A MICROPROCESSOR BASED SYSTEM FOR WIND TUNNEL MEASUREMENTS

C. Ravikumar, N. Balakrishnan and V.S. Holla

Department of Aerospace Engineering
Indian Institute of Science, Bangalore, India.

Abstract :

A 16-bit micoprocessor based system has been designed and developed for automatic flow field pressure survey and force measurements in the low speed wind tunnel at the Indian Istitute of Science. The instrumentation sub systems that are required for the above measurements under the processor control, the system processor unit, interfaces to standard peripherals, future expansion provisions and communication channel to other computer systems have all been developed in-house. Software has been designed to provide a powerful friendly and reconfigurable integrated instrumentation. The software also ensures real time data acquision, on-line pre-processing and storage of the data on a floppy. Software has also been developed on an inexpensive PC for the data presentation in color graphics. The design, development and implementation details of the system have been presented in this paper.

Introduction :

The closed circuit wind tunnel (CCWT) at the department of Aerospace Engineering, Indian Institute of Science, has been established in 1947. The test section of the tunnel has an elliptical cross-section of dimensions 7' x 5' and is being used for flow field surveys, force/moment and pressure survey measurements. Recent instrumentation set-up included a 3-D traverse mechanism powered by induction motors, pressure probes, manometer banks to read the pressures and a mechanical balance for force measurements. The probe traversing is done through a set of ON/OFF switches controlled manually to move the probe in the required direction over a test section of 96" x 48" x 36". A set of mechanical counters are used to indicate the traverse position. This arrangement provided a resolution of 0.0025" and 0.1" overall accuracy in probe positioning. The pressure probe used for flow field survey is a blunted conical nose 5 hole probe. Both U-tube manometer banks and reservoir type manometer banks are available for pressure data collection. For accurate pressure measurements a set of projection manometers indigeneously developed at the department are also available. These manually read manometers have a resolution of 0.2mm. In a typical tunnel run, the test model is mounted on the mechanical balance' struts and the aerodynamic forces and moments are measured manually by counter balancing the unknown loads with dead weights. Flow field data is collected through the pressure probe, fitted to the manually operated traverse meachanism and a manometer bank or through a set of 6 projection manometers. The pressure survey from the body tappings is made with a manometer bank. For the data reduction, the gathered data is first punched on computer cards and then fed to the main frame computer DEC system 1090 at the central computing facility of the institute.

System Overview :

In order to meet the increasing demand for the tunnel availability, the instrumentation system in the tunnel have been upgraded to automate most of the experimental procedures [1]. The imminent advantages due' to thie are faster and accurate data acquisition that is free from human errors, and reduction in to the aerodynamic quantities, which make the system self contained and improve the turn around time.

The modern technology in the fields of wind tunnel instrumentation and computer based systems, offer a wide choice of instrumenation and programmable controllers to automate a test facility. On the instrumenatation front, however, for most of the small- and medium-range test facilities, the choice is limited by several factors like the present circumstances of the tunnel operation, the exhorbitant cost factors involved in the inatrumentation and the required

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modifications to the tunnel to accomodate new instrumenation. Due to such reasons, the instrumentation in the above tunnel has been upgraded to facilitate automation instead of acquiring modern equipment like laser doppler velocimeters, etc. [2-8]. This upgradation work included the design and interfaces to control the mechanical instruments, the development of a new pressure measuring device and an analog DAS. A digital interface has been designed and developed to automate the 3-D probe traverse operation. A new 6-channel digital manometer has been designed and developed to acquire the pressure data from the 5-hole probe and the tunnel free stream. This sensor is based on automating the prassure measurement process of a conventional U-tube manometer under the control of a microprocessor. Instruments like scanivalve or an ESOP [7] would also claim a place in such an application. However, the ability to read accurately all the 6 channels simultaneously over a wide dynamic range, and the relatively low cost makes it a more suitable one for the present application.

To facilitate the automatic control of the model attitude, a new model mounting rig has been installed. The model mounting rig designed and developed by another group in the department provides the model control in the directions of pitch and yaw. For accurate force measurements, as an obvious choice, a 6-component strain gauge balance has been acquired. The present and the future experimental needs at the CCWT dictate that the data from the straingauge balance be acquired at a 1 KHz sampling rate and a resolution of at least 12-bits. In view of this and the possible future expansions, a 32-channel, 12-bit data acquisition system (DAS) has been included.

In order to cater to the needs of pressure plotting experiments and wake pressure surveys, a 48 port scanivalve vith an LVDT type pressure sensor has also been included in the system. The LVDT output ia acquired by the DAS.

The task of automating the experimental procedures could be effected by integrating the above individual subsystems with an appropriately selected programmable controller and DAS from the several high performance, commercially available, off-the shelf computer based systems. For example, systems like MACSYM, manufactured by Analog Devices, U.S.A. or DATA TRANSLATE (Data Translate Corporation, U.S.A.) [9] etc., offer high performance specifications and attractive capabilities. However, most of these modules are of general purpose nature.

Besides, the requirements in a wind tunnel call for several specialised acquisition and control functions that could not be met easily by the commercially available systems. For example, the interfaces to the 3-D traverse mechanism and the digital manometer are too specific to wind tunnel applications. Commercial systems generally do not meet these requirements and often require extensive tailoring, if chosen.

Alternatively, the above task can be implemented by designing a dedicated cost effective system processor using the easily available advanced microproceusors. A 16-bit microprocessor system has been designed and developed to meet these requirements. The present configuration of the system includes a CRT terminal for user interaction, an interface to standard printers for hard copy outputs, a MULTIBUS interface for any future expansions and a floppy disc controller for data storage. The block diagram of the system configuration is given in Figure 1.

Powerful hardware will be of little use without appropriate software. In many applications the software development bears a direct relationship with the available hardware. This often leads to a situation wherein an integrated approach that caters, with equal emphasis to both hardware and software aspects would be needed for a successful design exercise.

The software developed in assembly language initializes tho peripheral I/O chips and the interfaces to the instruments. The software for user interaction, provides a friendly environment for the user. In the set-up mode, a set of prompt and help messages allows the user to easily configure the instruments to the specific experimental needs. The software to control the experiment has been designed to sequence the control operations through the driver routines for, each of the interfaces, acquire the data in real time and process it on-line. The processed data is either printed or stored on a floppy in the IBM format. The data on the floppy can also be transferred to the mainframe computer DEC 1090 for detailed analysis, if needed.

