PROJECT TITLE

Computer Integrated Testing for the Transport Refrigeration Systems Industry

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I wish to dedicate this thesis to my fiancée Nicola and my family for their constant encouragement and support.

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Abstract

This is a study of a state of the art implementation of a new computer integrated testing (CIT) facility within a company that designs and manufactures transport refrigeration systems. The aim was to use state of the art hardware, software and planning procedures in the design and implementation of three CIT systems. Typical CIT system components include data acquisition (DAQ) equipment, application and analysis software, communication devices, computer-based instrumentation and computer technology. It is shown that the introduction of computer technology into the area of testing can have a major effect on such issues as efficiency, flexibility, data accuracy, test quality, data integrity and much more. Findings reaffirm how the overall area of computer integration continues to benefit any organisation, but with more recent advances in computer technology, communication methods and software capabilities, less expensive more sophisticated test solutions are now possible. This allows more organisations to benefit from the many advantages associated with CIT. Examples of computer integration test set-ups and the benefits associated with computer integration have been discussed.

Introduction

This is an investigation into the key features and the associated techniques involved in commercially implementing a state of the art Computer Integrated Testing (CIT) environment and was completed in conjunction with an industrial manufacturer of transport refrigeration units for trailer and truck applications. This area was investigated due to the growing need for providing more accurate estimates of product performance and reliability, which arose due to the growing demand of global competition for the development of new products in shorter times with higher performance rates, greater reliability and overall quality. This in turn promoted the need to perform detailed testing of materials, components, processes and systems.

Three CIT systems were installed throughout the duration of this project, which included an Applications Trailer and Truck CIT system, a Wind Tunnel CIT system and a Calorimeter testing system. Project involvement in the implementation of these systems included initial design consultation, data acquisition, PC and computer based instrumentation set-ups, software test template development and set-up, networking techniques, data analysis and presentation and the generation of reports.

The project was undertaken in the Thermo King research and development centre in Galway. This particular department was set-up in 1997, therefore a testing history was practically non-existent within the department. The test systems required were to perform several functions the main function being the testing of Thermo King's unit performances under several different conditions. The main objectives of the testing systems was to generate the most accurate information on product and component performances and make the information readily available to employees within the organisation to aid in the design of more sophisticated and efficient transport refrigeration units. Items that required close control throughout the project duration was to ensure products were not tested too much and that the correct product characteristics were identified for testing. These are very important from a cost point of view, as testing can be a very expensive process. Computer-based testing was investigated to achieve more accurate estimates of the product's reliability and efficiency over traditional methods.

In the past researchers combined the benefits obtained from software advancements in CIM with advancements in test automation to develop CIT systems. CIT have been in existence since the early 1980's. In 1986 David A. Seres presented a paper called Computer Integrated Testing, A New Architecture for Final Test. It was presented at the Proceedings of ATE West in California. [1] (David A. Seres, 1986). CIT was described as a flexible architecture that accommodates both analogue and digital testing as well as switching functions in a single reconfigurable instrument system. Seres placed much emphasis on software development, data collection and analysis. Even though the example of CIT concentrated on final test and involved the use of older standards such as IEEE-488, its overall description and realisation of the importance of software development in the area of CIT was essential to the steps taken in the development of more capable software packages.

In January 1993 a report was written in a joint Euro/Canadian programme to develop and evaluate a novel inspection concept. It was titled Computer Integrated Testing written by Kreier, Gribi, Durocher, Hay, Pelleties and Edelmann and can be found in the European Journal of NDT Vol. 2 No. 3. [2] (1993). The paper describes a joint project of Sulzer-Innotec and Tektrend International Incorporation. The results of their combined co-operation showed an advanced PC-controlled, CAD supported ultrasonic scanning, acquisition and evaluation system for use with immersion or water jet couplings. The study was conducted to detect flaws in fibre reinforced plastics using ultrasonic inspection. The problem presented was associated with the large amount of time required to prepare for a scan. They introduced the concept of CIT in an attempt to solve the problem. Data acquisition software (ARIUS II) was improved to allow for interaction with extended CAD, signal processing and recognition software. This resulted in a fully PC controlled inspection system with a wide range of facilities including calibration, transducer characterisation, evaluation, reporting and signal processing. The step taken in improving the software mentioned above opened the doors for the development of programming environments such as LabVIEW for developing specific applications and promoting interaction with other software packages. Today due to these types of advances all DAQ software has the ability to transfer data directly to spreadsheet programs for analysis and presentation.

Brian Roberts (electrical engineer at Advanced Kiffer Systems Inc., Cleveland) presented an interesting paper on the implementation of a state of the art computer integrated testing system for testing rods and wires. [3] (Brian Roberts, 1997). This paper was presented at the 67th Annual Convention of the Wire Association International, Atlanta Georgia, USA in April 1997. It detailed the use of eddy current testing to provide 100 percent inspection in a fast, simple and cost effective manner. Roberts maintained that 100 percent inspection was only possible due to the recent advances in the use of microprocessors and computers making automated systems feasible and practical. The paper highlighted the main duties of the computer to be included in areas such as set-up, monitoring, stability, pre-warning, data storage, documentation and remote displays. Digitally compatible eddy current test equipment was selected. Transducer analog signals collected were very small and required amplification before being converted to a digital representation. The computer was then used to perform several duties as mentioned above. Signals were transferred to the computer by fibre optics because of their immunity to electrical noise, and communication with the host network was achieved with an Ethernet link. Advantages achieved included fast test speeds (10,000 meters of wire per minute), simple and cost effective operation and computer initiation, control, correction and supervision.

This system proved to be successful, but since 1997 there have been many advancements in the area of software capabilities. Off the shelf inexpensive data acquisition and data analysis packages are now available that offer advanced built in functions, such as the ability to send an e-mail or make a mobile phone call when a predetermined event occurs. These types of functions were only available at that time in expensive software development packages. Also standard PCs sold today offer higher memory capabilities, greater processing power and larger hard disks so greater performance rates can be achieved. Advances in Internet technology and data management software packages contributed to the more sophisticated data retrieval and storage systems now available also allowing data to be access/retrieved from any location at any time.

A paper presented by Dawei, Jing and Shan maintains that CIT was at that time being developed for applications in industrial inspection. [4] (Dawei, Jing & Shan, 1998). CIT is described with the obvious advantages over conventional inspection methods. The paper also presents a CIT approach for fast testing of internal thread parameters such as pitch, angle and pitch diameter. It was presented at the Proceedings of the International Society for Optical Engineering 1998 but their arguments seem to be vague as CIT has been used for industrial inspection for many years.

Another paper was presented at the Proceedings of the Electrical Insulation Conference and Electrical Manufacturing and Coil Winding Conference in September 1997 on the implementation of a CIT system for electric motors. [5] (W. Benning, 1997). The paper laid down some interesting arguments for the implementation of automatic test systems. Two main reasons were put forward, firstly the increasing requirements of the customer and secondly the skyrocketing product liability confronting producers. These suggest the development of CIT systems for slightly different reasons. They do promote quality and the elimination of defects but also incorporate the reason referring to the growing commercial liability risks that face producers due to injury's attributed to defective products. In many organisation the aim is now towards all stages of product development in order to avoid defective production and eliminate liability risks.

This thesis begins with a description of CIT, from its origin through its associated key management factors to the expected benefits that can be attributed to its successful implementation. Chapter 2 details the analysis of the key components that make up a CIT system, which include PCs, data acquisition hardware and software, computer based instruments and computer based communication methods and devices. Chapter 3 is based on the requirement to gain knowledge of the functionality of components mentioned in chapter 2. This is required to aid in the selection of an adequate CIT system to meet all present and future application needs. The roll of networking in CIT systems has also been discussed along with a detailed description of basic networking technologies.

Chapter 4 highlights the key characteristics in the design of a CIT system. These characteristics have been applied to the CIT systems developed throughout this project, indicating the features that effect implementation and determine the type of instrumentation and DAQ equipment needed to satisfy the test requirements. Test characteristics along a detailed description of the data acquisition hardware and application software used in conjunction with the various CIT system implementations have been discussed. The 3 CIT systems have been examined in more detail in chapter 5 concentrating mainly on the implementation throughout the duration of this research project.

The last chapter refers to the techniques and broad range of software packages available for data analysis. It is important that this area be examined thoroughly as data management relates to the process of making the acquired data useful. The characteristics of experimental data have been examined along with the methods of presenting data. The various types of data analysis and presentation software programs have been described and compared in terms of initial cost, cost to modify, cost of support, cost of subsequent copies, risk of obsolescence, speed, customer acceptance, etc. The primary data analysis techniques have also been examined before presenting a range of software data acquisition and control templates developed throughout the project duration. A practical example of how Excel and Visual Basic was used for data analysis and presentation purposes in conjunction with the applications trailer and truck CIT system is also included. Finally the area of data presentation is covered along with data storage and retrieval before finishing with potential use and benefits that could be achieved with the integration of Internet/Intranet technology and the CIT systems.

Today CIT technology offers enormous varieties of data acquisition (DAQ) hardware, application and analysis software, communication and instrumentation options. A strong strategic plan must be drawn up to cover all areas of CIT implementation keeping in mind any future requirements that may arise. There has been an extensive amount of research completed on the topic of CIT but further research was required due to the new technologies advancing in today's industrial sectors.

Overall the research conducted throughout the duration of this project represents the vision of successfully integrating computer resources with man and machine in an attempt to automate and manage not only the testing function but all company activities. This leads to the cost effective, reliable, efficient production of products through an automated organisation. This research may be used throughout the development of a CIT environment. It details the elements that make up a CIT system and highlights the important factors for the successful use and management of CIT environments. Three examples of CIT system implementation within the transport refrigeration industry have been presented concentrating primarily on computer/instrumentation integration, data acquisition hardware and software set-ups and data management.

CHAPTER 1 INDUSTRIAL TESTING

1.1 Introduction

In this chapter an explanation of computer integrated testing (CIT) is presented. As the whole area of computer integrated testing comes from the computer integrated manufacturing philosophy a brief description of this topic is required. The need for test and the importance of developing a strong planning strategy are discussed. Testing in industrial environments along with the types of tests that are carried out have also been examined. Next CIT is explored by describing the architecture on which it is based. Disadvantages associated with out-dated test systems have been identified along with key issues related to the success of CIT systems. To sum up manual, automatic and CIT systems are compared illustrating throughput optimisation and minimised system idle time before highlighting the benefits associated with the introduction of CIT.

1.2 Computer Integrated Manufacturing

For the past 10 to 15 years the manufacturing function has been involved in the integration of electronic and computer technology, which began with the development of the microprocessor. This has come about due to the development and growth of sophisticated electronic and computer systems. In recent years manufacturers have installed "computers in virtually all types of materials handling and processing equipment and the move is now towards more fully automated factories and service systems" [6] (J. Monks. 1987). Joe Harrington originated the term 'computer integrated manufacturing (CIM) in America in 1973. The basic understanding of CIM "is that it conveys the concept of a semi or totally automated factory in which all processes leading to the manufacture of the product are integrated and controlled by computer"[7] (Allen Buckroyd, 1989). It involves the "integration of all manufacturing activities through the use of linked computer aids and a shared database" [8] (Chris McMahon, Jimmie Browne, 1998). The CIM philosophy incorporates such topics as computer-aided design (CAD), computer-aided process planning (CAPP), production planning and control (PP&C), computer aided quality control (CAQ), computer aided manufacturing (CAM) and computer integrated testing (CIT). CIM concentrates mainly on the planning and controlling of the data flow, data processing and data distribution in the plant and the CIM tools used include, models, algorithms, artificial intelligence methods, software engineering aids, computers, data communication systems, data acquisition systems along with analysis and presentation software tools. "The ideal situation for computer integrated manufacturing operations is the creation and design of new products on a computer, the conversion of those designs into operation instructions, and the actual production using the instructions" [9] (Muhlemann, Oakland & Lockyer, 1992).

1.3 The Need for Testing

"Most testing should in principle be unnecessary, since testing is performed primarily to confirm that the design works as intended, or to show up what features need to be changed in order to make it work" [10] (Patrick O'Connor, 1994). Errors in testing may occur and can be divided into two types such as:

- Type I error Accept a bad product
- Type II error Reject a good product

Proving that a product is good means that the function of the product must be verified. The product is tested e.g. to verify that the amplifier will amplify, that the transmitter will transmit, etc. If a normal domestic appliance is purchased the question may be asked, does it function as it is supposed to function? The consumer may wish to measure the performance, or degree of goodness, but this is not normally done due to lack of skill, lack of equipment, or because the user is confident that someone has done the checking for them in the factory. Therefore it is the responsibility of the test engineer in the factory, to measure the goodness of the product for the customer, thus it can be regarded as part of the specification of the product that having designed and manufactured it, we should also test it.

The cost of testing must be considered. Quality can be defined as "fitness for purpose with value for money" [11] (Allen Buckroyd, 1989). Therefore it is necessary to carry out only as much testing as required at optimal cost. Figure 1.1 demonstrates how the cost of a product can increase with each additional test stage. The figure shows the number of tests that can be carried out on a product such as component testing, integrated circuit testing, unit testing, process testing, system testing and field testing against the relative cost added to the product.

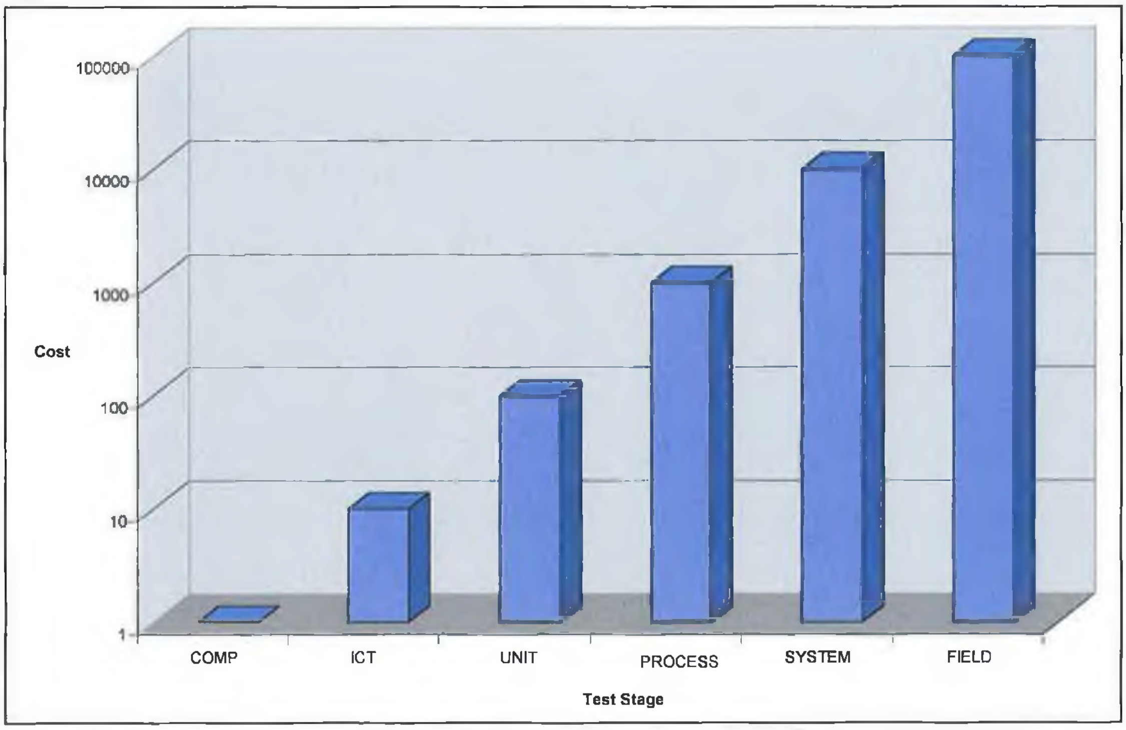

Figure 1.1 Cost of Test Increases Vs. Each Additional Test Stage

Proving that the product is not bad means that when it enters test, the product is likely to be faulty, therefore the test should include more stages with the objective of finding certain expected faults as soon as possible in the manufacturing process. This is necessary due to the cost increase for each successive test stage as illustrated in figure 1.1. The test should begin with a list of expected faults, that maybe available from similar company ventures or historical data. An important factor that should now be defined is the definition of a fault. Faults may not be easily categorised but usually fall into two categories:

- Catastrophic faults which will result in inoperable products.
- Marginal faults, which do not prevent operation, but impair performance to a greater or lesser degree.

These fault classifications are acceptable in general terms but they do not provide detailed information on the type of fault, therefore it is necessary to break them down into more useful and identifiable classifications such as:

- Dead or alive faults
- Reliability or time related faults
- Voltage or current induced faults
- Process related faults
- Shock or vibration induced faults
- Design faults
- Operator faults
- Packaging faults

Product design has a great effect on faults that appear in equipment, e.g. amplifier, which fails to attain the required gain. Reliability is another fault associated with design but maybe be awkward to identify, e.g. the choice of a weak component can cause early failure in the field rather then in the factory. Therefore the designer must take the responsibility to thoroughly inspect the design in order to expel as many errors and weaknesses as possible.

The test engineer must next decide on various other matters such as:

- How will the strategy be carried out?
- How long will the test development take?
- How long will the tests take?
- What skills will be necessary?
- What training will be necessary?
- How much will it cost?
- What management decisions will be required to carry out the strategy?

Jeffry A. Schutt (1998) [12] of Trace Labs has laid down some interesting rules related to a common sense approach to good testing. His suggested a test planning process, which is outlined below.

- Know and understand test objective
- Know and understand test procedures and requirements
- Know what data must be recorded
- Know pass/fail criteria, or expected results, if possible
- Know equipment to be used, i.e., availability, resolution, accuracy, range, capacity, calibration, etc.
- Know personnel requirements, i.e. training, competency, experience, etc.
- Take all necessary safety precautions
- Consider test tailoring, if practical and allowed
- Consider cost
- Schedule
- Expect the unexpected, have contingency plans if possible, be flexible, be prepared to adjust course based on results of testing.

These are excellent guidelines for the building of a strong test strategy and if used should provide a basis for the development of an efficient, reliable and cost effective test plan. Many problems that occur with test systems can be associated with the lack of vision and a poorly planned test strategy that results from ignoring several aspects of the planning strategies similar to those put forward by Jeffry A. Schutt.

Computer integrated testing (CIT) is more often associated with automatic testing than with manual testing hence it is necessary to explore briefly the ins and outs of automatic testing. The main difference of automatic test over manual test is that the control and pass/fail decisions are carried out using a controller, sequencer or computer. In its simplest form automatic test equipment (ATE) consists of an interface a controller containing some kind of program, which is connected to various measurement instruments. The program then sequences through a set of commands resulting in a response at the interface. These responses are interpreted by the measurement instruments, and passed back to the controller.

1.4 The Importance of Experimental Testing in Science and Engineering

Engineers and scientists give a large portion of their time to experimental work. The reasons for experimental work lies on the fact that scientific and technical advances rely primarily on the support that a critical test/experiment or series of tests/experiments, can give. Other reasons for experiments may be required to thoroughly test theories, validity and reliability. Adding to this carefully performed test may reveal new effects that require existing explanations to be modified.

Difficulties often occur in doing experiments, some experimental techniques take time to master and sometimes the experimenter is faced with a mass of data that requires careful examination before being able to draw out the important features.

Stages of a typical test/experiment are:

- The Aim – this is the starting point of a test, what do we want to find out? The clearer and more defined the aim the easier it gets to accomplish the planning to achieve that aim.

- The Plan – once the aim has been set out, a plan must be devised to achieve the aim. The type of equipment that is required is decided upon along with the quantities that need to be measured and the manner by which they are to be measured.

- Preparation – this stage involves the organisation of the test. The equipment selected is gathered and assembled.

- Preliminary Experimentation – experimentation is performed to ensure that the equipment works correctly. This stage is also important so as to promote familiarity with the operator of the equipment; indicating which features work well and which need further development. It also gives the operator a feel for the values to expect.

- Collecting Data – the data collection (acquisition) can now begin. Whether the data is collected by manually writing down readings form instruments or by recording data with the use of a sophisticated data acquisition (DAQ) system, it is important that the correct data be recorded, reducing the amount of time being wasted.

- Repeatability – here tests can be carefully repeated to verify whether the first set of data is representative and can be reproduced one or more times. Even though the repeated results will not be exactly the same, it helps to identify gross variations between sets of data, thus requiring investigation.

- Analysis of Data – this is the stage where we ask, what does this data tell us? If the test is performed with some hypothesis in mind, then this will indicate what data analysis methods should be adopted.

- What does the Data tell the Operator? – It is now time to decide whether the data is consistent with initial hypothesis or whether the evidence is inconclusive or even contradictory.

Reporting on the Test/Experiment – the finding should next be communicated in a clear and concise way. A report being prepared to describe the important features of the test such as the aim, method, data, analysis and conclusions.

1.5 Testing in Industrial Environments

In many factories, testing may not exist. However in industries such as electronics, testing is a fundamental part of the company activity. This gives "the supplier the opportunity to increase the likely-hood that his products will perform as specified in the design" [13] (Foston, Smith, Au, 1991). The design should be proven at the prototype stages. Tasks such as testing of software, verification of components, proving the manufacturing process and final test of the product itself are all essential parts of a companies responsibility. The first thing that must be done before a company considers integrating the testing activity with any other activity is to clearly identify why the actual testing has to be performed. Testing does not add any value to the product, but it should increase customer confidence. In general testing can be regarded as a necessary stage, which could only be eliminated if we could perfect our design and manufacturing processes. But in the real world this is next to impossible and manufacturers must accept the need for test at several stages, from the origin of design, through the various processing stages, to commissioning the final product. When the reasons for test have been established the need to address all the factors, which are affected by integration must be considered

1.6 Test Conditions

Most engineering products are required to operate inside a range of environmental conditions, which may include vibration, shock, temperature changes, corrosive atmospheres, electrical conditions, etc. Environmental conditions can influence performance, durability, and reliability so their effects should be included in the testing program. Environmental effects can be interactive, e.g. the combination of several conditions resulting in more severe results than any one effect on its own. The human aspect must also be taken into account. People working in production, packing, shipping, operations, maintenance and service all have an influence on the quality and life of the product.

1.7 Types of Test

Even with the use of modern automated equipment it is still impossible for a manufacturer to guarantee that every unit produced will be perfect. Some units will not work because they contain individual components that are faulty, or maybe because they were assembled incorrectly or due to damage caused in handling. Manufacturers prefer to discover these problems in the factory rather then get a bad reputation with their customers and that is one of the main reasons for testing. Testing is performed in all areas, from the initial design of a product through, prototype stages, purchasing of material and components, production processes to the final testing before the product is shipped. There is an endless amount of the various types of tests that can be carried out. This thesis will concentrate mainly on the aspects of CIT rather than actual test types for this reason only some test types have been described below.

1.7.1 Accelerated Testing

Testing under normal operating conditions requires a very long time, possibly even years, which makes testing under normal conditions very costly and impractical. This has resulted in the development of accelerated testing. This testing type has been described as a process "where units are subjected to a more severe environment than the normal operating environment so that failures can be induced in a short amount of test time" [14] (E. Elsayed, A. Chen, 1998). Then information about the reliability of the units under normal operating conditions can then be made. The accuracy of this procedure has a major effect on reliability estimates and decisions regarding warranties and preventive maintenance schedules.

"One important aspect of Accelerated Testing is the step by step strategy that can help obtain accurate and rapid initial information as results of product testing for reliability problem solving" [15] (Lev M. Klyatis, 1999). Normal industrial practice for accelerated testing results in information that is often inaccurate for solving reliability problems, highlighting that inaccurate development and implementation of accelerated testing techniques is one of today's problems. One major reason for this is the lack or absence of contact between accelerated testing and the field. However useful information can still be obtained for solving different reliability problems. "Successful accelerated testing relies on ensuring that all parties involved have reasonable expectations of what this product development tool can/cannot do just as mush as on good laboratory procedures" [16] (Hank Caruso, Abhijit Dasgupta, 1998).

1.7.2 Simulation Testing

This testing method is becoming increasing more popular. It involves the use of computer simulations of designs to test the performance. These computer simulations are widely used for the testing of analogue and digital electronic designs. Software based on finite element analysis can be used to determine distributions of mechanical stress, simulate behaviour under stress or vibration and determine temperature and electromagnetic field distributions. Two and three dimensional drawing software packages can be used to analyse designs for ease of assembly, conflict of moving parts, tolerances and accessibility. These types of testing techniques are much less expensive then making test hardware, and testing can begin at the design function. Normally simulation testing is only feasible if the design has been created on a computer but it is possible to transfer design details from paper to a computer for analysis. Many computer aided engineering (CAE) systems allow linking of the design to the appropriate analysis software.

1.7.3 Process Testing

Process testing is an imperative part of the test program for any product that is to be manufactured in quantity. Today's competitive world dictates the cost of a product and the more costly the processes used to produce the product the more costly the product becomes. The cost of manufacturing processes depends on the number and difficulty of the processes along with the cost of the production facilities. Facility costs include jigs, automation, and test equipment and they depend on the product and quantity produced. In most cases the larger the quantity to be produced the more effort and resources required to minimise the marginal costs of the production by the use of capital facilities. When producing new products, process problems occur and the only way of avoiding them during manufacturing is to test the production process during the development stage so as to improved them before production begins.

1.7.4 Component & Sub-Assembly Testing

For a product that consists of several sub-assemblies, it is necessary to consider testing at different levels of assembly. The testing of lower level components and assemblies is less expensive and can be carried out much easier. They prove more effective in exploring the limitations of the designs than testing the complete system. Most systems are made up of components and sub-assemblies that range from simple to complex. Complex items must be given priority because they represent the greatest risk. When items are purchased from external suppliers it must be ensured that the tests applied are adequate. This can be done by reviewing the suppliers test program or by conducting separate tests. Component and sub-assembly testing provides assurance that the products concerned can operate under the test conditions applied.

1.7.5 Software Testing

Software does not degrade or change in the ways that hardware products do. If a software program works once in a particular combination of circumstances it will always do so. The opposite is also true, if it fails once in a particular combination of circumstances it will always do so. For this reason software testing is not concerned with testing over time, but more so with testing to cover all possible situations in which errors in the program could cause the system to fail.

All tests performed should be carefully recorded, including test conditions and results. If errors are detected, they should be recorded, corrected and then re-tested. The test record is the only evidence that the software will work correctly under the test conditions specified.

1.8 Computer Integrated Testing

Computer integrated testing (CIT) is one of the fundamental sections of the computer integrated manufacturing philosophy. The CIT architecture is primarily based on a modular system comprised of configurable instruments controlled by a general-purpose computer. Special software tools, a windowing approach to software development and networking capability are also important elements of CIT. Similarly Internet technology can be useful in obtaining real-time data over the Internet or an in-house intranet using a standard browser, an Ethernet connection or modem. An essential part of CIT is the availability of data to personnel and the ease to which this data can be located. CIT offers the advantage of data integrity and data accuracy, and with the scope of Internet technology, data can be retrieved from anywhere regardless of when a test was completed. Another important consideration is data management, which refers to the analysis and presentation of data. This should be completed as quickly and accurately as possible to promote speed in analysis of results. CIT promotes the use of automatic analysis procedures along with instant or real-time analysis and presentation so as instantaneous results can also be achieved.

In the past testing was accomplished using single purpose, dedicated, unsupportable test units, which were developed as an after thought to the manufacturing process. The typical test system of the 1980's were usually developed by engineers and used by their technicians. These systems were adopted into the production test environment and soon customers started purchasing copies of the development test sub-systems for long-term maintenance and the testing of their products. In some areas these systems many still be operating adequately but their disadvantages are becoming more evident as competition for more sophisticated and reliable products grow. Some typical disadvantages include:

- Many systems use mechanical-based instruments, which require regular calibration.
- Usually controlled by out-date control systems with limited capability.
- Data typically recorded on paper fed chart recorders.
- Do not offer integrated computer system for control and monitoring.
- Cannot take advantage of the benefits that today's software technology offers.

- Data has to be transferred to computer for further analysis.

Today there is a high emphasis on adaptability and manageability, adaptability being the key to test automation. Adaptability in CIT means that the test system is not only set-up with the ability to test several versions of a component or product, but also to have the ability to alter it in functional capabilities to acquire other test results or to be used in other test environments. Manageability on the other hand refers to the total system throughput, scheduling and the need for training and support.

"Computer integrated testing capitalises on automation, and can be regarded as a systems-level approach to managing large volumes and a broad range of testing, with cost and schedule being among priority factors" [17] (Robert E. O'Connor, 1991). This statement is true, but CIT involves much more. It integrates equipment management, maintenance, data management, logistics, cost control, and personnel in a structured environment. A typical CIT facility can be operated in the same way as a manufacturing facility. The items scheduled for testing enter the test facility as raw materials. They proceed through the steps of preparation for test, diagnosis, repair, and final acceptance testing before being returned to service. CIT must also be responsible for monitoring test systems for availability, utilisation, calibration, maintenance, and efficiency for the purpose of attaining the benefits from the flexibility and versatility offered by test automation. All the subsystems of the computer integrated test facility must be monitored and controlled with data that is current and accurate. It was stated that "Engineers are quick to point out that the CIT environment is not appropriate for every test system" [18] (Robert E. O'Connor, 1991). It was suggested that CIT is best suited to managing a large testing facility, where there is a high volume of units under test, large numbers of test subsystems, stringent acceptance criteria, and a diverse staff of test technicians. This may have been true in the early 1990's, but due to the advancements of software capabilities, computer technology, and associated computer-based test equipment coupled with major price drops in the computer industry, CIT systems can now be cost effectively incorporated into smaller organisations. The CIT system implemented in its most basic form can still offer many advantages as described in the following sections

1.9 The Key to Successful Computer Integrated Testing

Successful CIT relies on the depth of the initial implementation analysis and the forward vision of the plan. For a successful CIT system:

- The test subsystems must be as generic and adaptable as possible. A test subsystem may be classified as generic if it uses all the same major components as every other test subsystem in the facility.
- Automation must be practical, but to the highest level possible. Here automation should be designed into test subsystems. To decide on the actual level of testing automation, a view of what is practical to automate and what makes good sense to leave manually operated is taken. The design of the subsystems must accommodate the dynamic characteristics of the units under test. Also the test equipment must be capable of adapting the variety of units under test by a number of simple software changes. System automation should also be considered and should permit automated, non-interfering, inquiry about the functional status of the test system. Information including availability of units under test, along with availability of the test system, and system operator should be accommodated.
- The subsystems should be interconnected with a local area network and tied to management workstations. The network is the link to provide the mechanism for transferring data regarding testing characteristics such as system loading, tester availability, units under test location and status, schedule requirements along with test criteria.
- Software for control of the entire system must be effective. CIT software should provide for data management, statistical analysis, instruction

presentation, test program creation and diagnostics. Extra software modules can be employed to customise applications.

- All hardware and software must be completely supportable.

1.10 Comparison of Manual, Automatic and CIT Test Systems

Figure 1.2 illustrates the main differences between conventional manual test systems, conventional automated test systems and CIT systems.

