 HIMEM: 36864: REM 36864=$9000
200 DIM SV%(1,255),KL(255),ED(255),DD(255),KE(255),EP(255)
500 D$ = CHR$ (4):R$ = CHR$ (13):YS = 10.6
1000 VBAT 3: INPUT "STARTING/FINAL EXP NO = ":NO,N9
1010 FOR XN = NO TO N9
1020 F$ = "SPEC-" + STR$(XN): GOSUB 5000: REM DATA READ
1030 GOSUB 3000: REM CALCULATION STEP
1040 GOSUB 2000: REM RESULT PRINT
1050 K = XN - NO:KE(K) = KE:EP(K) = EP
1060 INPUT "CONTINUE? (Y/N) ":AN$: IF LEFT$(AN$,1) > < "Y" THEN GOTO 1080
1070 NEXT XN
1080 GOSUB 5500
1090 PRINT R$;D$;"RUN MENU,D1"
1100 END
2000 POKE 34,2: HOME: VTAB 3
2010 INPUT "WANT TO PRINT OUT? (Y/N) ":AN$: IF LEFT$(AN$,1) = "N" THEN GOTO 2030
2020 PRINT R$;D$;"PR#1": POKE 1401,80
2030 HOME: VTAB 3
2040 FOR I = 1 TO 39: PRINT "*": NEXT I: PRINT
2050 PRINT "EXPERIMENT NO = ":XN
2060 PRINT "KINETIC ERG(VOLT^2) = ":KE
2070 PRINT "DISSIP ERG(VOLT^2) = ":EP
2080 FOR I = 1 TO 39: PRINT "*": NEXT I: PRINT
2090 PRINT R$;D$;"PR#0"
2100 RETURN : END
3000 POKE 34,2: HOME: VTAB 3: PRINT F$;" INTEGRATING..."
3010 FOR I = 1 TO SZ
3020 KL(I) = (SV%(0,I) - XO%) / (X1% - XO%)
3030 ED(I) = EO + SV%(1,I) * (E2 - EO) / (YS * 78.74)
3040 DD(I) = 20 * KL(I) + ED(I)
3050 NEXT I
3060 REM INTEGRATE FOR KE AND EP
3070 REM INTEGRATION USES TRAPEZOIDAL RULE
3080 KE = 0.0
3090 EP = 0.0
3100 FOR I = 1 TO SZ - 1
3110 DK = 10 ^ KL(I + 1) - 10 ^ KL(I)
3120 EM = (10 ^ (ED(I + 1) / 10) + 10 ^ (ED(I) / 10)) / 2
3130 DM = (10 ^ (DD(I + 1) / 10) + 10 ^ (DD(I) / 10)) / 2
3140 KE = KE + EM * DK
3150 EP = EP + DM * DK
3160 NEXT I
3170 RETURN : END
5000 POKE 34,2: HOME: VTAB 3: PRINT F$;" READING..."
**FILE: SPECAN **

5010 PRINT R$;D$;"OPEN ";F$;";D$"
5020 PRINT R$;D$;"READ ";F$
5030 INPUT SZ
5040 INPUT EO,E2
5050 INPUT XO%,YO%
5060 INPUT X1%,Y1%
5070 FOR I = 1 TO SZ
5080 INPUT SV%(0,I),SV%(1,I)
5090 NEXT I
5100 PRINT R$;D$;"CLOSE ";F$
5110 RETURN: END

5500 INPUT "SPEC-ASSY FILE NAME = ";G$
5510 SZ = K + 1
5520 PRINT R$;D$;"OPEN ";G$;";D$"
5530 PRINT R$;D$;"DELETE ";G$
5540 PRINT R$;D$;"OPEN ";G$
5550 PRINT R$;D$;"WRITE ";G$
5560 PRINT SZ;";NO:*;NO*SZ - 1
5570 FOR I = 0 TO SZ - 1
5580 PRINT KE(I);";EP(I)
5590 NEXT I
5600 PRINT R$;D$;"CLOSE ";G$
5610 RETURN: END
100 TEXT: HOME: FLASH: HTAB 7: PRINT "K.E. & D.E. CALCULATION": NORMAL
110 HIMEM: 36864: REM 36864 = $9000
200 DIM A(9), B(9), C(19), D(9), E(9), GA(9)
205 DIM VE(255), GT(255), XR(255), YH(255), ZA(255), DAS(255), NAD(255), TAM(255), RG(255), KE(255), DE(255)
500 D$ = CHR$ (4): R$ = CHR$ (13)
1000 VTAB 3: GOSUB 4000: REM REF'NED SYS FILE READING
1010 GOSUB 5000: REM OLD SPECASY READING
1020 FOR I = 0 TO SZ - 1
1030 OK = KE(I): OD = DE(I)
1040 GOSUB 3000
1050 GOSUB 2000: PRINT
1055 K = I
1060 INPUT "CONTINUE? (Y/N) "; AN$: IF LEFT$(AN$, 1) > "Y" THEN GOTO 1080
1070 NEXT I
1080 GOSUB 5500
1090 PRINT R$: D$; "RUN MENU,D1"
1100 END
2000 POKE 34, 2: HOME: FOR J = 1 TO 39: PRINT "*": NEXT J: PRINT
2010 PRINT "EXP NO= "; I + NO: TAB(16): "COEFF FN= "; CF$
2015 PRINT "KE= "; (3 / 2) * (GT(I) / 100 / RG(I)) ^2): KE(I)
3100 DE(I) = (1.54E - 4 / (VE(I) / 100) ^2): DE(I)
3200 RETURN: END
4000 INPUT "REF'NED SYS FILE NAME= ": F$
4010 PRINT R$: D$: "OPEN "; F$: "D2"
4020 PRINT R$: D$: "READ "; F$
4030 INPUT SZ, NO, N9, CF$
4040 FOR I = 0 TO SZ - 1
4050 INPUT VE(I), GT(I), XR(I), YH(I), ZA(I), DAS(I), NAD(I), TAM(I), RG(I)
4060 NEXT I
4070 PRINT R$: D$: "CLOSE "; F$
4080 RETURN: END
5000 INPUT "SPEC-ASSY FILE NAME= ": H$
5010 PRINT R$: D$: "OPEN "; H$: "D2"
5020 PRINT R$: D$: "READ "; H$
5030 INPUT SZ, NO, N9
5040 FOR I = 0 TO SZ - 1
5050 INPUT KE(I), DE(I)
5060 NEXT I
5110 PRINT R$:D$;"CLOSE ":G$
5120 RETURN : END
5500 INPUT "FINAL DATA FILE NAME= ":G$
5510 SZ = K + 1:SF = 1E3
5520 PRINT R$:D$;"OPEN ":G$,.D2"
5530 PRINT R$:D$;"DELETE ":G$
5540 PRINT R$:D$;"OPEN ":G$
5550 PRINT R$:D$;"WRITE ":G$
5560 Y$ = **
5570 Z$ = STR$(SZ):L = 6: GOSUB 8100
5580 Z$ = STR$(NO):L = 6: GOSUB 8100
5590 Z$ = STR$(NO + SZ - 1):L = 6: GOSUB 8100
5600 Z$ = STR$(SF):L = 6: GOSUB 8100
5610 Z$ = CF$:L = 10: GOSUB 8100
5620 PRINT Y$
5630 FOR I = 0 TO SZ - 1
5640 Y$ = **
5650 Z = XR(I):Z = Z * SF:L = 5: GOSUB 8000
5660 Z = YH(I):Z = Z * SF:L = 5: GOSUB 8000
5670 Z = ZA(I):Z = Z * SF:L = 5: GOSUB 8000
5680 Z = VE(I):L = 12: GOSUB 8500
5690 Z = KE(I):L = 12: GOSUB 8500
5700 Z = DE(I):L = 12: GOSUB 8500
5710 Z = DAS(I):L = 4: GOSUB 8000
5720 Z = NAD(I):L = 4: GOSUB 8000
5730 Z = TAM(I):L = 12: GOSUB 8500
5735 PRINT Y$
5740 NEXT I
5750 PRINT R$:D$;"CLOSE ":G$
5760 RETURN : END
8000 Z$ = STR$(Z)
8100 IF LEN(Z$) = L THEN GOTO 8120
8110 FOR M = 1 TO L - LEN(Z$):Z$ = " " + Z$: NEXT M
8120 Y$ = Y$ + Z$
8130 RETURN : END
8500 IF Z = 0 THEN Z$ = "0 ":SG$ = " ":PO$ = "00 ":SP$ = ":GOTO 8640
8510 IF SGN(Z) = -1 THEN Z = ABS(Z):SG$ = "-" :GOTO 8530
8520 SG$ = "+
8530 X = LOG(Z) / LOG(10):X1 = ABS(INT(X))
8540 ON SGN(X) + 2 GOTO 8550,8560,8570
8550 FOR XX = 1 TO X1:Z = Z + 10: NEXT XX:SP$ = ":GOTO 8590
8560 SP$ = " ":GOTO 8590
8570 IF X1 = 0 THEN GOTO 8560
8580 FOR XX = 1 TO X1:Z = Z / 10: NEXT XX:SP$ = " ":GOTO 8590
8590 IF LEN(STR$(Z)) = 1 THEN Z$ = STR$(Z) + ":GOTO 8610
8600  Z$ = STR$ (Z)
8610  IF  INT (X1 / 10) > 0 THEN PO$ = STR$ (X1): GOTO 8630
8620  PO$ = "0" + STR$ (X1)
8630  Z1$ = LEFT$ (Z$.L - 5)
8640  Z$ = SG$ + Z1$ + "E" + SP$ + PO$
8650  GOSUB 8100
8660  RETURN  :  END
100 TEXT : HOME : FLASH : HTAB 7: PRINT "MAKING NORMALIZED CALASSY": NORMAL
210 HIMEM : 36864 : REM 36864=$9000
500 D$ = CHR$(4):R$ = CHR$(13)
1000 VTAB 3: INPUT "ENTER NATURAL CONV CONSTANT = ";NT
1010 INPUT "ENTER FORCED CONV CONSTANT = ";ZT
1020 INPUT "ENTER NEW BASE VOLTAGE = ";EO
1030 GOSUB 5000 : REM OLD CALASSY READING
1040 GOSUB 3000: POKE 34,2: HOME
1050 FOR I = 0 TO SZ - 1
1060 GOSUB 3500: PRINT
1070 GOSUB 2000: PRINT
1080 INPUT "CONTINUE? (Y/N) ";AN$: IF LEFT$(AN$,1) = "N" THEN GOTO 1100
1090 NEXT I
1100 GOSUB 5500
1110 PRINT R$;D$;"RUN MENU, DI"
1120 END
2000 PRINT
2010 PRINT "XP= ";I + NO; TAB(11):"BV= ";BV(I); TAB(26):"AV= ";AV(I);";
2020 PRINT TAB(41);"E0= ";EO; TAB(26);"CV= ";CV(I); TAB(26);"VE= ";VE(I)
2030 RETURN : END
3000 AL = .0016
3010 OH = 0.20
3020 DT = OH / AL
3030 RP = 5.01 * (1 + OH) - .2
3040 BT = RP / (10 + RP) ^ 2
3050 SN = (NT ^ .8) * (BT ^ (.2)) * EO ^ (-.4)
3060 RETURN : END
3500 DR(I) = DT / BT * (1 / BV(I) ^ 2 - 1 / EO ^ 2)
3510 SO = (NT ^ .8) * (BT ^ (.2)) * BV(I) ^ (-.4)
3520 TC = SN / (2T + VE(I) ^ (-.4) + SN) - SO / (2T + VE(I) ^ (.4) + SO)
3530 TC = TC * ZT * VE(I) ^ (.4)
3540 SC = SO - SN
3550 DR(I) = DR(I) - SC - TC
3560 V2 = 1 / AV(I) ^ 2 - BT * DR(I) / DT
3570 CV(I) = (1 / V2) ^ .5
3590 RETURN : END
5000 INPUT "CAL-ASSY FILE NAME = ";F$
5010 PRINT R$;D$;"OPEN ":F$; .D2"
5020 PRINT R$;D$;"READ ":F$
5030 INPUT S2,NO,N9
5040 FOR I = 0 TO SZ - 1
5050 INPUT BV(I),AV(I),VE(I)
5060 NEXT I
FILE: DRIFT  CALC  A1
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5110 PRINT R$:D$;"CLOSE ":F$
5120 RETURN : END
5500 INPUT "REFINED CAL DATA F.N.= ":G$
5505 SZ = K + 1
5510 FOR I = 0 TO SZ / 2 - 1
5520 AV(I) = (CV(2 * I) + CV(2 * I + 1)) / 2
5530 CE(I) = (VE(2 * I) + VE(2 * I + 1)) / 2
5540 NEXT I
5550 PRINT R$:D$;"OPEN ";G$;,D2"
5560 PRINT R$:D$;"DELETE ";G$
5564 PRINT R$:D$;"OPEN ";G$
5570 PRINT R$:D$;"WRITE ";G$
5580 PRINT EO;",",SZ / 2 + 1
5585 PRINT EO;",",O."
5600 FOR I = 0 TO SZ / 2 - 1
5610 PRINT AV(I);",",CE(I)
5620 NEXT I
5630 PRINT R$:D$;"CLOSE ";G$
5640 RETURN : END
FILE: PLTCAL   BAS   A1
VM/SP CONVERSATIONAL MONITOR SYSTEM

100 TEXT : HOME : FLASH : HTAB 7: PRINT "PLOTTING CAL-CURVE": NORMAL
200 DIM PL(1,19),CM(1,13),CP$(1,0),CM$(0)
210 DIM B%(9),A$(19),CV%(1,1023),A(1,15)
220 GOSUB 6700: REM HIMEM SETTING SUBR
230 START = 36992:FRAME = 37004:ZLNDRW = 37118:MKTIC = 37221
240 CAPTIC = 37397:CURVE = 37513:DOTPLT = 37617
250 COMMENT = 37662:ENPLT = 37711:LINDRW = 37826
260 RTT = 38338:WDT = 38340:HGT = 38342
270 TCNM = 38344:TSFT = 38346:TLNG = 38348:FLAG = 38350
280 XREF = 38353:YREF = 38355:XLIM = 38357:YLIM = 38359
290 CMARY = 38369:CVARY = 38371:XRAD = 38373:YRAD = 38375
300 XZERO = 38361:YZERO = 38363:CRARY = 38365:CPARY = 38367
310 XH = 38377:YH = 38379:LPNMH = 38381:SYMBOL = 38383
1000 POKE 34,6: HOME
1010 PRINT "PLT-DEFAULTS READ & PLOT START "
1020 GOSUB 3000: REM PLT-DEFAULTS READ
1030 REM INITIALIZE PLOTTER
1100 REM FRAME (PL(I,J :I=0,1;J=0,1))
1110 POKE 34,6: HOME
1120 I1 = 0:J1 = 0:J2 = 1: GOSUB 4000: PRINT "FRAME DRAW ": VTab 9
1130 INPUT "WANT TO CHANGE ? (Y/N) ":;AN$: IF LEFT$(AN$,1) = "N" THEN GOTO 1150
1140 GOSUB 4200: GOTO 1110
1150 GOSUB 7000: CALL FRAME: REM (XREF,YREF,XLIM,YLIM)
1200 REM ZLNDRW (PL(I,J :I=0,1;J=0,1,2,3,4)
1210 POKE 34,6: HOME
1220 I1 = 0:J1 = 0:J2 = 1: GOSUB 4000: PRINT "ZERO AXIS DRAW ": VTab 9
1230 INPUT "WANT TO CHANGE ? (Y/N) ":;AN$: IF LEFT$(AN$,1) = "N" THEN GOTO 1250
1240 GOSUB 4200: GOTO 1210
1250 GOSUB 7100: CALL ZLNDRW: REM ((X/Y)ZERO,(X/Y)REF,(X/Y)LIM,FLAG(X/Y))
1300 POKE 34,6: HOME
1310 I1 = 0:J1 = 0:J2 = 1: GOSUB 4000: PRINT "TIC MARK DRAW ": VTab 9
1320 I1 = 0:J1 = 0:J2 = 1: GOSUB 4000: PRINT "TIC MARK DRAW ": VTab 9
1330 INPUT "WANT TO CHANGE ? (Y/N) ":;AN$: IF LEFT$(AN$,1) = "N" THEN GOTO 1350
1340 GOSUB 4200: GOTO 1310
1350 GOSUB 7200: CALL MKTIC: REM ((X/Y)ZERO,TCMN(X/Y),TSFT(X/Y),TLNG(X/Y),CRARY,CR%(J,K))
1400 REM CAPTIC (PL(I,J :I=0,1;J=0,1,2,3,4,5,6)
1410 POKE 34,6: HOME
1420 I1 = 0:J1 = 0:J2 = 1: GOSUB 4000: PRINT "TIC CAPT DRAW ": VTab 9
1430 I1 = 0:J1 = 0:J2 = 1: GOSUB 4000: PRINT "TIC CAPT DRAW ": VTab 9
1440 INPUT "WANT TO CHANGE PL ? (Y/N) ":;AN$: IF LEFT$(AN$,1) = "N" THEN GOTO 1480
1470 GOSUB 4200
1480 INPUT "WANT TO CHANGE CP$ ? (Y/N) "; AN$: IF LEFT$(AN$, 1) = "N" THEN GOTO 1500
1490 GOSUB 4300: GOTO 1410
1500 GOSUB 1000: CALL CAPTIC: REM (RTT(X,Y), WDT(X,Y), HGT(X,Y), (X/Y)ZERO, TCNM(X/Y), (CR/CP)ARY, CP$(I,O), CR%(, K)
1600 REM REDATA (PL(I,J :I=0; J=13, 14)
1610 POKE 34, 6: HOME: PRINT "READ DATA": VTAB 9
1620 I1 = 0: I2 = 1: J1 = 13: J2 = 14: GOSUB 4000: PRINT
1630 INPUT "WANT TO CHANGE ? (Y/N) "; AN$: IF LEFT$(AN$, 1) = "N" THEN GOTO 1650
1640 GOSUB 4200: GOTO 1610
1650 GOSUB 3300
1700 REM CURVE/DOTPLT (PL(I,J :I=0; J=2, 3, 13, 14, 15, 16). PL(1,17))
1710 POKE 34, 6: HOME: PRINT "CURVE/DOT PLOT ": VTAB 9
1720 I1 = 0: I2 = 1: J1 = 2: J2 = 3: GOSUB 4000
1730 I1 = 0: I2 = 1: J1 = 13: J2 = 14: GOSUB 4000: PRINT TAB(22); "PL(1,17) = ": PL(1,17): PRINT
1740 INPUT "WANT TO CHANGE ? (Y/N) "; AN$: IF LEFT$(AN$, 1) = "N" THEN GOTO 1760
1750 GOSUB 4200: GOTO 1710
1760 A = 2: GOSUB 7700
1770 ON A GOTO 1780, 1790
1780 CALL CURVE: GOTO 1795: REM (LPNMH, SYMBOL, RTT, WDT, HGT, CV%(I,K), CVARY)
1790 CALL DOTPLT: REM (LPNMH, SYMBOL, RTT, WDT, HGT, CV%(I,K), CVARY)
1795 INPUT "CONTINUE TO DOT- PLOT? (Y/N) "; AN$: IF LEFT$(AN$, 1) = "Y" THEN GOTO 1600
1800 REM REDATA (PL(I,J :I=0; J=2, 3, 13, 14)
1810 POKE 34, 6: HOME: PRINT "CURVE/DOT PLOT ": VTAB 9
1815 I1 = 0: I2 = 1: J1 = 13: J2 = 16: GOSUB 4000: PRINT
1820 I1 = 0: I2 = 1: J1 = 13: J2 = 14: GOSUB 4000: PRINT
1830 INPUT "WANT TO CHANGE ? (Y/N) "; AN$: IF LEFT$(AN$, 1) = "N" THEN GOTO 1850
1840 GOSUB 4200: GOTO 1810
1850 GOSUB 4500: REM CAL-COEFF FILE READING & CALC
1890 REM CURVE/DOTPLT (PL(I,J :I=0; J=2, 3, 13, 14, 15, 16). PL(1,17))
1910 POKE 34, 6: HOME: PRINT "CURVE/DOT PLOT ": VTAB 9
1915 I1 = 0: I2 = 1: J1 = 13: J2 = 16: GOSUB 4000: PRINT TAB(22); "PL(1,17) = "; PL(1,17): PRINT
1920 INPUT "WANT TO CHANGE ? (Y/N) "; AN$: IF LEFT$(AN$, 1) = "N" THEN GOTO 1960
1930 GOSUB 4200: GOTO 1910
1950 A = 2: FLASH: PRINT "PLOTTER CO-OR'S CALCULATING": NORMAL: GOSUB 7700
1990 CALL DOTPLT: REM (LPNMH, SYMBOL, RTT, WDT, HGT, CV%(I,K), CVARY)
1995 INPUT "CONTINUE TO CURVE- PLOT? (Y/N) " ; AN$: IF LEFT$(AN$, 1) = "Y" THEN GOTO 1800
2000 REM COMMENT (R,W, HT, X,Y, CM$(O))
2010 POKE 34, 6: HOME: PRINT "COMMENT DRAW ": VTAB 9
2020 GOSUB 4400
2030 GOSUB 8000: CALL COMMENT: REM (RTT, WDT, HGT, (X/Y)CRD, CMARY, CM$(O))
2040 INPUT "WANT TO CONTINUE ? (Y/N) "; AN$: IF LEFT$(AN$, 1) > < "N" THEN GOTO 2020
2050 POKE 34, 6: HOME: PRINT " PLOT END & PLT-DEFAULTS SAVE ":
GOSUB 3100: REM PLT-DEFAULTS SAVE
PRINT R$;D$;"RUN MENU,D1"
END

REM GENERAL LINE DRAW
POKE 34,6: HOME: PRINT " GENERAL LINE DRAW": POKE 34,8: VTAB 9
INPUT "A(0,11),A(1,11),A(0,12),A(1,12):RAW VALUE = ":A(0,11),A(1,11),A(0,12),A(1,12)
GOSUB 8100: CALL LINDRW
INPUT "CONTINUE? (Y/N) ":ANS$
IF LEFT$(ANS$,1) > "N" GOTO 2520

FM$ = "CALDEF"
PRINT R$;D$;"OPEN ";FM$;",D1": PRINT R$;D$;"READ ";FM$
FOR J = 0 TO 19
INPUT PL(0,J),PL(1,J)
NEXT J
INPUT CP$(0,0): INPUT CP$(1,0)
PRINT R$;D$;"CLOSE ";FM$
RETURN:

FM$ = "CALDEF"
PRINT R$;D$;"OPEN ";FM$;",D1": PRINT R$;D$;"DELETE ";FM$
PRINT R$;D$;"WRITE ";FM$
FOR J = 0 TO 19: PRINT PL(0,J);",";PL(1,J): NEXT J
PRINT CP$(0,0): PRINT CP$(1,0)
PRINT R$;D$;"CLOSE ";FM$
RETURN:

REM REDATA (PL(I,J :I=0',1;d=13,.14)
POKE 34, PEEK (37) - 1: HOME
PRINT R$;D$;"OPEN ";F$;",D2": PRINT R$;D$;"READ ";F$
FOR K = 0 TO SZ - 1
INPUT A(0,1),A(1,1)
A(0,1) = A(0,1) - EO
CV%(0,K) = INT (A(0,1) * PL(0,14) * PL(0,13) + 0.5)
CV%(1,K) = INT (A(1,1) * PL(1,14) * PL(1,13) + 0.5)
NEXT K
PRINT R$;D$;"CLOSE ";F$
PL(0,15) = SZ
RETURN:

FOR J = J1 TO J2
FOR I = I1 TO I2
PRINT TAB(2 + I * 20);"PL(*,I",",j,:" = ";PL(I,J):
NEXT J: PRINT
NEXT I
RETURN:

END
FOR I = I1 TO I2: PRINT "CP$(";I;">0 = ";CP$(I,O): NEXT I: RETURN : END
POKE 34, PEEK (37) - 1: HOME
INPUT "J ARG OF (I,J) OR CTRL-S = ": ;U$ 
IF U$ = CHR$ (19) THEN RETURN : END 
INPUT "I ARG OF (I,J) & VALUE: I,V = "; I$, V$ 
I = VAL (I$): U = VAL (V$)
PL(I,J) = V: GOTO 4210
RETURN : END
POKE 34, PEEK (37) - 1: HOME
INPUT "I ARG OF (IJ) OR CTRL-S = "; I$
IF I$ = CHR$ (19) THEN RETURN : END 
INPUT THEN TYPE STRING "; V$
I = VAL (I$): CP$(I,O) = V$: GOTO 4310
RETURN : END
REM INPUT "ROT, WDT, HGT = "; R, W, HT
INPUT "X,Y INCH = "; X, Y
INPUT "CM$(0) = "; CM$(0)
RETURN : END
REM REDATA (PL(I,J) : I=0,1; J=2,3,13,14)
POKE 34, PEEK (37) - 1: HOME
INPUT "CAL-COEFF FILE NAME = "; F$
PRINT R$; D$; "OPEN "; F$;, D2" 
PRINT R$; D$; "READ "; F$
INPUT A(0,10), A(0,11), A(0,12), A(0,13), A(0,14)
INPUT EO
PRINT R$; D$; "CLOSE "; F$
INPUT "# OF POLY-FITTED POINTS= "; SZ
IC = (PL(0,3) - PL(0,2)) / PL(0,14) / SZ
FLASH : PRINT "READING VALUES...": NORMAL
FOR K = 0 TO SZ
A(0,1) = PL(0,3) / PL(0,13) + K * IC 
A(1,1) = A(0,10) + A(0,11) + A(0,1) + A(0,12) + A(0,1) ^ 2 + A(0,13) + A(0,1) ^ 3 + A(0,14) + A(0,1) ^ 4
CV%(0,K) = INT (A(0,1) * PL(0,14) * PL(0,13) + 0.5)
CV%(1,K) = INT (A(1,1) * PL(1,14) * PL(1,13) + 0.5)
NEXT K
PL(O,15) = SZ + 1
RETURN : END
C = PEEK (116): D = PEEK (115): GOSUB 6500
VTAB 3: PRINT "PRESENT HIMEM = ": TAB( 33): A$
VTAB 4: HTAB 32: PRINT "": DTO: C = 256.21 = PEEK (37)
VTAB 5: PRINT "WANT TO CHANGE HIMEM Y/N = ": VTAB 5: HTAB 28: INPUT An$
IF An$ = "Y" THEN GOTO 6780
VTAB 5: HTAB 1: PRINT "INPUT NEW HIMEM 
VTAB 5: HTAB 17: INVERSE : PRINT "(4-HEX;$XXXX)=": NORMAL : VTAB 5: HTAB 32: INPUT A$
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6760 GOSUB 6800: B = C * 256 + D: VTAB 6: HTAB 32: PRINT ";B
6770 HIMEM: B:21 = PEEK (37)
6780 POKE 34, Z1: HOME : RETURN : END
6800 FOR I = 0 TO 5
6810 A(O,I) = ASC (MID$(A$,I,1))
6820 IF A(O,I) = < 57 THEN A(O,I) = A(O,I) - 48: GOTO 6840
6830 A(O,I) = A(O,I) - 55
6840 NEXT I
6850 C = A(O,2) * 16 + A(O,3): D = A(O,4) * 16 + A(O,5)
6860 RETURN : END
6900 A(O,1) = INT (C / 16): A(O,2) = C - A(O,1) * 16: A(O,3) = INT (D / 16): A(O,4) = D - A(O,3) * 16: A$ = "$"
6910 FOR I = 1 TO 4
6920 IF A(O,I) < 10 THEN A$ = A$ + STR$(A(O,I)): GOTO 6940
6930 A(O,I) = A(O,I) + 55
6940 NEXT I
6950 RETURN : END
7000 REM SUBR ZLNDRW (PL(I,J :I=0,1;d=0,1,2,3,4)
7010 B%(0) = INT (PL(I,0) * UPI): REM XREF
7020 B%(1) = INT (PL(I,0) * UPI) - 1: REM YREF
7030 B%(2) = INT ((PL(I,0) + PL(I,1)) * UPI) - 1: REM XLIM
7040 B%(3) = INT ((PL(I,0) + PL(I,1)) * UPI) - 1: REM YLIM
7050 FOR I = 0 TO 3
7060 POKE XREF + I * 2, INT (B%(I) / H): POKE XREF + I * 2 - 1, B%(I) - INT (B%(I) / H) * H
7070 NEXT I
7080 RETURN : END
7100 REM SUBR ZLNDWR (PL(I,J :I=0,1;J=0,1,2,3,4)
7110 FOR I = 0 TO 1
7120 IF PL(I,2) * PL(I,3) = > 0 THEN POKE Flag + I, 0:B%(I) = INT (PL(I,0) * UPI) - 1: GOTO 7140
7130 POKE Flag + I, 1:B%(I) = INT ((PL(I,0) - PL(I,2) * PL(I,1)) / (PL(I,3) - PL(I,2))) * UPI) - 1
7140 POKE XZERO + I * 2, INT (B%(I) / H): POKE XZERO + I * 2 - 1, B%(I) - INT (B%(I) / H) * H
7150 NEXT I
7160 RETURN : END
7200 REM SUBR MKTIC (PL(I,J :I=0,1;J=0,1,2,3,4,5,6)
7202 FOR I = 0 TO 1
7204 J = 1 - I
7206 POKE TSFT + J, INT (PL(J,5) * UPI): POKE TLNG + J, H - INT (PL(J,6) * UPI)
7208 NEXT I
7210 FOR I = 0 TO 1
7220 IF PL(I,2) * PL(I,3) = > 0 THEN B%(I) = INT (PL(I,0) * UPI) - 1: GOTO 7240
7230 B%(I) = INT ((PL(I,0) - PL(I,2) * PL(I,1)) / (PL(I,3) - PL(I,2))) * UPI) - 1
7240 POKE XZERO + I * 2, INT (B%(I) / H): POKE XZERO + I * 2 - 1, B%(I) - INT (B%(I) / H) * H
7250 J = 1 - I
7260 B%(I + 2) = INT ((PL(J,3) - PL(J,2)) / PL(J,4)): POKE TCNM + J,B%(I + 2)
7270 FOR K = 0 TO B%(I + 2)
7280 CR%(J,K) = INT ((PL(J,0) + PL(J,1) * PL(J,4) * K / ABS (PL(J,3) - PL(J,2))) * UPI) - 1
REM SUBR CAPTIC (PL(I,J :I=0,1;J=2,3,13,14,15,16),CP$(J,0 :J=0,1))
FOR I = 0 TO 1
FOR J = 1 - I
B%(I + 2) = INT ((PL(J,3) - PL(J,2)) / PL(J,4) / PL(J,12))
POKE TCNM + J,8%(I + 2) - INT (B%(I + 2) / H)
NEXT
FOR I = 0 TO 1
B%(5) = B%(5) + 209 + 9 - 1: REM ADDR OF 1ST ELEMENT OF CR% - 1
POKE CRARY, INT (B%(5) / H): POKE CRARY - 1,B%(5) - INT (B%(5) / H) * H
RETURN : END
NEXT
REM SUBR CURVE/DOTPLT (PL(I,J :I=0,1;J=2,3,13,14,15,16),PL(1,17))
POKE SYMBOL,PL(0,16): POKE RTT,PL(1,15)
POKE WDT,PL(1,16): POKE HGT,PL(1,16)
FOR K = 0 TO PL(0,15) - 1
IF (CV%(0,K) / PL(0,13)) > B%(I) THEN K1 = K: GOTO 7740
NEXT
FOR K = 0 TO PL(0,15) - 1
IF (CV%(0,K) / PL(0,13)) < B%(I) THEN K2 = K: GOTO 7770
NEXT
B%(5) = K2 - K1 + 1
POKE LPNMH, INT (B%(5) / H): POKE LPNMH - 1,B%(5) - INT (B%(5) / H) * H
IF CV%(I,K) = > B%(I) THEN CV%(I,K) = B%(I + 2)
7840 NEXT I
7850 NEXT K
7860 B%(5) = Peek (107) + Peek (108) * H: REM PL(1, 19) ARRAY ADDR
7870 B%(5) = B%(5) + 209 + 169 + 15 + 10 + 27 + 67 + 9: REM ADDR OF 1ST ELEMENT OF CV%
7880 B%(6) = B%(5) + 4 * K1 - 1: REM ADDR OF K1TH ELEMENT OF CV% -1
7890 POKE CVARY, INT (B%(6) / H): POKE CVARY - 1, B%(6) - INT (B%(6) / H) * H
7900 RETURN : END
8000 REM COMMENT (R,W,HT,X,Y,CM$(O))
8010 POKE RTT,R: POKE WDT,W: POKE HGT,HT
8020 B%(0) = INT (X * UPI) - 1: B%(1) = INT (Y * UPI) - 1
8030 FOR I = 0 TO 1
8040 FOR I = 0 TO 1
8050 FOR I = 0 TO 1
8060 B%(5) = Peek (107) + Peek (108) * H: REM PL(1, 19) ARRAY ADDR
8070 B%(5) = B%(5) + 209 + 169 + 15 + 7 - 1: REM ADDR OF 1ST ELEMENT OF CM$-1
8080 POKE CMARY, INT (B%(5) / H): POKE CMARY - 1, B%(5) - INT (B%(5) / H) * H
8090 RETURN : END
8100 REM LINDRW (A(I,J:I=0,1;J=11,12),PL(I,J:I=0,1;J=0,1,2,3,14))
8110 FOR K = 11 TO 12
8120 FOR I = 0 TO 12
8130 FOR I = 0 TO 12
8140 B%(J) = INT (((PL(I,0) + (A(I,K) * PL(I,14) - PL(I,2)) * PL(I,1) / (PL(I,3) - PL(I,2))) * UPI) - 1
8150 NEXT I
8160 NEXT K
8170 FOR I = 0 TO 3: POKE XCRD + I * 2, INT (B%(I) / H): POKE XCRD + I * 2 - 1, B%(I) - INT (B%(I) / H) * H: NEXT I
8180 RETURN : END
TEXT : HOME : FLASH : HTAB 7: PRINT "PLOTTING PROBE-LOC": NORMAL
200 DIM PL(1,19),CR%(1,39),CP$(1,0),CM$(0)
210 DIM BK%(9),AS%(9),CV%(1,1023),A%(1,15)
220 GOSUB 6700: REM HIMEM SETTING SUBR
230 START = 36992:FRAME 37004:ZLNDRW = 37118:MKTIC = 37221
240 CAPTIC = 37397:CURVE = 37513:DOTPLT = 37617
250 COMMENT = 37662:ENPLT = 37711:LINDRW = 37826
260 RTT = 38338:WDT = 38340:HGT = 38342
270 XREF = 38353:YREF = 38355:XLIM = 38357:YLIM = 38359
280 XZERO = 38361:YZERO = 38363:CRARY = 38365:CPARY = 38367
290 CMARY = 38369:CVARY = 38371:XCRD = 38373:YCRD = 38375
300 XHEREF = 38377:YHEREF = 38379:LPNMH = 38381:SYMBOL = 38383
310 UPI = 200:H = 256:R$ = CHR$(13):D$ = CHR$(4)
500 GOSUB 4500: REM BATH-DEFAULTS
510 POKE 34,6: HOME : VTAB 7: PRINT "BATH DEFAULTS": VTAB 9
530 I1 = 0:12 = 1:J1 = 1:J2 = 6: GOSUB 4700: PRINT
540 INPUT " WANT TO CHANGE ? (Y/N) ":AN$: IF LEFT$(AN$,1) = "N" THEN GOTO 560
550 GOSUB 4800: GOTO 510
560 GOSUB 5000: REM GRID PT-->VLTG CONV
600 POKE 34,6: HOME : PRINT "PLT-DEFAULTS READ & PLOT START "
610 PRINT R$;D$;"BLOAD BPLT1.OBJO,D1"
620 GOSUB 3000: REM PLT-DEFAULTS READ
630 GOSUB 5300: REM A(I,J)--->PL(I,d)
1000 REM INITIALIZE PLOTTER
1100 GOSUB 5000: REM INITIALIZE PLOTTER
1110 POKE 34,6: HOME : PRINT " FRAME DRAW ": VTAB 9
1120 I1 = 0:12 = 1:J1 = 0:J2 = 1: GOSUB 4000: PRINT
1130 INPUT " WANT TO CHANGE ? (Y/N) ":AN$: IF LEFT$(AN$,1) = "N" THEN GOTO 1150
1140 GOSUB 4200: GOTO 1110
1150 GOSUB 7000: CALL FRAME: REM (XREF,YREF,XLIM,YLIM)
1300 REM MKTIC (PL(I,J) :I=0,1;J=0,1,2,3,4,5,6)
1310 POKE 34,6: HOME : PRINT " TIC MARK DRAW ": VTAB 9
1320 I1 = 0:12 = 1:J1 = 0:J2 = 6: GOSUB 4000: PRINT
1330 INPUT " WANT TO CHANGE ? (Y/N) ":AN$: IF LEFT$(AN$,1) = "N" THEN GOTO 1350
1340 GOSUB 4200: GOTO 1310
1350 GOSUB 7200: CALL MKTIC: REM ((X/Y)ZERO,TCNM(X/Y),TSFT(X/Y),TLNG(X/Y),CRARY,CR%(J,K))
1400 REM CAPTIC (PL(I,J) :I=0,1;J=0,2,3,4,7,8,9,10,11,12,CP$(J,O :J=0,1))
1410 POKE 34,6: HOME : PRINT " TIC CAPT DRAW ": VTAB 9
1420 I1 = 0:12 = 1:J1 = 0:J2 = 0: GOSUB 4000
1430 I1 = 0:12 = 1:J1 = 2:J2 = 4: GOSUB 4000
1440 I1 = 0:12 = 1:J1 = 7:J2 = 12: GOSUB 4000
1450 I1 = 0:12 = 1: GOSUB 4100: PRINT
1460 INPUT " WANT TO CHANGE PL ? (Y/N) ":AN$: IF LEFT$(AN$,1) = "N" THEN GOTO 1480
1470 GOSUB 4200
1480 INPUT "WANT TO CHANGE CP$ ? (Y/N) ";AN$: IF LEFT$(AN$,1) = "N" THEN GOTO 1500
1490 GOSUB 4400: GOTO 1410
1500 GOSUB 7400: CALL CAPTIC: REM (RTT(X,Y),WDT(X,Y),HGT(X,Y),(X/Y)ZERO,TCNM(X/Y),(CR/CP)ARY,CP$(I,O),CR%(J,K)
1600 REM ELECTRODE SURFACE LINE DRAW
1610 POKE 34,6: HOME : PRINT "ELECTRODE DRAW"
1620 A(0,11) = 0:A(1,11) = A(1,1) - A(1,2): A(0,12) = A(0,12): A(1,12) = A(1,1)
1630 GOSUB 8100: CALL LINDRW
1640 GOSUB 8100: CALL LINDRW
1650 GOSUB 8100: CALL LINDRW
1700 REM COMMENT (R,W,HT,X,Y,CM$(O))
1710 POKE 34,6: HOME : PRINT * COMMENT DRAW *: VTAB 9
1720 GOSUB 4400
1730 GOSUB 8000: CALL COMMENT: REM (RTT,WDT,HGT,(X/Y)CRD,CMARY,CM$(O))
1740 INPUT "WANT TO CONTINUE ? (Y/N) ";AN$: IF LEFT$(AN$,1) > < "N" THEN GOTO 1720
1800 REM REDATA (PL(I,d :I=0;J=2,3,13,14,15,16),PL(1,17))
1810 POKE 34,6: HOME : PRINT * READ DATA *: VTAB 9
1820 I1 = 0: I2 = 1: J1 = 13: J2 = 14: GOSUB 4000: PRINT
1830 INPUT "WANT TO CHANGE ? (Y/N) ";AN$: IF LEFT$(AN$,1) = "N" THEN GOTO 1850
1840 GOSUB 4200: GOTO 1810
1900 REM CURVE/DOTPLT (PL(I,J :I=0;J=2,3,13,14,15,16),PL(1,17))
1910 POKE 34,6: HOME : PRINT " CURVE/DOT PLOT ": VTAB 9
1920 I1 = 0: I2 = 1: J1 = 2: J2 = 3: GOSUB 4000
1930 INPUT "WANT TO CHANGE ? (Y/N) ";AN$: IF LEFT$(AN$,1) = "N" THEN GOTO 1960
1940 INPUT "WANT TO CONTINUE ? (Y/N) ";AN$: IF LEFT$(AN$,1) > < "N" THEN GOTO 1980
1950 GOSUB 4200: GOTO 1910
1960 A = 2: GOSUB 7700
1980 CALL CURVE: GOTO 1700: REM (LPNMH,SYMBOL,RTT,WDT,HGT,CV$(I,K),CVARY)
1990 CALL DDTPLT: REM (LPNMH,SYMBOL,RTT,WDT,HGT,CV$(I,K),CVARY)
2000 CV$(O) = CV$(O,0) - 40: E$(1) = CV$(1,0) - 40: PNR = PNR + 1
2010 POKE RTT,8: POKE WDT,2: POKE HGT,2
2020 CMS$(O) = STR$(PNR)
2030 GOSUB 8030: CALL COMMENT
2040 POKE 34, PEEK (37) - 1: HOME
2100 INPUT " WANT TO CONTINUE? (Y/N) ";AN$: IF LEFT$(AN$,1) = "N" THEN GOTO 2150
2110 INPUT " CONTINUE W/OTHER INDENT? (Y/N) ";AN$: IF LEFT$(AN$,1) = "N" THEN GOTO 2200
2120 POKE 34,6: HOME : VTAB 7: PRINT " BATH DEFAULTS": VTAB 9
2130 I1 = 0: I2 = 1: J1 = 13: J2 = 6: GOSUB 4700: PRINT
2140 INPUT " WANT TO CHANGE ? (Y/N) ";AN$: IF LEFT$(AN$,1) = "N" THEN GOTO 2160
2150 GOSUB 4800: GOTO 2120
2160 GOSUB 5000: REM GRID PT-->VLTG CONV
2170 GOTO 1800
2200 POKE 34,6: HOME: PRINT " PLT END & PLT-DEFAULTS SAVE "
2210 CALL ENPLT
2220 GOSUB 3100: REM PLT-DEFAULTS SAVE
2230 GOSUB 4600: REM BATH-DEFAULTS SAVE
2240 PRINT R$:D$:"RUN MENU,D1"
2250 END
3000 PRINT R$:D$:"OPEN BHPLDEF,D1"
3010 PRINT R$:D$:"READ BHPLDEF"
3020 FOR j = 0 TO 19
3030 INPUT PL(0,j),PL(1,j)
3040 NEXT j
3050 INPUT CP$(0,0): INPUT CP$(1,0)
3060 PRINT R$:D$:"CLOSE BHPLDEF"
3070 RETURN:
3100 PRINT R$:D$:"OPEN BHPLDEF,DI"
3110 PRINT R$:D$:"DELETE BHPLDEF"
3120 PRINT R$:D$:"OPEN BHPLDEF"
3130 PRINT R$:D$:"WRITE BHPLDEF"
3140 FOR j = 0 TO 19: PRINT PL(0,);",";PL(1,0):
3141 NEXT j
3150 PRINT CP$(0,0): PRINT CP$(1,0)
3160 PRINT R$:D$:"CLOSE BHPLDEF"
3170 RETURN:
3300 REM REDATA (PL(I,J :I=0,1;d=13,14)
3310 POKE 34, PEEK (37) - 1: HOME
3320 INPUT " ENTER (1.VLTG 2.LOC): WHICH? (1/2) ":CH: ON CH GOTO 3320
3330 INPUT " TYPE RADIAL/AXIAL VLTG ":RVT,ZVT: GOSUB 5200: GOTO 3350
3340 INPUT " TYPE RADIAL/AXIAL LOC ":RL,ZL: GOSUB 5400
3350 HOME:: GOSUB 5500
3360 FOR j = J1 TO J2
3370 FOR i = I1 TO I2
3380 PRINT TAB( 2 + I * 20);"PL(";i",";j"); = ";:PL(I,J):
3390 NEXT i: PRINT
3400 NEXT j
3410 PRINT TAB( 2 + J * 20):"CP(";j",";i"); = ";:CP(J,I):
3420 NEXT J
3430 RETURN:
4000 FOR j = J1 TO J2
4010 FOR i = I1 TO I2
4020 PRINT TAB( 2 + I * 20):"PL(";i",";j"); = ";:PL(I,J):
4030 NEXT i: PRINT
4040 NEXT j
4050 RETURN:
4100 FOR i = I1 TO I2: PRINT "CP(*;i",";0) = ":CP(I,0): NEXT i: RETURN : END
4200 POKE 34, PEEK (37) - 1: HOME
4210 INPUT ".J ARG OF (I,J) OR CTRL-S = ":J$";
4220 IF J$ = CHRS$ (19) THEN RETURN : END
4230 INPUT "I ARG OF (I,J) & VALUE: I,V = ";:I$,.V$
4240 I = VAL (I$):J = VAL (J$):V = VAL (V$)
PL(I,J) = V: GOTO 4210
4260 RETURN: END
4300 POKE 34, PEEK(37) - 1: HOME
4310 INPUT "I ARG OF (I,J) OR CTRL-S = "; I$
4320 IF I$ = CHR$(19) THEN RETURN : END
4330 INPUT "THEN TYPE STRING ",; V$
4340 I = VAL(I$); CP$(I,0) = V$: GOTO 4310
4350 RETURN: END
4400 REM
4410 INPUT "ROT, WDT, HGT = "; R, W, HT
4420 INPUT "X, Y INCH = "; X, Y
4430 INPUT "CM$(0) = "; CM$(0)
4440 RETURN:
4500 PRINT R$; D$; "OPEN BATHDEF, D1"
4510 PRINT R$; D$; "READ BATHDEF"
4530 FOR 0 = I TO 6:
4540 INPUT A(0,0), A(1,6): NEXT J
4550 PRINT R$; D$; "CLOSE BATHDEF"
4560 RETURN:
4600 PRINT R$; D$; "OPEN BATHDEF, D1"
4610 PRINT R$; D$; "DELETE BATHDEF"
4620 PRINT R$; D$; "OPEN BATHDEF"
4630 PRINT R$; D$; "WRITE BATHDEF"
4650 FOR J = 1 TO 6: PRINT A(O,J); A(1,J): NEXT J
4660 PRINT R$; D$; "CLOSE BATHDEF"
4670 RETURN:
4700 FOR J = J1 TO J2
4710 FOR I = I1 TO I2
4720 PRINT TAB(2 + I * 20); "A("; I; ",", ; J; ") = "; A(I,J);
4730 NEXT I: PRINT
4740 NEXT J
4750 RETURN: END
4800 POKE 34, PEEK(37) - 1: HOME
4810 INPUT "J ARG OF (I,J) OR CTRL-S = "; J$
4820 IF J$ = CHR$(19) THEN RETURN: END
4830 INPUT "I ARG OF (I,J) & VALUE: I, V = "; I$, V$
4840 I = VAL(I$): J = VAL(J$): V = VAL(V$)
4850 A(I,J) = V: GOTO 4810
4860 RETURN: END
5000 POKE 34, 6: HOME: PRINT "GRID PT---> VLTG CONV": PRINT: VTAB 9
5010 INPUT "WANT TO PRINT OUT? (Y/N) = "; AN$: IF LEFT$(AN$, 1) > "Y" THEN GOTO 5025
5020 PRINT R$; D$: "PR#1": POKE 1401, 80:
5025 POKE 34, 8: HOME
5030 INPUT "# OF MESHES (RAD/AX) IAL = "; NR, NZ
5040 OR = (A(O, 6) - A(O, 5)) / NR: DZ = (A(1, 6) - A(1, 5)) / NZ
5048 PRINT "R1= "; A(0, 3); TAB(21); "A1= "; A(1, 3); TAB(41); "RVTO= "; A(0, 4); TAB(21); "ZVTO= "; A(1, 4)
FOR J = 0 TO NZ
FOR K = 0 TO 39: PRINT "*": NEXT K: PRINT
FOR I = 0 TO NR
RA = RA + A(I,3): DP = DP - A(I,3)
NEXT I
PRINT ":DP= ";DP; TAB( 21);"HT= ";A(I,1)
FOR K = 0 TO 39: PRINT "*": NEXT K: PRINT
NEXT d
PRINT R$;D$;"PR#0";
RETURN: END
REM VOLTAGE-->LOCATION ROUT
DP = (ZVT - A(1,4)) * 1.3523: ZL = A(1,1) - DP + A(1,3): DP = DP - A(1,3)
RA = 9.08 - RVT * 0.646: RL = RA + A(0,3)
RETURN : END
REM GRID PT-->POTENTIO VLTG
DP = A(1,1) - ZL + A(1,3): ZVT = A(1,4) + DP / 1.3523
RA = RL - A(0,3): RVT = 9.08 - RA / 0.646
RETURN : END
INPUT "WANT TO PRINT OUT ? (Y/N) ";AN$: IF LEFT$(AN$,1) > < "Y" THEN GOTO 5520
PRINT R$:D$;"PR#1": POKE 1401,80
PRINT "ZL= ";ZL; TAB( 21);"RL= ";RL; TAB( 41);"ZVT= ";ZVT; TAB( 21);"RVT= ";RVT
FOR I = 2 TO 5
A(IO,I) = ASC (MIDS (A$,I,1))
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6820 IF A(0,I) = < 57 THEN A(0,I) = A(0,I) - 48: GOTO 6840
6830 A(0,I) = A(0,I) - 55
6840 NEXT I
6850 C = A(0,2) * 16 + A(0,3): D = A(0,4) * 16 + A(0,5)
6860 RETURN : END
6900 A(0,1) = INT (C / 16):A(0,2) = C - A(0,1) * 16:A(0,3) = INT (D / 16):A(0,4) = D - A(0,3) * 16:A$ = "$"
6910 FOR I = 1 TO 4
6920 IF A(0,I) < 10 THEN A$ = A$ + STR$ (A(0,I)): GOTO 6940
6930 A(0,I) = A(0,I) + 55:A$ = A$ + CHR$ (A(0,I))
6940 NEXT I
6950 RETURN : END
7000 REM SUBR FRAME (PL(I,J :I=0,1;J=0,1,2,3,4,5,6)
7010 B%(0) = INT (PL(0,0) * UPI) - 1: REM XREF
7020 B%(1) = INT (PL(1,0) * UPI) - 1: REM YREF
7030 B%(2) = INT ((PL(0,0) + PL(0,1)) * UPI) - 1: REM XLIM
7040 B%(3) = INT ((PL(1,1) + PL(1,0)) * UPI) - 1: REM YLIM
7050 FOR I = 0 TO 3
7060 POKE XREF + I * 2, INT (B%(I) / H): POKE XREF + I * 2 - 1,B%(I) - INT (B%(I) / H) * H
7070 NEXT I
7080 RETURN : END
7200 REM SUBR MKTIC (PL(I,J :I=0,1;J=0,1,2,3,4,5,6)
7210 J = 1 - I
7220 POKE TSFT + J, INT (PL(J,5) * UPI): POKE TLNG + J,H - INT (PL(J,6) * UPI)
7230 NEXT I
7240 FOR I = 0 TO 1
7250 IF PL(I,2) * PL(I,3) = > 0 THEN B%(I) = INT (PL(I,0) * UPI) - 1: GOTO 7240
7260 B%(I) = INT ((PL(I,0) - PL(I,2) * PL(I,1) / (PL(I,3) - PL(I,2))) * UPI) - 1
7270 FOR K = 0 TO B%(I + 2)
7280 CR%(J,K) = INT ((PL(J,0) + PL(J,1) * PL(J,4) * K / ABS (PL(J,3) - PL(J,2))) * UPI) - 1
7290 NEXT K
7300 NEXT I
7310 B%(5) = PEEK (107) + PEEK (108) * H: REM PL(1,19) ARRAY ADDR
7320 B%(5) = B%(5) + 208 + 9 - 1: REM ADDR OF 1ST ELEMENT OF CR% - 1
7330 POKE CRARY, INT (B%(5) / H): POKE CRARY - 1,B%(5) - INT (B%(5) / H) * H
7340 RETURN : END
7390 REM SUBR CPTIC (PL(I,J :I=0,1;J=0,2,3,4,7,8,9,10,11,12),CP$(J,O :J=0,1))
7400 FOR I = 0 TO 1
7410 U = 1 - I
7420 B%(I + 2) = INT ((PL(J,3) - PL(J,2)) / PL(J,4) / PL(J,12))
7440 POKE TCNM + J,B%(I + 2): POKE RTT + J,PL(J,7)
7450 POKE WDT + J,PL(J,8)
7460 POKE HGT + J,PL(J,9)
7470 NEXT I
7480 FOR I = 0 TO 1
7490 J = 1 - I
7500 IF PL(I,2) * PL(I,3) = > 0 THEN B%(I) = INT ((PL(I,0) - PL(J,10)) * UPI) - 1: GOTO 7520
7510 B%(I) = INT ((PL(I,0) - PL(I,2) * PL(I,1)) / (PL(I,3) - PL(I,2)) - PL(J,10)) * UPI) - 1
7520 POKE XZERO + I * 2, INT (B%(I) / H): POKE XZERO + I * 2 - 1,B%(I) - INT (B%(I) / H) * H
7530 FOR K = 0 TO B%(I) + 2
7540 CR%(J,K) = INT ((PL(J,0) + PL(J,4) * PL(J,12) * K / ABS (PL(J,3) - PL(J,2)) - PL(J,11)) * UPI) - 1
7550 NEXT K
7560 NEXT I
7570 B%(5) = PEEK (107) + PEEK (108) * H: REM PL(1,19) ARRAY ADDR
7580 B%(5) = B%(5) + 209 + 9 - 1: REM ADDR OF 1ST ELEMENT OF CR% - 1
7590 POKE CRARY, INT (B%(5) / H): POKE CRARY - 1, B%(5) - INT (B%(5) / H) * H
7600 B%(6) = B%(5) + 169: REM ADDR OF 1ST ELEMENT OF CP$ - 1
7610 POKE CPARY, INT (B%(6) / H): POKE CPARY - 1, B%(6) - INT (B%(6) / H) * H
7620 RETURN : END
7700 REM SUBR CURVE/DOTPLT (PL(I,J :I=0,1;J=2,3,13,14,15,16),PL(1,17))
7702 POKE SYMBOL,PL(0,16): POKE RTT,PL(1,15)
7704 POKE WDT,PL(1,16): POKE HGT,PL(1,16)
7710 FOR K = 0 TO PL(0,15)
7720 IF (CV%(0,K) / PL(0,13)) = > PL(0,2) THEN K1 = K: GOTO 7740
7730 NEXT K
7740 FOR K = PL(0,15) - 1 TO K1 STEP - 1
7750 IF (CV%(0,K) / PL(0,13)) = < PL(0,3) THEN K2 = K: GOTO 7770
7760 NEXT K
7770 B%(5) = K2 - K1 + 1
7780 POKE LPNMH, INT (B%(5) / H): POKE LPNMH - 1, B%(5) - INT (B%(5) / H) * H
7790 B%(0) = 2000: B%(1) = 1400: B%(2) = 1999: B%(3) = 1399
7800 FOR K = K1 TO K2
7810 FOR I = 0 TO 1
7820 CV%(I,K) = INT ((PL(I,0) + CV%(I,K) / PL(I,13) - PL(I,2)) * PL(I,1) / (PL(I,3) - PL(I,2)) * UPI) - 1
7830 IF CV%(I,K) = > B%(I) THEN CV%(I,K) = B%(I + 2)
7840 NEXT I
7850 NEXT K
7860 B%(5) = PEEK (107) + PEEK (108) * H: REM PL(1,19) ARRAY ADDR
7870 B%(5) = B%(5) + 209 + 169 + 15 + 10 + 27 + 67 + 9: REM ADDR OF 1ST ELEMENT OF CV%
7880 B%(6) = B%(5) + 4 * K1 - 1: REM ADDR OF K1TH ELEMENT OF CV% - 1
7890 POKE CVARY, INT (B%(6) / H): POKE CVARY - 1, B%(6) - INT (B%(6) / H) * H
7900 RETURN : END
8000 REM = COMMENT (R,W,HT,X,Y,CM$(O))
8010 POKE RTT,R: POKE WDT,W: POKE HGT,HT
8020 B%(0) = INT (X * UPI) - 1:B%(1) = INT (Y * UPI) - 1
8030 FOR I = 0 TO 1
8040 POKE XCRD + 2 * I, INT (B%(I) / H): POKE XCRD + 2 * I - 1,B%(I) - INT (B%(I) / H) * H
8050 NEXT I
8060 B%(5) = PEEK (107) + PEEK (108) * H: REM PL(1,19) ARRAY ADDR
8070 B%(5) = B%(5) + 209 + 169 + 15 + 7 - 1: REM ADDR OF 1ST ELEMENT OF CM$-1
8080 POKE CMARY, INT (B%(5) / H): POKE CMARY - 1,B%(5) - INT (B%(5) / H) * H
8090 RETURN : END
8100 REM LINDRW (A(I,J=I=0,1;J=11,12),PL(I,J=I=0,1,J=0,1,2,3,14))
8110 FOR K = 11 TO 12
8120 FOR I = 0 TO 1
8130 J = (K - 11) * 2 + I
8140 B%(J) = INT ((PL(I,0) + (A(I,K) * PL(I,14) - PL(I,2)) * PL(I,1) / (PL(I,3) - PL(I,2))) * UPI) - 1
8150 NEXT I
8160 NEXT K
8170 FOR I = 0 TO 3: POKE XCRD + I * 2, INT (B%(I) / H): POKE XCRD + I * 2 - 1,B%(I) - INT (B%(I) / H) * H: NEXT I
8180 RETURN : END
APPENDIX F