The data presentation in an easy to interpret form, is also an important aspect of an integrated system. The color coded grphics technique developed by Winkleman et. al. [10], is a very useful tool for flow field visualisation and interpretation, But as it requirss sophisticated computer systems and image processing systemsit becomes unaffordable for small scale systems. However for the present system, graphics software has bees developed on an IBM PC compatible machine, to present the processed data in color graphics contour plots and velocity vector plots. The package exploits the capabilities of the PC and simplifies the flow field analysis.

A detailed description of the hardware and software for the user interaction, overall experiment automation and data presentation is given below.

System Processor Unit :

The block diagram of the system processor unit has been shown in Figure 2. The heart of this unit is a 16-bit microprocessor and numeric data processor pair, 8086-8087. The 8086, a third generation microprocessor, is capable of addressing upto 1Mb [11]. It operates on and transfers 16 bit data at a time. The inclusion of 8087 in the design *improves the processing speed phenomenally. Besides, the 8087's inherent capabilities to operate with 80 bit words, provide higher accuracy. The unit has been designed to accommodate the necessary memory and other programmable peripheral chips to interface the subsystems. Notable amongest them are -

- Programmable peripheral timers (Intel 8253) - to 'time stamp' the acquired data and to generate timer Interrupts for the data sampling purposes.
- Programmable interrupt controller (Intel 8259) - to process multiple interrupts (upto 8) from the sub-system modules and timer interrupts and draw to the attention of the processor when required [12].
- Universal synchronous and asynchronous transmitter/receivers (Intel 8251) - to support a CRT terminal for user interface, and to provide a programmable auxiliary RS-232C communication channel [13] for linking the system to other computers (a PC has been connected to this channel).
- A MULTIBUS interface - to facilitate any future expansions (upto 6).

Future expansion provisions have been simplified by designing a MULTIBUS interface to the present system [14,15]. The bus structure provides a common element for communication between a wide variety of system modules which include memory, digital and analog I/O expansion boards and peripheral controllers. It comprises of 20 data lines (equivalent to an address space of 1 Mb.), 16 bi-directional data lines, 8 multilevel interrupt lines and several bus control, timing and power supply lines. Modules that use the MULTIBUS have a master-slave relationship. The system processor, which is the bus master, drives the command and address lines and controls the bus. The present design provides six slots for tho slave units, out of which the first slot has been used for the 32 channel analog data acquisition system. A floppy disc controller has been used in the second slot.

3-D Traverse Automation :

Traverse mechanisms may employ either stepper motors or induction motors. One of the important factors that influence the choice of motors is the carriage load. Stepper motors are suitable for driving light carriages. But most often the carriage weight encountered in a typical medium and large size wind tunnel setup is considerably more. In such situations induction motors are preferred to stepper motors. Several interesting possibilities do exist for automating the probe traverse mechanism employing induction motors. The technique employed to interface the traverse mechanism to tho 16-bit processor makes it simpler to position the probe precisely.

The traverse mechanism employed in the CCWT has three motors to move the probe 96" along the flow direction (X-direction), 48" along the lateral direction (Y-direction) and 12" in vertical direction (Z-direction). In order to keep the traverse mechanism upstream effects to a minimum, the movement of the carriage in the Z-direction is limited to 1'. To cover the complete Z-direction the probe holder rod can be changed to extend the probe movement downwards.

Automating the above traverse mechanism usipg the microprocessor involves :

(i) Probe displacement sensing over a maximum distance of 96 inches.

(ii) Controlling the three motors to move the probe to the required position in all the three directions

(iii) Carriage limit sensing at either ends of each of the three directions, and

(iv) Software far easy programming of the module

One of the well known and accurate methods for position sensing is by using the Gray code scale. But considering the span of the present system, a 0.01" resolution will need a 14-bit Grey code scale. Due to the obvious difficulties involved in fabricating a 14-bit Gray code scale with 0.01" lines, often a potentiometric method is used for position sensing [16]. However, in the present system, in order to adhere to the simplistic design goal, an alternate method has been developed. In this method, provisions have been made to count the number of revolutions of the leadscrew of each motor with the required resolution, using IR optical sensors, MCT-8 [17]. The number of revolutions are counted using a software programmable interval timer (8253) interfaced to the processor. This avoids the problems associated with tho analog techniques. To control the 3 motors, a bidirectional motor control circuitry is designed using a simple logic circuit and relays. In order to safeguard the motors against the program and human errors, features like, carriage limit sensing, auto-motor OFF and interrupt to the processor are incorporated in the design. The electronic interface is shown in the Figure 3.

The software for this interface facilitates calibrartion of the traverse and forms a look-up table for the calibration constants. This calibration compensates for the errors duo to the inertia of the induction motors, mechanical gears and also the misalignment errors in each axis.

For probe position control the software allows the user to define the scan volume in the test section and other parameters. The features offered by this software include -

- Probe movement MANUAL / AUTOMATIC selections.
- Scan limits on each of the three directions.
- Number of segments within the limits in each direction.
- Different grid sizes for different segments within the scan limits.

Other options include

- Default grid selection.
- Grid size dynamically alterable without discontinuing the experiment.
- Calibration and forming a new look-up table for the correction terms to

6-Channel Digital Manometer :

The instrument is based on digital rending of the distance between the liquid levels in a U-tube manometer by mechanically traversing a carriage to which are fixed a pair of liquid level sensors. The carriage traverse is sensed by a distance sensor which produces a pulse per 0.1mm movement of the carriage. These pulses are counted by a free running counter. The microprocessor reads the level sensors' status and at the instants of the carriage crossing the liquid level meniscus, samples the free running counter. The readings are stored in the system memory. Once these readings are taken for all the channels, the difference in readings for each of the manometers is computed by the microprocessor and the data is available for printing or any further processing.

A semi automatic version of this instrument, in which TTL hardware has been used to read the liquid column height in a U-tube has been developed in the department of Aerospace Engineering, IISc [18]. However, in this prototype instrument, the motor contol is manual and a cam mechanism is used for the carriage movement. In view of the relatively large range of movement required for the present instrument, the mechanical design of this prototype has been changed considerably in the new Instrument to facilitate reliable operation under the control of the micrprocessor.

The machanical construction and the electronics interface to the processor have been shown in the Figures 4 [19]. The lense effect of a glass tube filled with alcohol is conveniently made use of, to sense the liquid level using IR optical sensors (MCT-8). The distance traverse by the carriage is sensed as a function of the motor drive so the readings are independent of the motor speed variations. Although the present design includes only 6-channels, with minor extensions, the interface can be implemented for as many channels as required with a suitable mechanical set-up.