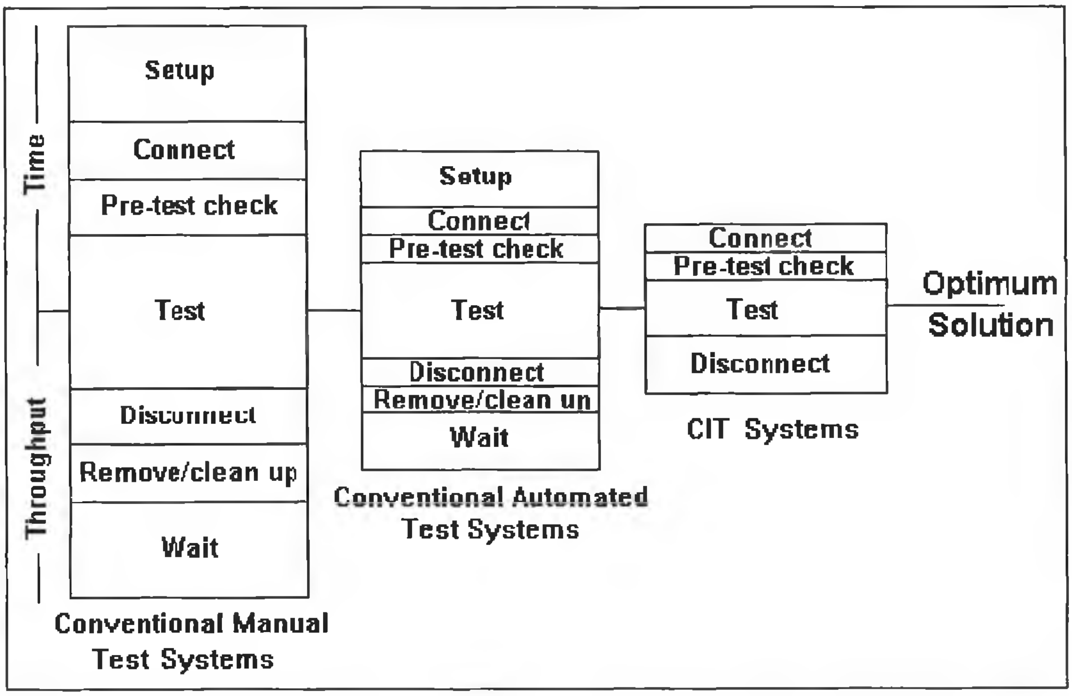

Figure 1.2 Comparison of Test Systems

From the figure it is visible that using a high level of automation maximises the systems throughput and eliminates test station idle time. Units are made ready for testing at the workstation, pre-test checks are carried out before they are placed in queue. Next they have to be transported to the central test station before being tested. They are then tested, disconnected and sent for shipping.

1.11 Benefits of Computer Integrated Testing

These are many including:

- Improved efficiency
- Faster throughput
- Enhanced quality

The use of a successful CIT systems can lead to a significant reduction in cost and development time for subassembly, inspection, functional test, final test and the design function. These CIT systems can also provide links into factory CIM systems. It involves the recording of results from several levels of system characteristics such as those put forward by 'Michael A. Thiemann (1986) [19]' in figure 1.3, which included the following:

- Test system hardware integration.
- Standard test system control.
- Test data analysis and documentation.
- Manufacturing integration (Networking).

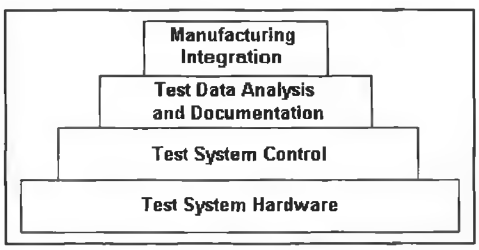

Figure 1.3 Levels of System Characteristics

He suggests that unless the test system achieves success in all these areas, it cannot be called computer integrated. Each level provided complex problems for the system manager, but many of these problems have been solved since the 1980's due to the ever-increasing progress in the development of better, faster, and more sophisticated test equipment. Also the advancement in computer technology has lead to a more easily integratable test systems. Data Acquisition Software is readily available today that can deal with almost any test environment.

CHAPTER 2 THE DATA ACQUISITION SYSTEM

2.1 Introduction

Data acquisition (DAQ) is an essential part of the overall CIT environment implementation and must therefore be discussed in detail. In its simplest form it can be described as a means or system of collecting data from an instrument or set of instruments. However as this chapter will show there are many more complicated issues that have to be dealt with.

As computers have become a major part of all business and technological functions, the area of computer based DAQ is an important area of research. Personal computers therefore have to be examined to identify specific component properties that enhance the area of DAQ. DAQ hardware is examined in detail identifying the different types of hardware available on the market today. Software, the driving force behind DAQ is an area that must be studied as there is a wide range of software options available from the simple instant results software (ThermoDAQ, IOtechs DaqVIEW and National Instruments Virtual Bench) to the more complex development packages (LabVIEW and Visual Basic). Instrumentation is a large area as there are many instruments that can be used in conjunction with a DAQ system, therefore in relation to this research project the instruments focused on are those directly related to this project. Communication devices are also discussed because of their importance in DAQ. In order for tests to be viewed from any PC in a company, or even from any computer in the world (Internet) the correct communication devices must be selected.

2.2 The Data Acquisition (DAQ) & Measurement System

"Data acquisition is the process of converting a physical phenomenon such as pressure or temperature into an electrical signal and measuring the signal in order to extract information" [20] (National Instruments Corporation, 2000).

DAQ systems differ, in that their make-up consists of a variety of different components. The overall make-up of the system depends on the requirements of the test engineer, which leads to DAQ systems being unique in there own right. Some systems may require the use of a host computer while others can operate quite successfully by stand-alone operation. PC dependent equipment relies on the intelligence of the PC and requires continuous connection to a PC for control, data transfer and set-up. Stand-alone units on the other hand, may eventually require the services of a PC for presentation purposes, but do not require connection for acquisition.

2.3 Types of Data Acquisition (DAQ)

There are several different types of DAQ systems, which are identified in table 2.1. Internal devices such as plug-in-boards are contained inside the PC and offer high acquisition speeds mainly due to the direct data-internal connections. The number of input channels offered on such boards are limited by the space available on the board, also the limited space at the rear panel the device can prove difficult to make the actual connections unless some type of fan out adapter or custom cables are used. Another common problem associated with plug in boards (figure 2.1) positioned inside the PC is electrical noise generated from components within the PC casing, leading to disturbances in measuring low-level signals.

External devices are essential due to the fact that portable PCs lack expansion slots, thus unable to accommodate plug-in-boards. These devices can be grouped by the type of PC communication ports they use, as done so in the table 2.1.

The DaqBoard/2000 plug-in board provides cost-effective, high-speed data acquisition for up to 470 I/O channels

Figure 2.1 PC Plug in Card/Board

Type	Medium	Feature
Internal Devices	Plug-in-boards	Fastest speed, non-portable, inconvenient installation
External Devices	Parallel Ports	Fast speed, portable, easy channel expansion & signal connection
	Serial port	Slow speed, portable easy signal connection
	PC Cards (PCMCIA)	Medium to fast speed, most portable, limited channels & signal connection
	USB Port	Slow to medium speed, portable, plug & play, easy signal connection
Stand-alone	Data loggers	Slow speed, portable, easy signal connection, no PC required
Interfaces	PC to IEEE 488, etc	Slow transfer speed, capabilities depend on specific instrument interfaced

Table 2.1 Data Acquisition Types

Stand-alone devices were around before the PC era, and can handle time-consuming data handling tasks without tying up the PC and are ideal for remote applications. Another approach to DAQ is to interface the PC to general-purpose measurement instruments using the IEEE-488 bus. This bus is available as a plug-in-board or as parallel or serial port adapters. IEEE-488 bus is the most common but some instruments communicate using others buses. These will be examined in more detail in section 2.6 (data acquisition hardware).

2.4 The Elements of the Data Acquisition (DAQ) System

In today's world most engineers and scientists use personal computers for DAQ in laboratory research, measurement and test, and industrial automation. Many applications use plug-in-boards to acquire data, and transfer it directly to computer memory, while others use DAQ hardware that is remote from the PC, but connected through parallel or serial ports. However to gain the best results from the PC based DAQ system, largely depends on each of the following system elements:

- The personal computer
- Hardware and hardware functionality
- Software and it's functionality
- Transducers (instrumentation)
- Communication devices

2.5 The Personal Computer

The personal computer (PC) can be defined as "A small, relatively inexpensive computer designed for an individual user" [21] (Internet.com Corporation, 2000). In price PCs can range anywhere from a few hundred Euro to over six thousand Euro. They are based on the microprocessor technology that enables manufacturers to put an entire CPU on one chip. Businesses use PCs for tasks such as word processing, accounting, desktop publishing and for running spreadsheet and database applications.

The type of computer used for DAQ systems can have a major effect on the maximum speed at which it is possible to acquire data. The introduction of PCMCIA (personal computer memory card international association), an industry group organised in 1989 to promote standards for a credit card size memory or I/O device. This device fits into a personal computer, usually a laptop and has lead to significant advances in the area of DAQ. The PCMCIA 2.1 standard was published in 1993 and as a result PC users were sure of standard attachments for any peripheral devices that followed the standard. This is now known as the PC card. A common example of a PC card is the 28.8 Kbps modem for laptop computers. Typical I/O devices include hard disks, keyboards, printers and the mouse. “An I/O describes any operation, program, or device that transfers data to or from a computer” [22] (TechTarget.com, Inc, 1999). The development of PCMCIA portable DAQ has rapidly become a more flexible option to desktop PC based DAQ systems.

For remote DAQ applications that use RS-232 or RS-485 serial communication, data throughput will usually be limited by the communication rates. Data transfer capabilities of the PC being used can greatly affect the performance of the DAQ system. All PCs are capable of programmed I/O and interrupt transfers. DMA (direct memory access) transfers that are not available on some computers, increases the system throughput by using dedicated hardware to transfer data into system memory. Using this method the processor is not burdened with moving data and is therefore free to take on more complex processing tasks.

Another factor that affects the PC performance is the hard disk, which may limit the system in acquiring large amounts of data. The maximum rate at which data is acquired and transferred to disk is governed by disk access time and the hard drive fragmentation. In cases where systems need to acquire high frequency signals, a high-speed hard drive should be selected to ensure enough free disk space to hold the data. Applications requiring real-time processing of high-frequency signals require a high-speed 32bit processor or a dedicated plug-in-processor such as a digital signal processing (DSP) board. If the application only acquires and scales a reading once or twice a second, a low-end PC is satisfactory. It must be mentioned that most windows environments offer the option of plug-and-play hardware configuration. "Plug and play referring to the ability of a computer system to automatically configure expansion boards and other devices" [23] (Internet.com Corporation, 2000).

2.6 Data Acquisition Hardware

Data acquisition hardware is an important element in the success of implementing a computer integrated test system. Modern microcomputer technology has simplified the process of installing, configuring and setting up high-performance DAQ systems. However the task of selecting the correct hardware for an application today requires a great deal of study, analysis and consideration. All systems will work, but some are better than others and offer different functions to suit wide varieties of applications. Some items that should be considered when selecting a suitable system include:

- Connection to the Internet or an Intranet. Real-time data can be obtained over the Internet or an in-house Intranet, by using a standard browser, an Ethernet connection or modem, and a PC.
- PC interface. PC's now perform everything from real-time control to high-speed DAQ. The major issue to consider is which PC bus architecture to use.
- Software support. Most DAQ hardware is compatible with most popular industrial software packages.

2.6.1 Selecting a System (Hardware)

It is possible to select a range of different products and configurations that will acquire and process data equally well. These include field-mounted devices such as DIN-rail signal conditioners or smart transmitters to plug-in-DAQ systems that can be installed in a PC. All these DAQ devices and systems have the same basic specifications and options available such as:

- Signal conditioning: signals from sensors have to be converted from its analogue form into a digital signal so as the host computer or controller can understand it. See chapter 3 section 3.2.3.
- Number of analogue input channels: Analogue inputs are usually specified as single-ended or differential input channels. Single-ended (SE) channels all reference to the same ground point where as the differential inputs (DE) have different reference points for each input, and therefore need two channels.
- Sampling rate: Sampling rates determines how fast an analogue signal is converted to digital format. A rule of thumb is to select a sampling rate that is twice as fast as is needed.
- Resolution: Resolution determines the smallest value change the system can detect. With most systems having 12- or 16-bit resolution, a 12-bit system resolves 1 part in 4,096, while a 16-bit system resolves 1 part in 65,536.
- Accuracy: Accuracy is a function of many variables in the system, including A/D non-linearity, amplifier non-linearity, gain and offset errors, drift, and noise.
- Analogue inputs: Typical voltage inputs include 0-1 V, 0-10 V, ±50 mV, ±100mV, ±0.5 V, ±5 V, and ±10 V. Other inputs include 0-20 mA, 4-20 mA, frequency, and resistance. Most of the process control measurement flow, temperature, pressure, and level fit one or more of these input ranges. Many DAQ products now have selectable or programmable analogue inputs that accept the signal, and send it to a 12-or 16-bit A/D converter.
- Analogue outputs: Analogue outputs are not normally part of the DAQ system, but must be mentioned because many DAQ suppliers offer analogue outputs on the same board and in almost all cases, a DAQ board has either 2 or 4 outputs.
- Digital I/O: Digital I/O can either be selected for input or output, However in

most circumstances, it may be possible to configure a DAQ board with digital inputs, outputs, or both in any combination.

2.6.2 Hardware Construction

The next question is 'How is the product built?' It must be remembered that accuracy is often dependent on the amount of noise picked up by the system. Most modern DAQ products minimise this problem in the following ways:

- Surface mount technology (SMT): Using SMT shortens the length of traces on circuit boards, which improves electrical noise resistance.
- ASICs: Application specific integrated circuits (ASICs) combine the functions of several components into one, which eliminate the connections between individual devices. This increases speed, improves accuracy and reduces exposure to noise.
- Reduced board size: This leads to a reduction in the size and number of traces, which in turn boosts speed and minimises noise.
- Isolated inputs: These protect the board from damage or disruption from any abnormal signals or noise.

2.6.3 Hardware Systems

As mentioned at the beginning of this chapter there are several different types of DAQ system, which determine the hardware to be used in an application. These can be divided as follows:

1. PC based DAQ hardware systems, which are made up of internal and external devices to acquire data. Internal devices are contained inside the PC in the form of

Plug-in-boards. External devices on the other hand are usually connected to a PC via a series of ports, such as parallel, serial and USB ports. PC cards must also be included.

2. Stand-alone hardware devices, these do not require the use of a PC to acquire data, but may need one for analysis and presentation procedures.

2.6.4 PC-Based Internal Data Acquisition

In the past, high-speed DAQ systems required expensive computer platforms. These systems were required to handle large amounts of real-time data and have enough computing power over to perform control and operator interface functions. Today's PC has the same amount of computing power as yesterday's high-end computer platforms. Trends today are geared towards plug-and-play systems that configure, install and calibrate themselves.

DAQ plug-in-boards/cards plug into the chassis of a desktop PC, a PC-compatible industrial computer, or an Apple Macintosh computer and have made control and measurement very economical. Basically signals from sensors or signal conditioners are wired to the PC and connected to the DAQ board/card. A typical plug-in DAQ board/card with 16 analogue input channels in the 1,000 to 2,000 Euro price range represents a cost of 62.50 to 125.00 Euro per measurement point as compared to 350 Euro or more per point for a conventional or communications-based system.

Many of the DAQ boards available today do not require periodic calibration. These Plug-in boards offer a great deal of software compatibility, virtually eliminating the need to write drivers or special software to interface them to a system. A typical plug-in DAQ board offers the following features:

- Analogue inputs: 8 DE or 16 SE
- Resolution: 12- or 16-bit
- Input range: mV and V
- Sampling rate: 30,000-330,000 samples/second
- Analogue outputs: 2
- Digital I/O: 8-16; and
- Base price: 200 to 1,200 Euro.

There are hundreds of DAQ board configurations available for PCs and Macs, many more are available with more inputs, higher resolution, and faster scanning speeds thus allowing for high-speed and high-accuracy DAQ

2.6.5 High-Speed Data Acquisition

Typically plug-in DAQ boards have a sampling rate of 30,000 to 250,000 samples/second. But with high-speed DAQ cards, sampling rates are 330,000 to 20 million samples/second and are used for such applications such as auto crash testing. At these speeds the DAQ board must be able to communicate with its computer via direct memory access (DMA), which allows for the transfer of large amounts of data directly to the computers memory. In most cases the board does not attempt to acquire 20 million samples every second because it would soon overflow the available memory. Boards are available that can acquire up to 500 million samples/sec for such applications as radar. The only sacrifice when using high-speed DAQ boards may be in accuracy and resolution.

2.6.6 High-Accuracy Data Acquisition

This is used where applications require greater accuracy and resolution. Higher resolution requires having an A/D converter with more bits. DAQ boards are available with resolution of 18 bits, 20bits and more, but at the higher resolution much smaller voltage changes can be identified. However to obtain maximum accuracy, speed must be sacrificed due to the fact that accurate A/D converters operate more slowly than low-precision devices. DAQ components require time to settle and convert to obtain the maximum accuracy.

2.6.7 Speciality Data Acquisition Boards

These may be used in cases where a special function is required and sometimes even standard boards may be modified to provide the required function such as high input isolation, timer interface etc. Some speciality boards may include thermocouple and RTD input and sensor direct connect for direct connection of field wiring from temperature sensors without additional external signal conditioning.

Other boards sometimes known as universal sensor input boards, in that they accept raw signals from thermocouples, RTD's, thermistors, strain gauges and linear variable displacement transducers (LVDT's) as well as resistance, variable reluctance, frequency and weight sensors. The PCI-20428W series include a variation of the most popular analogue and digital I/O functions. " Special function boards that perform either analogue input, output or digital I/O exclusively are available, as well as powerful multi-functional boards that combine these features in the most cost-effective way possible" [24] (Intelligent Instrumentation, 1998).

Digital I/O boards can provide from 40 to 240 channels of general-purpose digital I/O ports, for monitoring and controlling, relays, motors, switches, etc.
Sample and hold is available as an option on some DAQ boards. This function allows a number of channels to be sampled simultaneously while allowing the A/D converter to be shared among multiple channels.

2.6.8 Bus Architecture Options

Before the examination of bus architecture options it is necessary to understand what a bus is, it can be defined as "The group of conductors that interconnect individual circuitry in a computer" [25] (National Instruments, 2000). Typically a bus can be regarded as the vehicle to which I/O or other devices are connected.

Plug in DAQ cards are designed for 2 types of computers, PC's and compatibles and Apple Macintosh. Between these there are several types of bus architecture available and the selection of the correct one is important. Table 2.2 shows a list of the various buses available.

Bus acronym	Bus definition	Number of bits	Max speed MBPS
ISA	Industry standard architecture	8, 16	1.6
EISA	Extended ISA	8, 16, 32	33
MCA	Micro channel architecture	16,32	33
VESA	Video electronics standards association	32	132
PCMCIA	Personal computer memory card international association	8, 16, 32	132
PCI	Peripheral component interconnect	32, 64	132, 1056
PC/104	(ISA in a smaller, more rugged form factor)		132
USB	Universal serial bus	32	12
NuBus	(Macintosh bus)	32	33
PDS	Processor direct slot (Macintosh bus)	32	132

Table 2.2 Various Buses Available Today

ISA was the first industry standard architecture bus introduced in 1980. It can address 8 and 16 bit devices, and have DMA capability.

EISA (extended ISA) is a progression of ISA, with added support for intelligent bus master expansion cards, which is important because, if the DAQ board cannot take control as a bus master, it may not be able to transfer data any faster than an ordinary

ISA board. "EISA introduces the following improvements over ISA" [26] (Shanley, Anderson, 1995).

- Supports intelligent bus master expansion cards.
- Improved Bus arbitration and transfer rates.
- Facilitates 8, 16 or 32 bit data transfers.
- Automatic configuration of the system board and EISA expansion cards.
- Automatic steering of data during bus cycle between EISA and ISA masters and slaves.

MCA (micro channel architecture is a feature of IBM's PS/2 computer and few plug in DAQ boards are available for this system.

VESA (video electronics standards association) was developed to maximise throughput for video graphics.

PCMCIA (PC memory card international association) developed this interface for small computers such as laptops, and today almost all-portable PC's have PCMCIA slots. "Initially, its primary focus was defining PC Card standards for IBM PC compatible systems, the long term goal is to allow a variety of computer types and new computer products to freely interchange PC cards" [27] (D. Anderson, 1995).

PCI (peripheral component interconnect) this bus is a processor independent bus that supports up to 64-bit addressing, bus mastering, and burst transfer rates up to 1,056Mbps. This standard is still evolving and virtually every Pentium PC being shipped today has a combination of ISA/PCI or EISA/PCI buses.

PC/104 are intended for embedded computer applications, these cards are very small. They allow card modules to self-stack without backplanes or card cages and has pin-and-socket bus connectors designed for high reliability in harsh environments.

USB (Universal Serial Bus) is currently being offered in most commercial PC's. It's essentially an upgrade of the RS-232 port and will allow up to 127 USB devices to connect to a PC. The first full-featured PC based DAQ system to fully utilise the USB is the Personal Daq from IOtech. "USB, which is now being built into almost every new PC, provides both the high-speed communication and power to the Personal Daq which permits a simple, single-cable connection to the PC, with no battery of power cables required" [28] (Scensys Scientific & Engineering Systems Ltd., 1999)

Buses for apple computers are not as complicated as PC buses. Until recently apple buses were based on two architectures. NuBus and PDS (processor direct slot) both are 32 bits wide, the NuBus can be found in almost every Macintosh while PDS provides very high-speed communications. When considering plug-in-DAQ boards for either PC or Mac computers, it must be noted that computer processing hardware and DAQ boards are capable of handling any DAQ job imaginable.

2.6.9 PC-Based External Data Acquisition

"Until recently, plug-in-boards have been the dominant type of hardware for PC-based data acquisition" [29] (Adept Scientific, 1997). Recent developments in the area of DAQ has focused on external boxes, which plug into the external parallel, serial or PCMCIA port of the PC. These boxes are much easier to install on a laptop or desktop computer. Another advantage is their portability, which makes them ideal for the area of field-testing.

2.6.10 Stand-alone Components

Stand-alone DAQ systems collect data and send it to a processor over a data communication scheme. The major advantage of these communication-based systems is that they do not require the use of a processor. Stand-alone DAQ hardware can transmit its data to a PC, PLC, RISC workstation, mainframe computer, or the Internet. Unlike plug-in-DAQ systems these stand-alone systems can be located anywhere on the plant floor. When a DAQ system becomes very large, it tends to take up more processor time for DMA, slowing down powerful processors. In the case of stand-alone systems these problems do not exist and the DAQ can grow to be as large as necessary.

These systems are portable and operate with industry standard communications. "Stand-alone systems have more capability and flexibility and have been around for at least 35 years, since the first supervisory control and data acquisition systems of the 1960's" [30] (Omega Engineering, 1998). These stand-alone devices included chart recorders and other devices that generated real-time paper printouts and could handle time-consuming data gathering tasks. "Traditionally, stand-alone systems were slow and expensive, their speed was limited by the prohibitively high-cost of the onboard memory required for high-speed measurement. They were expensive because they included display and control panels that added to their cost" [31] (Fred Schraff, 1998).

Nowadays there is a new range of stand-alone devices. These that take advantage of lower price PC technology and are capable of operating without the presence of a PC. These systems offer independent operation, high-speed and large memory capacity. They are configured using a PC and a software interface. The PC also transfers instructions to the device via a temporary serial/parallel connection or a low cost PC card.

When setting up a stand-alone system the major question to be answered is 'How will the field I/O be connected?' the answer is in one of the following three ways.

1. DIN rail systems - Using the DIN-rail system, which is an easy way of connecting

sensor field wiring to signal conditioners, converters, power supplies, terminal blocks, modems, relays, and other devices to the field. This rail is either 32 or 35mm wide and provides a platform to which many devices can be mounted.

2. Rack-mounted systems - The use of rack-mounted DAQ systems have been around for a long time and involves I/O modules, subsystems and processors being installed in a standard 19 inch rack housed in a NEMA free standing or wall mounted enclosure. The subsystems usually mount horizontally across the enclosure, while I/O boards and processor cards mount vertically in the card chassis. This system can accommodate PLC I/O, data logging, remote I/O for computer field networks and just about every type of front-end or I/O on the market today.

3. Field-mounted systems - Traditionally mV sensor signals have been wired to a transmitter or transducer that converts the signal into a higher voltage or a 4-20mA current loop signal that is less susceptible to electrical interference. This technique is still widely used today but it is not possible to connect sensors to DAQ systems or computers via a digital signal. Field mounted devices such as transmitters and I/O devices have become very powerful digital devices and can be mounted at or near the sensor location and perform a wide variety of signal conditioning and processing functions locally.

Other elements of the stand-alone system that are worth mentioning include the following:

- Alarm modules are not used as much due to the availability of computer processors at all levels of a DAQ system, but when independent local alarm indication is needed they are ideal. These modules have one or more relay outputs for sounding audible alarms or illuminating a panel warning.
- Remote I/O's are used by many PLC's and computer-based control systems to

collect data in a far off location, from a work cell where sensors are concentrated, or from various locations in a plant. The remote I/O system serves, as a data concentrator minimising the amount of physical cabling required to directly connect each field I/O point.

2.7 CIT/ Data Acquisition Software

Software is a general term for computer programs as opposed to hardware, the physical components of the computer system. "Software products fall into two broad classes" [32] (I. Sommerville, 1996).

- Generic products – These are stand-alone systems, which are produced by a software developer and sold on the open market.
- Customised products – which are systems commissioned by a particular customer.

Software transforms the PC and DAQ hardware into a complete DAQ analysis, and display system. Without software the best DAQ hardware is useless, and DAQ hardware with poor software is almost useless.

2.7.1 Driver Software

The majority of DAQ applications use driver software. This software is directs programs the registers of the DAQ hardware. It manages its operation and its integration with the computer resources, such as processor interrupts, DMA, and memory. Driver software hides the low-level, complicated details of hardware programming, providing the user with an easy-to-understand interface.

Driver functions for controlling DAQ hardware can be grouped into analogue I/O, digital I/O, and timing I/O. It is important to make sure the driver has the functionality too:

- Acquire data at specified sampling rates
- Acquire data in the background while processing in the foreground
- Use programmed I/O, interrupts, and DMA to transfer data
- Stream data to and from disk
- Perform several functions simultaneously
- Integrate more than one DAQ board
- Integrate seamlessly with signal conditioning equipment

These among other function of the DAQ driver leads to a considerable amount of time being saved. It is very important that the driver software is compatible with the operating system being currently used and any system that may be used in the future, in order to capitalise on different features and capabilities of the operating system.

2.7.2 Application Software

This software is an additional way to program DAQ hardware. The software will also use driver software to control the DAQ hardware. The primary function of application software is to add analysis and presentation capabilities and also integrate instrument control with DAQ.

There are many DAQ equipment suppliers with endless amounts of hardware and software options to offer to the developer for almost any application imaginable, which makes it difficult to select the most adequate equipment for the application. Other options are available such as having software developed specifically for your application. The advantages to this is that not only is the software capable of carrying out exactly what is required, but room can be left for developing the package for future applications, the disadvantage being that this can be very expensive. There are many software developers producing DAQ application software some of which can be seen from table 2.3.

Company	**Software Name**
National Instruments	LAB VIEW
IOtech	DASYLab
Biodata Ltd.	Streamer & Windmill software
DataQ INST	WinDAQ
Astro-Med Inc.	Astro-link software
Intelligent Instrumentation	Visual Designer
Nicolet	Omnic software
Adept Scientific	Workbench
D-star Instruments Inc	Star-Chrom

Table 2.3 Software Developers & Packages

2.7.3 Software Selection

In the selection of a software package for application and control of the DAQ hardware, several factors must be taken into account. Firstly an understanding of the current and future application requirements and the types of tasks that may have to be performed is necessary. These may include verifying signal connections, logging and transferring data to disk, monitoring real-time data, controlling a test or process, performing mathematical manipulation, analysing the acquired data, generating reports or graphical representations and designing turnkey applications that can be used by lesser-skilled operators.

When the user knows the application requires, they can evaluate the software packages available. IOtech have suggested that “it is possible to group most windows-based software packages under one of 3 categories” as described below. [33] (Steve Lekas, 1996). He suggests that by understanding the differences between the three categories, allows the user to select a specific software package that performs the tasks and delivers the results that the application requires.

1. Software that provides instant results for dedicated functions such as data logging and display. Regardless of the complexity of the application, instant result software allows for the verification of signal connections and the viewing of the data being acquired. Many DAQ system suppliers supply instant result type DAQ software free with their products, where others make it available as an option. With this type of software, the user can quickly and easily configure the hardware and establish acquisition parameters without writing any code. Some software packages may allow for the setting up of triggering, sampling rates, datalogging and direct to disk acquisition in a point and click environment, sometimes offering the capability to customise the data real-time display. Some examples of this instant result software that is available on the market today include IOtech’s DaqView, National instruments’ VirtualBench and Scientific Software’s VisualSCOPE. Another common feature is the ability for the software to collect the data, then import the data into a software package such as Microsoft’s Excel, METLAB by the math works, or DSP Development’s DADiSP for data analysis and reporting.

2. Icon-based point-and-click software for interactively developing more advanced custom test applications. This type of software package has a means of configuring the DAQ set-up and analysis without the need to program. Some examples of icon-based interactive software include DASYLab from DASYTEC and Snap-Master from HEM Data. Using any of these software packages it is possible to alter the application by connecting a few icons to collect, analyse and

report the data. These packages offer a variety of data display formats, mathematical and statistical analysis functions, and reporting formats to meet the demands of the dynamic test environment. They are very easy to learn. Icon based DAQ software doesn't require the user to write a program, alternatively it offers a point and click option to build on screen block diagrams using a series of functional icons. Most of these packages also have extensive configuration, importing, analysis, graphing, control and reporting capabilities. Data can be acquired from any source including portable or desktop PC DAQ systems, signal conditioning and expansion options along with IEEE-488 and RS-232/422 data instruments.

3. Comprehensive programming environments that provide flexibility for creating complex algorithms and custom operator interfaces. This type of package is selected in situations where users require unique DAQ and control capability, which only they can generate. After the application has been developed a turnkey application may be required to suit the non-technical operator. It allows for the development of applications with demanding system requirements, such as algorithms and graphical interfaces. These Graphical programming environments tend to be expensive because of the development time involved, and today the leading graphical programming environments are LabVIEW and Visual Basic.

   LabVIEW created by National Instruments enables the users with a programming background to create complex DAQ, analysis, control and displays. It is based on the generation of block diagrams and the selection of procedural icons from a specific icon library. These icons are connected on a virtual worksheet.

   Visual basic has revolutionised programming by allowing a simple easy to use programming architecture. Its simple syntax and development tools make it ideal for any application whether it is simple or complex. Visual Basic and LabVIEW will be dealt with in more detail in the proceeding chapters.

The question may now arise why buy a software package when I can purchase a graphical programming environment package and create my own executables, well the answer is, 'money' of course. Why spend a month developing a data logging, analysis and presentation program when there is already one available on the shelf at a fraction of the development cost.