Mainframe Program Listings
FUNCTION ADF(I,J,LX,K)

FUNCTION FOR EVALUATION OF FIRST DERIVATIVES

C $$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$

C COMMON/CNUMB/NF,NK,NEP,NVI,NV2,NT,NMU,NRO,NTC,NSP,NMT

C COMMON/CCORD/IMIN(21),IMAX(21),X1(31),X2(21),R(21)

C COMMON/CGRID/IN,JM,JNL,INM,11,12,13,IA,IW(21),J1

C COMMON/CDIM/X(5),RE,RE

C COMMON/CIK/INK,NMK,NIK,NJN,NIJ,NJK,NS

C COMMON/CTHERM/TLM,NLM,TA,TA,TM,TW

C COMMON/CTRVL/VE,VC

C COMMON/CHEAT/HC,HW(4)

C COMMON/CROP/RGREF(5),ZMUREF(2),PR(10),GAMA

C COMMON/CF/LF,LI

C COMMON/CSW/RVOR(31,21)

C COMMON/CTURB/NTURB,NSCHEM,NVSC,RPX1,XI

C COMMON/CSW/SN1(20),SN2(21),SN3(21),SN4(20),SN5(21)

C COMMON/CB/BE(31),BW(31),BN(21),BS(21)

C COMMON/CAVM/AVM(60)

C COMMON/CHBL/HLW,HLEH,HLEH,HLS,HLD,HLM,POWR

C COMMON/CSUR/HS(2),TS(2)

C COMMON/CFUN/FUN(20)

C COMMON/CVOLT/VOLT

C COMMON/CIVT/TB

C COMMON/CYP/YP1(20),YP2(15),YP3(21),YP4(10),YP5(21)
FILE: ADF FORTRAN C1

VM/SP CONVERSATIONAL MONITOR SYSTEM

M=1
SIGN=1.
IF(I.EQ.1) M=3
IF(I.EQ.IN) M=5
IF(J.EQ.1) M=2
IF(J.EQ.JN) M=4
IF(J.EQ.J1.AND.I.LE.I1) M=4
IF(I.EQ.I1.AND.J.GT.J1) M=3
GO TO (1,2,3,4,5),M

C*** M=1, FOR POINTS NOT ON ANY OF THE BOUNDARIES
1 IF(LX.EQ.2) GO TO 11
  PN=1.
  BENQ=A(I+1,J,K)
  BWSR=A(I-1,J,K)
  BP=A(I,J,K)
  XENO=X1(I+1)-X1(I)
  XWSR=X1(I)-X1(I-1)
  GO TO 100
11 PN=-1.
  BENQ=A(I+1,J,K)
  BWSR=A(I-1,J,K)
  BP=A(I,J,K)
  XENO=X2(J+1)-X2(J)
  XWSR=X2(J+2)-X2(J)
  GO TO 100

C*** FOR POINTS ON THE SYMMETRY AXIS
2 IF(LX.EQ.1) GO TO 1
  PN=1.
  BENQ=A(I,J+1,K)
  BWSR=A(I,J-1,K)
  BP=A(I,J,K)
  XENO=X2(J+1)-X2(J)
  XWSR=X2(J+2)-X2(J)
  GO TO 100

C*** M=3, FOR POINTS ON THE BOUNDARY I=I1
3 IF(LX.EQ.2) GO TO 11
  PN=1.
  BENQ=A(I+1,J,K)
  BWSR=A(I+2,J,K)
  BP=A(I,J,K)
  XENO=X1(I+1)-X1(I)
  XWSR=X1(I+2)-X1(I)
  GO TO 100

C*** M=4, FOR POINTS ON THE BOUNDARY J=JN
4 IF(LX.EQ.1) GO TO 1
FILE: ADF  FORTRAN C1  VM/SP CONVERSATIONAL MONITOR SYSTEM  PAGE 003

C*** M=5, FOR POINTS ON THE BOUNDARY I=IN
5 IF(LX.EQ.2) GO TO 11
  PN=-1.
  BENQ=A(I-1,J,K)
  BWSR=A(I-2,J,K)
  BP=A(I,J,K)
  XENO=X1(I)-X1(I-1)
  XWSR=X1(I)-X1(I-2)
  SIGN=-1.
100 CONTINUE
  ADF=((XENO*XENO-XWSR*XWSR)*BP+
       XWSR*XWSR*BENQ-XENO*XENO*BWSR)/(XENO*XWSR*(PN*XENO+XWSR))
  ADF=SIGN*ADF
  RETURN
END
PROGRAM AND PRINT OUT CONTROL DATA

DATA NW,NF,NK,NEP,NV1,NV2,NT,NMU,NRO,IE,IV/3,4,5,6,7,8,9,10,12,6,16/

DATA IP,CC/1,0,0.006/
2,RP/1.1,2.0,2.1,2.0,5.0,7.0,5.3*1.0/
3,NTC,NSP,NMT/13,14,15/

DATA RSDU,SAN/10*0.0,10*0.0/

DATA ROREF/5*08.37E+03/
1,ZMUREF/2*2.29E-02/
2,PR/4*1.0,1.000,1.3,4*1.0/
3,TCREF/7.0E-03,5.0E-03,7.0E-03,7.0E-03,7.0E-03/
4,SPREF,HL/0.16,0.31,0.16,0.31,0.16,67.0/
5,TLN,TSM,TLSTATM,TW/300.0,300.0,300.0,300.0,300.0,300.0/
6,ES,EE,EM,SB/0.80,0.40,1.00,13.70/
7,BETA/2*0.0/
8,VE,VC,HG/0.0,5.0E-03/
9,GAMA/0.5/
1,HW/5.0E-02,5.0E-02,4.5E-02,5.0E-02/
2,CAPPA,E/0.0,0.40,9.0/
3,PI/3.1416/
DATA C1,C2,C3,CD/1.44,1.92,1.0,0.09/
4,WF,P/0.0,1.26E-06/

DATA INJN/21,17/
I,X/0.01,0.010,0.0130,0.0425,0.050/
2,RE,RM,RA,RAX/0.0075,0.0075,0.0125,0.0675/
3,I1,I2,IA,IAXI3,J1,J2,JAX/7,7,10,18,21,5,0,8,15/
4,(IMIN(I),I=1,17)/05*2,12*8/
5,(IMAX(I),I=1,17)/17*20/
6,THETA/0.0000/

DATA TAU,HCDD/O.0,0.0/

DATA INJ,/JN/21.17/
1,X/0.01,0.010,0.0130,0.0425,0.050/
2,RE,RM,RA,RAX/0.0075,0.0075,0.0125,0.0675/
3,I1,I2,IA,IAXI3,J1,J2,JAX/7,7,10,18,21,5,0,8,15/
4,(IMIN(I),I=1,17)/05*2,12*8/
5,(IMAX(I),I=1,17)/17*20/
6,THETA/0.0000/
DATA TAU,HCDD/O.0,0.0/
C************************ END

END

END ******************************************BLK00910 BLK00920
SUBROUTINE BOUND

COMMON/CNUM/NW,NF,NK,NEP,NV1,NV2,NT,NMU,NRO,NTC,NSP,NMT
COMMON/CCORD/IMIN(21),IMAX(21),Xi(31),X2(21),R(21)
COMMON/CGRID/IN,INM,JN,JNM,11,I2,I3,IA,IW(21),IW(21)
COMMON/CDIM/X(5),RE,RM
COMMON/CITER/NMAX,NPRINT,NITER,IP,IE,IVCC
COMMON/CCONT/Ci,C2,C3,CD
COMMON/CRLAX/RP(10),RSDU(IO),SAN(10)
COMMON/CEMP/WF,P,S(4)
COMMON/CHAT/NHR,NHI,NJRR,NJRI,NJZR,NJZI,NJU,NS
COMMON/CTHER/TCREF(5),SPREF(5),BETA(2),ES,EE,EM,SB,HL
COMMON/CTRL/TLT,TS,TLB,TA,TM,TW
COMMON/CANG/THETA
COMMON/FITER/MIT,MPRINT,CP
COMMON/CDVAR/A(31,21,20)
COMMON/CNAME/ANAME,ASYMBL
COMMON/CLF/LF,LI
COMMON/CSVOR/SVOR(31,21)
COMMON/CTURB/NCH,NSCHEM,NVISC,RPX1,XI
COMMON/CSNW/SN1(20),SN2(15),SN3(21),SN4(20),SN5(21)
COMMON/CB/BE(31),BN(21),BS(21)
COMMON/CAVM/AVM(60)
COMMON/CHBL/HLW,HLEH,HLEV,HLS,HLM,POWR
COMMON/CSR/HS(2),TS(2)
COMMON/BBB/BBE,BSW,BSN,BSB,BPP
COMMON/CSOR/SC/SPRIME
COMMON/CGEOM/FR1,FR2(15),FR3,FR4,FR5
COMMON/CAF/FUN(20)
COMMON/CVOLT/VOLT
COMMON/CAYT/TV
COMMON/CYF/YPI(20),YP2(15),YP3(21),YP4(10),YP5(21)
DIMENSION WW(15)
\[ \text{J11} = \text{J1} - 1 \]

\[ \text{C} \quad \text{AT THE CENTERLINE OF VESSEL} \]

\[ \text{R3Sq} = R(3) \times R(3) \]
\[ \text{R2Sq} = R(2) \times R(2) \]
\[ \text{BB} = \text{R3Sq} / (\text{R3Sq} - \text{R2Sq}) \]

\[ \text{DO 41 I=2,INM} \]
\[ \text{IF(I.LT.IW(1).OR.I.GT.I3) GO TO 41} \]
\[ A(I,1,NW) = (A(I,1,NF)-A(I,3,NF)) / R3Sq + (A(I,2,NF)-A(I,1,NF)) / R2Sq \]
\[ A(I,1,NW) = 8 \times A(I,1,NW) / A(I,1,NRO) / (R3Sq - R2Sq) \]

\[ \text{IF(NTURB.EQ.0) GO TO 41} \]
\[ A(I,1,NK) = \text{BB} \times A(I,2,NK) + (1 - \text{BB}) \times A(I,3,NK) \]
\[ A(I,1,NEP) = \text{BB} \times A(I,2,NEP) + (1 - \text{BB}) \times A(I,3,NEP) \]

\[ \text{IF(A(I,1,NK).LE.0.0) A(I,J,NK)=0.0} \]
\[ \text{IF(A(I,1,NEP).LE.0.0) A(I,J,NEP)=0.0} \]

\[ \text{CONTINUE} \]

\[ \text{C} \quad \text{AT SIDE WALL} \]

\[ \text{C} \quad \text{VORTICITY} \]

\[ \text{DX2}=X2(JN)-X2(JNM) \]

\[ \text{DO 42 I=I1,I3} \]
\[ Z=A(I,JN,NW) \]
\[ A(I,JN,NW)=3 \times (A(I,JN,NF)-A(I,JNM,NF)) / DX2 / DX2 / R(JN) / A(I,JN,NRO) \]

\[ \text{CONTINUE} \]

\[ \text{C} \quad \text{AT FREE SURFACE} \]

\[ \text{C} \quad \text{J12}=J1+1 \]

\[ \text{DO 44 J=J12,JNM} \]
\[ A(I,J,NW)=0.0 \]

\[ \text{CONTINUE} \]

\[ \text{C} \quad \text{AT THE BASE ELECTRODE SURFACE} \]

\[ \text{DX12}=(X1(I3)-X1(I3-1))**2 \]

\[ \text{DO 43 J=2,JNM} \]
\[ RSO=R(J)*R(J) \]
\[ A(I3,J,NW)=3 \times (A(I3,J,NF)-A(I3-1,J,NF)) / (DX12 + RSO \times Roref(2)) \]

\[ 1 - 0.5 \times A(I3-1,J,NW) \]

\[ \text{CONTINUE} \]

\[ \text{C} \quad \text{ON THE TOP ELECTRODE SURFACE} \]

\[ \text{C} \quad \text{FILE: BOUND FORTRAN C1} \]

\[ \text{VM/SP CONVERSATIONAL MONITOR SYSTEM} \]

\[ \text{PAGE 002} \]

\[ \text{BUO0460} \]
\[ \text{BUO0470} \]
\[ \text{BUO0480} \]
\[ \text{BUO0490} \]
\[ \text{BUO0500} \]
\[ \text{BUO0510} \]
\[ \text{BUO0520} \]
\[ \text{BUO0530} \]
\[ \text{BUO0540} \]
\[ \text{BUO0550} \]
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\[ \text{BUO0860} \]
\[ \text{BUO0870} \]
\[ \text{BUO0880} \]
\[ \text{BUO0890} \]
\[ \text{BUO0900} \]
FILE: BOUND FORTRAN C1