The resolution of the system is 0.1mm of liquid column. With the present mechanism, it may be noted that the accuracy of the readings is independent of the speed variations of the motor. This eliminates tha need for a precision motor and speed control circuitry. The accuracy of the unit is found to be better than 0.2mm. The range of the instrument is ±1000mm. The present designe requires 2.5 sec to acquire one set of 6 samples.

Instrumentation for Force Measurements and Pressure Surveys :

Force measurement instrumentation has buan implemented through a straingauge balance and a 32-channel analog DAS. A position encoder and a motor control interface has been designed to control the model on the new mounting rig designed by a separate group [20].

A 48-port scanivalve has been interfaced to the system processor as a part of the pressure survey instrumentation.

6-Component Strain Gauge Balance :

For accurate force measurements, 6 component straingauge balance has been acquired. It has eight strain gauge bridges to indicate all the six components of force/moments. These eight strain gauges provide electrical signals in the range of ±2 mv full scale with excitation voltage of 4 V dc. The straingauge balance has been calibrated for use in the present system [21].

32-Channel Data Acquisition System :

The 32-channel data acquisition system (expandable to 256 channels) has been shown in Fig.. .. It consists of 8 channel preamplifiers which are tailored to read the signals from the strain gauge balance, a 32 channel multiplexer, a gain selectable instrumentation amplifier, a sample and hold circuit and a buffered 12-bit successive approximation analog to digital "converter. The timing signals to sequence the operation of these blocks have been provided by a controller circuitry. This module is configured for memory mapped I/O and the address is jumper selectable. The module has been interfaced to the system processor through its MULTIBUS. The block diagram of the DAS is given in Figure 5.

Expansion upto 256 channels may be effected by utilizing the expander circuitry with minimum additional hardware of preamplifiers and multiplexers. Other hardware features include signal conditioning at the input end in the shape of hardware low pass filters, and input over voltage protection. In its configuration, the 8 low input channels accept inputs in the range of ± 2mv while the high level inputs allow inputs of ±5v full scale. The settling times of each component put together will amount to 38 u sec when the overall amplifier gain is 1, but will increase upto 100 u sec for a maximum gain of 1000. These figures imply that sampling rates upto 10 KHz are achievable while operating the amplifiers at maximum gain. The 12 bit data acquisition system provides an overall accuracy of 0.1%. This module has been wired for interrupt mode of operation in the system.

The analog data acquisition software allows the user to configure the module to the specific requirement of the experiment. The channel numbers to be sampled, bounds on input levels, scan rate and number of samples for averaging are programmable. The accuracy of the acquired data is further improved by automatic drift and gain error cancellations. Once the module is defined for an experiment, in order to acquire the data, the system processor issues a command to initiate the data conversion. Once the data conversion is complete, the data acquisition system will interrupt the processor so that the processor may read the converted data. During the conversion time, the processor can either proceed with other tasks assigned, or wait for the conversion to complete. Thia feature contributes to further processor time savings when the module is used in the timer interrupt mode. When the data acquisition is complete, the input levels on the selected channels are compared against the set limits.

Scanivalvs Pressure Measurement System :

Pressure survey experiments at the CCWT require multiple pressure measurement from a rake of pitot tubes traversed in a vertical plane, in the wake of the model, or from the tappings drawn from the model surface. In the system, a 48-port scanivalve (model 48d3) enables these measurements to be made using a single pressure transducer. Figure 6 shows the block diagram of the electronic interface to the system processor. In order to obtain the port numbers precisely, a 6-bit optical shaft position Gray encoder has been used on the scanivalve motor shaft. Optical Gray encoder has been designed using six sets of IR emitter and sensor pairs (MCT-8) mounted across an optical circular Gray code disc. The Gray code pattern on the disc with 48 levels, has been made using a coordinato-graph to ensure high precision, A bi-directional motor drive circuitry has been designed and developed (using transistors) to control the scanivalve motor operation. Based on the direction arid ON/OFF inputs to this block, the circuit drives the motor in the uppropriate direction, and thus provides a random access of a particular port.

The pneumatic multiplexed output is fed to a LVDT type pressure transducer which provides a ±5v output full scale with an accuracy of 0.1% over a range of 0 to 0.1 psi. Channel 10 of the earlier described data acquisition system has been used to read the analog output of this transducer. As a result, although the sampling rate on each channel of the data acquisition system is upto 10 KHz, the sampling rate of the ports is limited to 0.4Hz. This limitation is primarily due to the maximum motor speed of the scanivalve used, which is 3 rpm.

The software to control the pressure survey data acquisition offers two modes of scanivalve operation. In the first mode, scanivalve is operated in sequential port selection. In this mode the port numbers to be sampled and the sampling rate on each port are selectable by the user before starting the experiment. When this mode of operation is selected, the system homes the scanivalve to its port 0. Then the scanivalve motor is activated for a continuous operation and the port numbers are aontinuoualy sampled. The data is acquired within the dwell time, when the port number corresponds to the ports to be sampled. The second mode provides a random access of a particular port. For this mode also, selectable parameters are the same. However, in this mode, the scanivalve current port number is read and compared against the port to be sampled. The processor determines the direction in which the motor has to be rotated to reach the next port from which the data has to be read. Based on this, the proceesor controls the motor appropriately through the interface. On accessing the required port, the data is acquired as per the selected mode.

Software Design :

The software designed for overall system operation may be grouped into three parts, i.e., (i) systems software, (ii) user interaction software, (iii) experiment driver software and (iv) data presentation software. The software, excluding for the data present-ation has been developed in 8086 assembly langauago. The software for the data presentation has been developed on an IBM PC compatible machine so that the color graphics capabilities of the PC could be exploited. Besides it would ease the necessary modifications to the application software, which are often required from time to time.

The user interaction software for setting-up the experimentation provides a friendly interface, which enables the user to program the system for his experiment. During this exercise, the software ensures error-free parameter selection through a set of help messages and self explanatory queries. Once the system is "set" for the experiment, the configuration of the experiment is stored on the floppy and the experiment driver takes-over the control to initiate the actual conduct of the experiment. This part initializes and configures the subsystems instrumentation, and performs real-time data acquisition and control. The data is stored in the floppy disc. The software processes the data on-line and also responds appropriately to the interrupts from the subsystems instrumentation. The software also continuously updates tho display of the status information on the CRT terminal. The user may interrupt the process, through the terminal keyboard, either to hold/terminate the experiment or to modify the set-up information. On successful completion of the experiment, the control is transfered to ths data presentation eoftware.