2.8 Computer Based Instrumentation

"Computer based instrumentation is the right of choice to increase measurements throughput and lower the cost of making measurements" [34] (National Instruments, 1999). In considering cost the choice of instrumentation becomes increasingly important. In order to be competitive companies must invest in a set of technologies that lead to the building of faster products, improved quality and minimised expenditures. Therefore the faster a company can get the product tested the sooner it is available to be shipped to the consumer. Essentially the use of computer based instruments maximise the performance and lower costs of test. GPIB (general purpose interface bus) is the standard bus used for controlling electronic instruments with a computer it is also known as IEEE 488 bus. GPIB has set the standard for computer based instrumentation and still remains a top choice for engineers building automated test and measurement systems. But new PC technologies such as PCI, PXI and compact PCI are becoming more popular and offer faster throughput, lower costs and simplified multiple instrument synchronisation. For applications where test time is important computer based instruments including PXI, VXI modules and PC plug-in-boards gives the bottom line performance required for the automated test, measurement and DAQ system. Faster test throughput is accomplished by speeding up the transfer of data to the PC. Computer based instruments ensure the fasted data transfer possible. Benefits of using computer-based instruments over stand-alone instruments include:

- Increased test throughput - computer based instruments allow for faster set-up and data transfer times than with GPIB controlled instruments. Computer based instruments use high-speed PCI and compact PCI buses to improve measurement system throughput more than 20 times, when compared to the traditional stand-alone systems.

- Lower cost of ownership - they are less expensive to purchase and can be as low as half, that of comparable instruments. They also cost less to maintain and require less space than stand-alone instruments
- Simplified system Integration- computer based instruments are modular and very easily integrated to meet any unique test needs.

2.8.1 Transducers

Most measurement begin with a transducer, which "is a device that converts a measurable physical quantity, such as temperature, strain, or acceleration, to an electrical signal" [35] (IOtech, 1998). The most common transducers convert physical quantities such as voltage or resistance. These transducers are available in a wide range of measurements. Their features define many of the signal conditioning requirements of the DAQ system. They sense physical phenomena and provide electrical signals that the DAQ system can measure. Thermocouples, RTDs, thermistors, and IC sensors convert temperature into an analogue signal that an analogue-to-digital converter (ADC) can measure. Other sensors include strain gauges, flow transducers, and pressure transducers, which measure force, rate of flow, and pressure, respectively. In each of these cases the electrical signals produced are proportional to the physical parameters they are monitoring. Knowledge of transducer characteristics and operation parameters is essential to the developer of a CIT system. In this section it is necessary to deal with several sensor types that are directly related to the research program. For example temperature measuring devices, humidity sensors, pressure sensors, flow sensors and switching devices.

2.8.2 Temperature Measurement Sensors

A thermocouple is "a temperature measuring sensor that consists of two dissimilar metals joined together at one end called a junction that produces a small thermoelectric voltage when the junction is heated. The change in thermoelectric voltage is interpreted by thermocouple thermometers as a change in temperature occurs" [36] (Omega Engineering, 1998). These sensors provide an efficient and simple means of temperature measurement by generating a voltage that is a function of temperature.

How does it work?

All electrically conducting materials produce a thermal electromotive force (EMF), as a function of the temperature gradients within the material, this is called the seebeck effect. The amount of the seebeck effect depends on the chemical composition of the material used in the thermocouple. When two different materials are connected to create a TC, a voltage is generated. The voltage generated is the difference of the voltages created by the two materials. In principle a thermocouple can be made from almost any two metals, but in practice several thermocouple types have become standard because of there qualities, which consist of highly predictable output voltages and large voltage to temperature ratios. Common thermocouples include types J, K, T, S, R, N28, N14, E and B. In principle the temperature can be obtained from such a voltage by consulting standard tables or using linerisation algorithms. But in practice this voltage cannot be directly used, because the connection of the measuring device to the thermocouple wires generates the thermocouple to produce another thermal EMF that must be compensated for. For this reason cold junction compensation is used.

What is thermocouple linerisation?

Thermocouple voltage is proportional to, but not linearly proportional to the temperature at the thermocouple connection. There are several techniques for thermocouple linerisation, which include:

- Analogue techniques – which provides a voltage proportional to temperature from the thermocouple input. Also a voltage measurement can be made with an ADC and the temperature looked up in a table.
- It can also be accomplished using a polynomial approximation to the temperature versus voltage curve.

If care in the use of thermocouples in not taken it is possible that minor errors will give a highly inaccurate reading, so care of the following must be taken:

1. Thermocouple assembly - they are assembled in one of three ways, by twisting the wires together, by soldering the wires or by welding them and if done incorrectly will lead to inaccuracies.

    - Twisting the wires together is the most likely way that a thermocouple will produce large errors and where possible the junctions should not be formed in this way.
    - For measuring temperature, the junction can be soldered, but a soldered junction limits the maximum temperature that can be measured usually less then 200 degrees Celsius. This method introduces a third metal but should not create an error as long as both sides of the junction are at the same temperature.
    - Welding is the most preferred way but care must be taken to prevent any of the characteristics of the wires from changing as a result of the welding operation.

2. Decalibration - This is a serious fault condition and can result in temperature readings that appear correct. It occurs when the physical makeup of the wire is altered in a way that it no longer meets the NIST specifications (National Institute

of Standards & Technology). It may occur for a number of reasons such as, cold working of the metals, stresses placed on the cable during installation, temperature extremes, vibration or temperature gradients.

3. Insulation Resistance Failure - As the temperature increases the thermocouple insulation resistance will often decrease exponentially. This in turn can lead to two types of errors, leakage resistance with open thermocouple. This is where readings may be given inaccurately in high temperature applications because the insulation resistance can degrade to the point where the leakage resistance will complete the circuit. Secondly leakage resistance with small thermocouple wire, again in high temperature applications with small thermocouple wire the insulation can degrade to the point where a virtual junction is created.

2.8.3 Flow Measurement Devices

There are many different types of flow measurement devices available and the one chosen depends on the application requirements. The flow-measuring device, which was used through out the duration of this program is a product of Danfoss Instrumentation. It is called a massflo meter. This ‘Massflo’ flow meter is for the direct measurement of mass flowrate, total mass, density, temperature, volumetric flowrate or total volume. Typical application areas include:

- Measurement of flavour additives
- Control of valves for car engines
- Measurement of fuel consumption of engines
- Control of capacity of oil nozzles

A diagram of the flow-measuring unit can be seen from figure 2.2. Fuel flows from the source through a filter before entering the sensor on the bottom of the device. The fuel then passes into the unit. The sensor (mass flow meter type MASS 2100-DI 1.5mm figure 2.3) has an inside pipe diameter of 1.5mm and weighs approximately 2.6kg. It is made of stainless steel and has a mass flow measuring range of 0-65kg/h. It sends a signal back to the signal converter, which displays the value in user defined units. This Signal converter (MASS 3000) is equipped with 3 analogue outputs, 2 freq./pulse outputs and 2 relay outputs. It has two internal counters for the totalization of the total mass or total volume. It can be set-up to transfer the signal to a DAQ system for logging data by computer.

Figure 2.2 Flow Measuring System

Figure 2.3 Flow Meter Sensor

2.8.4 Pressure Measurement Devices

Pressure measuring instruments are used to measure either differential, absolute, gauge, level or flow measurements. There are several different types of transducer/transmitter available, which can be used to measure different pressure characteristics, some of which are as follows:

- Thin film and semi-conductor pressure transducers
- Unamplified output pressure transducers
- Amplified voltage output pressure transducers
- Current output pressure transmitters
- Level, depth and submersible pressure transducers
- Flush diaphragm pressure transducers
- High pressure transducers
- Differential pressure transducers

Some items to consider when using pressure transducers include:

Transducer outputs and their wiring configurations.

Most transducers have three main types of electrical outputs, millivolts (mV), volts (V), and current (mA). Transducers with the millivolt output are generally used for laboratory applications. They are small, relatively cheap and their low-level signals limit their range to about 2000 feet. They require a regulated power supply and are prone to electrical interference. Typical wiring configurations can be seen in figure 2.4.Transducers with an amplified voltage output are generally more suited in the light industrial environments. They usually have built in signal conditioning making them more expensive that the millivolt range. They are larger in size and signals can travel further with a better immunity to electrical interference. Typical wiring configuration can be seen in figure 2.5.

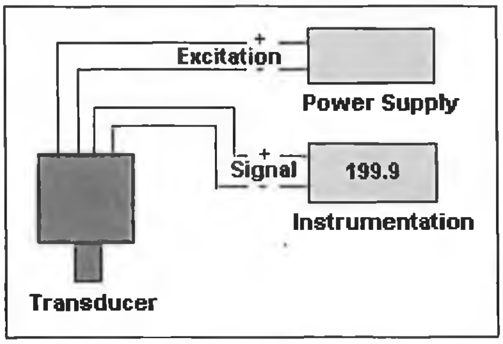

Figure 2.4 Wiring Configuration for mV Output Transducer

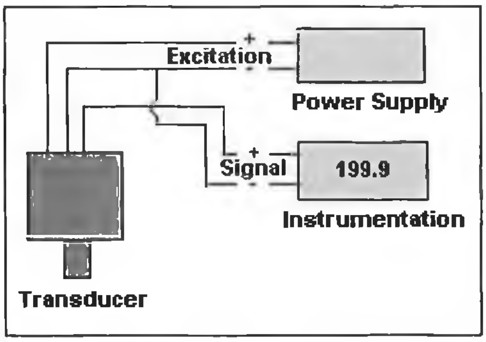

Figure 2.5 Wiring Configuration for V Output Transducer

Transducers with a current output are used in heavy industrial environments. They are larger and more costly then the millivolt and volt transducers, with the current signal being immune to stray electrical interference. The current signal can also be transmitted longer distances and are generally referred to as transmitters. Typical wiring configuration can be seen in figure 2.6.

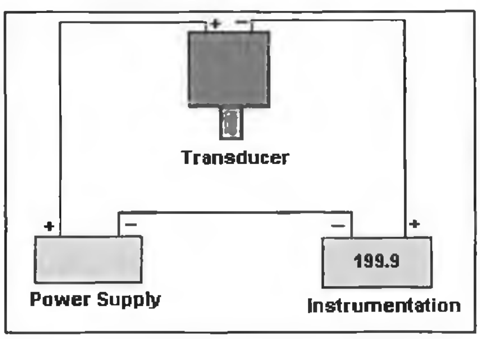

Figure 2.6 Typical Wiring Configuration for Current Output Transducer

Wiring one transducer to multiple readouts, recorders and computers.

One of the greatest advantages of a current signal is the setting up of a multi-instrument system. It allows for long distance transmission from instrument to instrument without electrical interference. Figure 2.7 is a typical example. Wiring a voltage signal to multiple instruments can be done (figure 2.8) but is more complicated. It can be wired in parallel to multiple instruments. This method assumes very high input impedance in the instruments being wired.

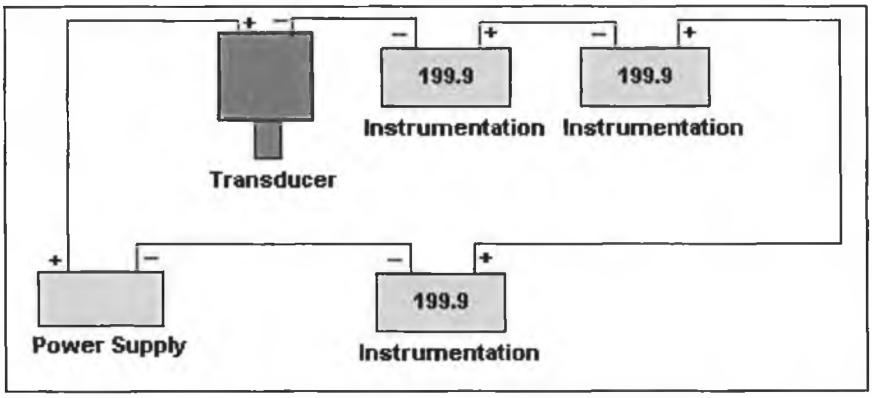

Figure 2.7 Multiple Instruments Current Loop

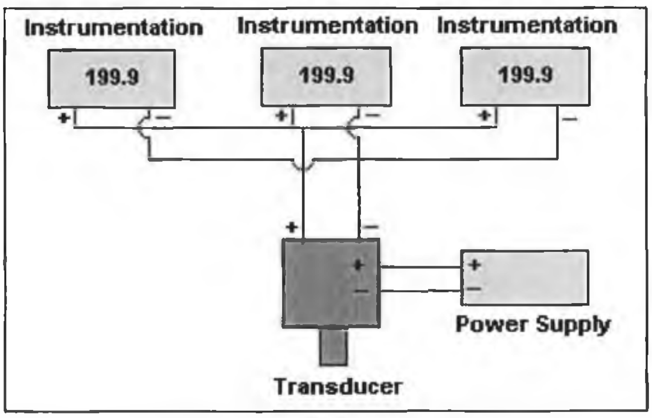

Figure 2.8 Multiple Instruments Wired in Parallel to a Voltage Output Transducer

Wiring multiple transducers to one recorder, computer, etc.

In the measurement of multiple pressures a switching device is required to switch between transducers, allowing each reading to be shown on the single recorder. Another way is to use a scanner instead of a meter and a switch. The scanner must have independent scaling on each channel. Some scanners offer independent current, voltage, or millivolt inputs to each channel allowing transducers with different outputs as well as different pressure ranges.

Using a milliamp signal with voltage input instrumentation.

In most cases instrumentation is set-up to receive voltage, and in order to use a current signal with instrumentation set-up for voltage a resistor is placed across the input terminals of the instrumentation. For example installing a 500ohm resister will convert 20mA to 10 volts using ohm's law.

Determining how many transducers can be excited from a power supply.

Multiple transducers can be excited from one power supply, the number of transducers is determined by the current draw of each transducer and the current capacity of the supply source.

The term's transducer and transmitter are often confused, the difference being that a transducer produces millivolts, amplified voltage, or current output, where as a transmitter produces current output only. The pressure transducers used in conjunction with this program are as follows.

- 3 of MBS7000 smart pressure transmitters- these were used in conjunction with the wind tunnel CIT test system, which is discussed in chapters 4, 5 and 6. They were used for measuring the pressure across the nozzles and for measuring the static pressure at the fan outlet.

- 1 Danfoss MBS 331221 pressure transmitter – is also used in conjunction with the wind tunnel for measuring the atmospheric pressure, this transducer has a range of 0-1.6bar/0-160kPa and an output of 4-20mA.

- 3 PTX510 pressure transducers (from Classic Technology)- used in conjunction with the applications testing system, discussed chapters 4, 5 and 6. Here the measurement of the discharge, throttling and suction pressures are taken from the units.

2.8.5 Humidity Measurement Devices

The very first humidity measurement devices were based on mechanical elements. The principle was based on the ability of these mechanical elements to change their dimensions when water was absorbed or desorbed. Other more common sensors nowadays are based on a hygroscopic film, which is a water solution of 2-5% lithium chloride. Two electrodes measuring the electrical resistance of the film derive the humidity. This sensor is known as the Dunmore element. Aluminium anodised to obtain a porous layer of aluminium oxide and covered by a thin film of gold also acts as a humidity sensor. The gold and aluminium constitute the two electrodes of a capacitor. The capacitance changes with the water absorbed into the porous layer. A quartz crystal covered with a hygroscopic material can also be used to measure humidity. Its principle is based on the weight dependent oscillation of the crystal. An indirect method of humidity measurement that is sometimes used includes the use of the psychometric chart. It consists of the measurements of temperature with dry and wet bulbs. The water is evaporated from the wet bulb by a fan and produces a decrease in the temperature measured by the thermometer. This decrease in temperature is related to the humidity in the air.

The humidity sensor used for the testing on the wind tunnel is a product of Status Instruments and is called a SEM164. Two-wire loop powered operation provides good noise immunity. The sensor is fitted with a PTFE membrane filter around the sensor guard body, to filter harmful dust and other airborne pollutants whilst allowing the moisture vapours to enter the sensing area of the probe.

2.8.6 Switching Measurement

These are probably the easiest to understand, but to understand them it is necessary to know what type of signal is being measured. They are primarily used in the measurement of digital on-off signals. In short they relay back information on the state of components or processes. For example if a component is switched on or energised the digital signal recorded would be in the on state thus detecting a voltage/current. Then when the device is switched off there would be no voltage/current detected thus indicating that the device is in the off state. In this type of measurement there is no particular sensor required. The circuit that produces a voltage/current signal when energised and no signal when de-energised must be identified and wired to the DAQ digital input module. The DAQ system can then identify when the device is in the on or off state.

2.9 Communication Devices

There are several types of communication devices available, from wireless networks to telephone modems, there are a wide variety of data communication devices available to suite any communication need. "Data communication is the process of transferring digital information (usually in binary form) between two or more points" [37] (W. Tomasi, 1998). A data communications network can be as simple as two PC's connected together through a public network or it can comprise of a complex network of one or more mainframe computers and thousands of remote terminals, PC's and workstations. Below are some of the more common communication devices used in industry today.

2.9.1 Modems

These are used to transmit data over long distances by the use of telephone networks. Special lines and some sort of modulation were required for the transmission of data over analogue telephone cables. "The equipment used to modulate and demodulate digital data for transmission over analogue facilities is called a modem" [38] (P. H. Young, 1994). A modem (figure 2.9) can be described as a device that transmits and receives serial, digital data using telephone wires, twisted pairs or fibre optic cable. Fibre optics is used where higher data rates are required. Most modems are RS-232-C compatible for interfacing with the terminal, computer equipment and can be connected directly to the telephone line. There are several different types of modems available on the market, which are as follows:

Figure 2.9 External Modem & Internal Modem

- Limited distance modem- this is a low cost communication device and is used to transmit data up to 12 miles. The normal rule of thumb for this modem is that as the distance increases the speed decreases.
- Fully isolated modem- for important data, protection is required against noise, voltage problems, etc. Optical isolation and dc-to-dc transformer coupling can create an isolation barrier of 1000V rms. (Root mean squared). An isolated modem has the same transmission speed as a limited distance modem.
- Signal-powered fibre optic modem- this modem is ideally suited to electrically noisy environments. The signals carried by fibre optic cables are not affected

by EMI (electromagnetic interference) or RFI (radio frequency interference).

- High-speed fibre optic modem- this device is capable of transmitting data at high-speeds up to 5Mbps 1.2 miles over an optic link. For both of the above fibre optic modems the transmitter/receiver plugs into the data port at both ends.

2.9.2 Wireless Systems

This involves the transmission of data by radio-frequency as opposed to the older systems where data was transferred via wiring. In many applications the installation of cabling can be very costly and may cause problems. " National Instruments now offers spread spectrum radio modems that very easily convert your FieldPoint system into a wireless I/O and DAQ system" [39] (National Instruments, 1999). FieldPoint DAQ system will be discussed in chapter 4. Radio frequencies are available in several different varieties.

- Microwaves- microwaves require a line of sight between aerials and are capable of transmitting data up to 32 miles.
- Unlicensed link- this operates in the 900-MHz band, and can work at distances up to 1 mile. With the use of aerials or repeaters a 90-mile distance can be reached at speeds up to 115kbps with a response time of 5-15 milliseconds between units.
- Spread spectrum- these are very useful and are used in environments where the 900MHz band is experiencing interference from telephones or other 900 band devices.
- Licensed RF- in cases where DAQ needs cannot be met using 900-MHz devices; licensed radio frequencies can be used, with the ability to connect up to 10,000 remote units.
- Trunked or cellular- typically applicable to hilly, mountainous or city regions

where the line of sight may be interrupted. Mobile phones are typical examples.

2.9.3 Protocol Converters

These converters are very useful in that they help in the interfacing of various types of hardware. They are particularly useful were DAQ systems mix and match components and transmit data over multiple interfaces. Several converters are available include, IEEE-488 to RS-232/422, RS-232 to RS-422 and RS-232 to RS-485. These standards will be dealt with in more detail in chapter 3.

2.9.4 Auto Diallers

The function of the auto dialler is to monitor the conditions at a remote site. If process is disrupted or something goes wrong, it alerts the users or other equipment. It is a small self-contained DAQ module that monitors one or more digital or analogue sensors. In nearly every case the auto dialler has automatic dial-out capability that will continue to call a series of phone numbers until someone answers before delivering a programmed voice alarm message.

CHAPTER 3 CIT TECHNOLOGY

3.1 Introduction

This chapter will focus on several important areas of the data acquisition (DAQ) system, such as analogue and digital functionality, analogue to digital conversion, digital to analogue conversion, signal conditioning, multiplexing and digital inputs and outputs. Transmission of both analogue and digital signals is also discussed. The area of transmission also covers interference and grounding procedures. In dealing with Computer Integrated Testing (CIT) systems, networking must also be considered. It is an essential part of the CIT system as it is the essence of data transfer. For this reason the basics of networking were examined and are presented at the end of this chapter.

3.2 Analogue Input/Output (I/O) Functionality

Today microprocessor based devices and digital computers have replaced analogue recording and display technologies in all but the simplest of data applications. Computers have had a major impact on the practice of DAQ, but it must be remembered that, they speak only in binary language. However manufacturing processes and natural phenomena are still by their nature analogue, therefore natural processes tend to vary smoothly over time, not discontinuously changing states e.g. from on to off, high to low. Analogue measurements such as pressure, temperature, and flow rate must be changed to a digital representation so as to be recorded by a computer.

Sensors used for measuring temperature, pressure and other analogue variables provide a varying electrical output to represent the measure of the variable. In order to make the signal readable by a computer it must first be converted to a digital number. This is accomplished by the method of an analogue to digital (A/D) conversion process. A/D conversion has two primary challenges, one of quantization, which refers to the uncertainty upon conversion of an analogue voltage to a digital number and one of sampling in time, referring to the lack of information gathered about the behaviour of a process between data points.

This second challenge requires special measures to be taken to ensure that no important data is lost. The Nyquist Theorem gives the relationship between the highest frequency contained in a signal and the minimum required sampling speed. Nyquist stated that "the sample speed should be twice the highest frequency component contained within the input signal" [40] (Omega Engineering, 1998). By ignoring the Nyquist Theorem the implications could include missing high frequency information, if the sample rate is not enough the presence of totally non-existent frequencies may be indicated.

3.2.1 Analogue to Digital (A/D) Conversion

There are various areas in engineering where analogue signals have to be processed in some way. "The phenomena that occurs in nature, such as temperature, pressure, liquid flow are all analogue quantities and if these phenomena are to be processed by a digital system, or computer, they must first be converted from the original analogue forms into equivalent digital signals" [41] (D. C. Green, 1999). This is where the area of A/D conversion comes into the equation. A/D conversion occurs when continuous electrical signals are converted to the digital language of computers using A/D conversion. This A/D converter can be housed in a PC board along with associated circuitry such as sample and hold circuits, an amplifier, a multiplexer, time and synchronisation circuits and signal conditioning circuitry. Logic circuits necessary for the control and transfer of data to computer memory are also needed. In determining the type of A/D converter to use, attention must be placed on the requirements of the analogue input transducer being used, such as;

- Accuracy, signal level, dynamic range, etc.
- Resolution, which is a measure of the number of levels used to represent the analogue input range i.e. it determines the converters sensitivity to a change in analogue input.
- Amplification of the signal, or input gain can be used to increase the sensitivity if the signals expected maximum range is less than the input range of the A/D converter.
- Absolute accuracy is a function of the reference voltage stability as well as the comparator performance. To know the accuracy of the system itself is of little benefit, but together with associated multiplexer, amplifier, etc it can prove to be more useful.
- Speed and throughput for a multi-channel device must also be considered. Speeds depend on the conversion time, acquisition time, transfer time and the number of channels being served by the system. Acquisition being the time required by the analogue circuitry to acquire the signal. Conversion is the time needed to produce a digital value corresponding to the analogue value. Transfer is the time needed to send the digital value to the host computer's memory. And finally throughput equals the number of channels being served divided by the time required to do all three functions.

3.2.2 Types of A/D Converters

All A/D converters are classified by the their resolution or number of bits. The four primary types of A/D converters used for industry and laboratory application are successive approximation, flask/parallel, integrating, and ramp/counting. Design features can be seen in table 3.1

Design	Speed	Resolution	Noise Immunity	Cost
Successive approximation	Medium	10-16bits	Poor	Low
Flash/parallel	Slow	12-18bits	Good	Low
Integrating	Slow	14-24bits	Good	Medium
Ramp/counter	Fast	4-8bits	None	High

Table 3.1 A/D Converters Design Features

Successive approximation- being the most common A/D converter design is used for general industry and laboratory applications. It offers an effective compromise between resolution speed and cost. An internal D/A converter and a single comparator are used to home in on unknown voltages by turning bits in the converter on until the voltage match to within the least significant bit.

Flash/parallel- is used when high-speed operations are required. This design uses multiple comparators in parallel to process samples at more than 100 MHz. But a large number of relatively expensive comparators are required (i.e. a 12 bit converter needs 4,095 comparators).

Integrating- this converter integrates an unknown input voltage for a specific period of time, then integrates it back down to zero. The time then is compared to the amount of time taken to perform a similar integration on a known reference voltage. Then the unknown input voltage can be found. Integrating converters are available at raw sampling rates of 10-500kHz.

Ramp/counter- similar to successive approximation, this type of A/D converter uses one comparator circuit and a D/A converter. The design progressively increments a digital counter and with each new count generates the corresponding analogue voltage and compares it to the unknown input voltage. When agreement is indicated the counter contains the digital equivalent of the unknown signal.

3.2.3 Signal Conditioning and Multiplexing

A/D converters usually have associated circuitry for signal conditioning, multiplexing, amplification and other functions. "Signal conditioning converts a transducer's signal so that an A/D converter can measure the signal" [42] (IOtech Inc, 1998). Signal conditioning includes amplification, filtering, differential applications, isolation, simultaneous sample and hold, current to voltage conversions, linerisation and more. Signal conditioning is an essential component to the DAQ system and by incorporating signal conditioning the system becomes better able to accept more sensor/signal types and broader signal ranges. It also increases the accuracy, reliability and functionality of the system. Figure 3.1 below shows the DAQ signal-conditioning configuration. The transducer is connected to the input of the signal conditioning electronics before the output of the signal conditioning is connected to the A/D converter. This A/D converter converts the analogue signal to a digital signal, which is transferred to a computer for processing and storage.

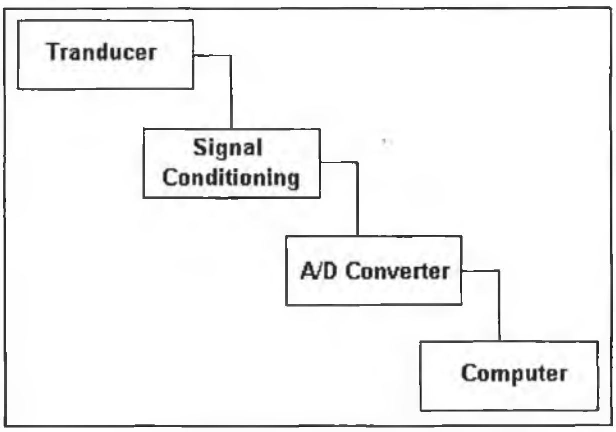

Figure 3.1 Generic Signal Conditioning Scheme

Figure 3.2 show some signal conditioning devices along with associated circuitry manufactured by National Instruments.

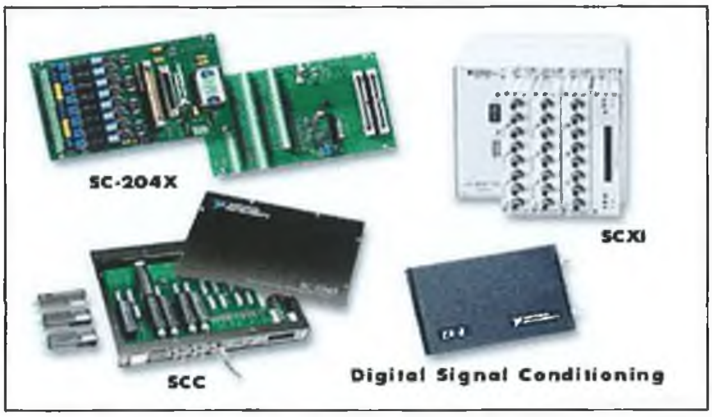

Figure 3.2 Digital Signal Conditioning Equipment

Signal conditioning offers many advantages such as:

- Isolation for signal protection
- Additional sensor measurement capabilities
- Amplification to increase resolution and noise immunity
- Filtering to remove noise and to prevent anti-aliasing
- Expand channel capacity
- Simultaneous sampling for time critical measurements

Several important circuitry associated with signal conditioning are as follows:

Sample and Hold- during DAQ individual channels are read sequentially which is called standard or distributed sampling. A reading of all channels is called a scan because each channel is acquired and converted at a slightly different time, thus a skew in sample time is created between data points. In the case where synchronisation among inputs is important, some DAQ cards simultaneous sample and hold circuitry. They can sample all channels within a few nanoseconds of each other thus eliminating phase and time breaks for all but the fastest processes. Typical simultaneous sample and hold circuitry can be seen in figure 3.3.

Figure 3.3 Simultaneous Sample and Hold Circuitry

Signal Scaling- A/D converters work best on signals of 1-10 V range, therefore low voltage signals may need amplification before conversion or high voltage signals may need to be attenuated. Amplifiers also have the power to boost A/D conversion resolution of low-level signals. Fixed gain amplifiers multiply all signals proportionally and increase sensitivity to low voltage signals. Programmable gain amplifiers (PGAs) can be configured to increase gain as the signal level drops increasing the systems dynamic range.

Current to Voltage Conversions - a 4-20mA current signal can be converted to a voltage signal using a simple resister.

Filtering- a variety of physical devices and circuits are available to help separate desired signals from specific frequencies of undesirable electrical noise such as AC line pick-up and other electromagnetic/radio frequency interference. A low pass filter is used where the signal is lower than the frequency of the noise. High pass filters are designed to handle interference from low frequencies.

Excitation- this is where voltages supplied by DAQ cards or discrete signal conditioners certain types of transducers such as strain gages.

Isolation- this is used to protect personnel and equipment from high voltages. These circuits overload while passing the signal of interest.

Multiplexing- Applications where multiple analogue signals must be converted to digital form and where speed is not a limiting factor, a single converter can be shared with multiple input channels via a switching mechanism called a multiplexer. This is a common feature due to the high cost of converters. Multiplexers also allow for amplification and other signal conditioning circuitry to be time shared among many channels. It also reduces the frequency which points are acquired. " There are two approaches to digitising multiple analogue signals" [43] (Biodata Ltd., 1998). One using an A/D converter for each input, permitting simultaneous sampling and ensuring that there is no reduction in the rate of sampling as the number of inputs are increased. Another is to use a single A/D converter and switch each signal in turn to the converter. This is a much cheaper method but it does not provide simultaneous sampling across the inputs.

3.2.4 Types of Analogue Inputs

When specifying analogue DAQ hardware we must consider whether to use:

- single ended
- or differential inputs.

With single ended configurations the signal sources and the input to the amplifier are referenced to ground. This is acceptable for high level signals where the difference in ground potentials will create an error resulting in current flowing through the ground conductor, known as a ground loop. Differential inputs connect both the positive and negative inputs of the amplifier to both ends of the signal source. Any ground loop induced voltage appears in both ends and is rejected as a common mode noise, the down side being that the differential connections are twice as expensive as the single ended inputs.

3.2.5 Types of Analogue Outputs and Timing

It is essential that the number of analogue and digital outputs for a system be known. In the case of analogue outputs an approximation of a continuously varying voltage to current is generated. A D/A converter is used to turn the computers digital representation into an analogue signal.