VM/SP CONVERSATIONAL MONITOR SYSTEM

C

GFC=COS(THETA)

DO 40 J=2,J1

II=IW(J)

XS=X2(J-1)/GFC+(X2(J)-X2(J-1))*GFC

RSQ=(XS*GFC)**2

DXN=(X1(J+1)-X1(J))/GFC

DX12=DXN+DXN

WW(J)=3.*(O.-A(J+1,J,NF))/DX12/RSQ/A(I,J,NRO)

WW(J)=WW(J)-0.5*A(J+1,J,NW)

40 CONTINUE

DO 48 J=2,J1

II=IW(J)

GF=SIN(THETA)/COS(THETA)

DWF=GF/(GF+(X2(J+1)-X2(J))/(X1(J+1)-X1(J)))

A(I,J,NW)=WW(J)

48 CONTINUE

C AT SIDE SURFACE OF TOP ELECTRODE (J=J1, I1<I<I2)

C -------------------------------

C EXIT IF ELECTRODE JUST TOUCHES THE METAL SURFACE

IF(I1.EQ.I2) GO TO 47

DX2=X2(J1+1)-X2(J1)

DX22=DX2**2

I1=I1+1

RSQ=R(J1)*R(J1+1)

XB=X2(J1+1)-X2(J1)

DO 45 I=I1,I2

Z=A(I,J1,NW)

DT=A(I,J1,NT)-A(I,J1+1,NT)

A(I,J1,NW)=3.*(A(I,J1,NT)-A(I,J1+1,NT))/DX22/RSQ/A(I,J1,NRO)

A(I,J1,NW)=A(I,J1,NW)-0.5*A(I,J1+1,NW)

A(I,J1,NW)=Z+RP(NW)*(A(I,J1,NW)-Z)

TCM=TCREF(1)

45 CONTINUE

47 CONTINUE

C RETURN

END
C ROUTINE TO CALCULATE LOTSIAKII CONSTANT, XI
C OUTPUT FILE ON LOGICAL UNIT # 17

IH=I3-1
IL=I1+1
C... FIND THE POWER FLOW:
C  -----------------------
PCASC=0.0
DO 60 J=2,JNM
   DR=R(J+1)-R(J-1)
   IL1=IL+1
   DO 60 I=IL,IH
   DX=X1(I+1)-X1(I-1)
   DV=R(J)*DR*DX/4.0
   PCASC=PCASC-P*A(I,J,NV2)*R(J)*A(I,d,NHR)**2*1E6*DV
60 CONTINUE
C----------------------------------------------------------------
C COMPUTE POWER LOST AS VISCOS DISSIPATION AT WALL
C -------------------------------------------------
PWALL = 0.0
CONST = 11.5/(ROREF(1)**0.5)
C TOP ELECTRODE FACE:
C  -------------------
DO 350 J=2,J1
   DR= (R(J+1)-R(J-1))/2.0
   DAREA= DR*R(J)
   PWALL = PWALL +(ABS(TAUW2(J))*1.5)*DAREA*CONST
   YPLUS = SQRT(TAUW2(J)*ROREF(1))*(X1(I1)-X1(I1))/ZMUREF(1)
   WRITE(25,999) YPLUS
350 CONTINUE
C BOTTOM ELECTRODE FACE:
C  ---------------------
DO 360 J=2,JNM
   DR= (R(J+1)-R(J-1))/2.0
   DAREA= DR*R(J)
   PWALL = PWALL +(ABS(TAUW3(J))*1.5)*DAREA*CONST
   YPLUS = SQRT(TAUW3(J)*ROREF(1))*(X1(IN)-X1(IH))/ZMUREF(1)
   WRITE(25,999) YPLUS
360 CONTINUE
C CYLINDRICAL WALL:
C  ----------------
DO 370 I=IL,IH
   N=I-IL+1
DX = (X(I+1)-X(I-1))/2.0
DAREA = RM*DX
PWALL = PWALL + (ABS(TAUW(N))**1.5)*DAREA*CONST
YPLUS = SQRT(TAUW(N)*ROREF(1))*(R(JN)-R(JNM))/ZMUREF(1)
WRITE(25,999) YPLUS
999 FORMAT( ',1PE10.2')
370 CONTINUE
C EFFICIENCY OF ENERGY CONVERSION
C ETA2 = (PCASC-PWALL)/PCASC
WRITE(6,400) ETA2,PWALL,PCASC
400 FORMAT( 'COMPUTED EFFICIENCY = ',F5.2)
1/'VISCOS DISSIPATION = ',1PE10.2
2/'TOTAL POWER FLOW = ',1PE10.2)
C---------------------------------------------
PINPT=ETA*PCASC
CALL VOL(GKK,SHEAR2)
IF(SHEAR2.EQ.0.0) GO TO 100
AVGVIS=PINPT/(SHEAR2*ROREF(1))
AI =AVGVIS**2*DIMNSN**3
XI =1.0/(AI**0.118)
PERFIN =AVGVIS*ROREF(1)/ZMUREF(1)
C---------------------------------------------
RETURN
100 XI=XISET
RETURN
END
SUBROUTINE CONVEC(AE,AW,AN,AS,I,J,K)
C$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
COMMON/CNUMB/NW,NF,NK,NPE,NV1,NV2,NT,NMU,NRO,NTC,NSP,NMT
COMMON/GRID/IMIN(21),IMAX(21),X1(31),X2(21),R(21)
COMMON/CITER/INM,JNM,J1,11,12,13,IA,IW(21),J1
COMMON/CDIM/X(5),RE,RT
COMMON/CITER/INM,NPRINT,NITER,IP,IE,IV,CC
COMMON/CCONT/C1,C2,C3,CD
COMMON/CREAL/RP(10),RSDU(10),SAN(10)
COMMON/CMP/WF,P,S(4)
COMMON/CHJ/NHR,NHI,NJRR,NJRI,NZR,NJZI,NJ,J4,NS
COMMON/CTRL/TLM,TSMTLS,TA,TM,TW
COMMON/CHEAT/HC,HW(4)
COMMON/CFP/ES(21),FEM(21),FSE
COMMON/CDROP/TAU,HCD,D,QS,QM
COMMON/CFLD/CU
COMMON/CPI/PI
COMMON/CTYP/LTYP
COMMON/CANG/THETA
COMMON/CFT/MIT,MPRINT,CP
COMMON/CVAR/A(31,21,20)
COMMON/CNAME/ANAME,ASYMBL
COMMON/CRIT/NWI,NWJ,NFI,NFJ,NIT,J,NTJ,NIKJ,NEJ,GOSA,TOTA
COMMON/CLF/LF,LI
COMMON/CSVOR/SVOR(31,21)
COMMON/CSN/NSCHEM,NVISC,RPI,XI
COMMON/CSV/NSN(20),SN2(15),SN3(21),SN4(20),SN5(21)
COMMON/CBE/B(31),BN(21),BS(21)
COMMON/CAM/AVM(60)
COMMON/CHB/HILW,HLEH,HLEV,HLS,HLH,POWR
COMMON/CSUR/H(2),H(2)
COMMON/CBB/BBE,BBE,BBN,BS,PPP
COMMON/CSOR/SOURCE,SPRIME
COMMON/CN/FR1,FR2(15),FR3,FR4,FR5
COMMON/CVF/FUN(20)
COMMON/CVOLT/VOLT
COMMON/CV/V(20),V(20),V(21),V(20),V(21)
COMMON/CPROD/GK(31,21)
C$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
COMMON/CNAME/ANAME,ASYMBL

C........... ROUTINE FOR CALCULATION OF AE, AW, AN, AS

C... CALCULATION MEAN MASS FLOW RATE AT FOUR TUBES OF THE TANK

DV=R(J)*(X1(I+1)-X1(I-1))*(X2(J+1)-X2(J-I))

G1PW=(A(I,J+1,NF)-A(I,J-1,NF)+A(I-1,J+1,NF)-A(I-1,J-1,NF))/DV

G1PE=(A(I,J+1,NF)-A(I,J-1,NF)+A(I+1,J+1,NF)-A(I+1,J-1,NF))/DV

G2PS=(A(I-1,J,NF)-A(I+1,J,NF)+A(I-1,J-1,NF)-A(I+1,J-1,NF))/DV

G2PN=(A(I-1,J,NF)-A(I+1,J,NF)+A(I-1,J+1,NF)-A(I+1,J+1,NF))/DV

C--------------------------------------------------------------------

C................ Account for the wall function

C... CYLINDRICAL WALL NEIGHBOR POINTS

G1PE=-(A(I,J-1,NF)+A(I,J,NF)+A(I+1,J,NF)+A(I+1,J-1,NF))/DV

G1PW=-(A(I,d-1,NF)+A(I,J,NF)+A(I-1,J,NF)+A(I-1,J-1,NF))/DV

BBD=BBE*FR1

BBW=BBW*FR1

BBN=0.0

G2PN=0.

TAUW=TAUW1(I-I)

IF(K.EQ.NH.NR.OR.K.EQ.NHI) GO TO 10

IF(K.EQ.NW) GO TO 10

IF(J.NE.JNM) GO TO 7

C--------------------------------------------------------------------

16 B1=FR1

B2=2.*R(J)*(X2(J+1)-X2(J-I))

SNW=SN1(I-1)

TWALL=A(I,J+1,NT)

160 CONTINUE

GO TO 24

C...... LOWER SURFACE OF TOP ELECTRODE
VM/SP CONVERSATIONAL MONITOR SYSTEM

**FILE:** CONVEC FORTRAN C1

---

```fortran
C  7 IF(I.NE.(I+W(J)+1)) GO TO 8
    IF(J.GT.J1) GO TO 8
    GF=SIN(THETA)/COS(THETA)
    G2PN=-(A(I,J+1,NF)+A(I,J,NF)+A(I+1,J,NF)+A(I+1,J+1,NF))/DV
    G2PS=-(A(I,J-1,NF)+A(I,J,NF)+A(I+1,J,NF)+A(I+1,J-1,NF))/DV
    G1PW=0.
    FRN=FR2(J)+(X2(J+1)-X2(J))/(X1(I+1)-X1(I))*GF
    FRS=FR2(J)-(X2(J)-X2(J-1))/(X1(I+1)-X1(I))*GF
    BBN=BBN*FRN
    BBS=BBS*FRS
    BBW=0.0
    TAUW=TAUW2(J)
    IF(K.NE.NK.AND.K.NE.NEP) GO TO 18
    DX=X1(I+1)-X1(I-1)
    UA1=A(I,J,NV2)-A(I,J,NV1)*GF
    UA2=A(I+1,J,NV2)-A(I+1,J,NV1)*GF
    UA=ABS(UA1+UA2)/DX
    YP=(X1(I)-X1(I-1))*COS(THETA)
    IF(K.EQ.NK) GO TO 20
    IF(K.EQ.NEP) GO TO 21
C---------------------------------------------------------------------
C  18 BI=FR2(J)
    B2=2.0*(X1(I+1)-X1(I-1))
    IF(K.NE.NT) GO TO 180
    SNW=SN2(J)
    TWALL=A(I-1,J,NT)
    GO TO 22
C---------------------------------------------------------------------
C  180 CONTINUE
    GO TO 24
C---------------------------------------------------------------------
C  C BOTTOM ELECTRODE SURFACE
C---------------------------------------------------------------------
C  8 IF(I.NE.(I3-1)) GO TO 9
    G2PN= (A(I,J+1,NF)+A(I,J,NF)+A(I-1,J,NF)+A(I-1,J+1,NF))/DV
    G2PS= (A(I,J-1,NF)+A(I,J,NF)+A(I-1,J,NF)+A(I-1,J-1,NF))/DV
    G1PE=0.
    BBE=0.0
    BBN=BBN*FR3
    BBS=BBS*FR3
    TAUW=TAUW3(J)
    IF(K.NE.NK.AND.K.NE.NEP) GO TO 26
    DX=X1(I+1)-X1(I-1)
    UA=ABS(A(I3-1,J,NV2)+A(I3-2,J,NV2))/DX
    YP=X1(I+1)-X1(I)
```

---

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VM/SP CONVERSATIONAL MONITOR SYSTEM

IF(K.EQ.NK) GO TO 20
IF(K.EQ.NEP) GO TO 21

26 B1=FR3
   B2=2./(X1(I+1)-X1(I-1))
   IF(K.NE.NT) GO TO 261
   SNW=SN3(J)
   TWALL=A(I+1,J,NT)
   GO TO 22
   CONTINUE
   GO TO 24

C------------------------------------------------------------------
C SIDE SURFACE OF TOP ELECTRODE
C-----------------------------
9 IF(J.NE.(J1+1)) GO TO 10
   IF(I.GT.I2) GO TO 10
   G1PE=(A(I,J+1,NF)+A(I,J,NF)+A(I+1,J,NF)+A(I+1,J+1,NF))/DV
   G1PW=(A(I,J+1,NF)+A(I,J,NF)+A(I-1,J,NF)+A(I-1,J+1,NF))/DV
   G2PS=0.
   BB5=0.
   BBE=BBE*FR4
   BBW=BBW*FR4
   TAUW=TAUW4(I-I1)
   IF(K.NE.NK.AND.K.NE.NEP) GO TO 28
   DX=2.(J1+2)-X2(J1)
   UA=ABS(A(I,J1+1,NV1)+A(I,J1+2,NV1))/DX
   YP=X2(J1+1)-X2(J1)
   IF(K.EQ.NK) GO TO 20
   IF(K.EQ.NEP) GO TO 21

C------------------------------------------------------------------
28 B1=FR4
   B2=2.*(R(J-1)/R(J))/(X2(J+1)-X2(J-1))
   IF(K.NE.NT) GO TO 280
   SNW=SN4(I-I1)
   TWALL=A(I,J-1,NT)
   GO TO 22
   CONTINUE
   GO TO 24

C------------------------------------------------------------------
20 SOURCE=UA*TAUW
   SPRIME=UA*CDMOD(I,J)*A(I,J,NRO)**2*A(I,J,NK)/TAUW
   GK(I,J)=SOURCE
   GKK(I,J)=UA**2
   GO TO 10
21 SOURCE = (CDMOD(I,J)**0.75)*(A(I,J,NK)**1.50)/CAPPA/YP
21 SOURCE = UA*CDMOD(I,J)*A(I,J,NRO)*A(I,J,NK)**2/TAUW
SPRIME=1.0
AE=O.
AW=O.
AN=O.
AS=O.
BBE=O.
BBW=O.
BBN=O.
BBS=O.

IF (NSCHEM.EQ.1) A(I,J,NEP)=SOURCE
GO TO 100
22 SOURCE=SOURCE*B1+B2*SNW*TWALL-B3
SPRIME=SNW*B2
GO TO 10
24 SOURCE=SOURCE*B1
10 CONTINUE

C  COMPUTE THE CONVECTION CONSTANTS
C
APP=1.
IF(K.EQ.NHR.OR.K.EQ.NHI) APP=P/A(I,d,NRO)
IF(K.EQ.NF) APP=O.
IF(K.EQ.NW) APP=R(J)*R(d)
IF(K.EQ.NT) APP=A(I,J,NSP)
AW=0.5*APP*(ABS(GIPW)+G1PW)
AE=0.5*APP*(ABS(GIPE)-G1PE)
AN=0.5*APP*(ABS(G2PN)-G2PN)
AS=0.5*APP*(ABS(G2PS)+G2PS)
100 CONTINUE
SUBROUTINE CORD

COMMON/CNUMB/NW,NF,NK,NEP,NVI,NV2,NT,NMU,NRO,NTC,NSP,NMT
COMMON/CGRID/IN,INM,JN,JNM,I1,I2,I3,IA,IW(21),Ji
COMMON/CDIM/X(5),RE,RM
COMMON/CITER/NMAX,NPRINT,NITER,IP,IE,IV,CC
COMMON/CCONT/C1,C2,C3,CD
COMMON/CRLAX/RP(iO),RSDU(IO),SAN(10)
COMMON/CEMP/WF,P,S(4)
COMMON/CHJ/NHR,NHI,NJRR,NJRI,NJZR,NJZI,NJU,NS
COMMON/CTHERM/TCREF(5),SPREF(5),BETA(2),ES,EE,EM,SB,HL
COMMON/CTEMP/TLM,TSMTLS,TA,TM,TW
COMMON/CTRVL/VE,VC
COMMON/CHEAT/HC,HW(4)
COMMON/CTAUW/TAUWI(20),TAUW2(15),TAUW3(21),TAUW4(IO),TAUW5(21)
COMMON/CFLD/CU
COMMON/CPI/PI
COMMON/CTYP/LTYP
COMMON/CANG/THETA
COMMON/FITER/MIT,MPRINTCP
COMMON/CDVAR/A(31,21,20)
COMMON/CNAME/ANAME,ASYMBL
COMMON/CCRIT/NWI,NWJ,NFI,NFJ,NTJ,NKI,NKJ,NEIJ,NEJ,GOJA,TOTA
COMMON/CLF/LF,LI
COMMON/CSVOR/SVOR(31,21)
COMMON/CSUR/HS(2),TS(2)
COMMON/CBB/BBE,BBW,BBN,BBS,BPP
COMMON/CSORSE/SOURCE,SPRIME
COMMON/CGEOM/FR1,FR2(15),FR3,FR4,FR5
COMMON/CAF/FUN(20)
COMMON/CVOLT/VOLT
COMMON/CVOLT/TB
COMMON/CYPM/YP1(20),YP2(15),YP3(21),YP4(10),YP5(21)
COMMON/CADD/JA,JAX,RA,RAX,IA
GRID GENERATION SECTION

\[ X_1(1) = 0.0 \]
\[ X_2(1) = 0.0 \]
\[ R(1) = X_2(1) \]

\[
\text{IM} = \text{I}_2 + J_1 - 1 \\
\text{IF(THETA.EQ.O.) IM} = \text{I}_2 \\
\text{I}_W(J_1) = \text{I}_2 \\
\text{I}_W(1) = \text{IM} \\
\text{GF} = \sin(\text{THETA})/\cos(\text{THETA}) \\
\text{XIM} = X(2) + \text{RE} \times \text{GF} \\
\]

\[
\text{DO 11 J=2,J} \\
\text{IW}(D) = \text{IW}(D-1) - 1 \\
\text{IF(J.GE.d1) IW}(D) = \text{I}_2 \\
\text{IF(THETA.EQ.0.) IW}(D) = \text{I}_2 \\
\]

\[
\text{DZ1} = X(1)/\text{FLOAT}(\text{I}_1-1) \\
\text{DZ3} = (X(3) - X(2))/\text{FLOAT}(\text{I}_A - \text{I}_2) \\
\text{DZ4} = (X(4) - X(3))/\text{FLOAT}(\text{I}_A - \text{I}_1) \\
\text{DZ5} = (X(5) - X(4))/\text{FLOAT}(\text{I}_N - \text{I}_A) \\
\]

\[
\text{DO 10 I=2,IN} \\
\text{IF(I.LE.I1) DXI = DZI} \\
\text{IF(I.GT.I1.AND.I.LE.I2) DXI = DZ2} \\
\text{IF(I.GT.I2.AND.I.LE.IA) DXI = DZ3} \\
\text{IF(I.GT.IA.AND.I.LE.IAX) DXI = DZ4} \\
\text{IF(I.GT.IAX.AND.I.LE.IN) DXI = DZ5} \\
\]

\[
\text{X1(I)} = X1(I-1) + DX1 \\
\text{DR1} = \text{RE}/\text{FLOAT}(J_1-1) \\
\text{DR2} = (\text{RA}-\text{RE})/\text{FLOAT}(J_1 - J_1) \\
\text{DR3} = (\text{RAX} - \text{RA})/\text{FLOAT}(J_1 - J_1) \\
\text{DR4} = (\text{RM} - \text{RAX})/\text{FLOAT}(J_1 - J_1) \\
\]

\[
\text{DO 50 J=2,JN} \\
\text{IF(J.GT.J1.AND.J.LE.J1) DX2 = DR1} \\
\text{IF(J.GT.J1.AND.J.LE.JA) DX2 = DR2} \\
\text{IF(J.GT.J1.AND.J.LE.JAX) DX2 = DR3} \\
\text{IF(J.GT.J1.AND.J.LE.JN) DX2 = DR4} \\
\text{X2(J)} = X2(J-1) + DX2 \\
\text{R(J)} = X2(J) \\
\]

\[
\text{DO 20 I=2,INM} \\
\text{DX1} = 1./(X1(I+1) - X1(I-1)) \\
\]
FILE: CORD FORTRAN C1

VM/SP CONVERSATIONAL MONITOR SYSTEM

BW(I)=DX1/(X1(I)-X1(I-1))
BE(I)=DX1/(X1(I+1)-X1(I))

20 CONTINUE
DO 21 J=2,JNM
DX2=1.0/(X2(J+1)-X2(J-1))
A1=DX2/(X2(J+1)-X2(J))
BN(J)=(1.+R(J+1)/R(J))*0.5*A1
A2=DX2/(X2(J)-X2(J-1))
BS(J)=(1.+R(J-1)/R(J))*0.5*A2
21 CONTINUE