The data presentation methodologies have been framed based on the common experiments conducted in the CCWT. These have been sub-divided into three catogories i.e., flow field data presentation, force/moment data presentation and pressure survey data presentation. The experiment driver software stores the data on a floppy, which can be readily presented in the form of tables. The data presentation in the form of plots can be obtained either through the main-frame computer DEC system 1090 or through an IBM PC compatible machine. The interactive nature of the packages developed improves the user's comprehension of a large volume of data by a choice of colors/patterns.

i) Systems software :

The system software initializes the peripheral interfaces and submodules for appropriate mode of operation. It also initializes the interrupt vector table for interrupt service handler. The software also ensures appropriate proceesor response for interface software and the application software.

ii) User interaction software :

The hardware has been designed, as described earlier, to cater to a wide spectrum of experiments like i) flow field survey, ii) force/moment measurements and iii) pressure surveys, wherein the range of several parameters, like the mode of operation of the sub modules, data acquisition specifications etc., would vary. Hence, for any specific experimentation needed by the user, there is a need to re-configure, by software, the individual sub-systems and the software-generated time-markers. The precise role of the user-interface software is to acquire the set-up data from the user through a set of queries and use it to configure the sub-systems accordingly.

The queries are self-explanatory and easily understandable. The permissible answers, parameter range etc. are displayed along with each query. In order to ensure error-free set-up entries, the software accepts the parameters that are allowable and in the case of incorrect entries, an error message is flashed on the CRT to warn the user and requests for a permissible answer. Figures 7 depicts the selection of the measurement options. For this selection, the user is also prompted with the expected answers. Once the required experiment is selected, the system draws the user's attention to verify the entries (Figure 7). The user is allowed to make any alterations to his selection. On confirming the selection, depending on the experiments selected, queries for configuring tho individual experiments are initiated. For example, to enter the set-up parameters for the DAS, the system displays tho default parameters required for the data acquisition and the mode of raw data output. For the convenience of the user, the cursor is placed against each of tho parameters 'on the screen, in the order shown, and waits for the user response. The eelection of the respective parameter's value is further simplified by showing the admissible response / range at the bottom of the screen.

Similar procedure has been adopted to configure experiments for flow field survey and the pressure surveys. For flow field survey, the user has to select the mode of the probe traverse control, either Manual or Automatic. This is followed by defining the probe traverse range and the grid size in the three directions. Besides, the pressure data acquisition through the 6-channel digital manomster has to be configured. In the case of the pressure survey experimentation, the user is requested to select the port numbers (of the 48 available ports on the scanivalve) to be sampled, the sampling period, and the number of samples for averaging. In this fashion, the user interaction for configuring the experiments has been made self-explanatory and simple.

The above user interaction software for the set-up has been developed in the assembly language of 8086. However, since the basic central processor board and the associated hardware have been interfaced to an IBM PC compatible machine, a separate user interaction routine which uses IBM PC as a stand-alone color terminal ha5 also been developed. The photograph presented in Figure 7 is from the IBM PC terminal , which hau an improved appearance as compared to the black and white terminal developed as part of the systems hardware.

iii) Experiment Driver :

The experiment driver part of the software configures and controls the subsystems, based on the parameters provided by the user, and acquires data in real time, The software also monitors the health of the instruments and continuously updates the status of the experiments on the CRT screen. The user may also interrupt the processor at any stage of the experiment, view the sot-up parameters through simple commands and alter them for the rest of the experiment. The experiment driver software for each of the experiments is discussed balow.

For force measurements, depending on the user set parameters, the in the manual mode, system prompts the user to set the model position in the required pitch and yaw. The user is then required to set the model position and press 'return' on the key board (in the automatic mode the same will be done by the system). When the key is pressed, the system initiates A/D conversion on each of the analog channels by first initializing the timer for sampling period and then by issuing a start conversion command to the data acquisition system. When the analog to digital conversion is complete, the DAS interrupts the processor so that the converted data is read by the procassor. The processor than looks for the acquired data, and if the data is available in the memory, it will be processed. At the intervals of the sampling period, the timer interrupts the processor to acquire the data precisely at the sampling intervals. The processor keeps track of the number of samples acquired and when this number reaches the sat value, the timer interrupt is disabled and the above process continues until the data collection at all the required angles is complete.

When flow field survey is selected, the driver software initializes the 3-D traverse interface module for automatic probe positioning. The probe is positioned using the user set-up information at the top left corner of the first cross-sectional plane in the test section. Depending on the step size (grid size), in each of the three directions, the probe is moved in the lateral dircetion (Y-direction) in the cross-flow plane. At each step, a flow settling time of about 1 second is allowed and then the data acquisition is effected through the 6-channel manometer. When the probe reaches the last grid point along that line, the probe is moved to the next step in the vertical direction (downwards) and the pressure data is collected. The direction of the probe movement along the lateral plane is then reversed. This process is continued to complete the scanning of each cross-flow plane. After collecting the flow field data from the first plane, the probe traverse is moved in the axial direction to place the probe in successive cross-flow planes and the data collection is completed. The pressure data from the 5-hole probe throught the manometer sub system is acquired in interrupt mode. This approach makes the best use of processor time and facilitates on-line data reduction while the data is acquired'.

In the case of pressure survey experiments, the scanivalve motor is controlled to access the required ports, in succession, as per user requirements. At each of the required ports, the pressure data from the LVDT pressure sensor is acquired through the analog DAS aa described above.

Once tho data acquisition for the selected experiments is completed, the data processing and presentation software receives the control. This part has been described in the next section.

The acquired data, depending on user requests, has to be bound checked, averaged and normalised. This processing is carried out by the central processor. If the data acquisition rates are low, the proceesor would have sufficient time to complete this processing while the data is being acquired. However, if the interval between the acquired data is small, the processor would continue to complete' the processing after completion of the data acquisition. The acquired and the processed data are then written in the auxillary storage in a format acceptable to IBM PC compatible machines for further processing and presentation.

iv) Data Presentation :

This part of the software that runs on the PC has the following functions to perform on the acquired data.

(i) Reduction of aerodynamic quantities from the acquired data,

(ii) Graphical--Velocity vector and contour colour maps of the measured data,

and

(iii) Force and pressure distribution plots.

Data processing software for force measurements includes computation of the aerodynamic coefficients. The local flow angle and the velocity magnitude have been obtained from the Plow field data, sensed by the five hole probe and the probe calibration data [22]. From this data other parameters of interest are also computed. Pressure survey data from the model or from the model wake is processed to yield the load distribution over the body or the pressure loss in the wake. These results are used to calculate the necessary aerodynamic quantities.