"Timing primarily refers to counters/timers, pacer clocks, and triggers, these components provide a DAQ system with the features associated with the synchronisation of data acquisition" [44] (A. Ruiz, H. Vromans, 1998). Counter/timer circuitry is useful for a variety of applications such as, triggering A/D conversions and indirectly generate interrupts, a frequency square wave generator for testing, an event counter for external pulse inputs and a timer delay generator. The advantage of this capability being present in hardware is that it can operate at much faster rate than a software-driven digital output. Every counter has clock input and the most important specifications for operating a counter/timer are its resolution and clock frequency. Resolution being the number of bits that the counter uses for counting while the clock frequency determines how fast it can toggle the digital source input. Triggers are primarily used to start DAQ and are very useful for high-speed applications. DAQ boards wait for a user-defined event to occur before it signals the DAQ board to start acquiring the data.

3.2.6 Digital to Analogue (D/A) Conversion

"After a signal has been processed digitally, it may be appropriate to convert back to an analogue voltage using a digital to analogue (D/A) converter" [45] (P. Lynn, W. Fuerst, 1996). A common D/A converter is often shared among multiplexed output signals. Standard analogue output ranges are essentially the same as analogue inputs: ±5V dc, ±10V dc, 0-10V dc and 4-20-mA dc. The logic circuitry for an analogue voltage uses a digital word or a series of bits to drop in a series of resistors from a circuit driven by a reference voltage. The key specifications of an analogue output include:

- Settling Time- time that is required for a D/A converter to respond to a set-point change.
- Linearity- refers to the device's ability to accurately divide the reference voltage into evenly sized increments.
- Range- reference voltage sets the limit on the output voltage achievable.

Amplifiers and signal conditioners are often needed because most unconditioned analogue outputs are limited to 5 mA of current, and a low-pass filter may also be used to smooth out the discrete steps in output.

3.3 Digital I/O Functionality

In contrast to analogue transducers that sense continuous variables such as temperature and pressure, many transducers provide an output that is one of two states: high or low, open or closed. Pulse signals are a form of digital I/O, with one ml of fuel being pumped through a flow meter corresponding to one pulse. Digital I/Os can be used for parallel communications among plug-in-expansion cards, also to generate clock and other timing signals. Already in the binary language of computers, digital inputs or outputs are much easier for microprocessor based DAQ systems to deal with than analogue signals. Acquiring an analogue signal is more complex than that of acquiring a digital signal, for this reason analogue I/O channels are more expensive.

3.3.1 Digital Inputs

Digital I/O cards can directly read many types of digital input signals from switch closures, or relay contacts, which may be read directly by digital I/O cards (figure 3.4). Other types of signals may need some signal conditioning to reduce higher level voltages. The most common type of digital input is the contact closure, which engages or disengages according to some process change. Then an applied electrical signal determines if the circuit is open or closed. Current flows if the circuit is closed, registering 1 at the computer interface. Therefore an open circuit will register 0 indicating that there is no current flow.

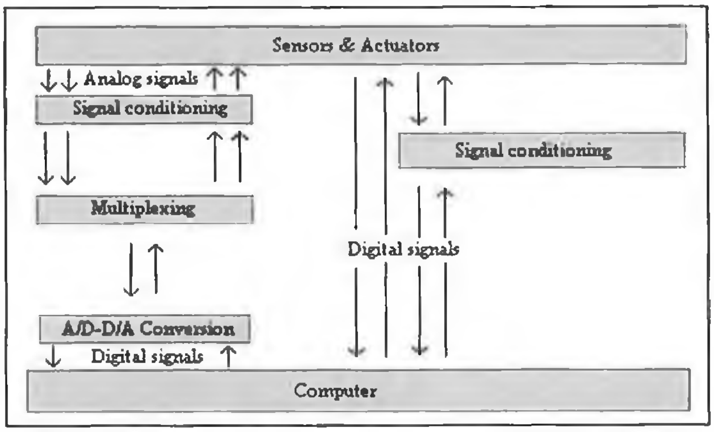

Figure 3.4 Signal-Processing Requirements for Digital and Analogue Signals

There is another type of digital input useful in DAQ systems, the hardware trigger, which allows an external event, i.e. a high reactor temperature or a low tank level.

3.3.2 Digital Outputs

A digital output provides a means of turning something on or off. Its applications range from driving a relay, turning on an indicator lamp, to transmitting data to another computer. Pulse I/O is a separate type of digital I/O. They are typically associated with frequency, counting, or totalization applications.

They are handled in much the same way as digital logic inputs, but the output of the sensing circuit is normally connected to a counter rather than a specific bit position in the input register.

3.4 Analogue Signal Transmission

In order to understand the way, in which an analogue signal is transmitted over a circuit, we must understand the relationship that makes analogue signal transmission possible. An understanding of the fundamental relationship between voltage, resistance and current that allows a continuously varying voltage or current to represent a continuous process variable is necessary. While charge flow is electric current, voltage is the work done in moving a unit of charge (coulomb) from one point to another. The unit of voltage is often called the potential difference, or the volt. The international system of units (SI) for electrical flow is the ampere (A), defined as one coulomb per second (c/s). A signal source of voltage, V will cause, current I, to flow through a resistor, R. German physicist George Simon Ohm (1787-1854) formulated the relationship between voltage, current and resistance, known as Ohm's law, and it can be defined as V=IR.

Most of the single channel analogue signal transmissions use dc variations in current or voltage to represent a data value, frequency variations of an ac also can be used to communicate information.

3.4.1 Types of Analogue Signal

DAQ signals can mostly be described as analogue, digital, or pulse. Analogue signals typically vary smoothly and continuously over time, digital signals are present at discrete points in time (figure 3.5).

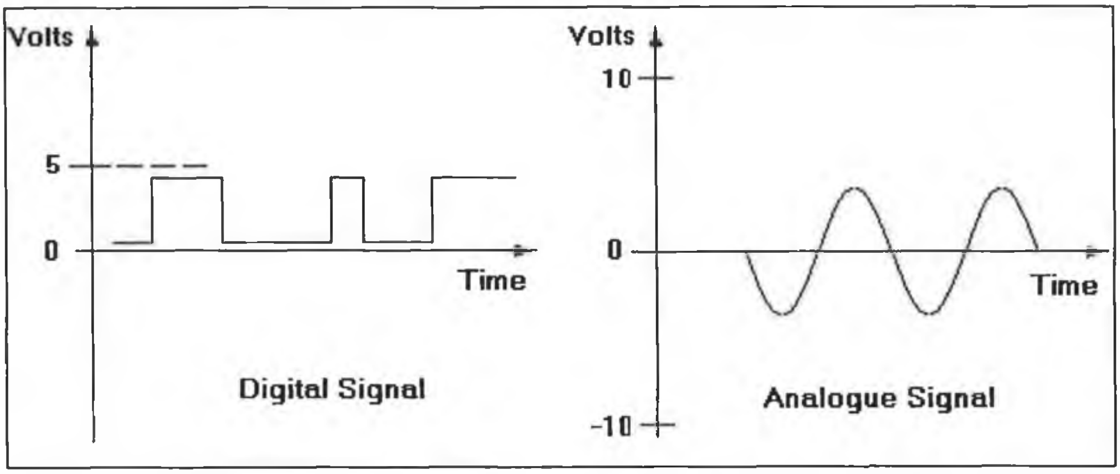

Figure 3.5 Analogue and Digital Signal Representations

Most applications have analogue signals that range over a specified current or voltage range, such as 4-20mA dc or 0-5 V dc. Digital signals are basically on/off. While analogue signals represent continuously variable entities such as temperatures, pressures, or flow rates. Computer-based controllers and systems understand only discrete on/off information. Therefore analogue signals have to be converted to digital representations.

3.4.2 Signal Interference

The protection of data integrity is one of the most critical requirements when transmitting analogue signals across a process plant or factory floor. Some signal degradation is unavoidable when transmitting low level analogue signals over wires. This may be due to noise and electrical interference, which are the two basic problems in analogue signal transmission. Noise can be divided into two categories based on the source, internal noise and external noise. Internal noise is caused by components associated with the signal itself, whereas external noise comes from natural or man-made electrical or magnetic phenomena and influence the signal as it is being transmitted. Noise can limit the ability to identify the sent message and hence limit information transfer. Some forms of internal and external noise includes:

- Electromagnetic interference (EMI)
- Radio-frequency interference (RFI)
- Electrical charge pickup from power sources
- Lightning bolts
- Electrical motors
- Switching of high-current loads in nearby wiring
- Leakage paths at the input terminals
- Signal conversion errors and uncontrollable process disturbances

Signal leads can pick up two types of external noise, by the common mode, which is noise picked up on both leads from ground. With normal mode noise enters the signal path as a differential voltage.

3.4.3 Grounding

Incorrect grounding leads to dangerous ground loops and susceptibility to interference. A ground is a conducting flow path for current between an electric circuit and the earth, and the wires used for grounds are usually made from materials of low resistance so as current takes the path of least resistance. When connected to the system, they provide a stable reference for making voltage measurements. These ground wires serve another purpose. They safeguard against unwanted common-mode signals and prevent accidental contact with dangerous voltages. There are many grounding techniques designed to protect the data as well as the equipment and the people using it. The two main ways in which the system should be grounded are as follows.

1. All the measuring and recording equipment should be that measurements can be

taken with respect to a zero voltage potential, ensuring that potential is not being introduced and that enclosures or cabinets around the equipment do not carry voltage.

2. The second ground is the signal ground, which should provide a solid reference for the measurement of all low-level signals. This should be grounded separate from the system ground.

3.5 Digital Signal Transmission

"The increasing performance required in today's operating environments is being fuelled by the need to transfer large blocks of data in an extremely short duration" [46] (Anderson, Shanley, (1995). The industrial networks that transmit data using digital signals, are often an important part of a DAQ or process control solutions. An understanding of network technologies is necessary when using DAQ systems in order to make the best implementation decisions. These decisions can greatly effect the ability to adopt the ever-changing technologies. If we take for example the type of network products selected for a DAQ application. It can greatly affect the final cost of the overall system.

The big problem with network technology is that it is changing at an incredible rate. The average user may spend several weeks doing research on the most adequate networking system to purchase, and by the time it is purchased the next selection of better, bigger and faster technology is available.

Any industry will benefit greatly by having a well designed integrated solution to data transmission enabling the user in all aspects of the business being able to retrieve plant and business data from any physical node (networked computer). "The actual data transfer between the computer or control and external devices is carried out in one of three methods" [47] (Chang, Wysk, Wang, 1990).

- Polling
- Interrupts
- Direct Memory Access (DMA)

The first two methods are used widely for data communications between two computers. DMA is used mostly for computer and peripheral device communication especially when large amounts of data need to be transferred such as computer to hard disk drive communications.

Putting together parts of new and existing networks is becoming more feasible with the use of bridging routing and media conversion technologies that link local area, wide area and industrial networks. With the Internet and wireless technologies, data transmission over large geographical areas is possible.

3.5.1 The Open Systems Interconnect (OSI) Network Model

Nearly all-digital network descriptions start with the OSI model. It explains the various layers of network technology. "The primary purpose of OSI standards is to serve as a structural guideline for exchanging information between computers, terminals and networks" [48] (W. Tomasi, 1994). In relation to the test systems implemented within Thermo King the main layer concentrated on was layer 7 or the physical layer. The best way to understand each layer is by examining the technology that it represents and the principles that were applied to arrive at the seven layers are as follows:

- A layer should be created where a different level of abstraction is needed.
- Each layer should perform a well-defined function.

- The function of each layer should be chosen with a view towards defining internationally standardised protocols.
- The layer boundaries should be chosen to minimise the information flow across the interfaces.
- The number of layers should be large enough that functions need not be thrown together in the same layer out of necessity, and small enough that the architecture does not become unwieldy.

The seven layer are described as follows:

1. The Application Layer is what the user sees. This layer represents the problem the user wants the system to solve. E-mail programs and Internet browsers are good examples, they allow the user to input and read data while connected between a client PC and a server somewhere on the Internet. In relation to the development of the three CIT systems the application layer refers to the various software interfaces used for controlling, programming and monitoring the various tests relaying information from the data acquisition units, which are connected to the various instruments used in the systems.

2. "The Presentation Layer handles code conversion between machines, data conversions and data encryption" [49] (J. D. Gibson, 1993). It also performs formatting on the data going to and from the application.

3. The Session Layer establishes the connection between applications and enforces dialogue rules, which specify the order and speed of data transfer between a sender and a receiver.

4. The Transport Layer is essentially an interface between the processor and the outside world. Its function is to generate addresses for session entities and ensures all blocks or packets of data have been sent or received. "If a packet is lost then this program provides the network independent transport service and makes sure that the

packet is sent again via a perfectly working route into the network" [50] (P. G. Ranky, 1985).

5. The Network Layer performs addressing, accounting, and routing functions on messages received from the transport layer. In the case of lengthy messages, this layer will break it up and sequence it over the network. This layer also uses a network routing table in order to find the next node on the way to the destination address.

6. The Data Link Layer establishes and controls the physical path of communication from one node to the next, with error detection. This layer performs media access control (MAC) to decide which node can use the media and when. The rules used to perform these functions also are known as protocols. Ethernet and token ring are examples of protocols.

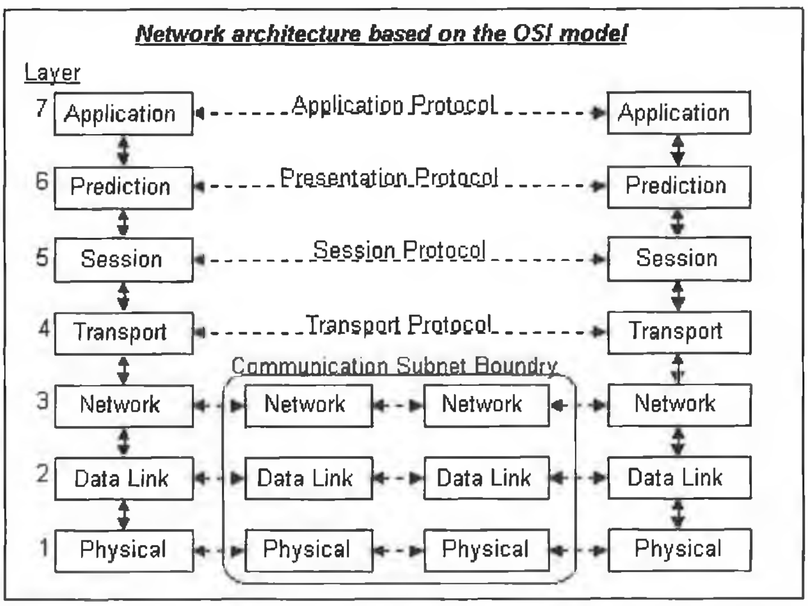

Figure 3.6 OSI Model

7. The Physical Layer is perhaps the most conspicuous layer from a cost point of view. It is relatively easy to understand and involves the labour and material costs of pulling cables, along with a physical infrastructure (conduits, raceways, and duct

banks) for maintaining cable integrity. This layer does not add anything to the message frame. It simply converts the digital message received from the data link layer into a string of ones and zeros represented by a signal on the media. In the set-up of the three CIT systems this layer was heavily concentrated on and covered the whole area of data communications. It represents the various data communication cables used in transferring information from the various sensors in the systems to the DAQ equipment and the cables from the DAQ equipment to the network or PC.

3.5.2 Physical Layer Options

The Physical Layer has been described as the layer "that controls the exchange of individual information bits over a transmission medium" [51] (Micheal Santifaller, 1994). There are several implementations of the physical layer. First network devices allow a wide range of connectivity options. The most common serial data exchange interfaces are RS- 232, RS-422, and RS-485 for connecting two or more devices together. All three interfaces use data terminal equipment (DTE) and data communication equipment (DCE) terminology (Figure 3.7). "Data communication is concerned with the exchange of digitally encoded information between two DTE's" [52] (F. Halsall, 1996).

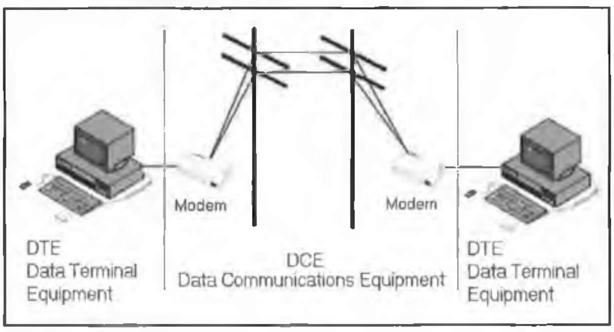

Figure 3.7 Serial Data Transmission

The DTE is the component that wants to communicate with another component, such as a PC communicating with another PC. The DCE is the component actually doing the communicating, or, performing the functions of the generator and receiver (A modem is a common example of a DCE). Mechanical, electrical, functional, and procedural aspects can categorise the interfaces between DTE and DCE. Mechanical specifications define types of connectors and numbers of pins. Electrical specifications define line voltages and waveforms and failure modes and effects. Functional specifications include timing, data, control and signal grounds, and which pin the functions use and the procedural interface shows how signals are exchanged.

3.5.2.1 RS-485 Standard

RS-485 a serial data transmission method which is officially known as EIA 485, or Standard for Electrical Characteristics of Generators and Receivers, defines a method for generating ones and zeroes as voltage pulses. An important element of RS-485 is that it allows for multiple receivers and generators, and it specifies cable characteristics in terms of signalling speeds and lengths. A typical cable is a shielded twisted copper pair, which is adequate for the typical signalling rate of 10 million bits per second (Mbps). This standard only defines the electrical characteristics of the waveforms but does not specify any media control functions that is strictly up to the device connected to the generator (usually a chip) and is usually good for cable lengths up to 2,000 feet.

3.5.2.2 RS-422 standard

Known as TIA/ EIA 422 B, Electrical Characteristics of Balanced Voltage Digital Interface Circuits by the Telecommunications Industry Association. It is similar to RS-485 and generally allows cable lengths up to 1.2 kilometres at up to 100 thousand bits per second (kbps). At 10 million bps (Mbps), cable lengths are limited to around 10 meters. Cable imbalance or high common mode noise levels results in cable lengths being reduced in order to maintain a desired signalling rate.

3.5.2.3 RS-232C standard

This standard is the most common form of serial data exchange officially known as EIA/TIA 232 E, Interface Between Data Terminal Equipment and Data Circuit-Terminating Equipment Employing Binary Data Interchange, again by TIA in association with the EIA. It was "developed to allow data equipment terminals to be connected to modems, to be able to transmit data over the telephone networks. The entire purpose of the standard was to ensure that the use of telephone lines to achieve computer communications would be handled in a way that would be acceptable to the telephone companies" [53] (F. H. Mitchell, 1990). The main difference between this standard and the RS-422 and RS-485 is that it defines the mechanical as well as the electrical interfaces. RS-232 is good for signal rates up to 20 kbps, at distances up to 50 feet. The most common mechanical interfaces are the D-sub 9 and D-sub 25 connectors.

These three standards are used in serial communication schemes for longer distances. There is one common parallel interface, known as the General Purpose Interface Bus (GPIB), or IEEE- 488. This standard allows for up to 15 devices to be interconnected, usually personal computers and scientific equipment or instruments. It allows for a high data signalling, rate up to 1 Mbps, but it is limited in length. The total bus length permitted is 20 meters, with no more than 4 meters between devices. The IEEE-488 bus is a multi-drop, parallel interface with 24 lines accessed by all devices. The lines are grouped into data lines, handshake lines, bus management lines, and ground lines. Communication is digital, and messages are sent one byte at a time.

Fibre optics are often used if user applications demand higher bandwidths. The term bandwidth technically means the difference between the highest and lowest frequencies of a transmission channel, in hertz (Hz). More commonly, it means the capacity or amount of data that can be sent through a given circuit. A bandwidth of 100 Mbps is standard using fibre optic cables. When first introduced, fibre was considered only for special applications because it was expensive and difficult to work with. In recent years, the need for greater bandwidth combined with easier-to-use fibre have made it more common. Tools and training for installing and troubleshooting fibre are readily available. There are three basic fibre optic cables available: multi-mode step index, multi-mode-graded index, and single-mode. LED's usually drives multi-mode fibres at each end of the cable, while lasers usually drive single-mode fibres. Single mode fibres can achieve much higher bandwidths than multi-mode fibres, but are thinner and physically weaker. Equipment costs for transmitting and receiving single mode fibre signals are much higher (at least four times) than for multi-mode signals. One distinct advantage of fibre optic cables is noise immunity. Fibre optic cables can be routed randomly through high noise areas.

3.5.3 Network Topologies

Topology is the term that refers to the method used to connect components on a network, the most common topologies being ring, bus, and star topologies (see figures 38, 3.9, 3.10). These may be able to take on the appearances of each other and still maintain their characteristics.

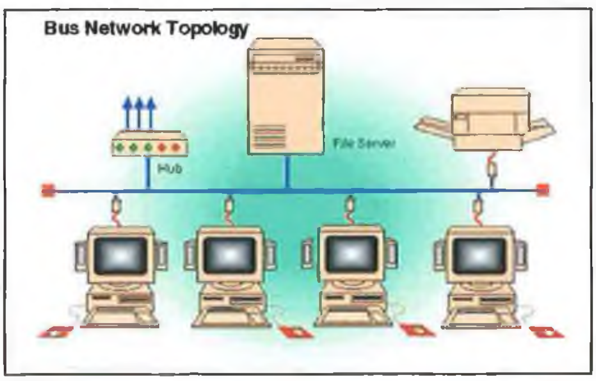

Figure 3.8 Bus Network Topology

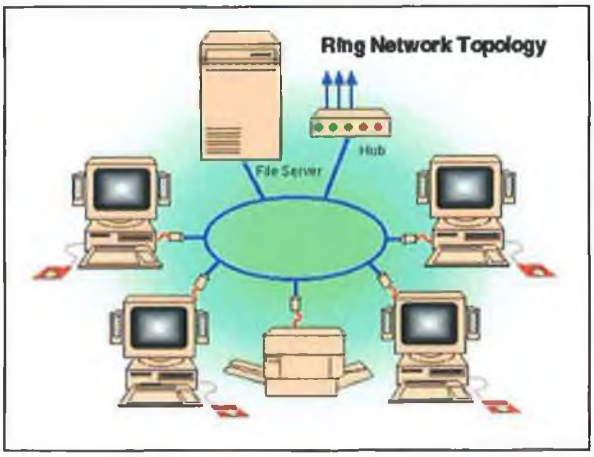

Figure 3.9 Ring Network Topology

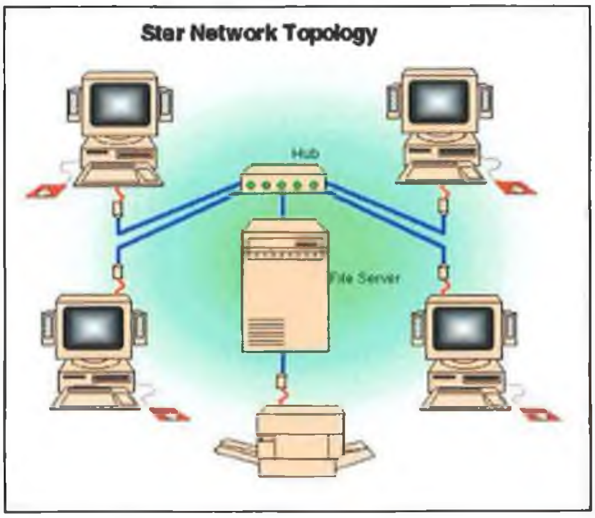

Figure 3.10 Star Network Topology

3.5.3.1 Token Buses & Rings

The media access control (MAC, which is a networking layer that determines which node can access the physical media), functions of token rings and buses are similar. ARCnet, developed by the Datapoint Corp. in the 1970s, is a token passing protocol that can be introduced in a bus or star topology by using co-axial or UTP cables. A token is passed around the bus or ring and whichever node has the token is allowed too communicate on the media. ARCnet runs at 2.5 Mbps, at the following lengths:

- 400 feet with 10 nodes using unshielded twisted pair (UTP) cable,
- 2,000 feet with a practical limit of up to 100 nodes using RC-62 coaxial cable in a coaxial star configuration (using a hub or hubs) and
- 1,000 feet with 10 nodes per 1,000 foot segment using RG-62 coaxial cable.

It uses active and passive hubs in the star configuration, with network cards on the devices that have switches for setting node numbers. The lowest numbered node is the master controller, giving permission to communicate to each node by number.
The IBM token ring protocol, standardised via IEEE-802.5, runs at 4 or 16 Mbps. Nodes on the ring connect to a multi-station access unit (MAU), which is a type of hub. MAUs can be connected together in a main ring, with segments, or lobes, from each MAU connected in a star configuration to devices with network interface cards. The length of the ring is limited to 770 meters and the maximum number of nodes allowed on a ring is 260 using shielded twisted pair (STP) cable. STP cable (150 ohm) is used most often, but UTP (100 ohm) cable can be used if passive filtering is provided for speeds up to 16 Mbps. Bridges can be used to connect rings. Jitter is an interesting problem that can arise on token ring networks, where nodes that are supposed to be synchronised with the master node receive distorted waveforms due to cable attenuation. The result is that each node operates at a slightly different speed. Jitter restricts the number of nodes allowed on the ring and suppressers are available that can help control this problem. Repeaters are available for extending the ring. Using phase-locked-loop (PLL) technology, a repeater can extend the main ring an additional 800 feet at 16 Mbps on category 5 copper UTP. Using a media converter, or fibre optic transceiver, conversion between copper and single-mode or multi-mode fibre is possible, thus extending main ring lengths up to 1.25 miles.

3.5.3.2 Ethernet

Ethernet is the most common bus topology used in business applications. It was originally developed by the Xerox Corp. "The Xerox Ethernet was so successful that Xerox, Digital Equipment Corp. (DEC) and Intel drew up a standard for a 10-Mbps Ethernet" [54] (A. S. Tanenbaum, 1996). This Ethernet standard was the bases for IEEE-802.3, specifying a Carrier Sense Multiple Access with Collision Detection (CSMA/CD) media access control protocol. This network standard provides functionality at the first two OSI network layers the physical and data link layers. This MAC protocol allows independent transmission by all nodes on a network segment. A node sends messages down the segment with data, addressing, and control bits. All other nodes see the message, but only the node with the destination address will acknowledge and receive the message. When the sending node is using the segment (transmitting), all other nodes with messages to send hear the carrier and do not send. This type of protocol is known as listen before send.

"Ethernet DAQ systems provide you with real-time, interactive I/O, allowing you to visualise your work environment over a network" [55] (Intelligent Instrumentation, 1998). Ethernet offers an open systems environment to integrate acquired data with a company's enterprise network, making data available for use with other networked resources, PCs, and workstations.

3.5.3.3 TCP/IP

The physical layer has been described, with implied functions at the data link and network layers. One common implementation of this function is Transmission Control Protocol/ Internet Protocol (TCP/IP) which is described as "the suite of communications protocols used to connect hosts on the Internet" [56] (Internet.com Corporation, 2000). On Novell networks, this function is called Sequenced Packet

Exchange/ Internet work Packet Exchange (SPX/IPX). Novell, Inc. is the largest and most popular provider of network operating system (NOS) software. It provides CSMA/CD and token passing options. The TCP and SPX protocols operate at the transport layer, and the IP and IPX protocols operate at the network layer.

3.5.4 Data Highway

Some sort of data highway, in larger organisations, allows high-speed, high-quality Internet working with good reliability. Data highways connect local area networks (LANs), wide area networks (WANs) and other forms of network segments together in one large network. The decision to build a data highway depends on the present and future needs of an organisation. But once it is implemented, growth becomes less painful. One common data highway is the Fibre Distributed Data Interface, or FDDI standard. FDDI is a dual-ring topology that can span up to 200 kilometres at 100 Mbps and is commonly used to connect LANs. Two rings of fibre carry data. All nodes attach to at least the primary ring, with some or all attached to the secondary ring. The idea is that if one ring breaks, the other automatically picks up the load. If both rings break at the same point, they automatically join together in one long ring.

3.5.5 Fieldbus & Device Networks

Industrial plants have used information technology (IT) for years, but with open IT standards, faster computers and emerging software, industrial networks are merging right into enterprise-wide IT solutions. PLCs and distributed control systems (DCSs) are offering Ethernet/ TCP/IP connectivity so that real-time information on plant processes is readily accessible by any workstation on the network (LAN or WAN). A plant manager can watch a graphic display of plant operations in one window while scanning accounting data in another. Object Linking and Embedding (OLE) and

Dynamic Data Exchange (DDE) can merge data streams, such as unit cost (from accounting) and production totals (from the plant floor) in one spreadsheet. Internet and Intranet browsers running Java or HTML applications access DAQ and control systems using standard LAN /WAN technologies. On plant and factory floors, industry has developed its own range of fieldbus or device networks for linking control devices with intelligent instrumentation. Device networks are used for discrete manufacturing automation and emphasises on high-speed transmission of smaller information packets. Field-bus on the other hand concentrates on process oriented instrument networks and usually sacrifices speed for more secure transmission of larger information packets.

3.5.6 Profibus Family

This is a fieldbus and device network technology used primarily in Europe, but gaining world-wide acceptance. The Profibus family follows an open network standard (EN50170) with hundreds of vendors supporting a common, interchangeable interface and protocol.

3.5.7 Foundation Fieldbus

The Fieldbus Foundation is a world-wide association of manufacturers and industry groups that have designed and manufactured another open fieldbus technology called Foundation. Software and hardware specifications have been written by design and marketing teams and many products are becoming available that conform to this standard. The Foundation protocol uses layers 1, 2, and 7 (physical, data link, and application layers). Layers 2 and 7 are considered bundled together in a communication stack. Foundation and Profibus look similar at first on the physical layer, the main differences are in signalling methods.

CHAPTER 4 TEST SYSTEM CHARACTERISTICS

4.1 Introduction

The focus of this chapter is on the design of test systems. Characteristics that surround the test system will be discussed, using an example of 3 CIT systems, which were designed throughout the duration of this research project. These systems included an applications trailer and truck CIT system, a wind tunnel CIT system and a calorimeter CIT system.

The characteristics of the systems were discussed by asking a series of questions, the answers to which showed what was being tested, why, what the requirements were, what type of test equipment was required and how the data was to be presented. Examination of the data acquisition (DAQ) hardware and software used in conjunction with this research project are also dealt with in this chapter.

4.2 Test System Characteristics

This is an important stage of the overall set-up for the computer integrated testing (CIT) systems. Firstly the CIT systems designed and implemented throughout the duration of this research project are as follows:

- Application trailer and truck testing
- Wind tunnel testing
- Calorimeter testing

To aid in the design of these systems several vital questions were asked, the answers to which, ultimately shaped the CIT environment. Once these questions were answered the systems could then be implemented. This project mainly concentrated on the set-up and running of the applications trailer and truck testing and wind tunnel testing systems, concentrating mainly on data acquisition set-ups, instrumentation integration, software test template development, PC networking set-ups, data analysis and presentation, and the actual performing of the various tests. The Calorimeter test system has only recently been installed therefore the opportunity to fully examine system operations was limited. Each of these systems has been examined in more detail in the next chapter. The questions that aided in the development of these systems are a good starting point and the answers helped to identify important requirements. They are as follows:

1. What is being tested?
2. What are reasons for the testing?
3. What types of tests are to be carried out?
4. What data is required to give the desired results?
5. What type of equipment is required?
6. What forms of instrumentation are required?
7. What types of standard test procedures must be followed?
8. How is the data to be analysed?
9. How is the data to be presented?
10. Where and how can the data be stored or accessed by personnel when required?
11. Can the systems be adapted to other environments?