23 CONTINUE
FR1=2.-(X2(JNM)-X2(JNM-1))/(X2(JN)-X2(JNM-1))
FR3=2.-(X1(I3-1)-X1(I3-2))/(X1(I3)-X1(I3-2))
FR4=2.-(X2(J1+2)-X2(J1+1))/(X2(J1+2)-X2(J1))
FR5=2.-(X1(I1+2)-X1(I1+1))/(X1(I1+2)-X1(I1))
DO 25 J=1,J1
II=II+1
25 FR2(J)=2.-(X1(II+2)-X1(II+1))/(X1(II+2)-X1(II))
RETURN
END
SUBROUTINE DISSIP

C**********************************************************************
COMMON/CNUMB/NW,NF,NK,NEP,NVI,NV2,NT,NMU,NRONTC,NSP,NMT
COMMON/CCORD/IMIN(21),IMAX(21),X1(31),X2(21),R(21)
COMMON/CGRID/IN,INMJN,JNMI1,12,I3,IA,IW(21),JI
COMMON/CDIM/X(5),RERM
COMMON/CITER/NMAX,NPRINT,NITER,IP,IEIV,CC
COMMON/CCONT/C1,C2,C3,CD
COMMON/CRLAX/RP(10),RSDU(10),SAN(10)
COMMON/CEMP/WF,P,S(4)
COMMON/CHJ/NHR,NHI,NJRR,NJRI,NJZR,NJZI,NJJ,NS
COMMON/CTHERM/TCREF(5),SPREF(5),BETA(2),ES,EE,EM,SB,HL
COMMON/CTRVL/VE,VC
COMMON/CHEAT/HCHW(4)
COMMON/CPROP/ROREF(5),ZMUREF(2),PR(10),GAMA
COMMON/CVF/FES(21),FEM(21),FSM,FSE
COMMON/CTURB/NTURB,NSCHEM,NVISC,RPXI,XI
COMMON/CSVOR/SVOR(31.21)
COMMON/CTAUEW/TAUEW1(20),TAUEW2(15),TAUEW3(21),TAUEW4(10),TAUEW5(21)
1,CAPPA,E
COMMON/CFLD/CU
COMMON/CPI/PI
COMMON/CANG/THETA
COMMON/CDVAR/A(31,21,20)
COMMON/CNAME/ANAME,ASYMBL
COMMON/CCRIT/NWI,NWd,NFI,NFJ,NTI,NTJ,NKI,NKJ,NEI,NEJ,GOSA,TOTA
COMMON/CLF/LF,LI
COMMON/CTYP/LTYP
COMMON/CSORSE/SOURCE,SPRIME
COMMON/CGEOM/FRI,FR2(15),FR3,FR4,FR5
COMMON/CAF/FUN(20)
COMMON/CVOLT/VOLT
COMMON/CAVT/TB
COMMON/CYP/YP1(20),YP2(15),YP3(21),YP4(10),YP5(21)
C**********************************************************************
DATA IVAR/0/
C .................CALCULATE DISSIPATION ENERGY
C
DO 31 J=1,JNM-1
IL=I1+1
ITOP=IL
IF(J.LE.J1) ITOP=IL+1
IH=I3-1
DO 31 I=ITOP,IH-1
IF(A(I,J,NK).LE.O.0) GO TO 41
A(I,J,NEP)=(A(I,J,NK)*XI)**1.7
GO TO 31
41 A(I,J,NK)=0.0
A(I,J,NEP)=O.O
31 CONTINUE
C GET DISSIPATION AT THE BOUNDARIES
C
DO 50 d=2,JNM
IL=I1+1
IH=I3-1
DO 50 I=IL,IH
IF(I.EQ.IL.AND.J.LE.01) CALL CONVEC(DI,D2,D3,D4,I,J,NEP)
C BOTTOM SURFACE
C
IF(I.EQ.IH) CALL CONVEC(D1,D2,D3,D4,1,J,NEP)
C CYLINDRICAL SURFACE
C
IF(J.EQ.JNM) CALL CONVEC(D1,D2,D3,D4,1,J,NEP)
50 CONTINUE
RETURN
END
FILE: EMFLOW FORTRAN C1

EM/SP CONVERSATIONAL MONITOR SYSTEM

REAL*8 ANAME(6,20), ASYMBL(14)
COMMON/CNUMB/NW,NF,NK,NEP,NVI,NV2,NT,NMU,NRO,NTC,NSP,NMT
COMMON/CCORD/IMIN(21),IMAX(21),XI(31),X2(21),R(21)
COMMON/CDIR/IN,INM,UN,UNM,11,12,13,IA,1W(21),J1
COMMON/CDIM/X(5),RE, RM
COMMON/CITER/NMAX,NPRINT,NITER,IP,IE,IV,CC
COMMON/CCONT/CI,C2,C3,CD
COMMON/CRFLAX/RP(10),RSDU(10),SAN(10)
COMMON/CEMP/WF,P,S(4)
COMMON/CTHERM/TCREF(5),SPREF(5),BETA(2),ES,EE,EM,SB,HL
COMMON/CTEMP/TLM,TSM,TLS,TA,TM,TW
COMMON/CTRVL/VE,VC
COMMON/CTAUW/TAUWI(20),TAUW2(15),TAUW3(21),TAUW4(10),TAUW5(21)
COMMON/CFLD/CU
COMMON/CPI/PI
COMMON/CANG/THETA
COMMON/FITER/MIT,MPRINT,CP
COMMON/CLF/LF,LI
COMMON/CSVOR/SVOR(31,21)
COMMON/CTURB/NTURB,NSCHEM,NVISC,RPXI, XI
COMMON/CSNW/SN1(20),SN2(15),SN3(21),SN4(20),SN5(21)
COMMON/CB/B(31),BW(31),BN(21),BS(21)
COMMON/CSVM/AVM(60)
COMMON/CHBL/HLW,HLEH,HLEV,HLS,HLD,HLM,POW
COMMON/CSUR/HS(2),TS(2)
COMMON/CBB/BBE, BBW,BBN,BBS,BPP
COMMON/CSORSE/SOURCE, SFRM
COMMON/CGEOM/FR1, FR2(15), FR3, FR4, FR5
COMMON/CAF/FUN(20)
COMMON/CVOLT/VOLT
COMMON/CAVT/TB
COMMON/CYP/YP1(20),YP2(15),YP3(21),YP4(10),YP5(21)
COMMON/CPROD/GK(31,21)
COMMON/CLREYN/LREYN,CDMOD(31,31)
DIMENSION GK(31,21),P1(31,21),P2(31,21),RFORCE(31,21)
DIMENSION XM(31),EPSIL(31,21),TIMIX(31,21)
DATA PIMIN,ETA/10.0,0.50/

C INITIAL SET UP SECTION
C
C.... IF INREAD=1 INITIAL GUESS FIELD IS READ IN ON UNITS 4 AND 8
INM=IN-i
JNM=JN-1
C*** READ ALPHAMERIC INFORMATION FOR HEADINGS AND TITLES
READ(5,200)ANAME,ASYMBL
C
READ IN INREAD,NMIN,NSCHEM,RPXI,NTURB
READ(5,205)INREAD,NMIN,NSCHEM,NMAX,NPRINT,RPXI,NTURB
1,NDATA,NFIELD,NFLOW,LREYN,NCHECK
C
DATA ECHO SEGMENT (IF NDATA=1)
C
IF(NDATA.EQ.0) GO TO 345
WRITE(6,208)
WRITE(6,210) CU,ZMUREF(2),ROREF(2),S(2),NMAX
DP=X(5)-X(1)
XIM=X(2)-X(1)
WRITE(6,220) RE,RM,DP,XIM
C
C CALCULATION SCHEMES IN OPERATION
C
IF(INREAD.EQ.0) WRITE(6,213)
IF(INREAD.EQ.1) WRITE(6,214)
IF(LTYP.EQ.1) WRITE(6,215)
IF(LTYP.EQ.2) WRITE(6,216)
IF(NUFR.B.EQ.0) WRITE(6,217)
IF(NSCHEM.EQ.0.AND.LREYN.EQ.1) WRITE(6,235)
IF(NSCHEM.EQ.1.AND.LREYN.EQ.1) WRITE(6,236)
IF(NFLOWS.EQ.0) WRITE(6,237)
IF(NFLOWS.EQ.1) WRITE(6,238)
IF(NFLOWS.EQ.2) WRITE(6,239)
IF(NFLOWS.EQ.3) WRITE(6,240)
IF(NFLOWS.EQ.4) WRITE(6,241)
IF(NFLOWS.EQ.5) WRITE(6,242)
IF(NFLOWS.EQ.6) WRITE(6,243)
IF(NFLOWS.EQ.7) WRITE(6,244)
IF(NFLOWS.EQ.8) WRITE(6,245)
IF(NFLOWS.EQ.9) WRITE(6,246)
IF(NFLOWS.EQ.10) WRITE(6,247)
IF(NFLOWS.EQ.11) WRITE(6,248)
IF(NFLOWS.EQ.12) WRITE(6,249)
IF(NFLOWS.EQ.13) WRITE(6,250)
IF(NFLOWS.EQ.14) WRITE(6,251)
IF(NFLOWS.EQ.15) WRITE(6,252)
IF(NFLOWS.EQ.16) WRITE(6,253)
IF(NFLOWS.EQ.17) WRITE(6,254)
IF(NFLOWS.EQ.18) WRITE(6,255)
IF(NFLOWS.EQ.19) WRITE(6,256)
IF(NFLOWS.EQ.20) WRITE(6,257)
IF(NFLOWS.EQ.21) WRITE(6,258)
IF(NFLOWS.EQ.22) WRITE(6,259)
IF(NFLOWS.EQ.23) WRITE(6,260)
IF(NFLOWS.EQ.24) WRITE(6,261)
IF(NFLOWS.EQ.25) WRITE(6,262)
IF(NFLOWS.EQ.26) WRITE(6,263)
IF(NFLOWS.EQ.27) WRITE(6,264)
IF(NFLOWS.EQ.28) WRITE(6,265)
IF(NFLOWS.EQ.29) WRITE(6,266)
IF(NFLOWS.EQ.30) WRITE(6,267)
IF(NFLOWS.EQ.31) WRITE(6,268)
IF(NFLOWS.EQ.32) WRITE(6,269)
IF(NFLOWS.EQ.33) WRITE(6,270)
IF(NFLOWS.EQ.34) WRITE(6,271)
IF(NFLOWS.EQ.35) WRITE(6,272)
IF(NFLOWS.EQ.36) WRITE(6,273)
IF(NFLOWS.EQ.37) WRITE(6,274)
IF(NFLOWS.EQ.38) WRITE(6,275)
IF(NFLOWS.EQ.39) WRITE(6,276)
IF(NFLOWS.EQ.40) WRITE(6,277)
IF(NFLOWS.EQ.41) WRITE(6,278)
IF(NFLOWS.EQ.42) WRITE(6,279)
IF(NFLOWS.EQ.43) WRITE(6,280)
IF(NFLOWS.EQ.44) WRITE(6,281)
IF(NFLOWS.EQ.45) WRITE(6,282)
IF(NFLOWS.EQ.46) WRITE(6,283)
IF(NFLOWS.EQ.47) WRITE(6,284)
IF(NFLOWS.EQ.48) WRITE(6,285)
IF(NFLOWS.EQ.49) WRITE(6,286)
IF(NFLOWS.EQ.50) WRITE(6,287)
IF(NFLOWS.EQ.51) WRITE(6,288)
IF(NFLOWS.EQ.52) WRITE(6,289)
IF(NFLOWS.EQ.53) WRITE(6,290)
IF(NFLOWS.EQ.54) WRITE(6,291)
IF(NFLOWS.EQ.55) WRITE(6,292)
IF(NFLOWS.EQ.56) WRITE(6,293)
IF(NFLOWS.EQ.57) WRITE(6,294)
IF(NFLOWS.EQ.58) WRITE(6,295)
IF(NFLOWS.EQ.59) WRITE(6,296)
IF(NFLOWS.EQ.60) WRITE(6,297)
IF(NFLOWS.EQ.61) WRITE(6,298)
IF(NFLOWS.EQ.62) WRITE(6,299)
IF(NFLOWS.EQ.63) WRITE(6,300)
IF(NFLOWS.EQ.64) WRITE(6,301)
IF(NFLOWS.EQ.65) WRITE(6,302)
IF(NFLOWS.EQ.66) WRITE(6,303)
IF(NFLOWS.EQ.67) WRITE(6,304)
IF(NFLOWS.EQ.68) WRITE(6,305)
IF(NFLOWS.EQ.69) WRITE(6,306)
IF(NFLOWS.EQ.70) WRITE(6,307)
IF(NFLOWS.EQ.71) WRITE(6,308)
IF(NFLOWS.EQ.72) WRITE(6,309)
IF(NFLOWS.EQ.73) WRITE(6,310)
IF(NFLOWS.EQ.74) WRITE(6,311)
IF(NFLOWS.EQ.75) WRITE(6,312)
IF(NFLOWS.EQ.76) WRITE(6,313)
IF(NFLOWS.EQ.77) WRITE(6,314)
IF(NFLOWS.EQ.78) WRITE(6,315)
IF(NFLOWS.EQ.79) WRITE(6,316)
IF(NFLOWS.EQ.80) WRITE(6,317)
IF(NFLOWS.EQ.81) WRITE(6,318)
IF(NFLOWS.EQ.82) WRITE(6,319)
IF(NFLOWS.EQ.83) WRITE(6,320)
IF(NFLOWS.EQ.84) WRITE(6,321)
IF(NFLOWS.EQ.85) WRITE(6,322)
IF(NFLOWS.EQ.86) WRITE(6,323)
IF(NFLOWS.EQ.87) WRITE(6,324)
C........... COMPUTE AND PRINT COORDINATES

C============================================
345 CONTINUE
CALL CORD
WRITE(6,9)
WRITE(6,12) I1,I2,I3,IA,IN,J1,JN
WRITE(6,101) (X1(I),I=1,IN)
WRITE(6,40)
350 CONTINUE
C======== INITIALIZE
C----------
CALL INIT
LV=NHR
IF(INREAD.EQ.1)GO TO 989
C..... IF READ IN NOT DESIRED THEN USE THE VALUES GENERATED BY INIT
GO TO 999
989 CONTINUE
C.......... READ IN SEGMENT; UNIT NUMBERS 4 AND 8
C------------------
DO 21 K=NHR,LV
DO 21 J=1,JN
21 READ(4,14) (A(I,J,K),I=1,IN)
DO 22 K=1,IE
DO 22 J=1,JN
22 READ(8,14) (A(I,J,K),I=I1,I3)
999 CONTINUE
23 CONTINUE
LI=1
CALL PROP(I)
C============== SOLVE MAXWELL'S EQUATIONS
C------------------
IF(LI.EQ.2) GO TO 100
IF(NFIELD.EQ.1) CALL FIELD
979 CONTINUE
IF(LF.EQ.2) GO TO 30
100 CONTINUE
C.......... PERFORM FLUID FLOW CALCULATIONS
C------------------
NITER=0
1 CONTINUE
NITER=NITER+1
C............... CAUSE ONE CYCLE OF ITERATION TO BE PERFORMED
C IF(NFLOW.EQ.0) GO TO 30

CALL EON
WRITE(15,109) XI

C------------------- TEST IF PRINTOUT TO BE PRODUCED -------------------
C
C IF(((NITER+NPRINT-IP)/NPRINT).NE.NITER/NPRINT) GO TO 10
WRITE(6,104) NITER,(RSDU(K),K=1,7),NWJ,NWI,NFJ,NFI,NJ,NFI
WRITE(6,107) (ASYMBL(K),K=8,14)
WRITE(6,108) NITER,(SAN(K),K=1,7),NKJ,NKI,NEJ,NEI
C
WRITE(15,109) XI
C WRITE(15,109) XI
10 CONTINUE

C............. TEST IF MAXIMUM NUMBER OF ITERATIONS PERFORMED .............
C
C IF(NITER.EQ.NMAX) GO TO 8
RES=0.
DO 7 K=1,IE
IF(ABS(RES).LT.ABS(RSDU(K))) RES=RSDU(K)
RSDU(K)=0.
7 CONTINUE
SANWF=0.
DO 3 K=1,IE
IF(ABS(SANWF).LT.ABS(SAN(K))) SANWF=SAN(K)
SAN(K)=0.
3 CONTINUE

C*** TEST IF CONVERGENCE CRITERION SATISFIED; IF NOT, BACK TO (1) ********
C
IF(ABS(SANWF).GT.0.001) GO TO 1
IF(NITER.LE.NMIN) GO TO 1
C
C------------------- "CONVERGED" ----------------------------------------
C
WRITE(6,105) NITER
GO TO 340

C------------------- "UNCONVERGED" -------------------------------------
C
8 WRITE(6,106) NITER
CALL CONLOT(XI, PERFIN, PCASC)
C CALCULATE THE LOCAL MIXING TIMES
C
DEPTH=X(5)-X(1)
DIMNSN=DEPTH
IL=I1+1
IH=I3+1
DO 900 J=1,JNM
DO 900 I=IL,IH
900 TIMIX(I,J) = 80.0*(DIMNSN**2/(1000.*A(I,J,NEP)))**0.333
CONTINUE
C CALCULATE THE TOTAL MIXING TIME FOR VESSEL
C XMASS=RM**2*DEPTH*ROREF(I)/2.0
PSPEC=PCASC/XMASS
TOTALT=80.0*(DIMNSN**2/(ETA*1000.*PSPEC))**0.333
C CALCULATE THE POWER INPUT PER TON MELT
PTON = PSPEC*1000.0
C........................................MAIN RESULTS PRINTED OUT HERE
C IF(PERFIN.GT.PIMIN)WRITE(6,250) PERFIN
IF(PERFIN.LE.PIMIN) WRITE(6,252) PERFIN
WRITE(6,254) PTON
WRITE(6,253) TOTALT
CALL PRINT(NW,NF,2)
CALL PRINT(NV1,NV2,1)
IF (NTURB.EQ.0) GO TO 355
C................................TURBULENT RESULTS PRINT OUT
CALL PRINT(NK,NEP,2)
CALL PRINT(NMU,NMU,2)
C..........................WRITE OUTPUT DATA FILE
C ..........................................................CONTINUE
355 DO 15 K=NW,IE
DO 16 J=1,JN
16 WRITE(7,14)(A(I,J,K),I=I1,I3)
15 CONTINUE
C DO 11 K=NHR,LV
DO 11 J=1,JN
11 WRITE(3,14)(A(I,J,K),I=1,IN)
1 CONTINUE
C CALCULATE GENERATION AND DISSIPATION ENERGY
C...ENERGY GENERATION:
C ----------------
50 CALL VOL(GK,PGEN)
C ----------------

C...DISSIPATION:
C...

DO 52 I=1,IN
DO 52 J=1,JN
EPSIL(I,J)=0.0
CONTINUE
52
IL=I+1
IH=I-1
DO 400 I=IL,IH
DO 400 J=2,JNM
EPSIL(I,J)=A(I,J,NEP)
CONTINUE
400
CALL VOL(EPSIL,PDISIP)
PDISIP=PDISIP*ROREF(I)

C...PRINT IT:
C -------
WRITE(6,410) PGEN,PDISIP,PCASC
410 FORMAT('TOTAL GENERATION= ',1PE10.2,'/TOTAL DISSIPATION= '
1,1PE10.2,'/TOTAL POWER INPUT= ',1PE10.2)

C************** STOP **************
969 CONTINUE
C *** SAVE DATA FOR PLOTTING (UNIT #9)
NX=I3-I1+1
NY=JN
WRITE(9,1233) NX,NY,J1,NSCHEM,CU,ETA
C COORDINATE DATA
C -------
DO 34 I=I1,I3
L=I-I1+1
34 XM(L)=X(I)-X(I1)
WRITE(9,1234) (XM(L),L=1,NX)
WRITE(9,1234) (X2(J),J=1,JN)
K=NJV1
C -------
DO 32 J=1,SY
32 WRITE(9,1234) (A(I,J,K),I=I1,I3)
C -------
DO 33 J=1,SY
33 WRITE(9,1234) (A(I,J,K),I=I1,I3)
FILE: EMFLOW  FORTRAN  C1  VM/SP CONVERSATIONAL MONITOR SYSTEM