The data presentation software for the force and pressure results is implemented in the usual manner through which multiple color plots of comparable parameters could be obtained. In the case of flow field data presentation, the software developed provides the user with the velocity vector plots on a HP7470 color graphics plotter. For a quick visualisation of the flow field around the model, a software package has been developed to present the velocity data (or local head loss) in the form of colour graphic contour plots on the PC. Using this package, the contours of selective magnitudes of the flow field may be plotted. Corresponding to the user's choice, the software first searches for and separates out the iso-magnitude data from the velocity data. Then the equivelocity contours are displayed in colour graphics. The range between the adjacent contours is shaded with different colour patterns. This provides a quick, visual appreciation of the flow field around the test model in an easy and inexpensive way. However, if some contours are closely spaced, depending on the actual layout of the contours, the patterns used to shade the regions may lead to confusion. This has been overcome by providing the user with an option to change the colour patterns after examining the contour plots presented on the screen. The available colour patterns are shown adjacent to the plot with an indication of the default colours assigned to the selected magnitude ranges. Through the key board, the user can select a pattern and give a command to fill up the selected contour region. Representative photographs of the color graphics displays of the flow field data have been given in Figures 8 and 9. The final forms of the displays oould also be saved for future reference.

Conclusions :

The hardware and the software of the integrated in8trumentation system that is suitable to small scale wind tunnel applications has been successfully designed and realised. The system has been installed in the CCWT at I.I.Sc. and tested, Representative color graphics plots have been presented. Since the important feature, in these plots is the different colors, the same may not be effectively seen in the final form of the paper. However, we expect a distinguishable gradation in the contour levels in the final pictures.

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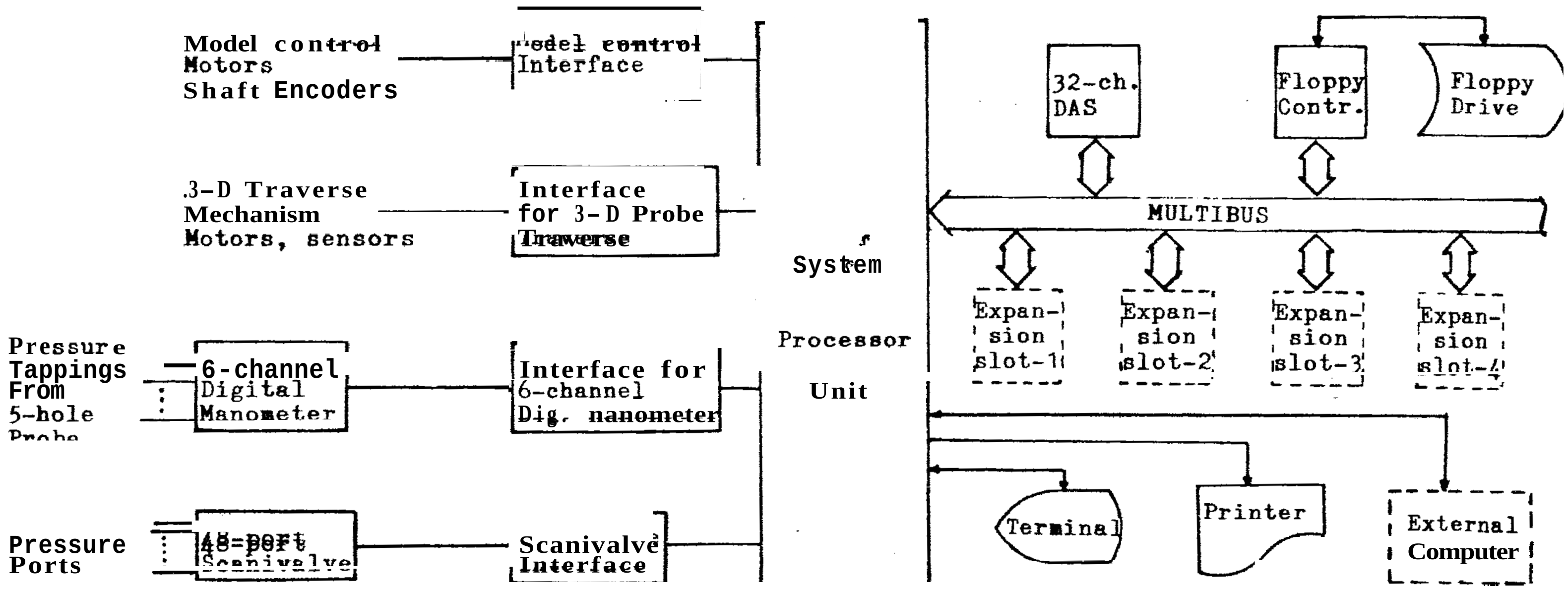