The first item that must be dealt with is a brief explanation of the types of test systems. Applications trailer and truck testing involves the mounting of refrigeration units onto a trailer or truck body. The characteristics of unit performance can then be measured by acquiring data from sensors placed in the bodies. A common test carried out in the area of applications is head to head testing, which involved the comparison of the performance characteristics of two similar units mounted on two similar bodies. Head to head testing therefore required the incorporation of two trailer and truck bodies in the test set-up. Another typical test carried out in the area of applications was multi-temperature testing. This type of test required the division of the trailer or truck body into 2 or 3 compartments. This is a typical requirement in the transportation of products so as different loads can be hauled at different temperatures. The host or main unit controls the front compartment of a multi-temperature system whereas remote evaporator units that were usually mounted to the ceiling were used to control additional compartments. Figure 4.1 shows the differences between a single compartment truck/trailer (A) and a multi-compartment truck/trailer (B). The difference being that a multi-compartment truck or trailer can haul different types of perishables requiring maintenance at different temperatures.

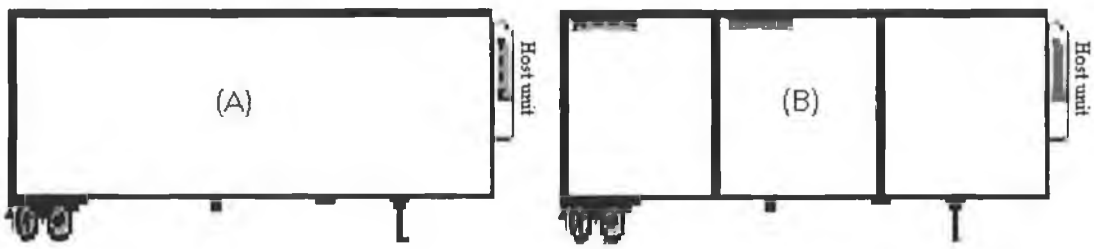

Figure 4.1 Single vs. Multi-Temp Trailer

Remote evaporators as seen in the middle and rear compartments on the multi-compartment trailer above (B), are controlled by the host unit on the front of the trailer and are used as independent temperature control devices.

Wind tunnel testing is somewhat different in that trailer or truck bodies are not required for testing. The objective of the test is to acquire a fan characteristic for trailer, truck or remote evaporator units. This is accomplished by measuring the volumetric airflow for various pressures. The wind tunnel is the apparatus used for this purpose. It is equipped with several types of computer based instruments which are described in detail in the next chapter.

Calorimeter testing is very similar to the area of applications testing and has only recently been installed. It is built as a calibrated temperature controlled chamber. This means the temperature of the chamber can be controlled to simulate environmental conditions in extreme situations. As mentioned this type of system is set-up to test the refrigeration units in a similar way to applications testing. It requires the use of trailer or truck bodies for which to mount the units on. Another type of test proposed for this system is multi-temperature testing, which has the same basic principle as that mentioned in applications trailer and truck testing.

4.2.1 What is being tested?

This first question requires the identification of the products that are to be tested. As this research project was completed in conjunction with a developer of mechanical transportation refrigeration units a brief description of the product and industry is necessary. The product being tested will have a major affect on the type of test system that is required and will determine the type of instrumentation required. In short the products were designed and produced so as distributors of food and other perishable goods could haul products to faraway destinations. The units when mounted on a truck or trailer body (figure 4.2) can adequately control the temperature of the produce being transported.

Figure 4.2 Trailer Unit & Truck Unit

There are two basic types of unit, which are:

- Multi-temperature control units
- And the single temperature control units.

Multi-temperature control units

This type of transport temperature control equipment was specially designed for maintaining multiple temperatures in trailer or truck bodies (figure 4.3). This is due to the distributors need to haul several products of food and perishables at once, some frozen, some fresh and some dry. There are several types of multi-temperature systems available to meet specific customer requirements therefore an understanding of each systems capabilities is required to properly apply them to its operations.

Figure 4.3 Multi-Temperature System

Thermo king multi-temperature systems can be divided into 2 groups:

- TC
- Invertables

The TC systems are designed to haul frozen products at -17^0C or below in the front compartment usually accessible through a side compartment, and fresh products at 0^0C to 10^0C in the rear compartment which can be loaded through the rear doors. If dry goods are to be carried it is recommended that a third compartment should be provided.

With TC systems the frozen front compartment is served by the nose mounted host unit, a remote evaporator serves the warmer rear compartment. This remote evaporator may be either wall mounted or ceiling mounted and there may be either one or two evaporators required either by the application or compartment size. Insulated bulkheads are used to separate the compartments.

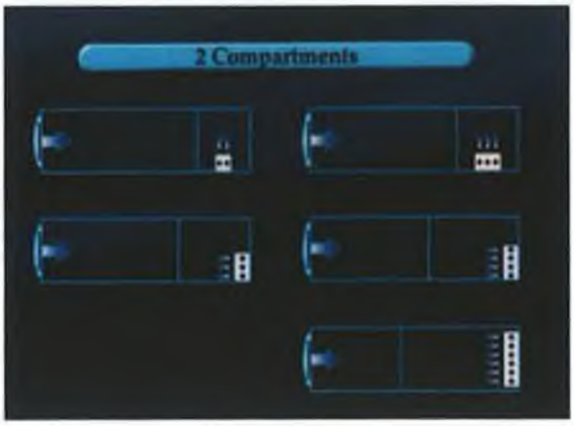

Figure 4.4 Two-Compartment Options

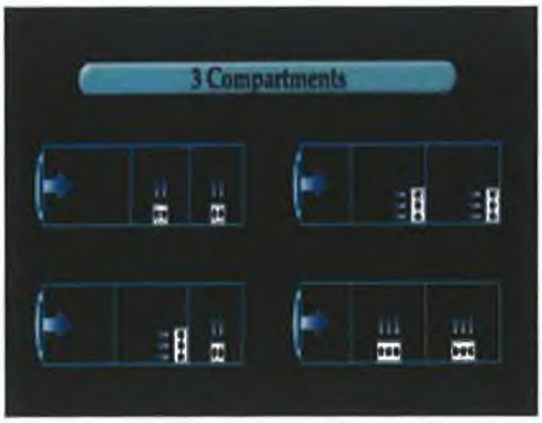

Figure 4.5 Three-Compartment Options

The newer TC models called TC-3 have become very popular with distributors in recent years. They offer a third compartment served by a second remote evaporator for a total of three-temperature control compartments.

The invertable units allow for the cooling or heating in any compartment at any time from -30^0C to 27^0C. Invertables can be divided into two basic groups, the TCI and DE systems. The TCI system uses the host unit to maintain the temperature of the larger compartment and remote evaporators to maintain the temperature in the smaller compartments.

DE (duel evaporator) has 2 evaporator coils completely confined in the host unit and uses a longitudinal insulated bulkhead to carry frozen or fresh loads in each side compartment. Adding a remote evaporator and bulkhead to a side compartment results in a DE-3 or a 3rd compartment.

With both the TC and Invertables, versatility is added with the capability of the units to haul single temperature loads from -30^{0}C to 27^{0}C, just remove the bulkheads, set the temperature on the host unit and leave the remote evaporator off.

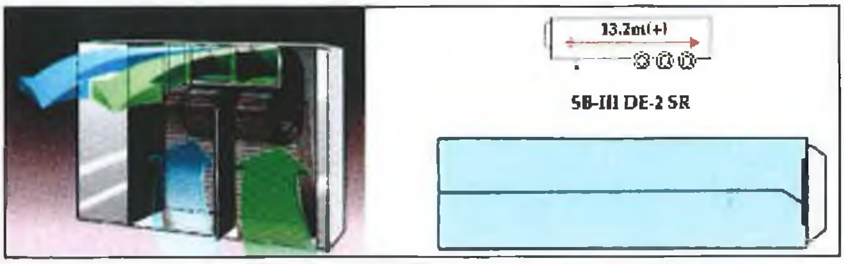

Figure 4.6 DE Configuration

Single temperature control units

In this case units are produced solely for the purpose of hauling single temperature loads. No bulkheads or remote evaporators are required.

4.2.2 Reasons for Testing the Product?

Applications, wind tunnel and calorimeter testing was required primarily for the investigation of overall unit performance under different conditions. In the past Thermo King used very basic testing systems for testing unit performance characteristics. E.g. for a fuel test the unit was connected to a barrel of fuel for operation. The barrel was then placed on weighing scales and measurements were taken before and after each test to calculate the fuel consumed. This set-up works but much more information can be achieved with a more sophisticated set-up. With the introduction of CIT the set-up now collects the instantaneous fuel consumption rate and sends it to a computer for instant manipulation and analysis. This set-up shows not only the fuel consumption rate at any particular time but also the cumulative fuel consumption, fuel consumed when the unit goes into high-speed operation or low-speed operation.

Typical reasons for testing in the areas of applications trailer and truck testing and calorimeter testing were similar and are as follows:

Temperature distribution/management capabilities of the units. This was one of the most important measurements taken, the trailer and truck bodies were fitted with thermocouple sensors, from these sensors it was possible to determine:

- Average temperature throughout the trailer or in the case of multi-temperature testing the average temperature throughout the individual compartments.
- The rate at which the unit could cool or heat the trailer/truck body or compartment.
- The temperature distribution measured at various points within the body or compartment.

The Heating and cooling capacity of the units. This can be calculated instantly by mathematical manipulation.

Fuel Consumption, which is a major concern as fuel can be expensive, a small saving in fuel can result in large savings in running costs of the units for the purchaser.

Pressure measurement in the area of applications and calorimeter testing involved the measurement of discharge, suction and throttling pressures. These were measured for monitoring purposes only and the information gathered was not incorporated into the test results. The wind tunnel was somewhat different in regards to pressure measurement requirements. Pressures such as static pressures and differential pressure measurements were essential to the test completion and will be described in more detail in the following chapter.

Determining the modes of operation was another measurement requirement, it was not required for every test but proved very useful in defrost testing. It involved recording information on the operation of the unit e.g. to examine when the unit was operating in heat, cool, high-speed, low-speed or defrost mode.

Reasons for wind tunnel testing were not as complex. The rate of airflow determines the temperature range in the cargo along with the ability to cool down the produce. Therefore the need to represent the units airflow characteristics was required. The result of a wind tunnel test ultimately showed the airflow of the unit against a number of set static pressures. The static pressures set mimics the static produced in a trailer or truck carrying a load.

4.2.3 What Types of Tests are Carried Out

The focus of this section will concentrate on the types of tests carried out in the area of applications trailer and truck testing, which was similar to the proposed testing for the calorimeter as described in chapter 5. Wind tunnel testing is more basic and will also be discussed in chapter 5.

Single temperature testing

Not only did the test system have to measure the overall unit/component performance, but it also had to be adaptable to many different test configurations. For trailer and truck testing there was several different types of test that the system would have to accommodate.

- Single trailer/single temperature tests, which involved the testing of one trailer without compartment divisions (whole trailer held at one temperature).
- Head to Head (two trailers)/single temperature, which was a test using two trailer bodies for comparing the overall performance of two different units. The testing of two trailer units was completed simultaneously and was referred to as head to head testing.

Many tests were carried out and some of results obtained were presented in graphical form as shown in chapter 6. Several Head to Head tests were completed mainly to compare capacities and performance between the company's units and the nearest competitor's units.

Multi-Temp Testing

In many situations a trailer is required to carry more then one type of produce, to be maintained at a specific temperature i.e. a load of ice cream at -20^{0}C, a load of chickens to be maintained at –12^{0}C and a load of fresh fruit at 0^{0}C. Where these types of conditions are required the trailer/truck bodies are fitted with a multi-temperature refrigeration unit, which allowed the trailer/truck body to be divided into a number of compartments (as already shown in figures 4.4 and 4.5). The temperature in each compartment can be controlled individually with the use of remote evaporator units. The remote evaporator units are fitted to the ceiling of the trailer/truck bodies. They are portable units and can be easily moved throughout the body.

The division between the compartments is called an insulated bulkhead and is easily installed and moved throughout the trailer/truck bodies to make compartments larger or smaller. The remote evaporator refrigeration units are controlled by a microprocessor (controller) on the host unit. These multi-temperature units can control a trailer/truck body with up to 3 compartments, which requires the use of 2 remote evaporators and two insulated bulkheads. Therefore the test system had to accommodate the following test configurations:

- Single trailer, 2 compartment tests
- Single trailer, 3 compartment tests
- Head to head, 2 compartment tests
- Head to head, 3 compartment tests

4.2.4 What Data is required to give the Desired Test Results?

Once the reasons for testing were established it was necessary to ask what data was required to see the desired test results? In the case of applications testing the following data was required:

- Duration of the test
- The fuel consumption rate
- Total fuel used throughout out the test
- Discharge and return air temperatures
- Ambient temperature of the surrounding test environment
- Temperature within the trailer/truck body
- Pressures taken from the discharge, suction and throttling valves
- Mode of operation (defrost, heat mode, cool mode, and high or low speed)

4.2.5 What Type of Equipment is Required?

The DAQ equipment selected for the applications, wind tunnel and calorimeter testing had similarities. Thermo King have there own network system in place, which was an advantage from the outset, this meant access to data and real-time tests could be viewed from any PC connected to the network throughout the company. Also if required this data could be viewed from anywhere in the world by Internet users. So in this case a networked DAQ system was selected. The next step was to select the equipment to transfer the data to computer. Keeping in mind that the equipment would also have to be applicable for field-testing, suggesting that a portable system with networking capabilities was required. In order to accommodate adaptability the applications testing system was designed so as it could be used as a field testing system if required.

The Fluke Corporation manufactures a small portable DAQ unit that was ideal for the applications and wind tunnel testing systems. This unit is called the fluke NetDAQ and comes in two model types. This unit was ideal as its structure allows for easy and quick connection. Also it was an excellent unit for portable DAQ applications, which was a major requirement in the area of field-testing.

National Instruments FieldPoint Modular DAQ hardware system was selected for the area of calorimeter testing because of its design. It was built to operate in the harsh environments of industrial applications and can operate over a wide temperature range, -40^0C to 70^0C. Modules can be added or removed as required to suit test requirements.

Both the Fluke NetDAQ and FieldPoint DAQ systems have been examined in more detail further on in this chapter. Other equipment requirements included a general purpose PC, a number of network hubs and several RS-232 cables for data communication and exchange.

4.2.6 What Type of Instrumentation is Required?

Staying with the area of applications testing four different types of instrumentation was required to acquire the data.

1. Temperature - A set of temperature sensors to be positioned at different positions in the trailer was required. It must be remembered that cost was a consideration

and the more sensors used, the most costly the testing operation became. Therefore a number of sensors were selected so the test system remained as cost effective as possible, while the demands to the test criteria were not jeopardised. Thermocouple sensors were selected to record the temperature values. These are temperature-measuring sensors that consist of two dissimilar metals joined at one end called a junction. When the junction is heated or cooled, a small thermoelectric voltage is produced. This thermoelectric voltage change is interpreted by thermocouple thermometers as a change in temperature (See chapter 2 - temperature measurement sensors).

2. Fuel flow rates – Measurement of fuel flow rates required the use of a flow meter. As mentioned weighing scales were previously used and placed under a barrel of fuel. Readings taken of the weight before and after the test would indicate the total fuel consumption throughout the test. This method was not reliable, as it did not inform the test engineer about the amount of fuel consumed at any particular time (fuel consumption rate). It also lacked information on the rate of fuel used when the unit was running at different speeds, which was of vital importance for showing the results of a fuel test.

   In order for the fuel consumption rate to be recorded by computer the type of instrumentation required would have to generate a voltage or current to coincide with the changing rate of fuel consumption. The data collected by a computer could be examined to determine the fuel consumption rate at different speeds and the total fuel consumed by the unit. The make up and design of the device capable of doing the tasks mentioned above can be seen in chapter 2 section 2.8.3.

3. Pressure - Measurement devices were required for measuring discharge, suction and throttling pressures on the refrigeration units. A series of pressure measurement devices were also needed for the wind tunnel.

4. Mode of operation - This operation is easily completed. The requirement in this case is to collect data on the different modes of operation e.g. whether the unit is running in:

    - Defrost mode
    - High speed
    - Low speed
    - Heat mode
    - Cool mode
    - Null mode

A wire was connected to related circuits or solenoids on the unit and connected back to the DAQ equipment. The computer was then capable of identifying whether these circuits, solenoids were energised or not thus telling the test engineer whether the unit was in heat or cool, high or low speed, etc.

4.2.7 What Standard Test Procedures must be followed?

When the testing environment was up and running, a set of standard test procedures was established so as a set of rules could be followed every time a unit required testing. These procedures can be seen in appendix A.

4.2.8 How is the Data to be Analysed?

The data acquired during applications testing was exported from the application software (ThermoDAQ) to Excel for analysis. The analysis procedures had to be standardised due to the variety of data that could be obtained. Each set of tests performed required different data types resulting in different analysis procedures to be performed. Additional data was not always required. In order for analysis procedures to remain consistent from test to test a standard procedure had to be agreed upon. It was decided that the development of a set of standard tests with room for additional data to be gathered, would be the best solution. If extra sensors were required, they would be incorporated into the system but the resulting data would not be included in the standard analysis results thus requiring further analysis of data. This was required so as the analysis procedure could be automated with the use of Visual Basic and Macros.

Extensive work was carried out on the development of a Visual Basic analysis program to suit any standard test performed in the area of applications. It was also developed with the intent to be adapted for analysis of results obtained from the calorimeter testing system. This program has been discussed in detail in chapter 6 along with the typical results obtained from running such programs.

4.2.9 How is the Data to be Presented?

It was decided that the data would be most useful presented in graphical form with a data sheet included to highlight other important information. Examples of these graphical displays along with explanations of the use of the data sheet will be discussed in more detail in chapter 6.

4.2.10 Where/How can Data be Stored/Accessed by Personnel when Required?

The testing carried out in this facility mainly focused on new units to aid in eliminating design flaws, to compare performances against competitors units, and to gain better and more accurate estimates of unit performances. Therefore test results were not available to be viewed by the public. The data was stored in a secure location on the local network within the company. This information was filed under the appropriate file names for easy location by personal with the correct access. (See section on data storage and retrieval in chapter 6.

4.2.11 Can the System be Adapted to other Environments?

The applications testing system has on occasion been adapted to testing in the field. Over the duration of this project the requirement arose to take the system into the field to demonstrate the capabilities of the units. Tasks therefore evolved to include the preparation of the system for field trials. This included the set-up and verification of sensors and signals, data acquisition set-up for operation without connection to the local area network, software template set-ups for the control of the tests.

4.3 The Fluke NetDAQ

“The Fluke Network data acquisition (DAQ) unit is a powerful combination of hardware and software integrated to deliver data directly over a network” [57] (Fluke Corporation, 1997). As mentioned this hardware was selected for use with the applications trailer and truck and wind tunnel CIT systems. It has trend link software enabling multiple users to view information in real-time from anywhere on the network. It is possible to view current, temperature, voltage, and more, on screen at the same time. It plugs directly into existing networks in an organisation and sends data directly through the network to a PC. It can also be connected directly to a PC or laptop for field-testing. A combination from one to twenty NetDAQs can be used in an integrated NetDAQ system measuring up to 400 channels. There are two models available, the NetDAQ 2645A and the NetDAQ 2640A, which is the unit that was used in two of the CIT systems in this research program. This model (figure 4.6) delivers extremely high accuracy and resolution to provide calibration-level performance. It measures up to 300V with 0.01% dc accuracy and 18-bit resolution, scanning 6 to 100 readings per second. The advantages of using this type of unit is that it saves the cost of setting up a new network, allows multiple users to simultaneously view data in real-time and can be used as a portable dedicated system connected to a notebook computer for maintenance, product validation and research.

Figure 4.6 Fluke Network Data Acquisition Unit (NetDAQ)

Several features that must be noted about the unit include:

- This unit has a unique built in signal conditioning panel, Flukes products were the first to integrate signal conditioning directly into the instruments, and any measurement function (thermocouple, RTD volts, frequency, or ohms) can be assigned to any or all channels.
- It has a removable universal input module that allows for the connection and measurement of virtually any electrical or physical parameter. Thermocouple reference junction compensation occurs automatically by sensing the temperature of the input modules isothermal block. Virtually any combination of sensor or signal can be connected into the input module, which is then plugged directly into the back of the DAQ unit.
- The device has been designed for industrial environments and can operate from -20^0 to 60^0 C. Its metal chassis shields against electromagnetic interference so as high measurement accuracy on low level signals regardless of surrounding noise can be maintained. The units have been tested to stringent shock and vibration standards and can withstand surges of up to 1500V input.
- Analogue circuitry is fully isolated channel to channel, input to output, and

input to ground.

- Scan triggers including push buttons, external and alarm triggers, scan all defined channels.
- Mx+B scaling is available on each channel.
- Front panel lockout prevents unauthorised tampering.
- Alarms, two for each channel can be independently set for high or low sense.
- Real-time clock provides precise time sampling of data.
- Closed case calibration for reliability operates on AC or DC power.

The versatile NetDAQ system offers flexible options for data distribution.

1. Configure a dedicated system- using one or more NetDAQ units with a PC or laptop for quick, easy data collection.
2. NetDAQs on the network- add the NetDAQ units to an existing network saving time and expense in setting up a large network. This allows for data access for all users on the network.
3. Quick reliable results- the system supports 3000 readings per second from multiple instruments ensuring high throughput for all units.

4.4 FieldPoint Data Acquisition Hardware

This hardware was selected for the calorimeter CIT system and is based on the advances of open industrial networks. These advances have made it easier to move DAQ and control functions out into the field by using networking technology to position DAQ hardware closer to the sensors and processes to generate significant cost savings and improved performance. The most obvious savings generated is signal wiring and the elimination of noise corruption that occurs when transporting analogue signals through long wires. National instruments supply a distributed I/O system called 'FieldPoint', which includes special capabilities to improve the reliability and maintainability of distributed systems. The FieldPoint modular I/O system is "for distributed monitoring and control applications, delivering rugged, reliable I/O in an industrial DIN rail package" [58] (National Instruments, 2000). The FieldPoint network module connects a series of analogue and digital I/O modules to an industrial network, which can include Ethernet, Foundation Fieldbus, RS-232, RS-485, or wireless communication. The advantage of the modular system is that it allows for mixing the best combination of I/O modules, thermal base style and network. It has an operating temperature rang of -40^0C to 70^0C. It is based completely on a modular architecture with 2, 8 and 16 channel I/O modules.

This hardware allows the user to independently choose the I/O, network and signal termination style that best fits the application. It include three classes of components that make up the system, these are as follows:

I/O modules (figure 4.7) - FieldPoint offers two general I/O modules, the standard 8 and 16-channel modules and the duel channel modules that allow for mix and match flexibility. These modules provide isolated analogue and discrete inputs and outputs for a wide range of signal and sensor types.

Figure 4.7 FieldPoint I/O Module

Terminal bases (figure 4.8)- The I/O modules are installed on to the terminal bases. This provides field-wiring connections along with module power and communications. The I/O module can be plugged and unplugged from the terminal bases without having to disconnect the field wiring.

Figure 4.8 FieldPoint Terminal Base

Network Modules (figure 4.9) – These provide the connectivity to open industrial networks. They communicate with the local I/O modules via a high-speed local bus formed by the linked terminal bases and the current options for the network modules as mentioned above are RS-232, RS-485, Ethernet and Foundation Fieldbus.

Figure 4.9 FieldPoint Ethernet Network Module

FieldPoint I/O modules deliver a high level of quality, robustness and flexibility. They offer a wide variety of I/O modules that deliver high accuracy analogue I/O, direct sensor connection, industrial grade discrete I/O, high speed counting and pulse generation. Figure 4.10 shows a group of modules together to make a DAQ hardware system.

Figure 4.10 FieldPoint Modules

4.5 ThermoDAQ Software

Thermo King decided to develop their own software so as they could benefit by making the hardware work the way they wanted. This software was primarily developed for the applications testing system but was further developed so as to accommodate the requirements of the wind tunnel system. (Refer to Thermo king internal software specification document TDAQspec). Advantages and disadvantages of developing their own software solutions are as follows.

- Advantages
  Build application to suit the industry
  Software more focused on the requirements set down by the test engineer
  Can be made adaptable to other test situations that may be required in the future
- Disadvantages
  Can be very expensive

Can become time consuming in that it has to be developed from scratch

Requires extra tests to be carried out to see if application is working correctly

ThermoDAQ is the name given to the software, which was developed for Thermo King in conjunction with the test engineers and a local software developing company (Blue Tree Systems). It is an instant results software package and according to Blue Tree Systems "ThermoDAQ software is the easiest way to manage your data storage and display requirements for Fluke data-logging units" [59] (Blue Tree Systems, 1998). This software is compatible with both models of the Fluke NetDAQ units along with the Fluke Hydra data-loggers, (which is another data logger unit supplied by Fluke Systems). The advantages to this software are many; the main one being that it was specially designed for the test application. This software is based on the principle that the NetDAQ unit which is connected to a network, be assigned a Base Channel Number (BCN) and a TCP/IP address. This BCN and TCP/IP address are inputted and stored in the NetDAQ unit, and when the user starts the ThermoDAQ software, it prompts for a list of NetDAQ units to use, by showing the BCN and TCP/IP address of each NetDAQ unit (figure 4.11). New units can be added or if there are too many units listed, they can be removed at this stage.

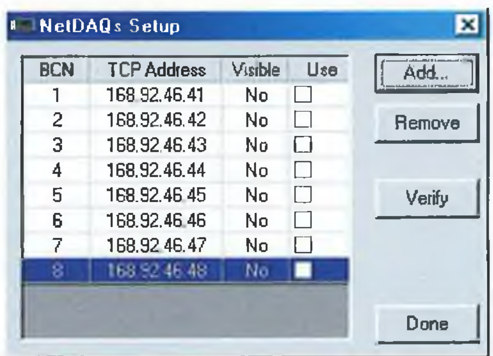

Figure 4.11 NetDAQ Set-up Dialog

As the NetDAQ units support the ability to measure almost any physical quantity the software also had to accommodate for the large range of possible measurements.

Therefore a list of transducer buttons were inserted on the user interface. These buttons accommodated the use of Digital I/O transducer types, Analogue voltage transducer types and a built in thermocouple transducer button. This last button was added to simplify the test set-up as temperature is the most important consideration in this industry. These can be seen from figure 4.12.

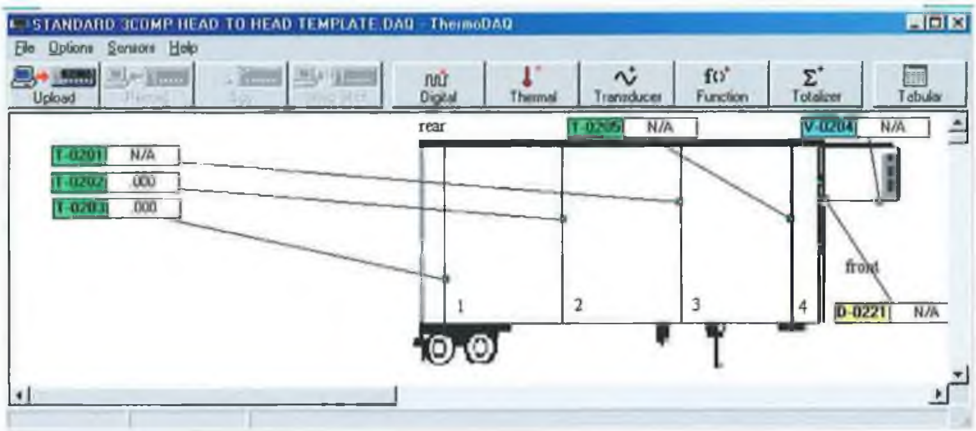

Figure 4.12 ThermoDAQ User Interface

4.5.1 Transducer Channel Set-up

When one of the transducer buttons is clicked a transducer object appears on the user interface. This object as show in figure 4.12 displays a sensor label and the current sensor value. At the time of creation the sensor assigns a default label and the current value is displayed as N/A. Also a small object is attached to the right-hand side of the transducer object which is called an Anchor. This Anchor is attached to the transducer object to allow the object to point to an area of a schematic where the transducer is located. If the transducer object is double clicked access is granted to the object properties dialog box which is shown in figure 4.13. Here several characteristics can be changed depending on the on the type of transducer button object selected.

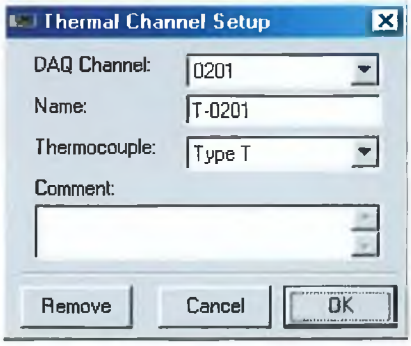

Figure 4.13 ThermoDAQ Thermal Object Properties Dialog Box

4.5.2 Transducer Object Properties for a Thermocouple Sensor

- DAQ channel – this is a drop down list box, which allows the user to select the NetDAQ channel to which the transducer is connected. To explain, take the value given in the figure 4.19, 0201. Here the first two digits refer to the BCN (Base Channel Number) and the last two digits refer to the channel number of that device. Each NetDAQ has the capability to measure 20 analogue channels, therefore a value of 0220 refers to NetDAQ with BCN 2 and channel 20 of that device.
- Name- here the user can enter a name to describe the value being measured e.g. Return Air Temp, Flow-rate in L/H.
- Thermocouple- allows the type of thermocouple to be selected from a drop down list (Type T is the default).
- Comment – allow for a comment to be made on each transducer.

4.5.3 Transducer Object Properties for a Digital Sensor

- DAQ channel –again this drop down menu operates in the same way as before, the only difference being that there are seven separate channels set aside on each

NetDAQ for digital sensors. Analogue channels from 1 to 20 and the digital channels listed from 21 to 27. Therefore a value of 0624 refers to a NetDAQ with BCN 6 and digital channel number 4.

- Name (Figure 4.14)- same as above, the user can enter a name to describe the value being measured e.g. High Speed, Low Speed, Cool, Heat, or Defrost.

Figure 4.14 ThermoDAQ Digital Object Properties for Digital Sensor

- ‘1’ State and ‘0’ State – user can assign a label to indicate the active state (reads a voltage) or inactive state (Zero voltage) of the digital input. E.g. when the user is measuring a refrigeration unit in high speed mode, taking that the high speed solenoid is generating a voltage when the unit is operating in high speed, in this case “yes” or “on” can be entered in the ‘1’ State text box and “no” or “off” in the ‘0’ State box. Then every time data is recorded with the unit in high-speed operation a value of “yes” or “on” will be recorded.
- Comment – again allows for a comment to be made on each transducer.

4.5.4 Transducer Object Properties for a Analogue Sensor

- DAQ channel – same as for the thermocouple sensor properties (Figure 4.15).
- Name - same as above, the user can enter a name to describe the value being measured e.g. Flow-rate L/H or Head Pressure.