30 CONTINUE
C
K=NK
-----
DO 121 J=1,JN
WRITE(9,1234) (A(I,J,K),I=I1,I3)
121 CONTINUE
C
K=NEP
-----
DO 122 J=1,JN
WRITE(9,1234) (A(I,J,K),I=I1,I3)
122 CONTINUE
K=NMU
C
-----
DO 123 J=1,JN
WRITE(9,1234) (A(I,J,K),I=I1,I3)
123 CONTINUE
C LOCAL MIXING TIMES
C
-----
DO 124 J=1,JN
WRITE(9,1234) (TIMIX(I,J),I=I1,13)
124 CONTINUE
STOP
C--------------------------------------------------------------------
C
F0 M A T T I N G
C
9 FORMAT('///',C0 0R D I N A T E D A ///)
12 FORMAT(4H I1=,12,4H 12=,I2,4H 13=,12,4H IA=,I2,4H IN=,I2)
14 FORMAT(7(1PE10.3))
40 FORMAT(27H THE ELECTRODE TIP SHAPE IS/)
125X,5HX2(J),25X,6HX1(II))
42 FORMAT(20X,E15.5,15X,E15.5)
101 FORMAT(25H DISTANCES IN DIRECTION-1/(/1H .7E15.5))
102 FORMAT(25H DISTANCES IN DIRECTION-2/(/1H .7E15.5))
103 FORMAT(36H MAXIMUM RESIDUAL FOR EACH VARIABLE://)
16HONITER,7(3X,A6),7X,'NWJ NWI NJ TNI'/ ///)
104 FORMAT(1H0,3X,3X,7(F9.4),5X,I2,5(I4))
105 FORMAT(32H THE PROCESS CONVERGED IN,I5,13H ITERATIONS)
106 FORMAT(32H THE PROCESS DID NOT CONVERGE IN,I5,13H ITERATIONS)
107 FORMAT(36H MAXIMUM RESIDUAL FOR EACH VARIABLE://)
16HONITER,7(3X,A6),7X,'NKJ NKE NWE NWE'///)
108 FORMAT(1H0,3X,3X,7(F9.4),5X,I2,3(I4))
109 FORMAT( ' XI= ',1PE10.2)
200 FORMAT(6A6)
205 FORMAT(5I5,F5.2,6I5)
208 FORMAT( ' INPUT DATA ///')
210 FORMAT(' CURRENT= ',1PE10.2,' KILO-AMPS'
1/ 'MOLECULAR VISCOSITY= ',1PE10.2,' KG/M-S'
2/'MELT DENSITY= ',1PE10.2, ' KG/(M-CUBE)' EMFO3160
3/'ELEC. CONDUCTIVITY OF MELT= ',1PE10.2, ' MHO-M' EMFO3170
4/'MAX.ITERATIONS FOR FLOW ',15) EMFO3180
213 FORMAT( 'COLD START CALCULATION; DATA NOT READ IN') EMFO3190
214 FORMAT( 'CONTINUATION CALCULATION; PREVIOUS DATA READ') EMFO3200
215 FORMAT( 'CURRENT TYPE IS =>A.C.' ) EMFO3210
216 FORMAT( 'CURRENT TYPE IS =>D.C.' ) EMFO3220
217 FORMAT('L A M I N A R FLOW CALCULATION') EMFO3230
218 FORMAT('T U R B U L E N T FLOW CALCULATION') EMFO3240
219 FORMAT('K-EPSILON TURBULENCE MODEL') EMFO3250
220 FORMAT( 'SPECTRAL MODEL FOR TURBULENCE') EMFO3260
221 FORMAT('E-M FIELD CALCULATIONS => O F F ') EMFO3270
222 FORMAT('E-M FIELD CALCULATIONS => O N') EMFO3280
223 FORMAT('FLOW CALCULATIONS => O F F ') EMFO3290
224 FORMAT('FLOW CALCULATIONS => O N') EMFO3300
225 FORMAT('USING LOW REYNOLD NUMBER MODEL') EMFO3310
226 FORMAT( 'BASE VALUE OF CONSTANTS ARE:') EMFO3320
1 'CD= ',F5.2/ EMFO3330
2 'C1= ',F5.2/ EMFO3340
3 'C2= ',F5.2 ) EMFO3350
250 FORMAT( '/ AUTOMATIC TURBULENCE CHECK; FLOW FOUND TO BE:' EMFO3360
1/10X,’.....T U R B U L E N T ’ EMFO3370
2/10X,’PERFORMANCE INDEX= ',F7.2) EMFO3380
251 FORMAT( 'AUTOMATIC TURBULENCE CHECK; FLOW FOUND TO BE:' EMFO3390
1/10X,’.....L A M I N A R ’ EMFO3400
2/10X,’PERFORMANCE INDEX= ',F7.2) EMFO3410
254 FORMAT(10X,’POWER INPUT= ',1PE10.2, ' WATTS/TON OF MELT’) EMFO3420
255 FORMAT(10X,’OVERALL MIXING TIME(95% MIXED)= ',F6.2, ' SECS//') EMFO3430
220 FORMAT( 'ELECTRODE RADIUS= ',1PE10.2, ' M') EMFO3440
1/'VESSEL RADIUS= ',1PE10.2, ' M' EMFO3450
2/'MELT DEPTH= ',1PE10.2, ' M' EMFO3460
3/'ELECTRODE IMMERSION= ',1PE10.2, ' M') EMFO3470
225 FORMAT(10X,'50H DRIVING FORCES ARE FIRST ELECTROMAG THEN BUOYANCY) EMFO3480
1233 FORMAT(4I4,2F5.2) EMFO3490
1234 FORMAT(5E13.5) EMFO3500
END EMFO3510
1 CONTINUE
C  UPDATE COEFFICIENT CD TO CD(MOD(I,J)) FOR
C  LOW REYNOLDS NUMBER MODEL OF TURBULENCE.
C
   IF(NTURB.EQ.0) GO TO 500
   DO 500 J=1,JNM
      IL=I+1
      IH=I-1
      DO 500 I=IL,IH
      FMU=1.0
      IF(LEYN.EQ.0.OR.A(I,JNEP).EQ.0.0) GO TO 400
      REYLOC=A(I,J,NRO)*A(I,J,NK)**2/(ZMUREF(i)*A(I,JNEP))
      FMU=EXP(-2.5/(1+REYLOC/50.0))
500  CONTINUE
C---------------------------------------------------------------------
C....................OBTAIN EFFECTIVE VISCOSITY
C--------------------------
C
   IF (NTURB.EQ.1) CALL VISCOS
C
C....................VORTICITY SUB-CYCLE
C
      GOSA=0.0
      TOTA=0.0
      CALL VORITY
      IF(GOSA.EQ.0.0.AND.TOTA.EQ.0.0) GO TO 10
      SAN(NW)=GOSA/TOTA
      GO TO 40
10   SAN(NW)=1.
40   CONTINUE
C....................STREAM FUNCTION SUB-CYCLE
C
      GOSA=0.0
      TOTA=0.0
      CALL STRFUN
      IF(GOSA.EQ.0.0.AND.TOTA.EQ.0.0) GO TO 20
      SAN(NF)=GOSA/TOTA
      GO TO 50
20   SAN(NF)=1.
50   CONTINUE
C....................VELOCITY DISTRIBUTION
C
      CALL VELDIS
      IF(NTURB.EQ.0) GO TO 120
C....................TURBULENT VARIABLE CALCULATIONS(ONLY IF NTURB=1)
C CHOOSE WHICH SCHEME OF CALCULATION IS DESIRED.
C NSCHEM=0 ... FOR K- EPSILON MODEL
C NSCHEM=1 ... FOR MSR MODEL.
C
C CALL WALL
NEND=NK
IF(NSCHEM.EQ.0) NEND=NEP

C DO 41 K=NK,NEND
GOSA=0.0
TOTA=0.0
IF(NSCHEM.EQ.0) CALL TURVAR(K)
IF(NSCHEM.EQ.1) CALL TURVAR(K)
IF(GOSA.EQ.0.0.AND.TOTA.EQ.0.0) GO TO 30
SAN(K)=GOSA/TOTA
GO TO 41
30 SAN(K)=1.
41 CONTINUE
C
C .......... INITIATE ITERATION ON BOUNDARY NODES
C
C
C 120 CALL BOUND
C...... CALL DISSIP IF SO DESIRED BY CHOICE OF SCHEME.
C
C IF (NTURB.EQ.1.AND.NSCEM.EQ.1) CALL DISSIP
C
C OUTPUT CDMOD(I,J) AS A CHECK
C
C DO 550 J=1,UNM
IL=I+1
IH=I3-1
WRITE(18,560)(CDMOD(I,J),I=IL,IH)
550 CONTINUE
560 FORMAT(10F5.2)

RETURN
END
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SUBROUTINE FIELD

COMMON/CNUMB/NW,NF,NK,NEP,NVI,NMT
COMMON/CCORD/IMIN(21),IMAX(21),XI(31),X2(21),R(21)
COMMON/CGRID/IN,JN,JM,JNMI,I2,I3,IA,IW(21),J1
COMMON/CDIM/X(5),RE,RM
COMMON/CITER/NMAX,NPRINT,NITER,IP,IE,IV,CC
COMMON/CCONT/C1,C2,C3,CD
COMMON/CRDAX/R(10),RSDU(10),SAN(10)
COMMON/CMP/WF,P(4)
COMMON/CHJ/NHR,NHI,NRR,NJRI,NZI,NJJ,NS
COMMON/CTHERM/TCREF(5),SPREF(5),B(2),ES,EM,SB,HL
COMMON/CTEMP/TLMTSM,TLS,TA,TM,TW
COMMON/CTEMP/VE,VC
COMMON/CTHE/HC,HE(4)
COMMON/CMP/RP(IO),RSDU(IO),SAN(10)
COMMON/CFILTER/MIT,MPRINT,CP
COMMON/CDVAR/A(31,21,20)
COMMON/CCNAME/ANAME,ASYMBL
COMMON/CCWIT/NTINTJ,NKI,NKd,NEI,NEJ,GOSA,TOTA
COMMON/CLF/LF,LI
COMMON/CSVOR/SVOR(31,21)
COMMON/CTURB/NSCHEM,NVISC,RPXI,XI
COMMON/CSW/S(15),SN(21),SN(20),SN(21)
COMMON/CBE(31),BN(21),BS(21)
COMMON/CAV/AVM(60)
COMMON/CHBL/HW,HLEH,HLEV,HLS,HLM,POWR
COMMON/CSUR/HS(2),TS(2)
COMMON/CSV/B,BS,BS2,BP
COMMON/CSO/FR1,FR2(15),FR3,FR4,FR5
COMMON/CAF/FUN(20)
COMMON/CAVT/TB
COMMON/CYP/YP(1,20),YP(1,15),YP(2,15),YP(3,15),YP(4,10),YP(5,10)

NIT=0
CONTINUE
GOSA=0.
TOTA=0.

CONVECTION HAS ZERO EFFECT ON MAGNETIC DIFFUSION EQN.

AE=0.
AW=0.
AN=0.
AS=0.

CALCULATE MAGNETIC INDUCTION AT INTERIOR POINTS

LV=NHI.
IF(LTYP.EQ.2) LV=NHR.
DO 17 I=NHR,LV
  DO 11 J=2,JNM
    IL=IMIN(J)
    IF(J.EQ.J1) IL=I1+1
    IH=IMAX(J)
    CALL SOURCE(SOURCE,I,J,K)
    RISQ=I./R(J)/R(J)
    SOP=A(I,J,NS)
    BBE=4./(A(I+1,J,NS)+SOP)*RISQ*BE(I)
    IF(I.EQ.(I-1).AND.I.LE.J1) BBE=4./(A(I,J,NS)+SOP)*RISQ*BE(I)
    BBW=4./(A(I,J-1,NS)+SOP)*RISQ*BW(I)
    IF(I.EQ.(I+1)) BBW=4./(A(I,J,NS)+SOP)*RISQ*BW(I)
    BBN=16./(A(I,J,NS)+SOP)/(R(D+1)+R(J))**2)*BN(J)
    IF(J.EQ.(J1-1).AND.I.LE.J1) BBN=BBN*(A(I,J,NS)+SOP)/(2.*SOP)
    IF(I.EQ.(I-1).AND.I.LE.J1) BBN=BBN*(A(I,J,NS)+SOP)/(2.*SOP)

ANUM=(AE+R(J)*R(J)*BBE)*A(I+1,J,K)
1+(AW+R(J)*R(J)*BBW)*A(I-1,J,K)
2+(AN+R(J)*R(J)*BBN)*A(I,J+1,K)
3+(AS+R(J)*R(J)*BBS)*A(I,J-1,K)+SOURCE
ADNM=AE+AW+AN+AS+R(J)*R(J)*(BBE+BBW+BBN+BBS)
GO TO 21

POINTS ON ELECTRODE FACES

SOURCE(SOURCE,I,J,K)
RISQ=I./R(J)/R(J)
SOP=A(I,J,NS)
BBE=4./(A(I+1,J,NS)+SOP)*RISQ*BE(I)
BBW=4./(A(I,J-1,NS)+SOP)*RISQ*BW(I)
BBN=16./(A(I,J,NS)+SOP)/(R(J-1)+R(J))**2)*BN(J)

ANUM=(AE+R(J)*R(J)*BBE)*A(I+1,J,K)
1+(AW+R(J)*R(J)*BBW)*A(I-1,J,K)
2+(AN+R(J)*R(J)*BBN)*A(I,J+1,K)
3+(AS+R(J)*R(J)*BBS)*A(I,J-1,K)+SOURCE
ADNM=AE+AW+AN+AS+R(J)*R(J)*(BBE+BBW+BBN+BBS)
GO TO 21
C TOP ELECTRODE SIDE SURFACE(J=J1,I1<I<I2)
C
30 BB=(X2(J1)-X2(J1-1))/(X2(J1+1)-X2(J1))*A(I,J1-1,NS)/A(I,J1,NS)
ANUM=R(J-1)*R(J)+R(J-1)*A(I,J-1,K)+BB*R(J)*R(J)+A(I,J+1,K)
ADNM=R(J)+R(J+1)*BB
GO TO 21
C
C BOTTOM ELECTRODE SURFACE(I=I3)
C
14 CON1=A(I3,J,NS)/S(3)
CON=CON1
XQ=X1(I)-X1(I-1)
XR=X1(I+1)-X1(I)
BB=1./(1.+XQ/XR*CON)
ANUM=BB*A(I-1,J,K)+(1.-BB)*A(I+1,J,K)
ADNM=1.
GO TO 21
C
C TOP ELECTRODE, AXIAL SURFACE(I=IW)
C
15 CON=A(I-1,J,NS)/A(I,J,NS)
RSQ=R(U)*R(J)
X1Q=X1(I)-X1(I-i)
X1R=X1(I+1)-X1(I)
X2Q=X2(J)-X2(d-1)
X2R=X2(J+1)-X2(d)
BB1=CON*X1Q/X1R
BB2=CON*X2Q/X2R
BINC=X1Q/X2Q*SIN(THETA)/COS(THETA)
ANUM=A(I-1,J,K)+BB1*A(I,J,K)+BB2*R(J)*R(J+1)*A(I,J+1,K)
ADNM=1.+BB1+BINC*(1.+BB2)
GO TO 21
C
RELAX THE NEW VALUES
C
A(I,J,K)=ANUM/ADNM
C
ERROR CALCULATIONS
C
GOSA = GOSA + ABS(Z - A(I,J,K))
TOTA = TOTA + ABS(A(I,J,K))
C ............. STORE MAXIMUM RESIDUAL
C
IF(ABS(RS).LE.ABS(RSDU(K))) GO TO 6
RSDU(K) = RS
6
CONTINUE
19
CONTINUE
11
CONTINUE
IF(GOSA.EQ.0.AND.TOTA.EQ.0) GO TO 7
SAN(K) = GOSA/TOTA
GO TO 8
SAN(K) = 1.
8
CONTINUE
17
CONTINUE
C
---------------------------------------------------
C BOUNDARY CONDITIONS(i=1,j<j1)
C
J1=J1+1
XQ=X1(2)-X1(1)
XR=X1(3)-X1(1)
BB=XR*XR/(XR*XR-XQ*XQ)
DO 10 K=NHR,NHI
DO 10 J=2,J11
A(1,J,K) = BB*A(2,J,K) + (1.-BB)*A(3,J,K)
10
CONTINUE
C
---------------------------------------------------
C BOUNDARY i=IN
C
XQ=X1(IN)-X1(INM)
XR=X1(IN)-X1(INM-1)
BB=XR*XR/(XR*XR-XQ*XQ)
DO 151 K=NHR,NHI
DO 151 J=2,JNM
A(IN,J,K) = BB*A(INM,J,K) + (1.-BB)*A(INM-1,J,K)
151
CONTINUE
C
---------------------------------------------------
C j=1, 1<i<IN
C
DO 25 K=NHR,NHI
DO 25 I=1,IN
A(I,1,K) = A(I,2,K)
25
CONTINUE
C
---------------------------------------------------
C CONVERGENCE CRITERION CHECK
C
CFI = ABS(RSDU(NHR))
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CF2 = ABS(RSDU(NHI))

CFF = CF1

IF(CF1.LT.CF2) CFF = CF2

IF(CFF.LE.CP) GO TO 9

NIT = NIT + 1

RSDU(NHR) = 0.

RSDU(NHI) = 0.

C------------

PRINTOUT CHECK

K1 = NIT/MPRINT

K2 = K1 + MPRINT

IF(NIT.NE.K2) GO TO 5

WRITE(6,104) NIT,CFI,CF2

104 FORMAT(/,6H NIT=,I4/,6H CFI=,E14.8,6H CF2=,E14.8/)

5 CONTINUE

C------------

MAXIMUM ITERATION CHECK

IF(NIT.LT.MIT) GO TO 1

WRITE(6,106) NIT

106 FORMAT(32H THE FLD.EQN DID NOT CONVERGE IN,15,13H ITERATIONS)

LF = 2

GO TO 20

C-----------------

CALCULATE CURRENT DENSITY

9 CONTINUE

DO 29 J = 1, JN

DO 191 I = 1, IN

IF(I.LT.I1.AND.J.GT.J1) GO TO 191

IF(I.EQ.I1.OR.I.EQ.IN) GO TO 192

IF(J.EQ.J1.AND.J.LE.I1) GO TO 192

IF(J.EQ.J1.OR.J.EQ.JN) GO TO 192

A(I,J,NJRR) = ADF(I,J,1,NHR)*R(J)

A(I,J,NJRI) = ADF(I,J,1,NHI)*R(J)

IF(I.EQ.I1.AND.J.GT.J1) GO TO 191

A(I,J,NJZI) = ADF(I,J,2,NHI)*A(I,J,NHI)+2.

A(I,J,NJZI) = ADF(I,J,2,NHR)*A(I,J,NHR)+2.

191 CONTINUE

29 CONTINUE

C-----------------

MODIFICATIONS FOR CURRENT AT THE BOUNDARIES

C AT I=IW , I<J1
C
DO 27 J=2,J1
II=IW(J)
A(II,J,NJRR)=(A(II,J,NHR)-A(II+1,J,NHR))/(X1(II+1)-X1(II))*R(J)
A(II,J,NJRI)=(A(II,J,NHI)-A(II+1,J,NHR))/(X1(II+1)-X1(II))*R(J)
1,NHR)/((X2(J+1)-X2(J))/R(J)
A(II,J,NJZI)=(R(J+1)*R(J+1)*A(II,J+1,NHR)-R(J)*R(J)*A(II,J,1,NHR))/(X2(J+1)-X2(J))/R(J)
CONTINUE
C
CONTINUE
DO 28 J=2,JNM
A(I3,J,NJRR)=(A(I3,J,NHR)-A(I3,J,NHR))/(X1(I3)-X1(I3-1))*R(J)
A(I3,J,NJRI)=(A(I3,J,NHI)-A(I3,J,NHR))/(X1(I3)-X1(I3-1))*R(J)
CONTINUE
IF(I1.EQ.I2) GO TO 32
DO 31 I=I1,I2
A(I,J1,NJZR)=(R(J1+1)*R(J1+1)*A(I,J1+1,NHR)-R(Ji)*R(Ji)*A(I,J1,1,NHR))/(X2(J1+1)-X2(J1))/R(di)
A(I,J1,NJZI)=(R(di+i)*R(di+1)*A(I,J1+1,NHI)-R(di)*R(Ji)*A(I,J1,di,NHI))/(X2(di+1)-X2(J1))/R(di)
31 CONTINUE
32 CONTINUE
DO 115 I=1,IN
DO 115 d=I,JN
IF(d.GT.Ji.AND.I.LT.Ii) GO TO 115
A(I,J,NJJ)=500.*A(Id,NJd)/A(I,J,NS)
115 CONTINUE
C
DO 200 I=I1,I3
N=I-Ii+1
JL=J1
IF(I.GT.I2.AND.I.LE.IW(1)) JL=J1-(I-I2)
IF(I.GT.IW(1)) JL=1
DO 201 J=1,JN
AVM(J)=R(J)*A(I,J,NJd)
200 FUN(N)=FINT(JL,JN,2,1,1)
201 CONTINUE
C
DO 202 N=1,N3

202        AVM(N)=FUN(N)
         SUMI=FINT(1,N3,1,I1,1)
         POWR=2.*PI*SUMI
         VOLT=POWR*1.414/CU
         CURR=CU/1.414
         IF(LI.EQ.2) GO TO 37
         WRITE(6,110) NIT
         CALL PRINT(NHR,LV,2)
 37        CONTINUE
         WRITE(6,204) VOLT,CURR
110       FORMAT(32H THE FIELD EQUATION CONVERGED IN, I5,13H ITERATIONS)
204       FORMAT(/,9HVOLTAGE=,F10.3H CURRENT=,F10.4)
20        CONTINUE
         RETURN
         END
FUNCTION FINT(NL,NU,ND,NI,NJ)
COMMON/CCORD/IMIN(21),IMAX(21),X1(21),X2(21),R(21)
COMMON/CGRID/IN,INM,JN,JNM,I1,I2,I3,IA,IW(21),J1
COMMON/CAVM/AVM(60)
NU1=NU-1
SUMA=0.
Do 10 N=NL,NU1
IF(ND.EQ.2) Go To 1
I=N+NI-1
DX=0.5*(X1(I+1)-X1(I))
Go To 2
1 J=N+NJ-1
DX=0.5*(X2(J+1)-X2(J))
CONTINUE
2 CONTINUE
10 SUMA=SUMA+(AVM(N)+AVM(N+1))*DX
FINT=SUMA
RETURN
END
SUBROUTINE INIT

COMMON/CNUMB/NW,NF,NK,NEP,NV1,NV2,NT,NU,NRO,NTC,NSP,NMT
COMMON/CCORD/IMIN(21),IMAX(21),Xi(31),X2(21),R(21)
COMMON/CGRID/IN,INM,JN,JNM,I1,I2,I3,IA,JW(21),JI
COMMON/CDIM/X(5),RE,RM
COMMON/CCITER/NMAX,NPRINT,NITER,IP,IE,IV,CC
COMMON/CCONT/C1,C2,C3,CD
COMMON/CRLAX/RP(IO),RSDU(IO),SAN(10)
COMMON/CTEMP/TLM,TSM,TLS,TA,TM,TW
COMMON/CDIM/X(5),RE,RM
COMMON/CPROP/ROREF(5),ZMUREF(2),PR(10),GAMA
COMMON/CVF/FES(21),FEM(21),FSM,FSE
COMMON/CDROP/TAU,HCD,D,QS,QM
COMMON/CTAUW/TAUWi(20),TAUW2(15),TAUW3(21),TAUW4(10),TAUW5(21)
COMMON/CFLD/CU
COMMON/CPI/PI
COMMON/CTYP/LTYP
COMMON/CANG/THETA
COMMON/CFIT/MIT,MPRINT,CP
COMMON/CDVAR/A(31,21,20)
COMMON/CNAME/ANAME,ASYMBL
COMMON/CRIT/NWI,NWd,NFJ,NTJ,NKI,NKd,NEI,NEJ,GOSA,TOTA
COMMON/CLF/LFLI
COMMON/CSVOR/SVOR(31,21)
COMMON/CTURB/NTURB,NSCHEM,NSC,RPXI,XI
COMMON/CSW/SN1(20),SN2(15),SN3(21),SN4(20),SN5(21)
COMMON/CB/BE(31),BW(31),BN(21),BS(21)
COMMON/CAVM/AVM(60)
COMMON/CHBL/HLE,HLEH,HLEV,HLS,HLD,HLM,POWR
COMMON/CSUR/HS(2),TS(2)
COMMON/CBB/BBE,BBW,BBN,BBS,BPP
COMMON/CSOR/RB,FB,FB2,FB3,FB4,FB5
COMMON/CFUN/FUN(20)
COMMON/CVOLT/VOLT
COMMON/CVAT/TB
COMMON/CV/YP(20),YP2(15),YP3(21),YP410,YP5(21)

C... INITIALISE ALL VALUES TO ZERO
C ----------------------------- 
DO 30 K=1,20 
DO 30 J=1,JN 
DO 30 I=1,IN 
A(I,J,K)=0.0 
30 CONTINUE 
C MAGNETIC INDUCTION GUESS FIELD 
DO 31 J=1,J1 
DO 31 I=1,I2 
A(I,J,NHR)=CU/(2.0*PI*RE*RE) 
31 
C GUESS FIELD FOR TEMPERATURE 
DO 50 J=1,JN 
DO 50 I=1,I3 
IF(D.GT.Di.AND.I.LT.I1) GO TO 50 
A(I,J,NT)=300.0 
IF(J.LE.J1.AND.I.LE.I2) A(I,J,NT)=300.0 
IF(I.EQ.I3) A(I,J,NT)=300.0 
50 CONTINUE 
C FIXED BOUNDARY CONDITIONS 
DO 11 I=I1,IN 
11 J12=J1+1 
A(I,JN,NHR)=CU/(2.0*PI*RM*RM) 
A(I1,J,NHR)=CU/(2.0*PI*R(J)+R(J)) 
12 CONTINUE 
C DO 20 J=1,JNM 
IL=I1+1 
IF(J.LE.J1) IL=IW(J)+1 
IH=I3-1 
DO 20 I=IL,IH 
A(I,J,NK)=1.0E-05 
A(I,J,NEP)=1.0E-06 
20 CONTINUE 
C DO 14 J=1,JN 
DO 14 I=1,IN 
14 SVOR(I,J)=0.
C
17
RETURN
END