FIG. 1. CONFIGURATION OF TEE SYSTEM

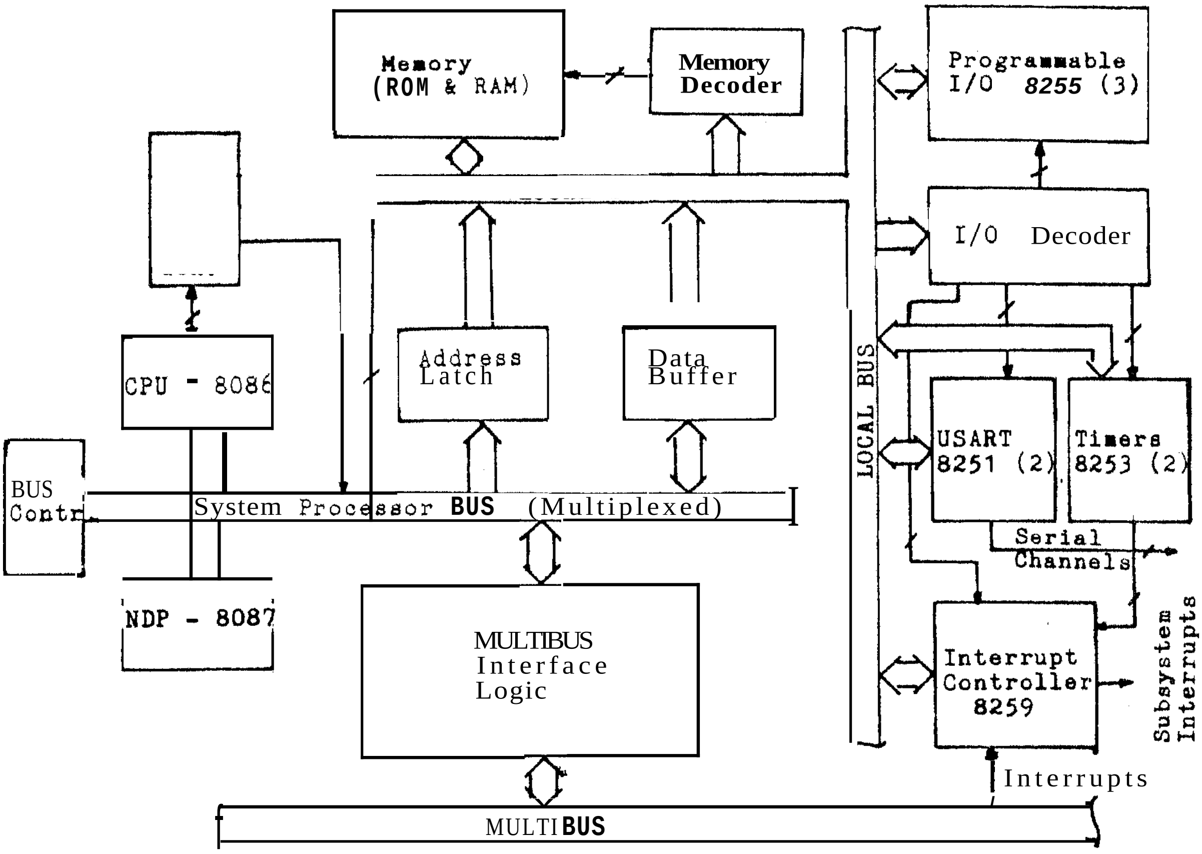


FIG. 2. SYSTEM PROCESSOR UNIT

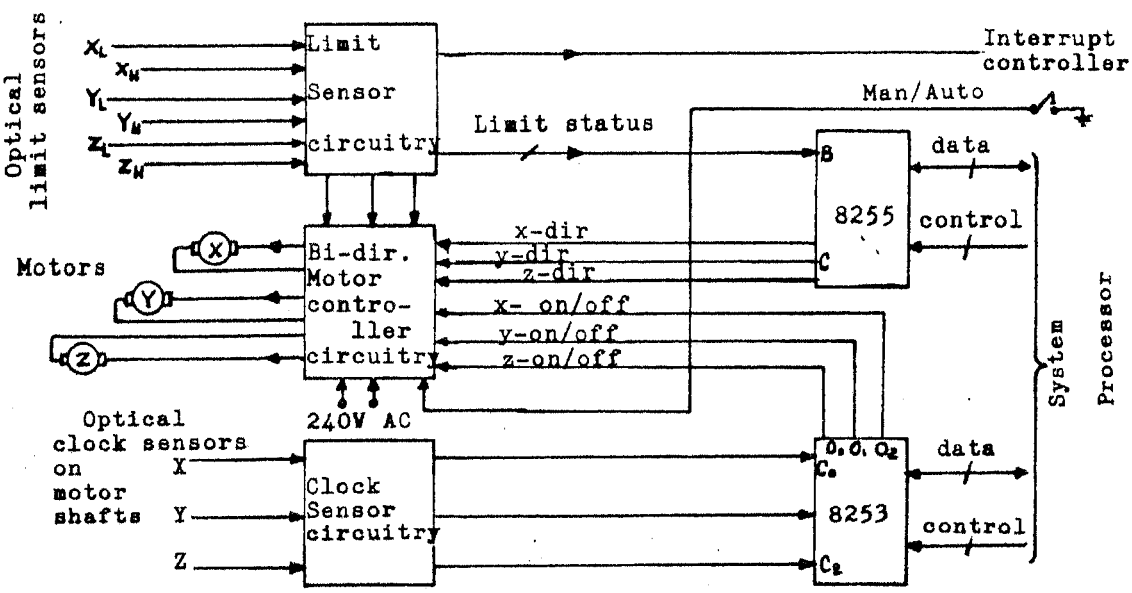
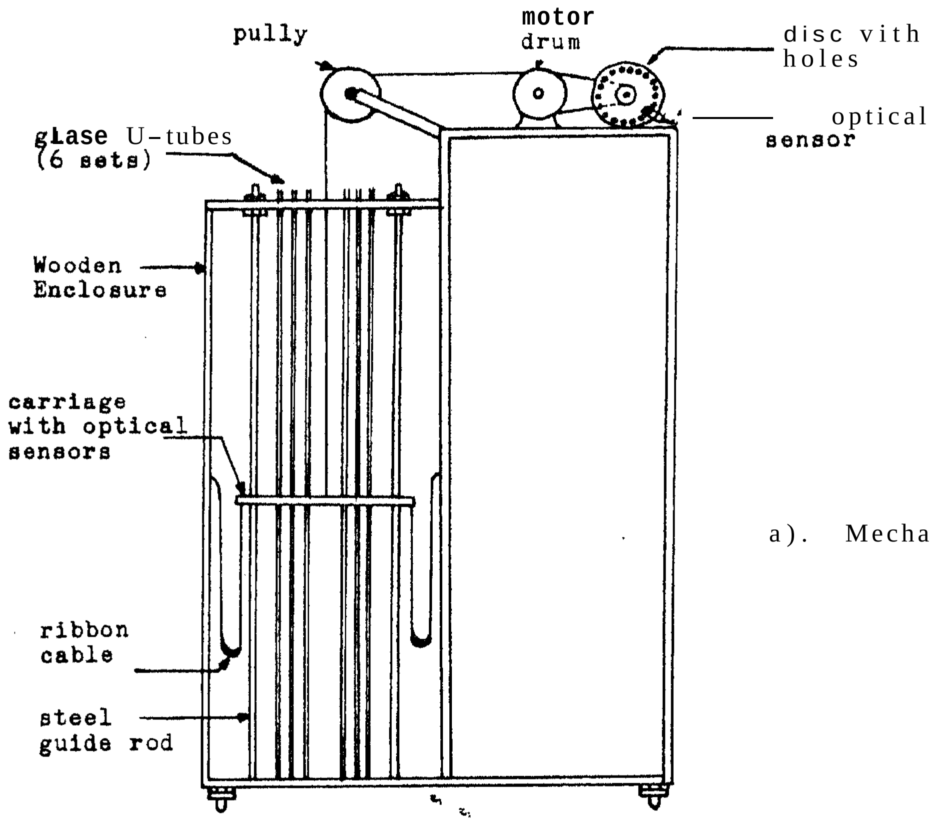
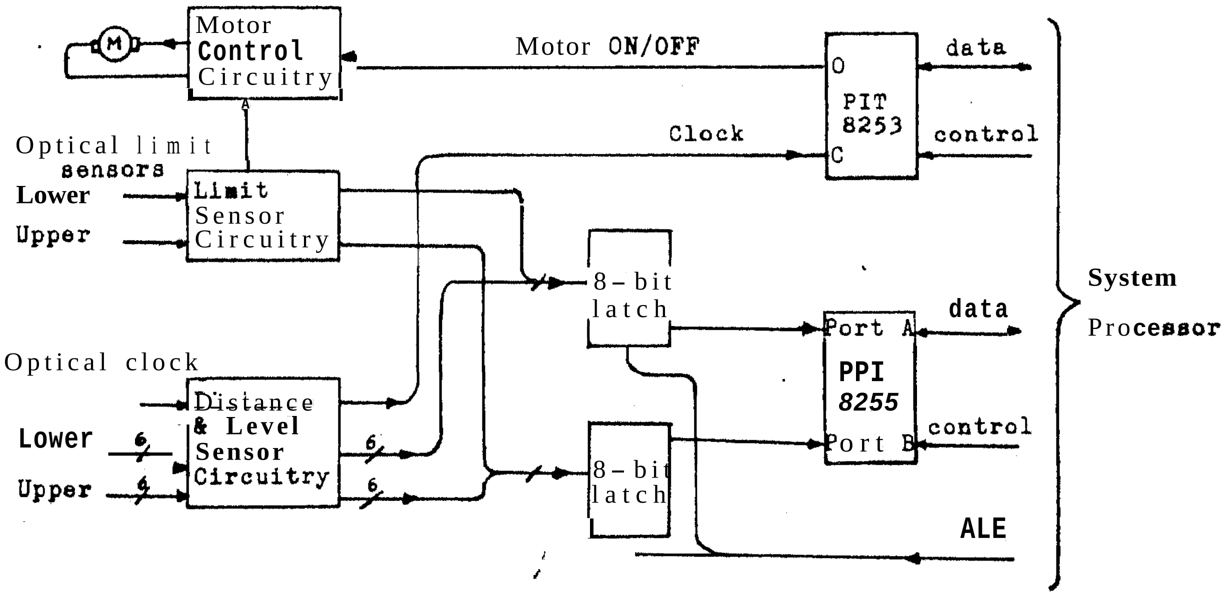