- Slope M and Constant B – user can calibrate a transducer by entering coefficients for M and B. The transducer is calibrated using the formula Y = Mx +B where M is the slope of the line and B is the value where the line intersects the Y axis. This is the transducer properties window where the user assigns M and B values enabling the voltages recorded from the flow meter and pressure transducers to be represented in easily understood quantities.
- Range – this is a drop down list to set the voltage range for the input channel. This channel defaults auto range (-50 to + 50v) however if high accuracy is required then a range should be specified.
- Comment – again allows for a comment to be made on each transducer.

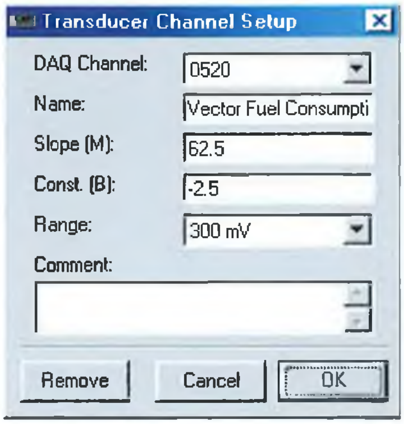

Figure 4.15 ThermoDAQ Analogue Object Properties Dialog Box

Another useful feature that ThermoDAQ provides is the input bitmap option. ThermoDAQ allows the user to display a bitmap on the interface. This is very useful for monitoring the tests and also for visitor or not technical persons to see where and what data is being collected. Here the use of the anchor is visible. This ThermoDAQ software is being used with the truck and trailer applications, field-testing and Wind Tunnel testing applications.

For the area of calorimeter testing LabVIEW was selected as the primary software to be used for DAQ purposes. This type of software is known as a graphical programming environment and is used in areas that require unique DAQ and control capability. Turnkey application can be developed to suit the non-technical operator. Development time can be lengthy and expensive but the results are much more application orientated with the possibility of graphical real-time representations.

4.6 LabVIEW

LabVIEW empowers the user to build solutions for scientific and engineering systems, it gives the flexibility and performance of a powerful programming language without the associated difficulty and complexity. This software tool has lead to the development of faster ways to program instrumentation and DAQ systems and can be used to prototype, design, test, and implement instrument systems, which leads to a reduction in system development time and an increase in productivity.

Barry E. Paton of Dalhousie University describes LabVIEW as “simply the most elegant programming language for data acquisition, analysis, simulation or computer control of instruments, techniques or processes” [60] (Barry E. Paton, 1999).

National Instruments describes LabVIEW as “A highly productive graphical programming environment that combines to use graphical development with the flexibility of a powerful programming language and offers an intuitive environment, tightly integrated with measurement hardware, for engineers to quickly produce solutions for data acquisition, data analysis and data presentation” [61] (National Instruments, 1999).

4.6.1 How is LabVIEW used?

It is used to build virtual instruments (VIs) instead of actually writing programs. A front panel user interface can be created quickly and easily, giving the user interactive control of the software system. To specify the functionality the user must assemble block diagrams, which is the actual program, so the time consuming task of converting ideas into cryptic code in not necessary. Objects such as numeric displays, meters, gauges, thermometers, tanks, LED's, charts, graphs and more can be added to the front panel of the virtual instruments by selecting them from a control palette. The front panel is used to control the virtual instruments while providing real-time feedback from the system. It is possible to build sophisticated control algorithms by using the PID control toolkit. It is easy to create remote monitoring systems as well by using the virtual instruments server or TCP and UDP networking VIs in LabVIEW.

4.6.2 LabVIEW and Real-Time Data Acquisition Systems

LabVIEW is ideal for high-speed real-time DAQ and analysis. It lets the user acquire and output data with all DAQ hardware. It contains both simple and sophisticated functions to give the user maximum power and flexibility with DAQ boards. In order to perform an in-line analysis as data is collected, LabVIEW features an impressive analysis library, rich in statistics, evaluations, regressions, linear algebra, signal generation algorithms, time and frequency-domain algorithms, windowing routines, and digital filters. In addition to the analysis functions built into LabVIEW, the signal-processing suite is available for joint time-frequency analysis, third-octave analysis, digital filter design, wavelet and filter bank design, and dynamic signal analysis.

LabVIEW has built in compatibility with hardware libraries for GPIB (general purpose interface bus)/ VXI/ PXI/ computer based instruments, RS-232/485 protocol, plug-in-DAQ, analogue/digital/counter timer I/O, signal conditioning, distributed acquisition, image acquisition and machine vision, motion controls and PLC's data loggers. LabVIEW which is an open development environment can connect or communicate to any other application through Active X, the Internet, SQL, DLLs, shared libraries, datasocket, TCP/IP, DDE, and other protocols. LabVIEW applications execute at compiled speed for optimal performance.

Advantages include

- Simplified tasks- LabVIEW add on software packages makes complex tasks like sending data to the internet, image acquisition, database programming easier by integrating these tools into the LabVIEW development environment.
- Easier solutions- it empowers uses to design and implement there own systems and because LabVIEW programming is very similar to standard flow chart notation it is very easy to learn
- Better investment- as your program/application needs change LabVIEW has the flexibility to be easily modified without the need for new equipment. The users also have access to a complete instrumentation lab at less then the cost of a single commercial instrument.
- Faster development- LabVIEW accelerates development by a factor of 4 to 10 over traditional programming, you can rapidly prototype, design and modify systems in a short amount of time.
- Complete environment- it has extensive acquisition, analysis and presentation capabilities within a single package, so you can create a complete solution.

LabVIEW systems can be implemented in test and measurement as well as process monitoring and control applications. In the area of thermal images, infrared cameras are used to measure the emission of thermal, or infrared energy that cannot be seen with the naked eye. LabVIEW can be used to automatically acquire and measure thermal images. IMAQ Vision software can then be used to test for quality and consistency. "Applications for using LabVIEW and the pattern matching and blob analysis of IMAQ Vision together with a thermo vision camera, range from evaluating products inside opaque packaging to inspecting electronic components" [62] (National Instruments, 2000).

CHAPTER 5 CIT SYSTEMS IMPLEMENTATION

5.1 Introduction

This chapter will focus on the three CIT systems designed and implemented during this research project. As mentioned before the project concentrated mainly on the application trailer and truck testing systems and the wind tunnel testing system. It stretched from the inception of design through the various data acquisition (DAQ), instrumentation and software set-ups to the final analysis of data and preparation of reports. Each test system has been described in detail beginning with the applications test system. Calorimeter testing is the latest system that has been developed and the proposed testing to be carried out has been examined.

5.2 Trailer/Truck Applications Testing

The overall set-up for the applications testing of trailer and truck units was practically identical. The major differences being the smaller truck bodies required less instrumentation. Therefore we will focus on the trailer application test system, which was more complicated due to the larger number of sensors required to adequately instrument the system.

5.2.1 Trailer Applications Testing System

The key characteristics that were required have been mentioned in chapter 4. They are temperature distribution values, fuel consumption rate data, modes of operation and pressure values. Below is a detailed explanation of the set-up of this test system.

5.2.2 Description of CIT Applications Test Area/Bay

The trailer applications testing bay is approximately 20m long x 11.2m wide and holds two 13.6m trailers. A large automatic lifting door was positioned at one end of the bay so as the large trailer bodies could be transported in and out as required. The two identical trailer bodies 13.6m long x 2.6m wide x 2.6m high were placed in the bay and were fitted with large casters so as they could be easily manoeuvred into position. The area was fitted with an exhaust system to extract fumes from the trailer units. It was also equipped with 6 Ethernet ports, 3 compressed air points, a number of power points and 2 fans used to keep a constant air temperature throughout the bay. An exit at the top end of the bay leads to the R&D workshops and two entrances on the right hand side of the bay leading to the newly installed calorimeter. An overview of the trailer test bay can be seen from figure 5.1.

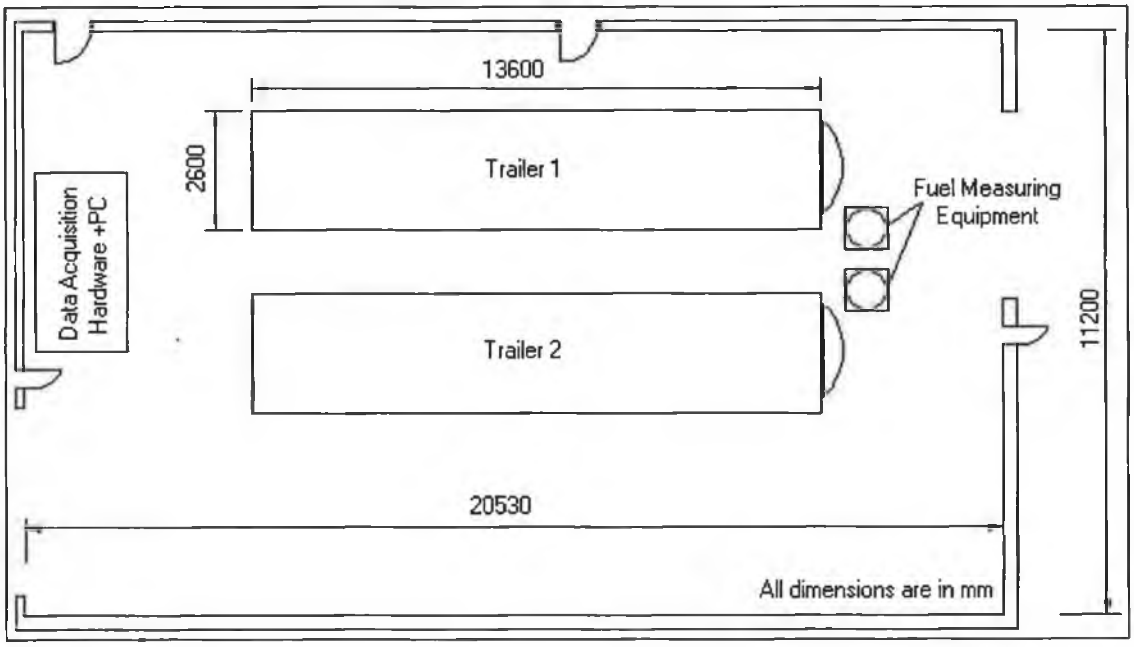

Figure 5.1 Layout of Applications Trailer Bay

5.2.3 CIT Applications Instrumentation

The instrumentation used in this testing bay comprised of:

- 46 Thermocouple sensors on each trailer body (figure 5.2).
- 1 Flow meter for each trailer unit (figure 5.3).
- 3 Pressure transducer for each trailer unit (figure 5.4).

Figure 5.2 Temperature Sensors Distributed within the Trailer Body

Figure 5.3 Flow Meter

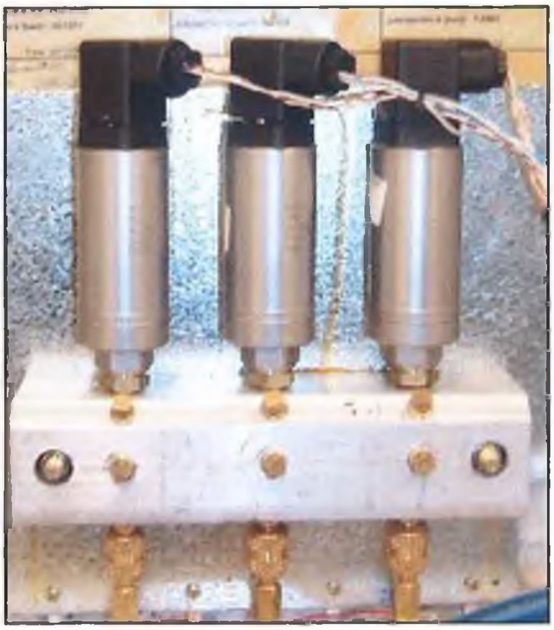

Figure 5.4 Pressure Transducers

5.2.3.1 Temperature sensors

Type T thermocouples were used for temperature sensing within the trailer bodies. The set-up of these sensors was very simple. The thermocouple wire was rolled out from the temperature measuring point back to the DAQ instrumentation input point. The type of thermocouple used was made of two different types of material, copper (Cu) and constantan (Cu-Ni) with the capability of sensing temperatures between -200 to 350^0C (-328 to 662^0F). These sensors were ideal for applications where moisture was present. So this sensor was ideally suited to the application as the temperature range being measured lies between -35^0C to 40^0C and the presence of condensation was not uncommon. The 46 thermocouples placed on each trailer were divided as follows:

- 35 sensors used for measuring the temperature throughout the 13.6m trailer. They were arranged in an 'A and V' configuration at 7 different locations (called zones) equi-spaced throughout. Each zone consisted of 5 sensors as shown in figure 5.5.

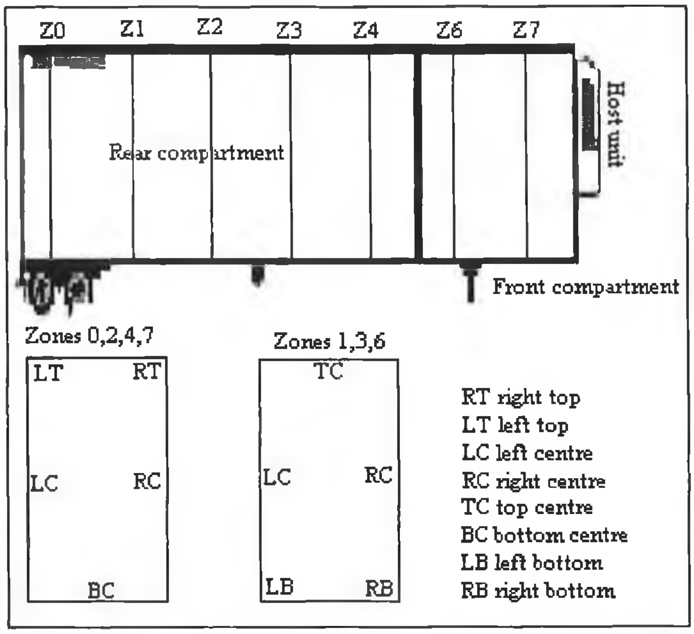

Figure 5.5 Position of Sensors on Trailer Bodies

- 1 sensor on the outer case of the trailer for recording the ambient temperatures. This sensor consists of several thermocouples, which are averaged back to one point to give one average ambient temperature about the trailer.
- 1 discharge sensor averaged in the same way as the ambient sensor, which is used to record the average temperature values from the discharge air duct inside the trailer body. The discharge air is the air being forced into the trailer body by the refrigeration units main or host unit.
- 1 return sensor averaged at source used to record the average temperature values from the return air duct inside the trailer body. The return air is the air being removed for the trailer and is positioned below the discharge air duct.
- 1 discharge sensor for remote evaporator (middle compartment), which was required in the case of multi temperature testing. This sensor also averaged at source.
- 1 return sensor for remote evaporator (middle compartment) (averaged).
- 1 discharge sensor for remote evaporator (rear compartment) required to accommodate three- compartment testing (averaged).

- 1 return sensor for remote evaporator (rear compartment) (averaged).
- 1 sensor averaged for the front of the bulkhead in the middle compartment.
- 1 sensor averaged for the rear of the bulkhead (middle compartment).
- 1 sensor averaged for the front of the bulkhead in the rear compartment.
- 1 sensor averaged for the rear of the bulkhead (rear compartment).

5.2.3.2 Fuel Flow Measurement

A flow meter for each trailer was built to record the amount of fuel being used by the transport refrigeration units. The device used for measuring the fuel consumption was specially designed for this application. It is capable of measuring the fuel consumption of all/any transport refrigeration unit that has diesel engine operation. This versatile flow-measuring device is made up of a sensor, filter, fuel pump and signal converter for which a full explanation can be seen in chapter 2 section 2.8.3.

5.2.3.3 Pressure Measurement

Measurement of the discharge, throttling and suction pressures were the main consideration in the area of pressure measurement. The use of 3 PTX 510 pressure transducers (from Classic Technology) were incorporated into the system for this purpose, these were the recommended instruments put forward by the Air Conditioning and Refrigeration Institute standard for mechanical transport refrigeration units. The three transducers were placed in a special casing for protection purposes (figure 5.4). These pressure transducers were not used for every test as they were taken purely for monitoring purposes to ensure adequate unit operation.

5.2.3.4 Measurement for the Various Modes of Operation

No specialised instrumentation was required for this operation. Solenoids on the host units are used to energise the various modes; i.e. the high-speed solenoid is energised when the unit goes into high-speed, thus generating a voltage. When the unit is not in high-speed no voltage is generated. Therefore when a wire is connected from this solenoid to the digital I/O single ended input module of the DAQ equipment, the ability to view when the solenoid is energised and not energised is possible. This results in viewing real-time information on the operation speed of the unit. In the same way it is possible to view real-time data on weather the unit is operating in heat mode, cool mode or defrost mode.

5.2.4 CIT PC-Based Hardware Set-up

The DAQ hardware consisted of a number of NetDAQ units (described in chapter 4 section 4.3), a general purpose PC with network connection, several RS232 cables and a network hub. A stand for the NetDAQ stacking was also used. The number of NetDAQs that were needed depended on the type of test to be carried out. For the standard tests as shown in table 5.1, 3 to 5 NetDAQs were required for all standard test variations. However it was recommended to have another NetDAQ on standby in the event that other data be required for other purposes.

The NetDAQ boxes were connected to a hub via the RS-232 cables. The hub was then connected to the network in the same manner. It was then possible to access, view and start/stop any test from any networked PC providing the correct software and access was available. There was no requirement to have a PC in the vicinity of the DAQ equipment when the system was up and running, but the presence of a PC has its advantages. However a PC solely dedicated to a test system has its advantages.

- A PC at the set-up and troubleshooting stages is a must. It enables the user to see any problems that may be encountered more easily, reducing set-up times.

- For the purposes of presentation/company visits it is very impressive to see the actual system in operation and to be able to view the result simultaneously.

- In situations where extra data from other components of the system were required, the incorporation of extra sensors was required, thus requiring the services of a PC for signal verification.

Test Type Description	**Number of Sensors (Analogue)**	**Number of NetDAQs**
Single trailer, single temperature test	42	3
Single trailer, two compartment test	46	3
Single trailer, three compartment test	50	3
Head to Head trailer, single temperature test	80	4
Head to Head trailer, two compartment test	88	5
Head to Head trailer, three compartment test	96	5

Table 5.1 Standard Tests

5.2.5 Instrument Integration

The instrumentation's input modules located at the rear of the NetDAQ boxes are removable cartridges that can hold 20 differential ended analogue instrumentation sensor connections. The thermocouples, pressure transducers and the flow meters were all connected to this removable cartridge as seen from figure 5.6. The cartridge was then fitted to a slot at the rear of the NetDAQ to receive information from the connected analogue signals. At the rear of the NetDAQ there was a digital I/O module for connecting the digital single ended inputs from the unit modes (figure 5.7). This module required a ground for operation and was used to acquire information from the various operation modes.

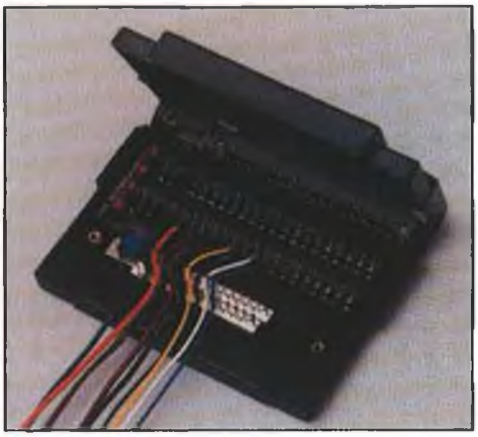

Figure 5.6 NetDAQ Cartridge

Figure 5.7 digital I/O module

5.2.6 CIT Test Software

In this application the software selected was the ThermoDAQ software previously described in chapter 4 section 4.5. This software is ideal for the application, simple to use and falls into the category of 'instant results DAQ and display software'. It has the ability to collect data then export it into a software package such as Microsoft's Excel for data analysis and reporting. Even though the software can't produce real-time graphical representations of the temperature distributions or fuel flow, it was user friendly and required very little software set-up/programming, as was the case with the highly versatile LabVIEW package. This software can be quickly and easily adjusted to suit any test requirement, which is not as easily accomplished with LabVIEW.

The ThermoDAQ display screen of the PC had a separate node for each sensor connected. This node displayed the value of the quantity being recorded i.e. for a thermocouple the value being received was in ^{0}C and for the flow meter, litres / hour. This data was recorded at different speeds set by the user at the start of each test. Several software templates used in the applications trailer and truck and the wind tunnel testing systems have been presented in chapter 6.

5.2.7 Trailer Test Results, Data Analysis, Presentation and Reports.

When a test was completed the data recorded could be viewed from the ThermoDAQ software or imported to a package such as Microsoft Excel, METLAB or DSP development's DADiSP for analysis. Excel was selected due to its popularity in the engineering world. This is a highly productive package and with the use of Excel's Macro and Visual Basic functions, data reduction and analysis is made simpler. After the data was imported a series of operations were required to extract the useful information so as to understand the test results by simple graphical representations. For each different type of test conducted there was a set procedure for analysing the data, the types of tests carried out. Typical analysis results have been presented in chapter 6.

In the case of a standard single trailer single temperature test the Excel spreadsheet consisted of a column with the recorded time interval, 38 columns for thermocouple values, 1 column for fuel consumption rate values, 3 columns for pressure values and 5 columns for modes of operation values. If the test required the comparison of two refrigeration units simultaneously (Head to Head), then double the information would be recorded. In the case of multi-temperature testing where the trailer was divided up into a number of compartments and the analysis of the test became more complex. The complexity arose from the sizes of the loads i.e. the front compartment may be 5 metres long today but depending on the size of the load it could be 8 or 3 metres next week. For this reason the analysis had to accommodate for every size of compartment possible. In the case of three compartments testing, this became even more complex and increased the number of possible compartment size configurations.

The number of different data analysis configurations had to be flexible in order to cover all possible test configurations (for different tests a different data analysis procedure had to be taken).

In the primary stages Excel macros were used to automate data analysis procedures, but with the large number of different tests possible it was not a viable solution. An Excel based Visual Basic program was developed specifically for this application. A custom button was placed on a toolbar of the Excel program. By initiating this new test button, a number of dialog boxes would appear with a number of options to describing the type of test performed. The dialogs allowed compartment sizes to be selected before a series of Macros were run to analyse the test data. Typical test reports can be seen in appendix B. Data management and the generation and use of Macros will be dealt with in more detail in chapter 6.

5.2.8 Benefits of the CIT Environment

- Increased test throughput
- Less maintenance required
- Real time mathematical manipulation is possible
- Tests could be completed with increased efficiency, increased flexibility, improved quality and better data accuracy

- DAQ hardware was a self-contained unit, which simplified connection. (No PC cards had to be fitted to the PC).
- Test control and monitoring was possible form any networked PC.
- The viewing of real-time instrument measurements was possible.
- Data analysis was completed in a matter of seconds after the completion of the test.
- Set-up times for varying test requirements were quick.
- User friendly software tools.
- Standard test procedure drawn up to aid new users (appendix A).
- Adaptable to a large number of trailer test requirements.
- Components within this system were not permanent fixtures and the system was easily adapted for field-testing.

5.2.9 Truck Applications Testing

Truck applications testing was very similar to the trailer applications testing system. The main difference being the number of temperature sensors required to instrument up the truck bodies. The truck bodies were only 7 metres in length as opposed to the 13.6 metre (trailer bodies), it was decided that 20 temperature sensors was adequate for measuring the temperature changes throughout the truck body. They were arranged similar to the arrangement within the trailer bodies, in an 'A and V' configuration at 4 different locations equi-spaced throughout, as can be seen from figure 5.8. The fuel consumption and modes of operation were also important characteristics of the tests. Data analysis, presentation and reporting were carried out in similar ways to the trailer system and the set-up procedures and test reports can be seen in appendix A and B respectively.

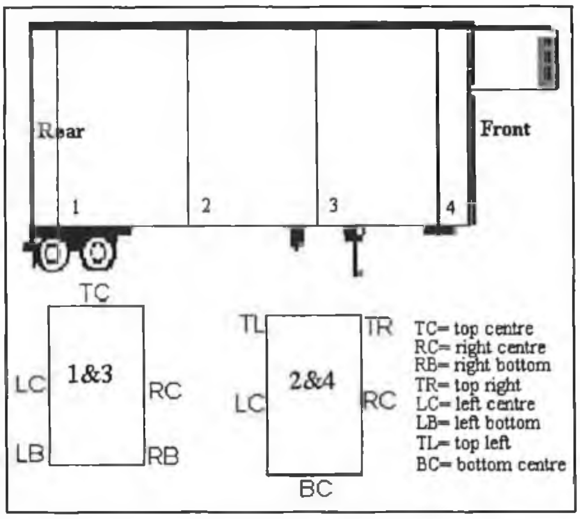

Figure 5.8 Truck Thermocouple Sensor Layout

5.3 Wind Tunnel Testing System

Cooled air from the evaporator of a transport refrigeration unit can be regarded as the final medium, which maintains perishable cargoes at the correct temperature. The rate of airflow determines temperature range in the cargo and also the ability to cool down the produce. Airflow occurs when there is a difference between pressures, air will flow from a region of high pressure to one of low pressure and the bigger the difference the faster the flow. This wind tunnel was designed for the purpose of measuring the pressure against the volumetric airflow of the company's truck and trailer evaporator and condenser blowers along with multi-temperature remote evaporators. This wind tunnel (figure 5.9) was designed and built in Thermo King. It is approximately 3.07m long x 1.5m wide x 0.75m high with an opening at one for the unit to be attached. The tunnel was made up of several layers, the first layer being a diffuser section. These sections can be seen clearly from figure 5.10.

The use of perforated plates as diffusing baffles both upstream and down stream from the nozzles makes it possible to confine the nozzles in a comparatively short duct length. These plates with Ø4mm holes staggered were used to diffuse the stream of air entering the tunnel over the whole area of the nozzles. Next the air passes through a laminator section. The purpose of this section was to create an orderly flow of air through narrow tubes resulting in air flowing in a straight line, this type of flow is called laminar flow and is directly proportional to the driving pressure. This section is made of an 80mm wide series of honeycomb shape sections. The nozzle plate section is next (figure 5.11), of which there are 2 different types.

Figure 5.9 Wind Tunnel in Operation

- Remote evaporator/truck size air flow 3500m^3/hr 6 nozzle plate
- Trailer size air flow 6000m^3/hr 3 nozzle plate

The number of nozzles has to be selected carefully for correct airflow measurements; also the correct plate must be selected and installed. To aid in the selection process of the correct plate and the number of nozzles to use, a small Excel data sheet was drawn up to aid the selection process (see appendix C). A specially machined lid can close off nozzles if required. The flow rate can then be calculated from the pressure differential measured across the set of nozzles.

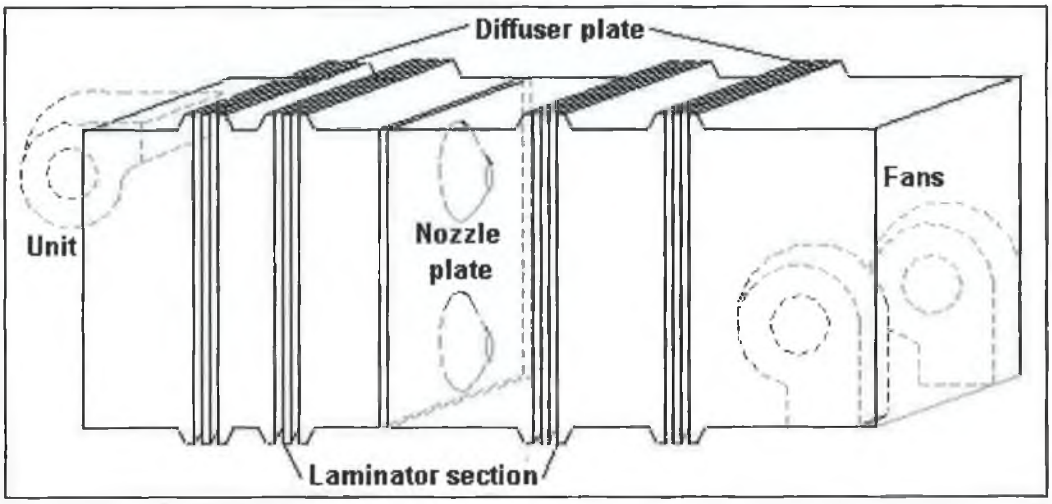

Figure 5.10 Wind Tunnel Construction

Figure 5.11 Nozzle Plate with 6 Nozzles

After the nozzle plate section another laminator and diffuser section are present before meeting the end wall. Two compensation fans were positioned at the base of the end wall (figure 5.12). They were used to build up a static pressure, as a product load would do in a trailer or truck. The compensation fans allowed for fine control of the outlet static pressure, compensating for the pressure drop in the measurement system. The fan frequency ranges from 20 to 55 Hz and in order to take the measurement the frequency must be within range. A damper is fitted to the fans, which allows for coarse control of the airflow.

The wind tunnel was built to the ANSI/ASHRAE standard 51- 1985. This standard was derived to establish uniform methods for laboratory testing of fans and other air moving devices to determine performance in terms of flow rate, pressure, power, air density, speed of rotation, and efficiency, for rating or guarantee purpose. It is the purpose of this standard to specify the testing procedures to be used for design, production, or field-testing.

Figure 5.12 Compensation Fans

5.3.1 How it works

The fan outlet static pressure is set on the inverter, a signal is then sent to the compensation fans to either increase or decrease in speed in an attempt to reach the static pressure set by the inverter. Relative humidity, static pressure at the fan outlet, temperature, atmospheric pressure and the differential pressure across the nozzles are all measured. When the set pressure is reached data is recorded using the snapshot function on the ThermoDAQ software (see CIT Wind Tunnel Software Set-up). This function then records one line of data from the sensors at that particular time. Next the static pressure on the inverter is changed and again the fan either increases or decreases in speed to compensate for the change in static pressure, the procedure continuous in this manner until enough data is collected. When the test is completed the airflow rate is calculated from the data recorded and plotted on a graph against the static pressure, which in turn indicates the ability of the unit to cool the cargo.

5.3.2 CIT Wind Tunnel Instrumentation

Several sensors were used to instrument up the wind tunnel, which included the following:

- 2 MBT 5252 Danfoss temperature sensors, capable of measuring temperatures in the range of -50^0C to 200^0C (figure 513).

- 1 Danfoss MBS 331221 pressure transmitter for measuring the atmospheric pressure, this transducer has a range of 0-1.6bar/0-160kPa and an output of 4-20mA (figure 5.14).

- 3 Danfoss MBS7000 differential pressure transmitters for measuring the pressure across the nozzles and for measuring the static pressure at the fan outlet (figure 5.15).

- 1 Status Instruments SEM164 humidity sensor, with a range of 0-100% RH and an output of 4-20 mA (figure 5.16).

Figure 5.13 MBT 5252 Temperature Sensor

Figure 5.14 MBS 7000 Pressure Transmitter

Figure 5.15 MBS 331221 Pressure Transmitter

Figure 5.16 SEM164 Humidity Sensor

5.3.3 CIT Wind Tunnel Data Acquisition Hardware Set-up

The DAQ equipment for the wind tunnel consisted of one NetDAQ unit (as previously described in chapter 4 section 4.3). A general purpose PC with a network connection and a network hub were also required. The NetDAQ had 20 analogue channels of which only 7 were required, these are as follows.