DO 17 I=I1,IH
A(I,JN,NT)=TLS

IN100910
IN100920
IN100930
IN100940
IN100950
JX=JN/10
IF(JX.LT.1) JX=1
IX=IN/10
IF(IX.LT.1) IX=1
DO 10 K=NBEGIN,NTOTAL
WRITE(6,100) (ANAME(L,K),L=1,6)
IB=I3
JX=1
DO 2 L=1,IN,IX
J=JN+1-L
WRITE(6,103) (A(I,J,K),I=I1,IB,1)
WRITE(6,105) J
2 CONTINUE
WRITE(6,104) (I,I=I1,IB,1)
10 CONTINUE
IF(LP.EQ.2) GO TO 20
C WRITE(6,1) HLW,HLEH,HLEV,HLS,HLD,HLM,POWR,VOLT
N1=I3-I1-1
J12=J1+1
C WRITE(6,6) (SN1(N),N=1,N1)
C WRITE(6,7) (SN2(N),N=2,J1)
C WRITE(6,8) (SN3(N),N=2,JNM)
C WRITE(6,15) (YP1(N),N=1,N1)
C WRITE(6,16) (YP2(N),N=2,J1)
C WRITE(6,17) (YP3(N),N=2,JNM)
C WRITE(6,19) (YP5(J),J=J12,JNM)
C WRITE(6,212) VE,TB
20 CONTINUE
RETURN
100 FORMAT(1H1,30X,21HTHE DISTRIBUTION OF .6A6/
126X.5H-------------------------------------------------/
240X.3H---------------------------------------------------/
1 FORMAT(/,5H HLW=,E10.3,6H HLEH=,E10.3,6H HLEV=,E10.3
1,5H HLS=,E10.3,5H HLD=,E10.3,6H HLM=,E10.3,6H
2/6H VOLT=,E10.3)
103 FORMAT(/(1H .10(1PE10.3)))
104 FORMAT(4H I/(1H .7X,9(12.8X),12))
105 FORMAT(105X,12)
201 FORMAT(/,32H TEMP. DISTRIBUTION IN ELECTRODE)
203 FORMAT(/,10H J =.12./,10(3X,F8.1))
207 FORMAT(/,4H YL=,F10.4,4H YS=,F10.4)
212 FORMAT(/,4H VE=,E12.4,4H TB=,F12.2)
6 FORMAT(25HOVALUES FOR SN1(N) ARE/(1H .5E14.4))
7 FORMAT(25HOVALUES FOR SN2(N) ARE/(1H .5E14.4))
8 FORMAT(25HOVALUES FOR SN3(N) ARE/(1H .5E14.4))
15 FORMAT(25H0VALUES FOR YP1(N)) ARE/(1H,5E10.3)) PRIO0910
16 FORMAT(25H0VALUES FOR YP2(J)) ARE/(1H,5E10.3)) PRIO0920
17 FORMAT(25H0VALUES FOR YP3(N)) ARE/(1H,5E10.3)) PRIO0930
19 FORMAT(25H0VALUES FOR YP5(J)) ARE/(1H,5E10.3)) PRIO0940
END        PRIO0950
SUBROUTINE PROP(L)

C$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$

COMMON/CNUMB/NW,NF,NK,NEP,NVI,NV2,NT,NMU,NRO,NTCN
COMMON/CCORD/IMIN(21),IMAX(21),XI(31),X2(21),R(21)
COMMON/CGRID/IN,INM,JN,JNM,I1,12,13,IA,IA(21),J1
COMMON/CDIM/X(5),RE,RM
COMMON/CITER/INMAX,NPRINT,NITERIPIE,IV,CC
COMMON/CONT/C1,C2,C3,CD
COMMON/CRLAX/RP(10),RSRU(10),SANU(10)
COMMON/CEMP/WF,PS(4)
COMMON/CHJ/NHR,NHI,NJRR,NJRI,NJIZ,NJJJ,NS
COMMON/CHJ/MNAX,NNMAX,MPRT,EE,EM,SB,HS
COMMON/CTRVL/VE,VC
COMMON/CHET/HC,HW(4)
COMMON/CPROP/RXPF(5),RMPF(2),PR(10),GAMA
COMMON/CVF/FC(21),AF(21),FUE,FE
COMMON/CTAUW/TAU1(20),TAU2(15),TAU3(21),TAU4U(10),TAU5(21)
1,CAPPA,E
COMMON/CFLD/CU
COMMON/CPI/PI
COMMON/CTYP/LTYP
COMMON/CANG/THETA
COMMON/FIERT/MIT,MPRINT,CP
COMMON/CDV/LA(31,21,20)
COMMON/CNAME/ANAME,ASYMBL
COMMON/CCRIT/NIWJ,NF2,NF2,N2,NTJ,NK2,NEJ,NEJ,GOSA,TO
COMMON/CLF/LI
COMMON/CSVR/SV(31,21)
COMMON/CTURB/NTURB,NSCHEM,NNIS,RPX, XI
COMMON/CSNW/SN(20),SN2(15),SN3(21),SN4(20),SN5(21)
COMMON/CBE/B(31),BW(31),BN(21),BS(21)
COMMON/CAM/CAM(60)
COMMON/CHBL/HL,HLEH,HLEV,HLS,HLD,HLM,POWR
COMMON/CSUR/HS(2),TS(2)
COMMON/CBB/BBE,BBW,BSB,BS,
COMMON/CSORSE/SOURCE,SPRIME
COMMON/CGEOM/F1,F2(15),F3,F4,F5
COMMON/CAF/FUN(20)
COMMON/CVOLT/VOLT
COMMON/CVOL/TB
COMMON/CVAT/TB
COMMON/CYP/YP(20),YP2(15),YP3(21),YP4(10),YP5(21)

C$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$

IF(L.EQ.2) GO TO 1
DO 2 I=1,IN
  DO 2 J=1,JN
  IF(I.LE.I1.AND.J.LE.J1) GO TO 3
  IF(I.LT.IW(J).AND.J.LT.J1) GO TO 3
  IF(I.GT.I3) GO TO 3
  A(I,J,NRO)=ROREF(2)
  A(I,J,NMU)=ZMUREF(1)
  A(I,J,NTC)=TCREF(2)
  A(I,J,NSP)=SPREF(2)
  GO TO 2
  A(I,J,NRO)=ROREF(1)
  A(I,J,NTC)=TCREF(1)
  A(I,J,NSP)=SREF(I)
  A(I,J,NS)=S(1)
  A(I,J,NMU)=ZMUREF(1)
  CONTINUE
  DO 10 I=I1,I3
  DO 10 J=I,JN
  IF(I.LT.IW(J).AND.J.LT.J1) GO TO 10
  A(I,J,NS)=S(2)
  CONTINUE
  IF(L.EQ.1.OR.L.EQ.2) GO TO 5
  ** RECALCULATE VE,VC **
  HRM=HLEH
  HCON=SPREF(1)*(TLM-TA)+HL
  AMELT=HRM/HCON
  Z=VE
  VE=AMELT/(R(J1)*R(J1))
  VC=VE*R(J1)/R(JN)
  HCD=HCD*VE/Z
  CONTINUE
  RETURN
END
COMMON/CLREYN/LREYN,CDMOD(31,31)
C BRANCH TO DIFFERENT SOURCE POINTS
C
GO TO (1,2,3,4,5,6,7,8,8),K
C Dummy Sources
C
8 SOURCE=0.0
RETURN
C
FOR RE(H)/R
C
1 SOURCE=WF*P*A(I,J,NHI)
RETURN
C FOR IM(H)/R
C
2 SOURCE=-WF*P*A(I,J,NHR)
RETURN
C
SOURCE=(1.0E+06)*P*R(D)*SOURCE
SVO(I,J)=SOURCE
RETURN
C
STREAM FUNCTION
C
4 SOURCE=A(I,J,NW)
RETURN
C
TURBULENCE ENERGY
C
5 CONTINUE
B1=ADF(I,J,1,NVI)
B2=ADF(I,J,2,NV2)
B3=ADF(I,J,2,NVI)
B4=ADF(I,J,1,NV2)
B5=A(I,J,NV2)/R(J)
SHEAR2=(2.0*(B1**2+B2**2+B5**2)+(B3+B4)**2)
GK(I,J)=SHEAR2
DK=A(I,J,NRO)*A(I,J,NEP)
SOURCE=GK(I,J)-DK
RETURN
C------------------------------------------------------------------

SOR00910 C TURBULENT ENERGY DISSIPATION
SOR00920
C------------------------------------------------------------------

SOR00930 6 CONTINUE
SOR00940 IF(A(I,J,NK).EQ.0.0) GO TO 100
SOR00950 TERM1=0.0
SOR00960 TERM2=C1*GK(I,J)*A(I,J,NEP)/A(I,J,NK)
SOR00970 F2=1.0
SOR00980 IF(LREYN.EQ.1) REYLOC=A(I,J,NRO)+A(I,J,NK)**2/(ZMUREF(2)
SOR00990 1*A(I,J,NEP))
SOR1000 IF(LREYN.EQ.1.AND.REYLOC.LE.10.0) F2=1.0 -. 3*EXP(-REYLOC**2)
SOR1010 C2MOD=C2
SOR1020 F2
SOR1030 TERM3=C2MOD*A(I,J,NRO)*(A(I,J,NEP)**2)/A(I,J,NK)
SOR1040 SOURCE=TERM1+TERM2-TERM3
SOR1050 RETURN
SOR1060 SOURCE=0.0
SOR1070 RETURN

C------------------------------------------------------------------

SOR1080 C TEMPERATURE
SOR1090 C------------------------------------------------------------------

SOR1100 7 CONTINUE
SOR1110 IF(J.GT.JI) GO TO 9
SOR1120 Z=X1(I3)-X1(I2)
SOR1130 SOURCE=A(I,J,NJU)-QS/(3.14*R(J1)*R(J1)*Z)
SOR1140 GO TO 10
SOR1150 SOURCE=A(I,J,NJU)
SOR1160 RETURN
SOR1170 C------------------------------------------------------------------

SOR1180 RETURN
SOR1190 END
SUBROUTINE STRFUN

COMMON/NUMB/NW,NF,NK,NV1,NV2,NT,NMU,NRD,NTC,NSP,NMT
COMMON/CORD/IN(21),IMAX(21),XI(31),X2(21),R(21)
COMMON/GRID/IN,JN,NJN,M11,12,13,IA,IAW(21),J1
COMMON/DIM/X(5),RE,RM
COMMON/ITER/NMAX,NPRINT,NITER,IP,IE,IV,CC
COMMON/CONT/C1,C2,C3,CD
COMMON/LAX/RP(10),RSDU(10),SAN(10)
COMMON/EMP/WF,P,S(4)
COMMON/RCRAX/RP(10),RSDU(10),SAN(10)
COMMON/EMP/WF,P,S(4)
COMMON/CHEAT/HC,HW(4)
COMMON/CFLD/CU
COMMON/CPI/PI
COMMON/CANG/THETA
COMMON/FITER/MITMPRINT,CP
COMMON/DFVAR/A(31,20)
COMMON/CNAME/ANAME,ASYMBL
COMMON/CRIT/NWI,NWJ,NFI,NFJ,NTI,NTJ,NKI,NKJ,NEI,NEJ,GOSA,TOTA
COMMON/CLF/LF,LI
COMMON/CSVOR/SVOR(31,21)
COMMON/CTURB/NTURB,NSCHEM,NVISC,RPXI,XI
COMMON/CSNW/SN1(20),SN2(15),SN3(21),SN4(20),SN5(21)
COMMON/BE/BE(31),BE(31),BE(21),BE(21)
COMMON/CNV/AVM(60)
COMMON/CHBL/HLS,HLW,HLEH,HLEV,HLS,HLD,HLM,POWR
COMMON/CSUR/HS(2),TS(2)
COMMON/CBB/BBE,BBN,BS,BP
COMMON/CSORSE/SOURCE,SPI
COMMON/CFUN/CP(20)
COMMON/CVOLT/VOLT
COMMON/CVAT/TB
COMMON/CP/YP(20),YP(21),YP(21),YP(40),YP(40)

C$Z=0$

Z2=0.
DO 22 I=1,NF
DO 22 J=2,JNM
IF(ABS(Z2).LT.ABS(A(I,J,NF))) Z2=A(I,J,NF)
22 CONTINUE
DO 21 J=2,JNM
IL=I1+1
IF(J.LE.J1) IL=IW(J)+1
IH=I3+1
DO 21 I=IL,IH
RISQ=1./R(J)/R(J)
ROP=A(I,J,NRO)
BBE=4./(A(I+1,J,NRO)+ROP)*RISQ*BE(I)
BBW=4./(A(I-1,J,NRO)+ROP)*RISQ*BW(I)
BBN=16./(A(I,J+1,NRO)+ROP)/((R(J)+R(J))**2)+BN(J)
BBS=16./(A(I,J-1,NRO)+ROP)/((R(J)+R(J))**2)+BS(J)
CALL SOURC(SOURCE,I,J,NF)
C CALL CONVEC(AE,AW,AN,AS,I,J,NF)
ANUM=BBE*A(I+1,J,NF)+BBW*A(I-1,J,NF)+BBN*A(I,J+1,NF)
+BBN*A(I,J-1,NF)+SOURCE
ADNM=BBE+BBW+BBN+BBS
IF(ADNM.EQ.0.) GO TO 5
Z=A(I,J,NF)
A(I,J,NF)=ANUM/ADNM
IF(Z.EQ.0.0.AND.A(I,J,NF).EQ.0.0) GO TO 8
RS=1.-Z/A(I,J,NF)
GO TO 6
8 RS=0.0
6 CONTINUE
GOA=GOSA+ABS(Z-A(I,J,NF))
TOTA=TOTA+ABS(A(I,J,NF))
Z1=RP(NF)
IF(J.GE.J1) Z1=0.2
A(I,J,NF)=Z+Z1*(A(I,J,NF)-Z)
IF(ABS(RS).LE.ABS(RSDU(NF))) GO TO 5
RSDU(NF)=RS
NFJ=J
NFI=I
5 CONTINUE
21 CONTINUE
RETURN
END
SUBROUTINE TURVAR(K)

COMMON/CNUMB/NW,NF,NK,NEP,NVI,NV2,NT,NMU,NRO,NTC,NSP,NMT
COMMON/CGRID/IN,INM,INJ,INM,IA,IW(21),J1
COMMON/CITER/NMAX,NPRINT,NITERIP,IE,IV,CC
COMMON/CCONT/C1,C2,C3,CD
COMMON/CRLAX/RP(10),RSDU(10),SAN(10)
COMMON/CEMP/WF,P,S(4)
COMMON/CHJ/NHR,NHI,NJRR,NJRI,NJZR,NJZI,NJJH,NS
COMMON/CTHERM/TCS(5),SPREF(5),BETA(2),ES,EE,EM,SB,HL
COMMON/CTEMP/TLM,TSM,TLS,TA,TM,TW
COMMON/CTRVL/VE,VC
COMMON/CHEAT/HC,HW(4)
COMMON/CDF/P/GK(31,21)
COMMON/CFLD/CF
COMMON/CPI/PI
COMMON/CANG/THETA
COMMON/CFILTER/MIT,MPRINT,CP
COMMON/CVAR/A(31,21,20)
COMMON/CNAME/ANAME,ASYMBL
COMMON/CLF/LF,LI
COMMON/CTYP/LTYP
COMMON/CSVOR/SVOR(31,21)
COMMON/CTURB/NTURB,NSCHEM,NVISC,RPXI,XI
COMMON/CSNW/SN1(20),SN2(15)
COMMON/CB/B(31),BN(21),BS(21)
COMMON/CAVM/AVM(60)
COMMON/CHBL/HBW,HLEH,HLEV,HLS,HLM,POWR
COMMON/CSUR/HS(2,2),TS(2)
COMMON/CBB/BBW,BBN,BBS,BPP
COMMON/CSVOR/SOURCE,SPRIME
COMMON/CAV/CAV(20)
COMMON/CY/V/YP(20),YP2(15),YP3(21),YP4(10),YP5(21)
COMMON/CPRD/GK(31,21)
COMMON/Cshear/Gkk(31,31)
DATA NBAL/0/
C
C...........FIRST GET THE CURRENT VALUE OF XI BASED ON OLD K.ENERGY FIELD.
C
C
IF(NSCHEM.EQ.0) GO TO 800
XIOLD=XI
CALL CONLOT(XI,PERFIN,PCASC)
XINew=XI
XI=XIOLD+RPXI*(XINew-XIOLD)
IF(XIOLD.EQ.0.) XI=XINew
C
C
800 CONTINUE
Z2=0.
DO 23 I=1,I3
DO 23 D=2,JNM
IF(ABS(Z2).LT.ABS(A(I,J,K))) Z2=A(I,J,K)
23 CONTINUE
ENSUM=O.0
GENSUM=O.0
DISSUM=O.0
DO 31 J=2,JNM
IL=I+1
IF(J.LE.J1) IL=IW(D)+1
IH=I3-1
DO 31 I=IL,IH
BPP=A(I,J,NMU)
BBE=(A(I+1,J,NMU)+BPP)/PR(K)*BE(I)
BBW=(A(I-1,J,NMU)+BPP)/PR(K)*BW(I)
BBN=(A(I,J+1,NMU)+BPP)/PR(K)*BN(D)
BBS=(A(I,J-1,NMU)+BPP)/PR(K)*BS(J)
36 SPRIME=O.
CALL SORCE(SOURCE,I,J,K)
CALL CONVEC(AE, AW, AN, AS, I, J, K)
ANUM=(AE+BBE)*A(I+1,J,K)+(AW+BBW)*A(I-1,J,K)+(AN+BBN)*A(I,J+1,K)
+ (AS+BBS)*A(I,J-1,K)+SOURCE
ADNM=AE+AW+AN+AS+BBE+BBW+BBN+BBS+SPRIME
IF(ADNM.EQ.0.) GO TO 6
IF(Z.EQ.O.O.AND.A(I,J,K).EQ.O.O) GO TO 3
VM/SP CONVERSATIONAL MONITOR SYSTEM

RS=1.0 - Z/A(I,J,K)
GO TO 9
3 RS=0.0
5 CONTINUE
GOSA=GOSA+ABS(Z-A(I,J,K))
TOTA=TOTA+ABS(A(I,J,K))
Z1=RP(K)
C IF(J.GE.10) Z1=0.2
A(I,J,K)=Z1=RP(K)*(A(I,J,K)-Z)
IF(A(I,J,K).LE.0.0) A(I,J,K)=0.0
C IF(NBAL.EQ.0) GO TO 100
   CALCULATE ENERGY BUDGET
C IF(ABS(RS).LT.ABS(RSDU(K))) GO TO 6
RSDU(K)=RS
IF(K.EQ.NEP) GO TO 7
NKI=I
NKJ=J
GO TO 6
7 NEI=I
NEJ=J
6 CONTINUE
31 CONTINUE
   IF(NBAL.EQ.0) RETURN
   CALL VOL(GK,GENVOL)
C ... PRINT OUT THE ENERGY BUDGET
C IF(K.EQ.NK) WRITE(6,200) ENSUM,GENSUM,DISSUM,GENVOL
C200 FORMAT('ENERGY BALANCE= ',1PE10.2)
C 1/ 'GENERATION= ',1PE10.2
C 2/ 'DISSIPATION= ',1PE10.2
C 3/ 'GENERATION #2 ',1PE10.2)
C RETURN
END
SUBROUTINE VELDIS
COMMON/CNUMB/NW,NF,NK,NEP,NVi,NV2,NT,NMU,NRO,NTC,NSP,NMT
COMMON/CCORD/IMIN(21),IMAX(21),X1(31),X2(21),R(21)
COMMON/CGRID/IN,INM,JN,JNM,I1,I2,I3,IA,IAW(21),d1
COMMON/CDIM/X(5),RE,RM
COMMON/CITER/NMAX,NPRINT,NITER,IP,IEIV,CC
COMMON/CCONT/C1,C2,C3,CD
COMMON/CRLAX/RP(10),RSDU(10),SAN(10)
COMMON/CFEMP/WFP,S(4)
COMMON/CANG/THETA
COMMON/FITER/MIT,MPRINT,CP
COMMON/CFLD/CU
COMMON/CPI/PI
COMMON/CLYP/LYP
COMMON/CANG/TGAMMA
COMMON/CDVAR/A(31,21,20)
COMMON/CNAME/ANAME,ASYMBL
COMMON/CCRIT/NWI,NWJ,NFJ,NTJ,NTJ,NKJ,NKJ,NEI,NEJ,GOSA,TOTA
COMMON/CL/F/L,F
COMMON/CSVOR/SVOR(31,21)
COMMON/CTURB/NTURB,NSCHEM,NVISC,RPX1,X1
COMMON/CSNW/SNW1(20),SN2(15),SN3(21),SN4(20),SN5(21)
COMMON/CT/B/BE(31),BN(21),BS(21)
COMMON/CAM/VAM(60)
COMMON/CHBl/HW,HEH,HLEH,HLS,HLD,HLM,
COMMON/CSUR/HS(2),TS(2)
COMMON/CBB/BBE,BBN,BBS,BPP
COMMON/CSORSE/SOURCE,SPRIME
COMMON/CGEDM/FR1,FR2(15),FR3,FR4,FR5
COMMON/CAF/FUN(20)
COMMON/CVOLT/VOLT
COMMON/CAY/TB
COMMON/CYP/YP1(20),YP2(15),YP3(21),YP4(10),YP5(21)
DO 50 J=2,JNM
IL=I1+1
IF(J,LE.,J1) IL=IW(J)+1
IH=I3-1
DO 51 I=IL,IH
    A(I,J,NV1)=ADF(I,J,2,NF)/R(J)/A(I,J,NRO)
    A(I,J,NV2)=ADF(I,J,1,NF)/R(J)/A(I,J,NRO)
  51 CONTINUE

50 CONTINUE
IL=IW(1)+1
IH=I3-1
RR=R(2)*R(2)/(R(3)*R(3))
DO 54 I=IL,IH
    A(I,1,NV1)=2.0*(A(I,2,NF)-RR*RR*A(I,3,NF))
    1/(R(2)*R(2)*(1.-RR)*A(I,1,NRO))
  54 CONTINUE