FIG. 3. 3-D PROBE POSITION CONTROL INTERFACE



a). Mechanical **Set-up**



b). Electronics **Interface**

FIG. 4. 6 - CHANNEL **DIGITAL MANOMETER**

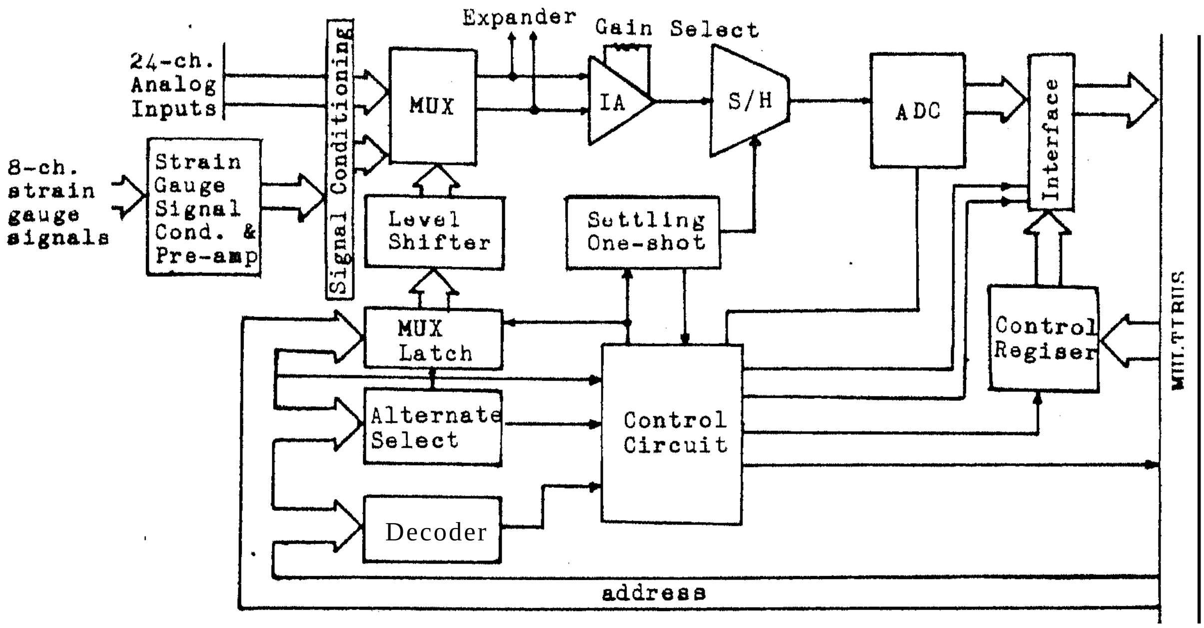


FIG. 5. 32 - CHANNEL ANALOG DATA ACQUISITION SYSTEM

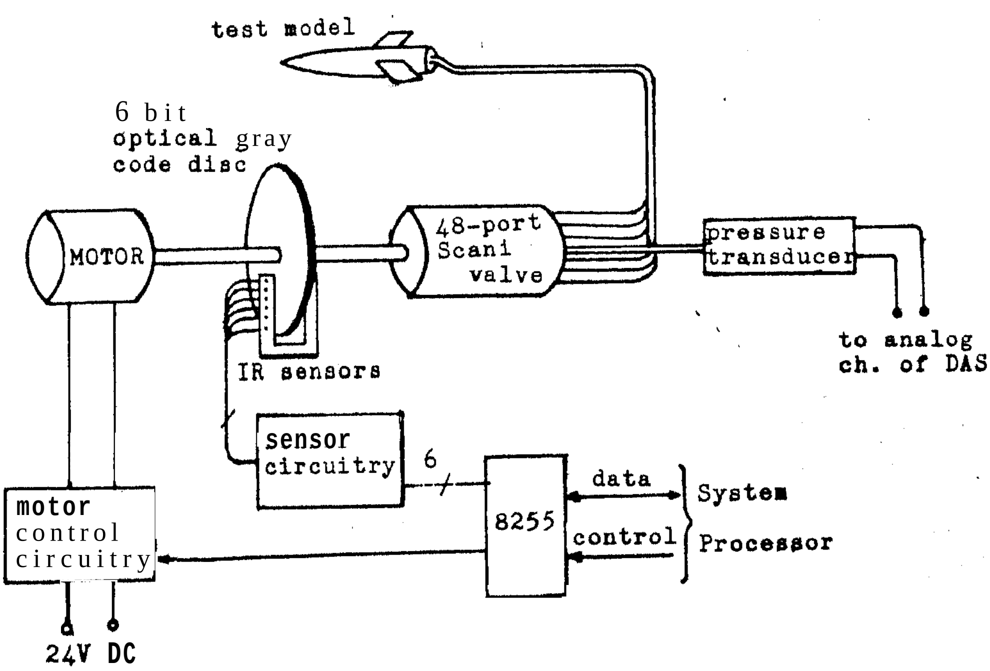


FIG. 6. SCANIVALVE INTERFACE

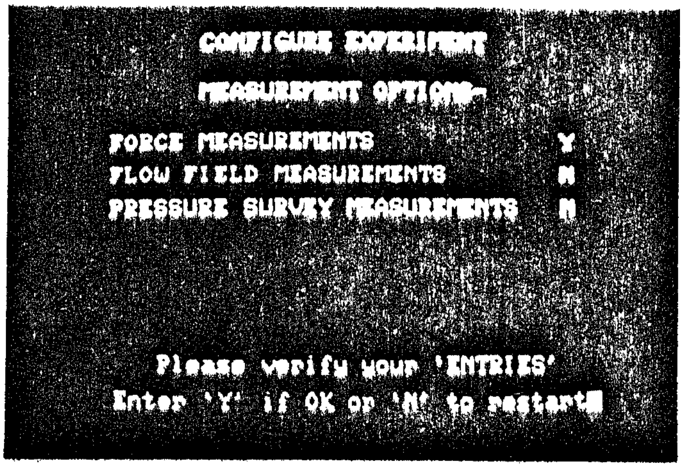


FIG. 7. **USER INTERFACE** – Set-up Mode

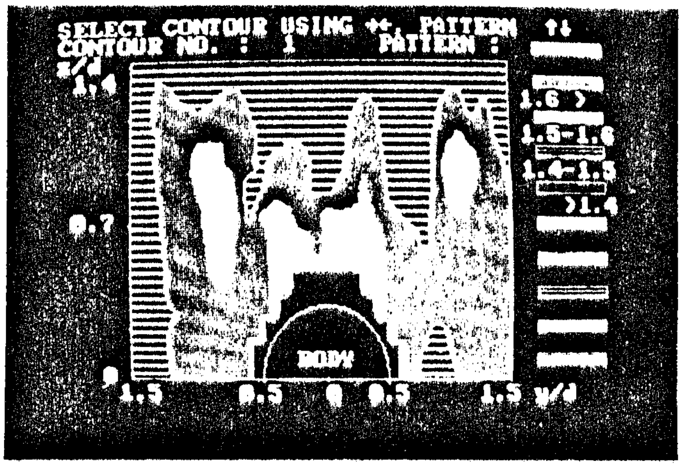


FIG. 8.

COLOR GRAPHICS **ISOMAGNITUDE** PLOTS
– Equivelocity Contours at x/d = *2.4*
alpha = 18, Vinf = 30 m/s (body :
ogive nose-cylinder body of l/d=10)
-- Color pattern selection

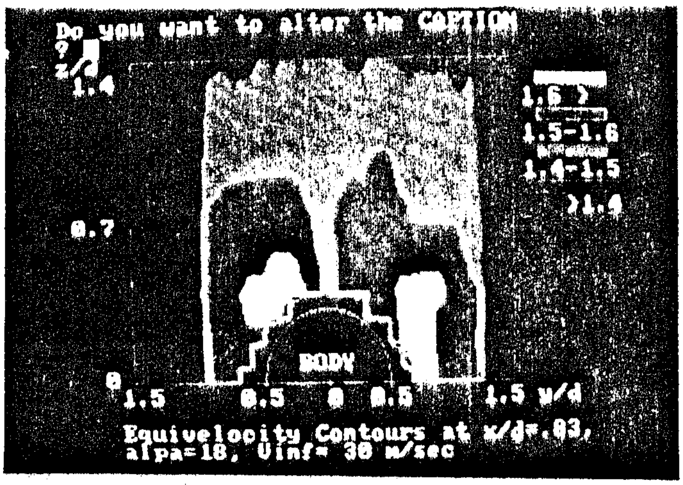
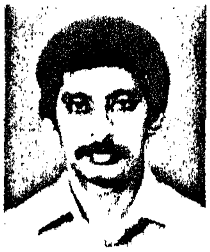


FIG. *9.*

COLOR GRAPHICS PLOTS – continued
-- after completing the color pattern
selection and before saving the picture.

BRIEF BIOGRAPHIES OF AUTHORS

C. Ravikumar graduated in 1979 from Nagarjuna University, Guntur, India and received M.Sc. degree in engineering physics and instrumentation in 1981 from Osmania University, Hyderabad, India. In 1981 he joined the department of Aerospace Engineering, Indian Institute of Science, Bangalore, India where he was employed as a Scientific Assistant. At the Indian Institute of Science he had also completed a research oriented M.Sc. (Engg) degree. His fields of interest include microprocessor based instrumentation, microcomputer systems and computer engineering.



N. Balakrishnan received the BE degree in electronics and communications from the University of Madras, India in 1972 and the Ph.D. degree from the department of Aerospace Engineering, Indian Institute of Science, Bangalore, India in 1979.

In 1973 he joined the Department of Aerospace Engineering where he is currently employed as Associate Professor. His fields of research interest include numerical electromagnetics, space craft antennas, computer science and microprocessor systems.

Prof. Balakrishnan is a life member of the Instrument Society of India and is on the editorial board of the Current Science Journal. He is the recipient of the UNESCO/ROSTCA award for outstanding contributions in the area of computers and informatics for the year 1985. He is the Convener of the Centre for Microprocessor Applications and also the Centre for Science Information at the Indian Institute of Science. He is also a consultant to leading Government and Private industries

V.S. Holla received the B.Sc. (1956) and B.Ed. (1960) degrees from Mysore University, India, the M.Sc. (Mathematics) degree from Karnataka University in 1961 and the Ph.D. degree from Indian Institute of Science, Bangalore, India, in 1969. He joined the department of Aerospace Engineering, Indian Institute of Science in 1965 as a Technical Assistant and is currently an Associate Professor in Aerodynamics. His interests are in Theoretical and Experimental Aerodynamics and has been working in this area for the last 22 years.

Prof. Holla is a member of the Aeronautical Society of India. He is also on the Editorial Board of the Journal of Aeronautical Society of India, as an Associate Editor since 1980.