Channel 1, atmospheric pressure measured from MBS 331221-pressure transmitter.
Channel 2, fan outlet static pressure measured from MBS 7000 pressure transmitter.
Channel 3, differential pressure on nozzles measured from MBS 7000.
Channel 4, nozzle inlet pressure measured from MBS 7000.
Channel 5, nozzle inlet temperature measured from MBT5252 temperature sensor.
Channel 6, fan inlet temperature measured from MBT5252 temperature sensor.
Channel 7, nozzle inlet relative humidity measured from SEM164 humidity sensor.
Figure 5.17 shows the computer, NetDAQ and inverter used in conjunction with the wind tunnel.

Figure 5.17 PC, NetDAQ and Inverter for Control of Compensation Fans

5.3.4 CIT Wind Tunnel Software Set-up

The software used was the same as that used in the applications testing system, which was the ThermoDAQ software as described in chapter 4 section 4.5. A special function had to be added to this software for testing on the wind tunnel. This function was called the snap shot function. Its purpose was to record one line of data when the snap shot button was clicked. Tests carried out using the wind tunnel were relatively short. The software had the capability to perform mathematical manipulations on the data being acquired, therefore instant flowrates could be achieved. Results of typical tests have been presented in chapter 6 along with the ThermoDAQ software test template.

5.4 Calorimeter Testing System

The calorimeter was built as a calibrated box type chamber/cold room, this chamber, being capable of accommodating a 13.6m trailer. The dimensions of the chamber are as follows:

- Height 5.0m
- Length 17.7m
- Width 5.2m

The chamber is temperature controlled with 150mm thick insulated sidewalls and ceiling and 150mm HD floor. An insulated door was installed at the entrance to the chamber so as the large trailer bodies can be moved in and out accordingly. The false ceiling of the chamber houses the cooler and fans for the system.

This system consists of 4 large 6-cylinder Copeland compressors with a single main cooler and condenser. A Danfoss ADAP-KOOL control system was used to achieve the fine control of the temperature along with 4 additional coolers to achieve fine control close to the condensers in the case of single temperature testing. This system was set-up for use over a range of different test scenarios, testing system performance at ATP, ARI standards.

Multi-temperature testing as shown in figure 5.18 was projected to comprise of 70% of the testing to be carried out. The temperature within the chamber was to vary from –29 to +50^{0}C. Three insulated calorimeter boxes were adopted for multi-temperature calorimeter testing as shown. Box 1 holding the host unit while boxes 2 and 3 hold the separate remote evaporators. In this case the system is set up to test prototype multi-temperature systems and components.

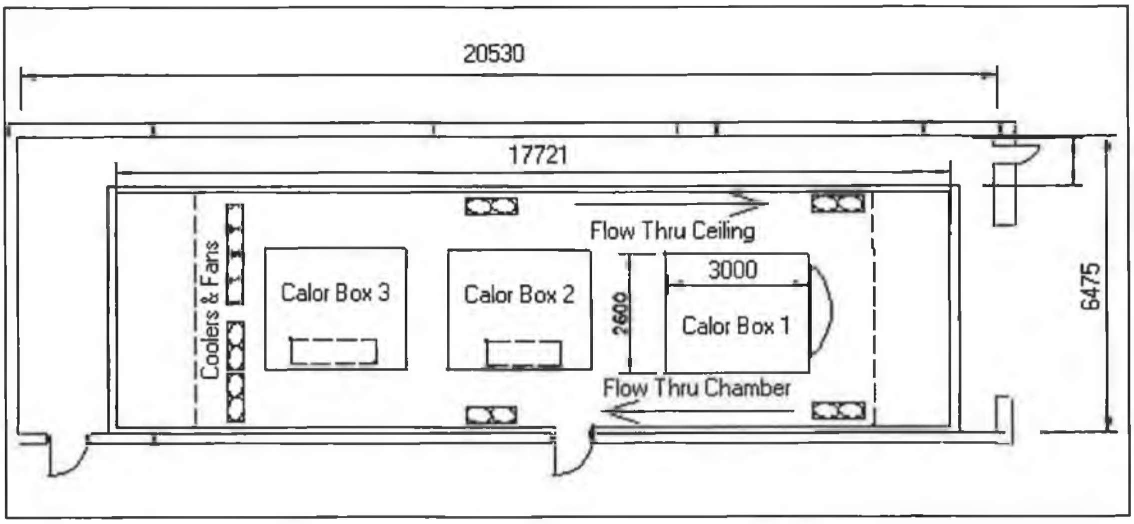

Figure 5.18 Multi-Temperature Calorimeter Testing Layout

Test metrics includes individual capacity, total nominal capacity, capacity availability during multi-temperature operation, heating capacity of evaporators and systems during heat and inversion cycles. Refrigerating capacity is to be measured via load cells in each of the boxes, which are automatically controlled or manually set to achieve specific temperature during measurement of individual and multi-temperature performance respectively. Heating capacity can be measured via airside temperature rise, with wind tunnel measurements in low ambient at constant and rising box temperature and also by airflow estimation.

Single temperature unit performance testing (figure 5.19) was proposed to comprise of approximately 10-20% of the testing to be carried out in the calorimeter. It was thought that 2 units may be tested simultaneously by the use of small coolers to achieve local temperature control. Most tests were to take place on prototype systems and components, test metrics including refrigerating capacity, heating capacity and defrost capacity. The temperature in the chamber would vary from +25 to +50^{0}C. The refrigerating capacity would be measured via automatically controlled load cells in each of the boxes. Heating capacity can be measured by estimation of airflow or by using the wind tunnel in the cells. Defrost could be monitored for variation in capacity and airflow before and after defrost. The temperature in the chamber is to be controlled to achieve target temperature at the condenser air inlet of one unit (master) and to use the local coolers to achieve target temperature of the other unit (slave).

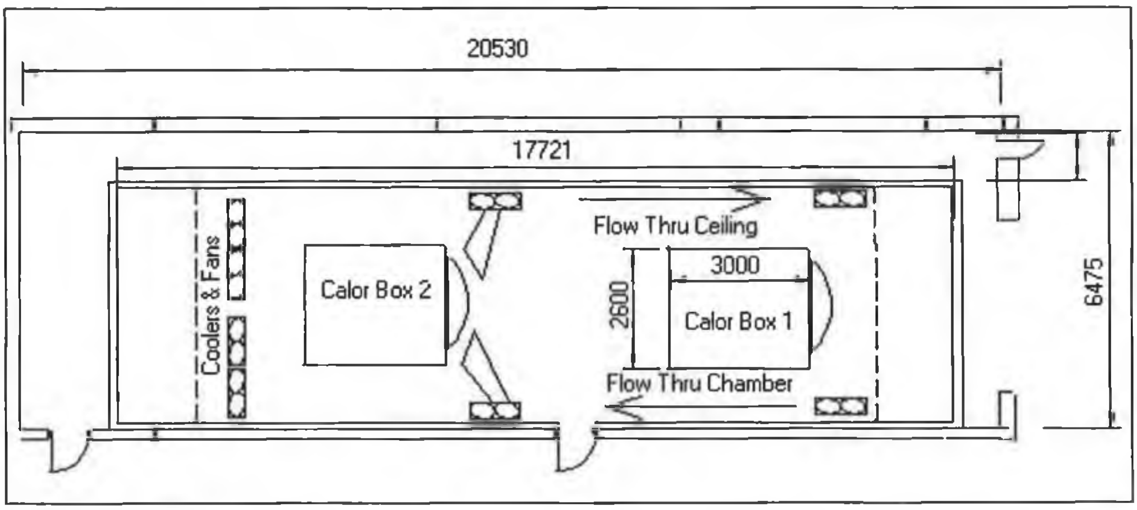

Figure 5.19 Single Temperature Testing Calorimeter Layout

Simulation Trailer/Truck applications testing was to take up 15-20% of testing. The trailer or truck (figure 5.20) would be tested at a controlled ambient of 30 to 50^{0}C or –20 to –29^{0}C in order to validate prototype design and ensure product capability at reduced and elevated temperatures. Test metrics included the test of fuel consumption and temperature management during operation of single or multi-temperature units in extreme and standard conditions.

Temperature control and fuel consumption would be measured using the same procedure as used in applications testing. Instantaneous capacity could be measured by estimation of airflow and temperature change across the evaporator.

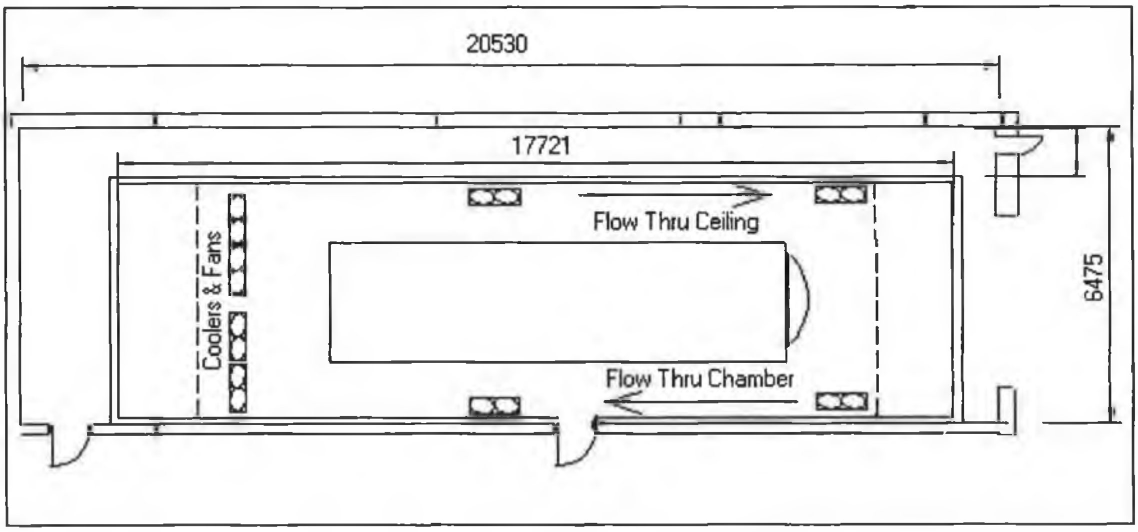

Figure 5.20 Simulation Trailer/Truck Applications Testing

5.4.1 CIT Calorimeter Data Acquisition Hardware Set-up

The DAQ control system was required to monitor and record ambient temperature and condenser air inlet temperature. This measurement defines the test conditions and is relayed from the DAQ module to communicate with the ADAP-KOOL system. The control of the box temperatures inside the calorimeter cells is controlled by the use of a controller module, which monitors the relevant temperatures inside the separate cells and vary the power input to the load cells to achieve the target temperatures.

FieldPoint modular DAQ hardware was used in conjunction with the calorimeter. The FieldPoint modular hardware has been described in chapter 4 section 4.4. From figure 5.21 it can be seen that the DAQ system is made up of twenty-seven FieldPoint modules. These were positioned in a protective case mounted on three lengths of DIN rail. Each length of DIN rail holds one Ethernet network module along with eight terminal bases and I/O modules. The total modular set-up was capable of measuring 192 channels (each module measuring 8 channels); these were divided up as follows:

- 20 (FP-TC-120) 8 channel thermocouple input modules for thermocouple types J, K, R, S, T, E, B, N & mV. Resulting in a total of 160 thermocouple-sensing channels. Thermocouple measurements taken with the FP-TC-120 are filtered to remove 50 to 60 Hz noises, self-calibrated, and cold junction compensated. The input signals are digitised using a high-accuracy, 16-bit resolution with a stable voltage reference and built in calibration circuitry. This module uses a cold junction sensor that's embedded in the terminal base for accurate cold-junction compensation. Also an onboard micro-controller compensates and linerises the thermocouple reading to the NIST-90 standard.

- 1 (FP-CTR-500) 8 channel 16-bit counters. This module includes 8 16-bit counters, complimented by four gate inputs and four outputs, that can be configured to operate in a number of different modes. The features of the gate inputs include, external enable/disable counting, any gate can control any or all counters and can be used as general-purpose discrete inputs. The features of the outputs include, toggle or pulse terminal count and they can be used as general-purpose discrete outputs. This module works with 10-30VDC devices.

- 2 (FP-AI-100) 8 channel 12-bit analogue input modules. These can be used to monitor 8 millivolt, volt, or current loop inputs from a variety of sensors and transmitters. This module includes input-output isolation, over-ranging, plug and play operation and onboard diagnostics that ensure installation and maintenance are as trouble-free as possible. Each channel can be configured individually for a number of voltage or current input ranges.

- 1 (FP-AO-200) 8 channel current output module 0-20mA, 4-20mA. This module has eight 0-20mA or 4-20mA analogue output channels, generated using a 12-bit DAC. It has a built in over-ranging capability with an actual full-scale range of 21mA. Each output channel includes a monitoring circuit and LED indicator for open current loop detection. An open circuit or fault on any channel, caused by a broken wire, miss-wiring, or faulty loop power supply, which in turn lights the corresponding LED. This error connection can also be reported to the network module and host software.

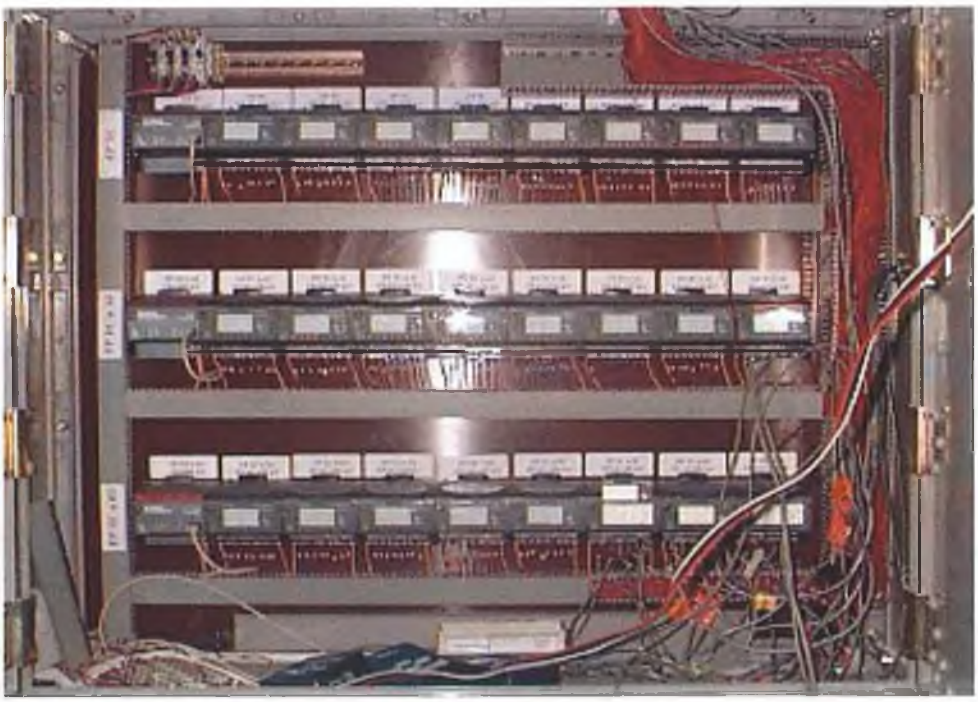

Figure 5.21 FieldPoint DAQ Set-up for Calorimeter

- FP-TB-1 terminal bases were used, which is a general-purpose terminal base suitable for any I/O module. Twenty-four terminal bases in total were required for the set-up, each base having 36 screw terminals.

- FP-1600 Ethernet network modules are connected to the network for signal transportation purposes. Up to nine modules can be connected to a high-speed Ethernet network via each FP-1600 network module. The module has up to 100Mb/s data communication rates to deliver high performance network connection. It manages communications between the host PC and the modules via a local high-speed bus formed by the terminal bases.

5.4.2 CIT Calorimeter Instrumentation

The instrumentation used in conjunction with the calorimeter is similar to those described in the applications testing system, which includes a flow meter for fuel measurement, thermocouples for temperature measurement and pressure Transducers for pressure measurement.

5.4.3 CIT Calorimeter Software Set-up

LabVIEW was selected as the primary software for control and monitoring of the DAQ process. The main advantage of LabVIEW over the ThermoDAQ software package is that real-time graphical and pictorial representations can be achieved. With this package dedicated programs can be developed to suit any environment, and it can control outputs from the system to maintain constant chamber temperatures. Programs can be developed quickly to suit any test requirement. They can also be adjusted or adapted to similar test situations. The LabVIEW development environment works well with the FieldPoint hardware as they are both products of the National Instruments Corporation. LabVIEW has been dealt with in detail in chapter 4, outlining the main characteristics of the package and the many advantages that can be attributed to using it. Visual interfaces created for the calorimeter CIT system using LabVIEW have been described in chapter 6.

CHAPTER 6 DATA ANALYSIS, PRESENTATION & MANAGEMENT

6.1 Introduction

This chapter will focus on data analysis, which covers the areas of data reduction and presentation. The primary tools of data analysis are process monitoring, mathematical manipulation and statistical analysis. Programming languages, graphical representations, spreadsheets, Macros, Visual Basic, development environment packages such as LabVIEW along off-the-shelf software packages are also discussed. Present research focuses on the use of Excel and its associated functions, which are important in the analysis of results gathered throughout this program. Examples of software screen displays and control functions are also dealt with in this chapter.

6.2 Characteristics of Experimental Data

Measurements made during a test generate raw data, which must be recorded, presented and analysed. There is a need to display numerical data in a way that helps analysis of the data. It is helpful to be able to view the data as a whole so as trends such as the existence of linear relationships can be identified. A tabular representation is a desirable way to present data and aid in the manipulation process, while a graph offers a pictorial representation. A number of questions to consider when gathering data are:

What units are associated with each measurement? The unit of measurement needs to be clearly defined, because if a particular test was repeated in different laboratories they could be compared with the original results. The SI system of units is perhaps the most widely used system of units.

How much variability is there in the data?
Can the size of a quantity be estimated before it is measured?
What should be included in the table of data?

6.3 Graphical/ Pictorial Representations of Data

"The advantages of pictorial presentations of data are that it gets over the essential facts very quickly and creates an impact. For large amounts of data it is a good way for indicating trends" [63] (Mazda Fraidoon, 1998). The ability to take in information when it is presented in a picture far outreaches our ability to interpret large amounts of numerical data. When data is represented pictorially, trends can be detected more easily, this is particularly true when tests consists of hundreds and thousands rows of data, which is common when a computer is used to gather data. Therefor a pictorial view of data in the form of graphs is an excellent way to present data. A graph will indicate the following:

- The range of measurements made.
- The uncertainty of each measurement.
- The existence of absence of a trend in the data gathered.
- Which data points did not follow the general trend exhibited?

6.4 Dealing with Uncertainties

All tests have at least one thing in common and that is that each measurement made is subject to experimental uncertainty. When the term uncertainty arises it refers to the level of repeatability that is possible e.g. if repeated measurements of a particular quantity was taken, most like indications of variations would result. It is possible to reduce uncertainty but impossible to completely eliminate it.

Uncertainty in a single measurement

Mistakes are often made in recording a measurement, so if there is only one measurement of a quantity taken, a high degree of confidence has to be relied upon in that measurement. In order to cut down the degree of uncertainty the measurement should be taken again to ensure that the measured value is correct. But there are cases were it is difficult to make repeated measurements of a quantity, e.g. when a quantity changes with time. In these situations it may have to be acceptable that a single measurement in the best that can be done.

Calibration uncertainty

Instruments that are used in laboratories have been calibrated against a standard and sometimes come with a calibration certificate. If engineers around the world need to compare their measurements they have to be sure that their instruments agree on what is a metre, a volt, a second or whatever is being measured.

6.5 Statistical Approach to Variability in Data

Statistics can be described as the science of assembling, organising and interpreting numerical data and so is an ideal tool for assisting in the analysis of experimental data. It is possible to adapt an approach of basing the determination of the uncertainty in a quantity on the spread of data obtained through repeated measurements of a quantity, and not be concerned with assessing the uncertainties in individual measurements. This approach is valid when we have made sufficient measurements to satisfactorily describe the spread in data due to random uncertainties.

6.6 Spreadsheets in Data Analysis

Spreadsheets can be used to show the results of calculations in graphical as well as numerical form and to allow data to be easily added to and modified. They are mostly used in situations where a computer is used to assist data gathering. Then the data could be transferred to the system for analysis and presentation purposes. Spreadsheets have been available since the early 1980s for microcomputers and since that time they have developed to an extent where they have become very powerful tools for analysing and presenting all forms of scientific and technical data. Excel is one of the most widely recognised spreadsheet packages available today.

6.7 Reporting Results

A report is an important tool in the communication of results and a well-written report can be a vital factor when decisions are made about providing support so that work can continue. Writing a good report requires practice. Actively looking for the strengths and weaknesses in reports written by others is a good way to identify what makes a competent report. A report should be complete but concise, have a logical structure and be easy to read. A report should be written, keeping in mind that persons with differing backgrounds and interests may read it. Some may want to compare experimental methods and results where others may require more basic information such as, what conclusions have been drawn, do they seen reasonable and are they supported by the data.

Structure of a report – report writing requires that all aspects of a test/experiment be reviewed so as a logical and consistent account of the work can be prepared. That layout of the report has a big impact on its clarity; it is usual for a report to be laid out in the following sections.

- Title – the title of the report should be brief and informative.
- Abstract – this is an overview of the test and its findings, it should be brief between 50 and 150 words and avoid the details that a reader will meet in later sections. The goal of an abstract is to get straight to the point by communicating what was done, why it was significant and what the major findings were.
- Introduction – this stage of the report describes the background to the test and the particular goals of the test or set of tests. A reader will get bored if to much detail is given and be confused if to little is given. If the work has followed on from someone else's it is usual to refer to that work. The length of the introduction depends on the report but it is unlikely that it would exceed 20% of the whole report.
- Materials and Methods – this is the main description of how the test was performed and the materials/samples/components used. All-important details especially diagrams need to be included.
- Results – in is not necessary to display all the data obtained in the experiment in this section of the report. Sufficient representative data should be included so that any discussion that follows or conclusions drawn can be seen to be well supported by the data.
- Discussion – this section deals with the interpretation of the results that have been presented. The discussion should focus in the important points of the test otherwise a reader is likely to become lost in a mass of unnecessary detail.
- Conclusion – here a need to refer back to the purpose of the test is necessary, what was the aim of the test and how far did the tests performed go in achieving that aim? If others have carried out similar tests then it is usual to compare results.
- Acknowledgements – tests and experiments in science and engineering are usually co-operative ventures and those who have contributed to the work deserve to be acknowledged.
- Appendices – in long reports, material may have to be included in an appendix. Take for example the derivation of an equation or a computer program written to assist in the analysis of data.

- References – these are an important part of a report in that they give the reader access to information concerning the background to the work, details of similar work completed by others. There are two main methods of giving references in a report. The first is to add a superscript number close to the point at which the reference is relevant. Then in the reference section of the report, consecutive lists of numbers appear. Adjacent to each number is the appropriate reference. The reference is given in a standard form, which includes the name of the authors, the year of publication, the journal or book title and the page number.

6.8 Data Acquisition Software Programs for Presentation and Analysis

The first question that must be raised at this point is whether to write custom software or buy an off-the-shelf package. Custom made software is more expensive in that development time can be weeks or even months. It usually requires the involvement of at least two people, the application expert who knows exactly what the program should be capable of, and the programmer for writing the software. Off-the-shelf software can usually be configured by the application expert, thus reducing development time due to the elimination of communication problems between the expert and the programmer. Table 6.1 shows the relative merits of writing programs versus the off-the-shelf approach.

6.8.1 Off-the-Shelf Software

The majority of application is suited to off-the-shelf programs, the drawback being the high cost of software licenses. Off-the-shelf programs are at their best in the related areas of support cost, modification cost, and risk of obsolescence. If the right software vendor is chosen the user can expect regular upgrades, which should accomplish the following while protecting the investments made in existing application software:

- Fix bugs
- Incorporate new features
- Provide customer support
- Maintain backward compatibility

An area of off-the-shelf software that was traditionally weak was the options available for customisation and flexibility. Most packages now offer developer toolkits for creation of custom features.

Attribute	**Write it**	**Buy it**
Initial cost	Low	High
Cost of subsequent copies	None	Relatively high
Customisation	Infinite	Restricted
Cost to modify	High	Low if desired changes are part of upgrades
Cost of support	High	Low if upgrades address bugs in a timely manner
Customer acceptance	Low	High
Risk of unusable program	High	Low if right vendor is selected
Risk of obsolescence	High	Low if right vendor is selected
Speed	High	Low
Use of system resources	Low	High

Table 6.1 Cost of Writing vs. Buying Software

6.8.2 Custom Software Approach

This may be effective in situations where many versions of the software package are required. The high cost of subsequent copies of off-the-shelf software would outweigh the cost of writing up custom software. Another situation would be in the area of unusual applications where suitable off-the-shelf software could not be located. Another reason to write custom software packages is to minimise the use of system resources, such as processing power and memory. It may be found that custom written programs can perform quite adequately on DOS machines with minimal memory. This can significantly reduce the total cost of the DAQ system. Some common problems associated with custom software include.

- Obsolescence mainly because software must incorporate the latest advances in the field.
- High cost of modification and customer support.

Component software is said to address many of the problems associated with support and modification of custom programs.

6.8.3 Component Software

This software is written with object orientated languages, it tends to be self-documenting and lends itself to standardisation. Component software uses programming languages such as Visual Basic, C++, or Java to create blocks of software, which perform specific functions. Blocks of software can be tested independently of each other, can then be put into a library for later use. Blocks used by one programmer can be used by another to create a software program. A DAQ software program written with component software is essentially a collection of linked blocks of software and because the operation of each block of code has been tested and verified, programming only requires the correct linking of these blocks. Table 6.2 illustrates the advantages of component software over custom software programs.

The latest developments in object component software development for Microsoft environment includes objects based on Microsoft's Component Object Model (COM) and it's distributed extension, DCOM. Formally known as 'Active X Controls' these objects are created with development systems such as Visual Basic, Visual C++, Borland Delphi and Microsoft Internet explorer. All objects are tested within the development system and follow a prescribed specification. Active X objects run within Object Linking and Embedding (OLE) control containers and communicate with each other and with other OLE compliant software.

Drawbacks of Custom Software	Component Software Solution
High initial cost	Software blocks written by others for similar applications can be reused; much of the initial programming effort is eliminated
High cost to modify	New component software blocks can be easily added to existing programs.
High cost to support	Can be controlled if original program blocks are tested properly
Low customer acceptance	Brand name development environments such as Visual Basic increase customer acceptance.
High risk of obsolescence	Risk is lessened because new features can be added by adding new blocks of software (assuming the original platform is still viable)

Table 6.2 Advantages of Component Software

6.8.4 Semi-Custom Software

A compromise to custom software development and off-the-shelf software is available. These graphically orientated programming environments consist of a group of function blocks; each dedicated to a DAQ or data manipulation task. The users can connect the function blocks to create applications and also fill in the blanks within each block to configure the software for their specific applications.

Drawing tools along with standard symbols are also provided to create presentation screens. These screens are then linked to function block fields to create animation and live data displays. Table 6.3 shows some of the main differences between semi-custom software option and off-the-shelf software.

Attribute	**Semi-Custom**	**Off-the-Shelf**
Cost per range of functions	Low	High
Cost of customising for application	Moderate	Low
Ease of use	Moderate	Very easy
Customer acceptance	Moderate	High
Risk of obsolescence	Moderate	Low
Speed	Slow	Moderate
Use of hardware options	High	Moderate

Table 6.3 Semi-Custom Development vs. Off-the-Shelf Packages

6.9 Primary Data Analysis Techniques

The primary data analysis techniques include Process Monitoring, Mathematical Manipulation and Statistical Analysis.

6.9.1 Process Monitoring

Process monitoring can be regarded as the simplest and most widely used data analysis techniques. Typical examples include:

- Monitoring the setpoint, the output.
- Plotting one analogue variable against another analogue variable.
- Comparing sets of measured variables to desired results.

This method is typically used in process industries to analyse the continuous production of various products. At the most basic of levels, software systems replace functions previously performed by panel instruments. This is accomplished by the creation of a numerical or graphical representation of the panel instrument and this is the basic function of virtually all process monitoring software. It offers a function of storing the displayed data for later analysis. New methods of data visualisation can be implemented to create physical representations of plant processes. For example the level of a liquid in a tank can be shown to rise or fall based on an analogue variable being recorded. Another powerful technique given with process monitoring software is the imitation of specialised laboratory instruments such as oscilloscopes. Software can be used along with a PC to create a virtual instrument capable of equalling its world counterpart. The virtual instrument can simultaneously imitate many different types of instruments resulting in substantial cost savings.

6.9.2 Mathematical Manipulation

Analysis of data often requires the derivation of mathematical relationships. Many software packages are available to perform these types of functions but most of these programs are not capable of DAQ, they only perform data analysis and presentation. They are designed to work in conjunction with DAQ programs and tend to be used not only for analysis of collected data but also for off line analysis of entered or stored data. This type of program can perform calculations on either real-time data or stored data and multiple channels of data can be plotted against time. Most programs support standard mathematical calculations of arithmetic, trigonometric, calculus, logic, correlation, and basic statistical functions.

6.9.3 Statistical Analysis

This type of software in widely used in industrial applications for Statistical Process Control (SPC), quality control, and quality acceptance. The software programs analyse the data to derive information with respect to the statistical relationships between or among data points. The most common functions include the derivation of the mean, standard deviation, range, moving average and the cumulative sum. Other statistical functions include chi-squared analysis, single variable regression, multiple linear regression, correlation, pareto analysis, distribution analysis and random number generation. Many charts can also be generated with this type of software such as x bar, histograms and probability plots.

6.10 LabVIEW Implementation & the Calorimeter Testing System

As mentioned in chapter 4 LabVIEW was selected as the application software for the calorimeter CIT system. Figures 6.1 and 6.2 show some of the software developments to date. Representations can be developed to monitor any features required. The interface in figure 6.1 shows several features including real-time graphs, a series of soft controls in the form of virtual switches, buttons and adjustable markers.