40 CONTINUE
RETURN
END
SUBROUTINE VISCOS

COMMON/CNUMB/NW, NF, NK, NEP, NV1, NV2, NT, NMU, NRO, NTC, NSP, NMT
COMMON/CCORD/imin(21), imax(21), x1(31), x2(21), r(21)
COMMON/CGRID/IN, INM, JN, JNM, T1, T2, IA, IW(21), J1
COMMON/CDIM/X(5), RE, RM
COMMON/CITER/NMAX, NPRINT, NITER, IP, IE, IV, CC
COMMON/CCONT/C1, C2, C3, CD
COMMON/CRLAX/RP(10), RSDU(10), SAN(10)
COMMON/CEMP/W.F, P(4)
COMMON/CHDL/HDR, NHI, NJRI, NJTI, NJZ, NQJ, NS, N
COMMON/CTHERM/TCREF(5), SREF(5), BETA(2), ES, EE, EM, SB, HL
COMMON/CTEMP/TLM, TSM, TLS, TA, TM, TW
COMMON/CTRLV/VE, VC
COMMON/CHET/HW, HW(4)
COMMON/CRDOP/RORF(5), ZMUREF(2), PR(10), GAMA
COMMON/CVF/FES(21), FEM(21), FSM, FSE
COMMON/CDROP/TAU, HCD, D, OS, OM
COMMON/CTAUW/TAUW1(20), TAUW2(15), TAUW3(21), TAUW4(10), TAUW5(21)
COMMON/CTAUW/TAUW1(20), TAUW2(15), TAUW3(21), TAUW4(10), TAUW5(21)
COMMON/CTAUW/TAUW1(20), TAUW2(15), TAUW3(21), TAUW4(10), TAUW5(21)
COMMON/CTAUW/TAUW1(20), TAUW2(15), TAUW3(21), TAUW4(10), TAUW5(21)
COMMON/CTAUW/TAUW1(20), TAUW2(15), TAUW3(21), TAUW4(10), TAUW5(21)
COMMON/CTAUW/TAUW1(20), TAUW2(15), TAUW3(21), TAUW4(10), TAUW5(21)
COMMON/CTAUW/TAUW1(20), TAUW2(15), TAUW3(21), TAUW4(10), TAUW5(21)
COMMON/CTAUW/TAUW1(20), TAUW2(15), TAUW3(21), TAUW4(10), TAUW5(21)
COMMON/CTAUW/TAUW1(20), TAUW2(15), TAUW3(21), TAUW4(10), TAUW5(21)
C*** CALCULATE TURBULENT VISCOSITY
I31=I3-1
DO 10 J=1,JNM
DO 11 I=I1,I31
IF(J.LE.J1.AND.I.LE.IW(J)) GO TO 12
IF(A(I,J,NEP).LE.0.0.AND.A(I,J,NK).LE.0.0) GO TO 20
A(I,J,NMT)=A(I,J,NRO)*CDM0D(I,J)*(A(I,J,NK)**2)/A(I,J,NEP)
GO TO 21
20 CONTINUE
A(I,J,NMT)=0.
21 CONTINUE
Z=A(I,J,NMU)
EMU=ZMUREF(1)
A(I,J,NMU)=EMU +A(I,J,NMT)
A(I,J,NMU)=Z+RP(NMU)*(A(I,J,NMU)-Z)
12 CONTINUE
11 CONTINUE
10 CONTINUE
RETURN
END
SUBROUTINE VOL(P, VAL)

COMMON/CNUMB/NW, NF, NK, NEP, NV1, NV2, NT, NMU, NRO, NTC, NSP, NMT
COMMON/CCORD/IMIN(21), IMAX(21), XI(31), X2(21), R(21)
COMMON/CGRID/IN, INM, JN, JNM, I1, I2, I3, IA, IW(21), J1
COMMON/CDIM/X(5), RE, RM
COMMON/CITER/INMAX, NPRINT, NITER, IP, IE, IV, CC
COMMON/CCONT/C1, C2, C3, CD
COMMON/CGRID/RP(10), RSDU(10), SAN(10)
COMMON/CCHL/NHR, NJR, NJZ, NNP, NNP2, NNP3, NNJ, NS
COMMON/CTHERM/TREF(5), SPREF(5), BETA(2), ES, EE, EM, SB, HL
COMMON/CTEMP/TLM, TSM, TLMSTA, TM, TW
COMMON/CTRVL/VE, VC
COMMON/CDROP/TAU, HCD, D, QS, QM
COMMON/CTAUW/TAUW1(20), TAUW2(15), TAUW3(21), TAUW4(10), TAUW5(21)
COMMON/CFLD/CU
COMMON/CPI/PI
COMMON/CANG/THETA
COMMON/FCITER/MIT, MPRINT, CP
COMMON/CDVAR/A(31, 21, 20)
COMMON/CCRT/IN, INJ, NF1, NF2, NT1, NT2, NK1, NE1, NE2, GOSA, TOTA
COMMON/CLF/LF, LI
COMMON/CTYP/LTYP
COMMON/CSVOR/SVOR(31, 21)
COMMON/CTURB/NTURB, NSCHEM, NVISC, XPI, XI
COMMON/CSNW/SN1(20), SN2(15)
COMMON/CEBE/B(31), B(31), BN(21), BS(21)
COMMON/CAND/CAM(60)
COMMON/CHBL/HLEW, HLEH, HLS, HL1, HLS, HLM, POWR
COMMON/CSUR/HS(2), TS(2)
COMMON/CSB/BHE, BBW, BBN, BBS, BNP
COMMON/CSOR/SOURCE, SPRIME
COMMON/CGEOM/FR1, FR2(15), FR3, FR4, FR5
COMMON/CAF/FUN(20)
COMMON/CVOLT/VOLT
COMMON/CAVLT/TB
COMMON/CVOL/YP(20), YP2(15), YP3(21), YP4(10), YP5(21)

DIMENSION P(31, 21)

C... ROUTINE TO CALCULATE THE VOLUME INTEGRAL OF FUNCTION P
C TO CALCULATE THE LOTSIAKII CONSTANT

VAL=0.0
DO 100 J=2,JNM
IL=IW(J)+1
DO 100 I=IL,INM
DR=(R(J+1)-R(J-1))/2.0
DX=(X1(I+1)-X1(I-1))/2.0
DV=R(J)*DR*DX
    IF(I.EQ.IL.OR.I.EQ.IH)DV=1.5*DV
    IF(J.EQ.JNM) DV=1.5*DV
VAL=VAL+P(I,J)*DV
100 CONTINUE
DO 150 I=IL,IH
VAL=VAL + P(I,1)*R(1)**2*(XI(I+1)-XI(I-1))/4.0
150 CONTINUE
RETURN
END
SUBROUTINE VORITY
COMMON/CB/BE(31),BW(31),BN(21),BS(21)
COMMON/CDVAR/A(31,21,20)
COMMON/CNUMB/NW,NF,NK,NEP,NV1,NV2,NT,NMU,NRO,NTC,NSP,NMT
COMMON/CCORD/IMIN(21),IMAX(21),X1(31),X2(21),R(21)
COMMON/CCRIT/NWI,NWJ,NFI,NFJ,NTI,NT,NKI,NKJ,NEI,NEJ,GOSA,TOTA
COMMON/CRLAX/RP(10),RSDU(10),SAN(10)
COMMON/GRID/IN,INM,JN,JNM,I1,I2,I3,IA,IW(21),dI
COMMON/CTHERM/TCREF(5),SPREF(5),BETA(2),ES,EE,EM,SB,HL
COMMON/CB/BBEBBW,BBN,BBS,BPP
COMMON/CSORSE/SOURCESPRIME

C------------------------------------------------------------------------
C SOLUTION OF VORTICITY TRANSPORT EQUATION
C------------------------------------------------------------------------

IL=I1+1
IF(J.LE.J1) IL=IW(J)+1
IH=I3-1
DO 11 I=IL,IH
DO 11 J=2,JNM
RSQ=R(D)*R(D)
BBE=2.*RSQ*BE(I)
BBW=2.*RSQ*BW(I)
BBN=(R(D+1)*R(J+1)+RSQ)*BN(D)
BBS=(R(D-1)*R(J-I)+RSQ)*BS(D)
SOURCE=0.0
CALL CONVEC(AE,AW,AN,AS,I,J,NW)
C......................IMPLICIT VORTICITY CALCULATIONS
TERMI=A(I+1,J,NW)
TERM2=A(I-1,J,NW)
TERM3=A(I,J-1,NW)
TERM4=A(I,J+1,NW)
TERM5=0.0
IF(I.NE.(I1+1)) GO TO 14
DX12=(X1(I1+1)-Xi(I1))**2
TERM2=TERM2+(TERM2-TERM2+13.*(A(I1,J,NF)-A(I1+1,J,NF))/(DX12*RSQ*A(I1,LJ,NRO))
TERM5=0.5*(AW+A(I-1,J,NMU)*BBW)
C..................CALCULATE NEW VORTICITY...........................
14 CONTINUE
ANUM=(AE+A(I+1,J,NMU)*BBE)*TERMI
1+(AW+A(I-1,J,NMU)*BBW)*TERM2
2+(AS+A(I,J,NMU)*BBS)*TERM3
3+(AN+A(I,J+1,NMU)*BBN)*TERM4
+SOURCE
ADNM=AE+AW+AN+AS+A(I,J,NMU)*(BBE+BBW+BBN+BBS)+TERM5
IF(ADNM.EQ.0.) GO TO 4
Z=A(I,J,NW)
A(I,J,NW)=ANUM/ADNM

C.................... RELAXATION AND RESIDUE CALCULATIONS
IF(Z.EQ.0.0.AND.A(I,J,NW).EQ.0.0) GO TO 1
RS=1.0-Z/A(I,J,NW)
GO TO 3
1 RS=0.
3 CONTINUE
GOSA=GOSA+ABS(Z-A(I,J,NW))
TOTA=TOTA+ABS(A(I,J,NW))

C.............................................................
Z1=RP(NW)
C IF(J.GE.1) Z1=O.1
A(I,J,NW)=Z+Z1*(A(I,J,NW)-Z)

C..............................
IF(ABS(RS).LE.ABS(RSU(NW))) GO TO 4
RSU(NW)=RS
NWJ=J
NWI=I
4 CONTINUE

C.............................. DIAGNOSTIC AIDS
WRITE(15,997) AE,AW,AN,AS,TERM1,TERM2,TERM3,TERM4
997 FORMAT(8(IPE10.2))
WRITE(15,998)I,JA(I,J,NW)
998 FORMAT(215,IPE10.2)
WRITE(15,998) I,J,A(I,J,NF)

C..............................
11 CONTINUE
RETURN
END
SUBROUTINE WALL
COMMON/CNUMB/NW,NF,NK,NEP,NV1,NV2,NT,NMU,NRO,NTP,NSP,NMT
COMMON/CGRID/IMIN(21),IMAX(21),X1(31),X2(21),R(21)
COMMON/CITER/NMAX,NPRINT,NITER,IP,IE,IV,CC
COMMON/CDIM/X(5),RE,CM
COMMON/CRLAX/RP(10),RSDU(10),SAN(10)
COMMON/CMP/WF,P,S(4)
COMMON/CTHERM/TCREF(5),SPREF(5),BETA(2),ESEE,EM,SB,HL
COMMON/CTEMP/TLM,TSM,TLS,TA,TM,TW
COMMON/CTRVL/VE,VC
COMMON/CHJ/NHR,NHI,NJJR,NJRI,NJZI,NJZI,NS
COMMON/CTHERM/TCREF(5),SPREF(5),BETA(2),ESEE,EM,SB,HL
COMMON/CTEMP/TLM,TSM,TLS,TA,TM,TW
COMMON/CTHR/THETA
COMMON/CTYP/LTYP
COMMON/CFILTER/MIT,MPRINT,CP
COMMON/CDVAR/A(31,21,20)
COMMON/CNAME/ANAME,ASYMBL
COMMON/CCRIT/NWI,NWJ,NFI,NTJ,NTI,NKJ,NKJ,NEJ,NEJ,GOSA,TOTA
COMMON/CLF/LF,LI
COMMON/CSVOR/SVOR(31,21)
COMMON/CTURN/NTURN,NSCHEM,NVIS,RPX1,RI
COMMON/CSNW/SN1(20),SN2(15),SN3(21),SN4(20),SN5(21)
COMMON/CB/BE(31),BN(21,20)
COMMON/CAV/A(31,21,20)
COMMON/CCSV/SCSV(31,21)
COMMON/CSUR/HS(2),TS(2)
COMMON/CSB/BBF,BBF,BBF,BBF
COMMON/CSOL/SOURCE,SPRIME
COMMON/CAM/CAM(20)
COMMON/CPL/CPL(20)
COMMON/CLREYN/LREYN,CDM(31,31)
FILE: WALL FORTRAN C1

VM/SP CONVERSATIONAL MONITOR SYSTEM

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PRL=SREF(2)*ZMUREF(1)/TCREF(2)
RECPRT=1./PR(NT)
PRRAT=PRL+RECPRT
PJAY=9.*(PRRAT-1.)/(PRRAT**0.25)
ANJ=ZMUREF(1)/ROREF(2)

*********** AT J=JN,TAUW1, SN1
YP=X2(JN)-X2(JNM)
ZL=X1(I3)-X1(I1)
IL=I1+1
IH=I3-1
DO 1 I=IL,IH
N=I-IL+1
A1=ROREF(2)*CDMOD(I,J)**0.25
A2=A1*SQRT(A(I,JNM,NK))
YPP=YP*A2/ZMUREF(1)
UP=ABS(A(I,JNM,NV1))
IF(YPP.GT.11.5) GO TO 2
TAUW1(N)=ZMUREF(1)*UP/YP
GO TO 3
2 TAUW1(N)=CAPPA*UP*A2/ALOG(YPP*E)
GO TO 3
3 CONTINUE

TAUGR=ROREF(2)*BETA(1)*9.81*(A(I,JNM,NT)-A(I,JN,NT))*YP/2.
TAUWM=TAUW1(N)+TAUGR
TAUEM=TAUW1(N)+0.5*SPREF(2)*A(I,JNM,NMT)
DTG=A(I,JNM,NJ)*YP/2.*TCS
F1=TAUGR+TAUWM+TAUEM+DTG
PN=-1.

CONTINUE

TCS=TCREF(2)+0.5*SPREF(2)*A(I,JNM,NMT)
DTG=A(I,JNM,NJ)*YP/2.*TCS
F1=TAUGR+TAUWM+TAUEM+DTG
PN=-1.

16 CONTINUE

CONTINUE

IWM(IW+1)=IW
F1=TAUGR+TAUWM+TAUEM+DTG
PN=-1.

CONTINUE

DO 4 J=2,J1
II=IW(J)
YP=(X1(I1+1)-X1(I1))*COS(THETA)
A1=ROREF(2)*CDMOD(I,J)**0.25
A2=A1*SQRT(A(I1+1,J,NK))
YPP=YP*A2/ZMUREF(1)

CONTINUE

WAL00460
WAL00470
WAL00480
WAL00490
WAL00500
WAL00510
WAL00520
WAL00530
WAL00540
WAL00550
WAL00560
WAL00570
WAL00580
WAL00590
WAL00600
WAL00610
WAL00620
WAL00630
WAL00640
WAL00650
WAL00660
WAL00670
WAL00680
WAL00690
WAL00700
WAL00710
WAL00720
WAL00730
WAL00740
WAL00750
WAL00760
WAL00770
WAL00780
WAL00790
WAL00800
WAL00810
WAL00820
WAL00830
WAL00840
WAL00850
WAL00860
WAL00870
WAL00880
WAL00890
WAL00900
UP1=A(II+1,J,NV2)*COS(THETA)-A(II+1,J,NVI)*SIN(THETA) WAL00810
UP=ABS(UP1) WAL00820
IF(YPP.GT.11.5) GO TO 5 WAL00830
TAUW2(J)=ZMUREF(1)*UP/YP GO TO 6 WAL00840
TAU2(J)=CAPP*UP*A2/ALOG(YPP*E) WAL00850
CONTINUE 6 WAL00860
TAU1=A(II+1,J,NJZR)*A(II+1,J,NHR)+A(II+1,J,NJZI)*A(II+1,J,NHI) WAL00870
TAU2=A(II+1,J,NJRR)*A(II+1,J,NHR)+A(II+1,J,NJRI)*A(II+1,J,NHI) WAL00880
TAU=TAU1*COS(THETA)+TAU2*SIN(THETA) WAL00890
TAUEM=ABS(TAU) WAL00900
TAU1M=TAU1M*(1.OE+06)*P*R(J)*YP/4. WAL00910
PN=0. WAL00920
IF(UP1.GT.0.) PN=-1. WAL00930
TAUW2(J)=ABS(TAUW2(J))+ABS(TAU2M)*PN WAL00940
TAUW2(J)=ABS(TAUW2(J)) WAL00950
CONTINUE 4 WAL00960
CONTINUE C WAL00970

*** AT I=I3-1,1<J<JNM SN2 (J)=ABS(STAN)*RREF(2)*SREOF(2)*UP2 F2(J)=1. WAL00980
SN2(J)=ABS(STAN)*RREF(2)*SREOF(2)*UP2 YP2(J)=YP2 WAL00990
CONTINUE 40 WAL01000
CONTINUE C WAL01010

YP=X1(I3)-X1(I3-1) WAL01020
DO 7 J=2,JNM WAL01030
A2=A1*SQRT(A(I3-1,J,NK)) WAL01040
YP=YP+A2/ZMUREF(1) WAL01050
UP=ABS(A(I3-1,J,NV2)) WAL01060
IF(YPP.GT.11.5) GO TO 8 WAL01070
TAUW3(J)=ZMUREF(1)*UP/YP GO TO 9 WAL01080
TAUW3(J)=CAPP*UP*A2/ALOG(YPP*E) WAL01090
CONTINUE 8 WAL01100
CONTINUE C WAL01110
TAUW3(J)=ABS(TAUW3(J))+ABS(TAUEM)*PN WAL01120
TAUW3(J)=ABS(TAUW3(J)) WAL01130
IF(A(I3-1,J,NV2).GT.0.) PN=-1. WAL01140
TAUW3(J)=ABS(TAUW3(J))+ABS(TAU2M)*PN WAL01150
TAUW3(J)=ABS(TAUW3(J)) WAL01160
FRIC=TAUW3(J)/(UP*UP*ROREF(2))
DT=A(I3-1,J,NT)-A(I3,J,NT)
IF(DT.LE.0.) DT=0.
18 CONTINUE
TCS=TCREF(2)+A(I3-1,J,NMT)*SPREF(2)*0.5
DTG=A(I3-1,J,NJJ)*YP*YP/(2.*TCS)
F3=1.
STAN=FRIC*RECPRT/(1.+PJAY*SQRT(FRIC))
SN3(J)=ABS(STAN)*ROREF(2)*SPREF(2)*UP+F3
YP3(J)=YP3
1 CONTINUE
C *** AT J=J1+1,I1<I<I2
IF(I1.EQ.I2) GO TO 15
YP=X2(J1+1)-X2(J1)
IL=I1+1
I2=I2-1
DO 10 I=IL,I2
N=I-IL+1
A1=ROREF(2)*CDMOD(I,J)**0.25
A2=A1*SQRT(A(I,J+i,NK))
YPP=YP*A2/ZMUREF(1)
UP=ABS(A(I,J1+i,NVI))
IF(YPP.GT.11.5) GO TO 11
TAUW4(N)=ZMUREF(I)*UP/YP
GO TO 12
11 TAUW4(N)=CAPPA*UP*A2/ALOG(YPP*E)
12 CONTINUE
TAUEM=A(I,J1+1,NJRR)+A(I,J1+1,NHR)+A(I,J1+1,NURI)*A(I,J1+1,NHI)
TAUEM=TAUEM*(1.0E+06)*P*R(J)*YP/4.
PN=0.
TAUW4(N)=ABS(TAUW4(N))+ABS(TAUEM)*PN
FRIC=TAUW4(N)/(UP*UP*ROREF(2))
STAN=FRIC*RECPRT/(1.+PJAY*SQRT(FRIC))
SN4(N)=ABS(STAN)*ROREF(2)*SPREF(2)*UP+F3
YP4(N)=YP4
10 CONTINUE
15 CONTINUE
20 CONTINUE
RETURN
END
NOMENCLATURE

a  Radius of heated cylinder (m)
B  Magnetic Flux Intensity (Tesla)
C ,  Constants in the \( \kappa - \epsilon \) Turbulence Model
C ,  Diffusivity of mixing species in the melt (m^2/sec)
C  Depth of melt (m)
D(k)  3-Dimensional Turbulence Energy Density Spectrum
D  Electric Field
f(r)  Spatial Autocorrelation Function for turbulence
F  Electromagnetic Force field
g  Local Turbulence Energy generation term
G  Total Turbulence Energy generation over entire volume of melt
H  Magnetic Induction (Amps/m)
I  Total current (Amps)
I  Lotsianskii Integral in XI Model of Turbulence
J  Current Density (Amps/m^2)
k  Wavenumber (m^{-1})
k  Wavenumber of Energy Containing Eddies
l  Energy Containing length scale
L  Characteristic Vessel Dimension (m)
L  Characteristic size of Large Scale Eddies (m)
M  Mass of melt
N  Magnetic Interaction Parameter
p  pressure in the fluid
P  Stirring Power input to the system (Watts)
P_t Specific Power input (Watts/Ton of Melt)
PI  Stands for Performance Index used to evaluate degree of Turbulence
q  RMS Turbulent Fluctuating Velocity
R_e Radius of electrode (m)
R_m Radius of vessel (m)
r  Radial location in the melt (m)
t  time (secs)
t_m Mixing time for 95% homogenisation (sec)
T  Temperature
U  Mean Velocity (m/sec)
u'_{i,j} Fluctuating velocity components
V  Mean Nondimensional Velocity
x  Axial Location in melt (m)

\lambda  Taylor Microscale
\Lambda  Length scale for concentration fluctuations corresponding to \lambda
\phi  Turbulence Dissipation rate per unit mass (W/Kg·sec)
\Phi  Total Turbulence Dissipation Rate (W/sec)
\sigma  Electrical Conductivity (mho·m)
\rho  Density of the fluid (Kg/m^3)
$\mu_0$ Magnetic Permeability of Free Space

$\eta$ Magnetic Diffusivity, Efficiency of Turbulence Generation

$v$ Molecular Kinematic Viscosity of Fluid (m$^2$/sec)

$\mu$ Molecular Viscosity of Fluid (Kg./m-sec)

$\alpha$ Thermal Diffusivity of Fluid (m$^2$/sec)

$\omega$ Vorticity

$\gamma$ Stream Function

$\mu_{eff}$ Turbulence Enhanced Viscosity (Kg/m-sec)

$\mu_t$ Turbulent Contribution to Viscosity (Kg/m-sec)

$x$ Kinetic Energy of Turbulent Fluctuations (W/Kg)

$\epsilon$ Local Rate of Turbulence Energy Dissipation (W/Kg-sec)

$\sigma_\epsilon$ 'Prandtl Number' for $\epsilon$ Transport

$\sigma_k$ 'Prandtl Number' for $x$ Transport

$\xi$ Primary Variable in the XI Model of Turbulence

$\tau$ Time constant for Mixing (66% mixed)

$\tau$ Shear Stress Tensor
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MHD Cylinder