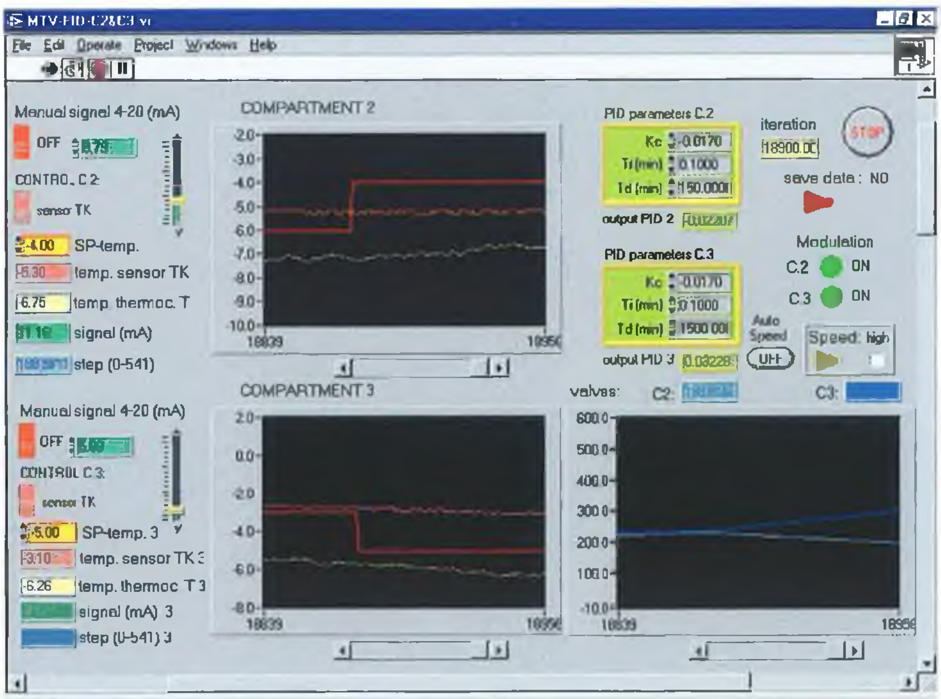

Figure 6.1 LabVIEW Graphical Interface for Calorimeter CIT System

Figure 6.2 shows a LabVIEW interface developed for a 3-compartment multi-temperature test. Again similar controls and graphs have been incorporated and the overall solution promotes a user-friendly environment. When the test is completed the data recorded can be easily exported to Excel for analysis.

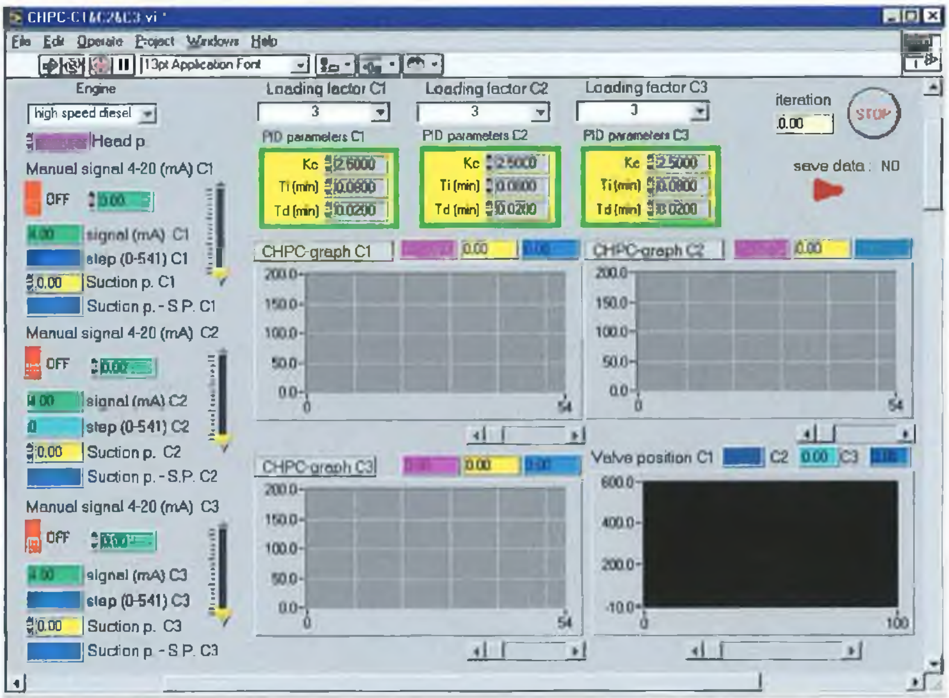

Figure 6.2 Three Compartment Multi-Temperature Calorimeter Test

The logic that controls the actions and motions of the interface is represented behind the screen built with the use of block diagrams as shown in figure 6.3.

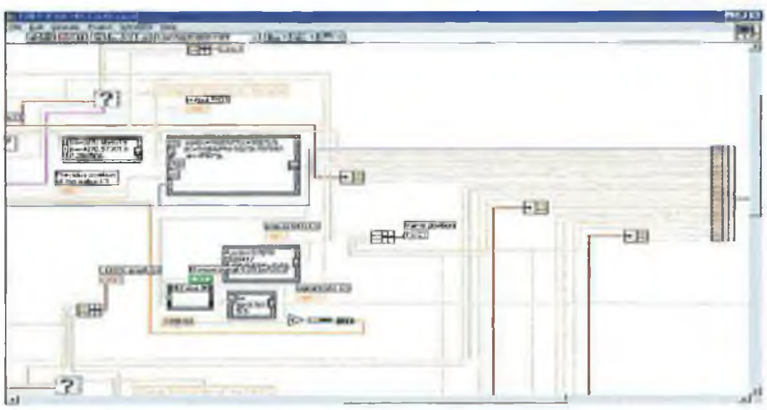

Figure 6.3 Block Diagrams

6.11 CIT Software Template Set-ups for Applications & Wind Tunnel Systems

The generation of application software test template was of major consideration throughout the duration of the project. The development of new templates was required for each different set of tests. Templates for applications and wind tunnel systems were created using the ThermoDAQ software, which has already been discussed in chapter 4. This software was a custom built package developed for the area of application trailer and truck testing. It had some glitches that had to be addressed before it could totally utilise the features of the DAQ hardware associated with the applications and wind tunnel CIT systems.

Figure 6.4 illustrates a template developed for standard multi-temp head to head tests. It shows two groups of data, which represent sensors located in exactly the same positions on each trailer.

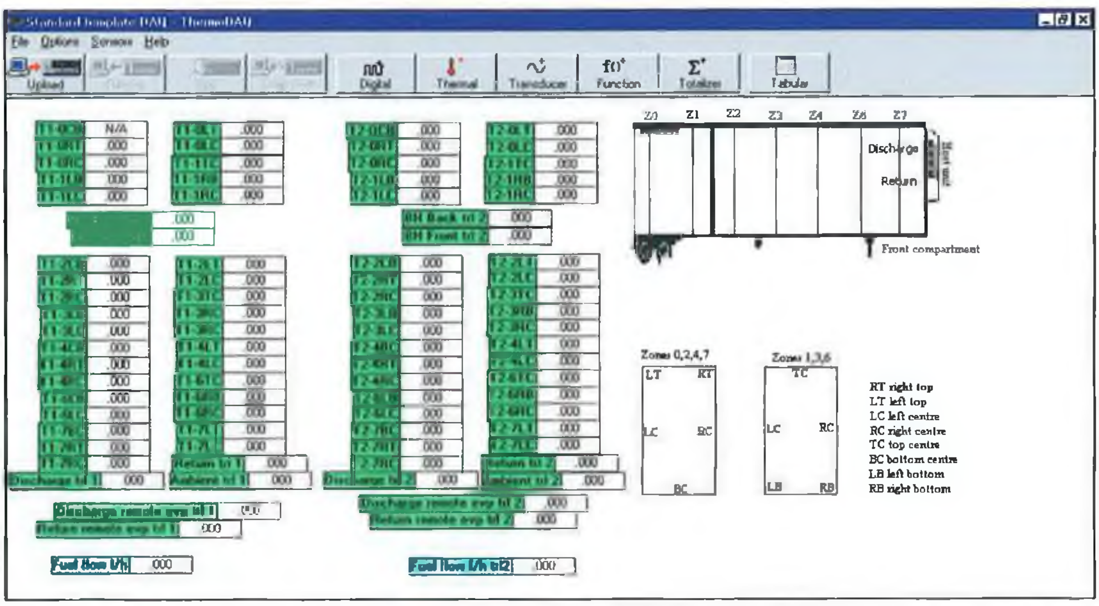

Figure 6.4 Standard Head to Head Template

A schematic diagram can be placed on the interface for presentation and sensor identification purposes. Temperature sensors (green labels) represent the numerous sensors located within the trailer. The NetDAQs contain an isothermal block, which allows for a more accurate temperature measurement readings to be acquired. The blue label indicator near the bottom of the template represents the flow measurement transducer, which measures the rate of fuel consumed in litres per hour.

Figure 6.5 shows a different scenario. This template was developed for a single trailer with 2 compartments, an insulated bulkhead and a remote evaporator unit. The bulkhead divides the trailer in two compartments. The rear compartment contains 5 temperature measuring zones leaving two zones in the front compartment (as seen in the schematic on the interface panel). The main difference between this template and the template shown in figure 6.4 is that pressure transducers were used to record the discharge, suction and throttling pressures. Another difference is the presence of the orange coloured labels. These represent functions of thermal (green) and transducer (blue) labels. E.g. take the orange function label called Zone 0. When the function button on the toolbar is pressed an orange label is inserted on the worksheet. If the label is double clicked a set-up dialog appears (figure 6.6).

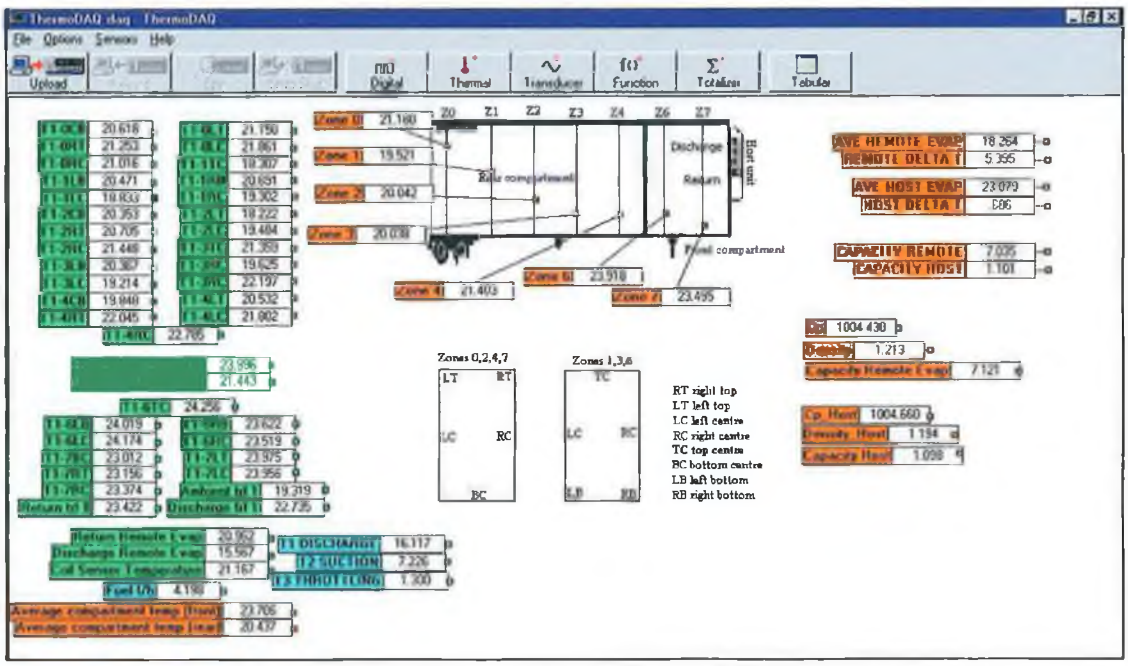

Figure 6.5 Single Trailer 2 Compartment Multi-Temperature Template

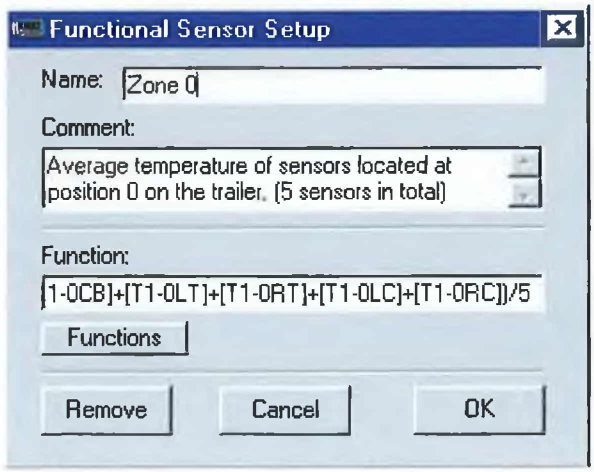

Figure 6.6 Functional Sensor Set-up Dialog

This dialog prompts for a name (Zone 0) a comment (Average temperature of sensors located at position 0 on the trailer. 5 sensors in total) and a function (([T1-0CB]+[T1-0LT]+[T1-0RT]+[T1-0LC]+[T1-0RC])/5). This function is extremely useful as any formula can be inserted or a function can be selected from a list of commonly used functions (figure 6.7). In this case the 5 sensors labelled T1-0CB to T1-0RC are added and divided by 5 to get the average temperature of that zone. This average temperature calculation is completed in real-time so the data can be viewed instantly. In the same way the average of each compartment and the capacity of both the host and remote units can be computed.

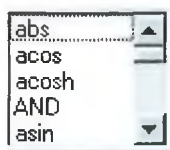

Figure 6.7 Drop-down Menu offering a Range of Commonly used Functions

Another useful feature available with this software is the use of the anchor, which is visible from the interface. It is used to show the location of the sensors as indicated from labels marked Zone 0 to 7.

The next figure (6.8) shows a template developed for head to head truck testing. Here the use of digital I/Os can be seen. The yellow labels represent digital signal inputs, which are very useful and give information in the form of 'on' or 'off' data. They are useful for indicating when a switch or circuit is energised. In this case they were required to transmit information on the units operation modes. E.g. to determine whether the unit was operating in heat/cool, High/Low Speed or Defrost mode. The digital sensor set-up dialog shown in the ThermoDAQ Software section (chapter 4) allows for the user to input preferred display names such as HIGH, LOW, HEAT, COOL, or DEFROST as was done in this case.

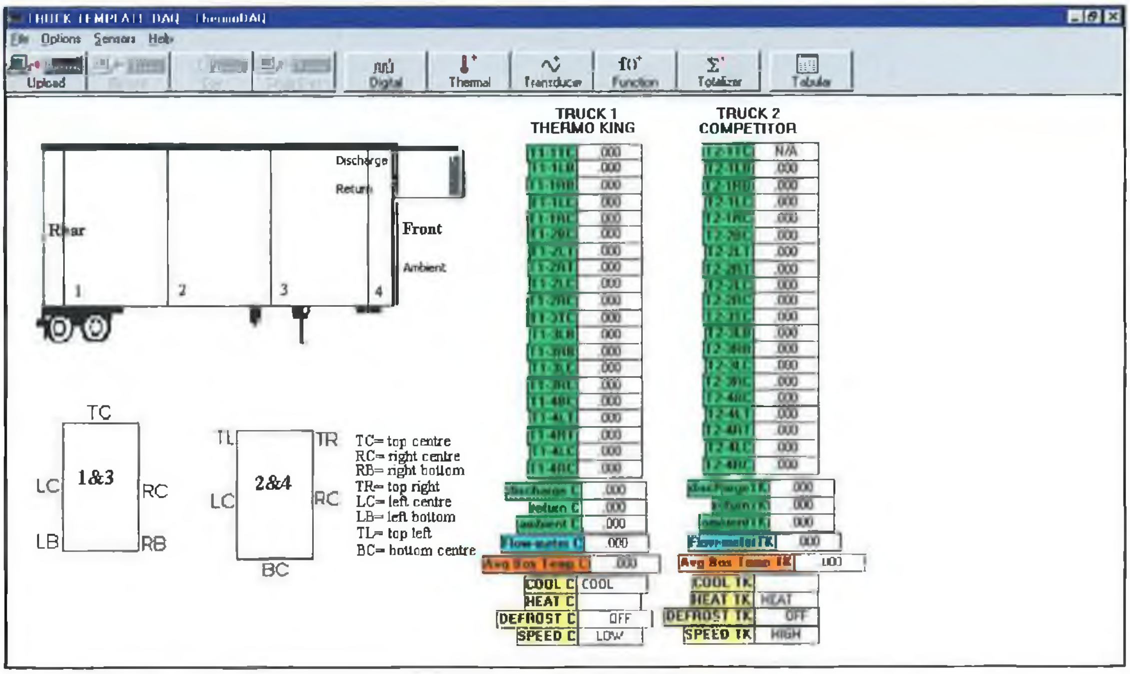

Figure 6.8 Head to Head Truck Test Template

The next template (figure 6.9) shows a ThermoDAQ interface developed for a field test. This particular field test was carried out over seas for a major food distribution centre. It was a head to head test of a Thermo King unit against its nearest competitor unit. The set of tests required a multi-temperature set-up with 3 compartments in each trailer body. As the schematic on the interface shows each trailer required two remote evaporators and two insulated bulkheads. Again the project involvement concentrated on the CIT system set-up, which included data acquisition and sensor integration, PC set-up, application software (ThermoDAQ) template development, instrumentation set-up and operation, test control, monitoring, data analysis, presentation and reporting. This particular test required the use of 12 thermocouple sensors positioned inside each of the trailer bodies (4 in each compartment). A sensor for measuring ambient temperatures along with discharge and return air temperatures of both the host and remote evaporator units were also required. The fuel consumed was also a critical measurement requirement in the test.

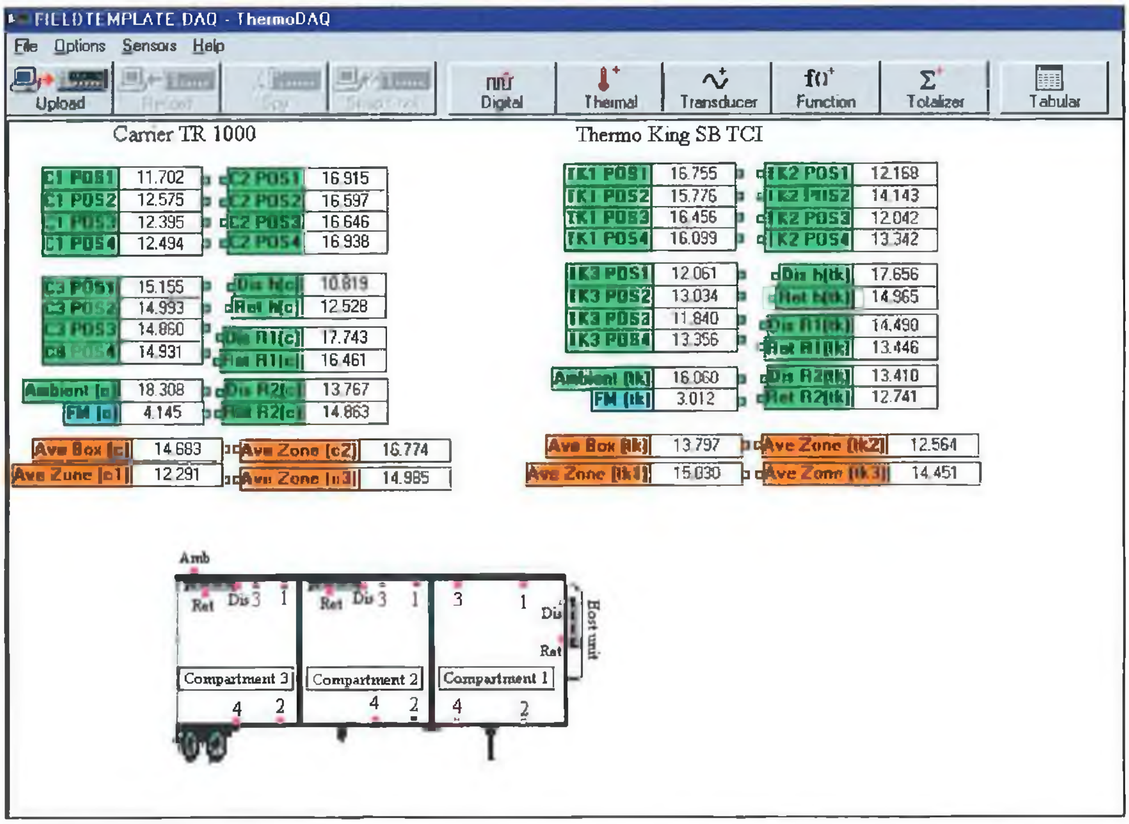

Figure 6.9 Head to Head 3 Compartment Multi-Temperature Field Test Template

Templates generated for wind tunnel tests are somewhat different as can be seen from figure 6.10. The template shows the use of a number of transducers collecting information from various positions on the wind tunnel. In order to calculate the airflow of the unit under test a number of functions were added to the interface.

Formulas and constants were then added into these functions to calculate the resulting airflow. This template is adequate for any test performed on the wind tunnel as the same result is sought each time a test is performed.

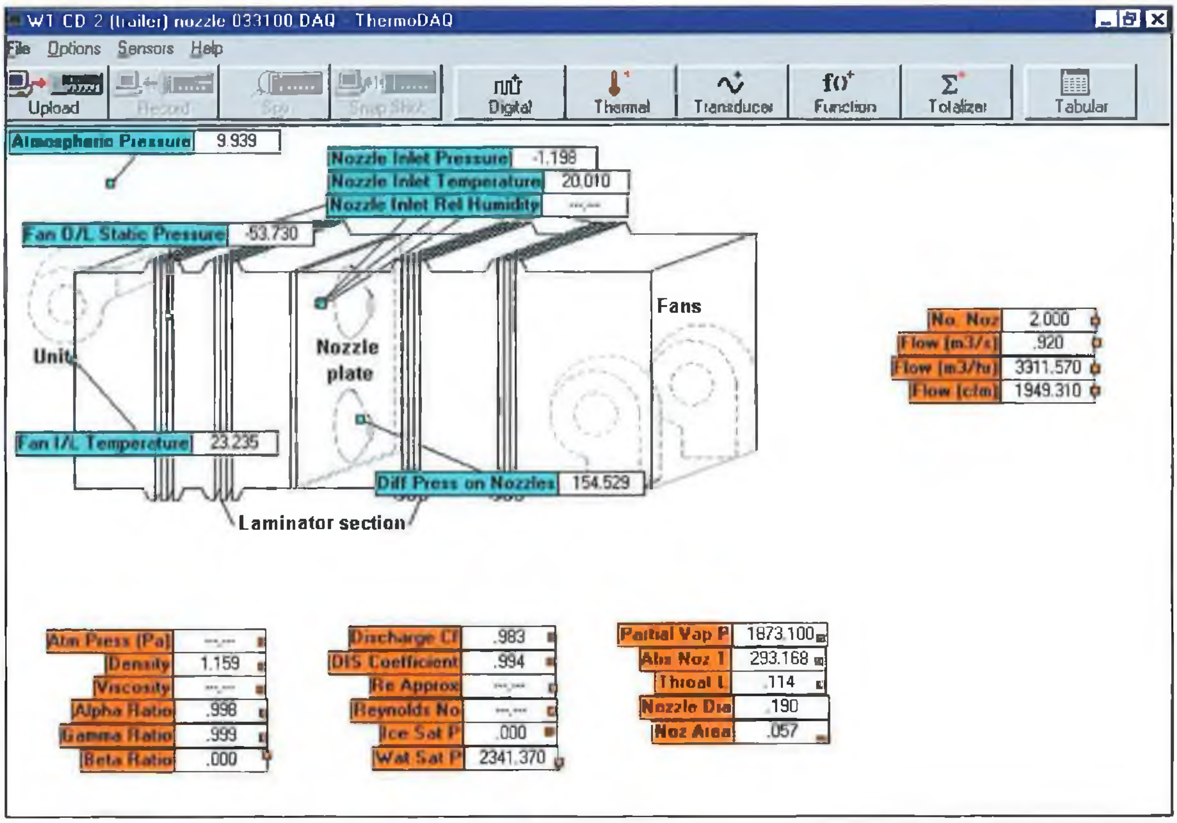

Figure 6.10 Standard Wind Tunnel Software Template

6.12 Data Analysis Using Microsoft Excel & Macros

"Microsoft Excel is a powerful spreadsheet program that can be used to efficiently store and work with lists of data, calculate numbers, and create reports and charts" [64] (Catapult Inc, 1997). Microsoft Excel is probably the most widely used spreadsheet program in the western world. A brief introduction to the features of Excel is the best way of understanding what it is and the purposes for which it is used.

The file that is used too save work completed in Excel is called a workbook, which contains worksheets, chart sheets and Macro sheets. Worksheets are made up of cells, which are addressed in the form of rows and columns. Data must be entered into the cells of the worksheet before the desired analysis of the data can be performed with the use of menu commands and dialog boxes. Charts can be added to the workbook, graphically representing data on the cells of the worksheets. A worksheet can contain text, numbers, formulas, and embedded charts. When analysing data it is often convenient to display an embedded chart on the same worksheet containing the data. Alternatively charts can be put on a separate sheet in the workbook. Excel can be used to create a number of basic chart types such as bar and column charts, pie charts, line charts, XY scatter charts, area charts, doughnut charts, radar charts, surface charts, bubble charts, stock charts, cylinder charts, cone charts and pyramid charts.

Macro sheets in Excel contain Visual Basic for Application (VBA) code and are called module sheets. This VBA code can be created manually by typing or automatically by recording actions that are taken using Excel.

Excel has three analysis tools useful for summarising single-variable data. The descriptive statistics analysis tool provides measures of central tendency, variability, and skew-ness. The histogram analysis tool provides a frequency distribution table, cumulative frequencies, and the histogram column chart. The rank and percentile analysis tool produces a table with the original data sorted in ascending order with rank numbers and percentiles. These tools are appropriate for data without a time dimension. For data collected over time, the time sequence plot of the data must be examined to detect patterns.

6.12.1 Data Analysis of CIT Environment Data

As mentioned in the previous chapter, data was acquired via the DAQ hardware and software before being transported to a PC through a network. All DAQ software offers the export option so as data can be exported to a spreadsheet program such as Excel for analysis. The data at this stage is in its most basic (raw) form and is not easily interpreted by viewing the various cells of numerical information. To extract useful information from the data, it must be analysed. Analysing the data means manipulating it to extract the useful information. This is accomplished by:

- Performing mathematical manipulations.
- Creating graphical representations of trends found in the data.
- Creating data sheets to show results found.
- Highlighting or extracting important pieces or groups of data and placing them on a data sheet.

This was a lengthy process as each test carried out usually lasted between 6 to 8 hours, which was represented on a spreadsheet by 1440 to 1920 rows of data, data being logged every 15 seconds. In cases where shorter logging intervals were used the task became more difficult and sometimes confusing.

The applications testing system was a very good area to concentrate data analysis on because of the variations that were present in each series of tests performed. Test variations required slightly different instrumentation set-ups, which resulted in sometimes more or less sensors being used to monitor the system. Tests such as single temperature testing on a single trailer/truck unit, varied from similar tests on situations carried out using two trailer/truck units simultaneously, in that twice as many sensors were required, thus doubling the information to be analysed. Multi-temperature testing variations provided more complex possibilities. Two or three compartment tests were carried out with compartment sizes varying from test to test. Also two multi-temperature trailer/truck units tested simultaneously had to be considered.

Each series of test carried out could last from 2 days up to 3 weeks depending in the importance and amount of information required. Therefore data analysis procedures changed regularly. Macros were introduced into the area of data analysis in an attempt to automate the process of data reduction/presentation (analysis). Macros were written/recorded for analysis requirements at the beginning of each series of test. These Macros significantly reduced the time spent on analysing the large amounts of data. They were produced to sort the data, perform important calculations, produce a data sheet for each test detailing the results of the test, and produce a number of graphical representations showing all trend variations throughout the duration of the test. These Macros worked very well and after an 8 hour test the data could be analysed in a matter of seconds, which eliminated the need for the manual analysis of the data, which in some cases could take up to 2 hours. Typical results obtained from the various tests can be seen towards the end of this chapter.

6.12.2 Visual Basic Based Super Macro

Visual Basic can be described as a development environment that enables the user to focus on the problem in hand rather than the technical complications of programming in a Windows environment. Visual Basic has also been described as "a super power tool that can be used to create Windows applications" [65] (Bob & Karl Albrecht, 1996). It is essentially used to create visual interfaces that look and feel like those that are seen everyday in ordinary Windows applications. Code can be written to make the visual interface respond to users the way that the programmer wants it to respond. It has been suggested that the Visual Basic development cycle can be accomplished by following some simple instructions [66] (Wallace Wang, 1994). The Visual Basic development cycle is as follows:

1. Decide what you want the computer to do.
2. Decide how the program will look on the user interface.

3. Draw the user interface using common parts such as Windows menus and command buttons, these parts of the user interface are called objects or controls.
4. Define the name, colour, size and appearance of your user interface objects, an objects characteristics are called its properties.
5. Write instructions in basic code to make each part of the program do what is required, these basic instructions are called commands.
6. Run the program.
7. Look for any bugs if it does not work correctly.

"In 1996, National Instruments introduced Component Works, a set of Active X controls to simplify the development of measurement and automation applications. Today, these Component Works controls have become a component of Measurement Studio designed specifically for Visual Basic users" [67] (Jeff Laney, 2000). Active X controls being used for extending Visual Basic programs. With Measurement Studio it is possible to take advantage of the power, flexibility and connectivity of the Visual Basic development environment and provides a set of Active X controls for producing complex measurement and automation applications.

In the present research, Macros worked very well with the applications testing and could be easily adaptable to calorimeter testing. But there was a need for a standard Macro that could handle any test situation in the applications trailer and truck testing area, keeping in mind adaptability to calorimeter testing situations.

Before this Macro could be written, tests had to be standardised with a degree of flexibility for performing small variations if the need arose. These standard tests were mentioned in the previous chapter, to recap they are as follows:

- Single trailer, single temperature tests.
- Head to head, single temperature tests.
- Single trailer, 2 compartment tests.

- Head to head, 2 compartment tests.
- Single trailer, 3 compartment tests.
- Head to head, 3 compartment tests.

With two and three compartment tests, the number of different compartment size variations introduced a degree of complexity into the analysis. This was the major difficulty in generating the super Macro. For example a two-compartment trailer body with a front compartment size of 8m leaves 5.6 m in the rear. In this situation the front compartment has 20 temperature sensors measuring the changing temperature values leaving 15 sensors in the rear compartment. The complexity now arises when the sizes of the compartments are changed. The number of sensors in the compartment may change requiring the manipulation of different data at the analysis stage. In the case of three-compartment testing the process becomes even more complex. After much research and investigation into the best way of writing up this data analysis program it was decided that a Visual Basic front would be a user friendly and informative solution.

Four dialog boxes were constructed for the data analysis program. Each box consisted of a series of options. The user was given a number of choices to select from, in order to analyse the results that were imported from the DAQ software to Excel. Figure 6.11 is the first dialog box that appears on the screen (floating over the data) when a custom button is selected. A choice of three test types was available to choose from. Each option represents a different type of test performed and when the selection is made another dialog appears with further options to chose from, these options being specifically related to the test type chosen.

Figure 6.11 Visual Basic Interface 'Select the Type of Test' Dialog Box

When a single temperature test is performed the dialog in figure 6.12 appears, offering the option of a single trailer/ temperature test or a double trailer test (Head to Head). Another option offered is the selection of the time interval to which the data was acquired. This final option is required to give a degree of flexibility when performing time dependent automatic mathematical manipulation.

When two- or three-compartment multi-temperature tests are performed, other dialogs appear (figures 6.13 & 6.14). In the case of two-compartment testing the size of the front compartment is required, the remaining compartment size is then determined automatically. A check box was constructed for analysing Head to Head tests and can be clicked on or off when required. The option for time interval is also available in this dialog.

The three-compartment test dialog requires the sizes of the front and middle compartments, before it can automatically determine the size of the rear compartment. Similar to the two-compartment dialog it has a check box for analysing Head to Head test results. Another feature is a small button to check the comp size, which insures that the user selects a correct compartment configuration.

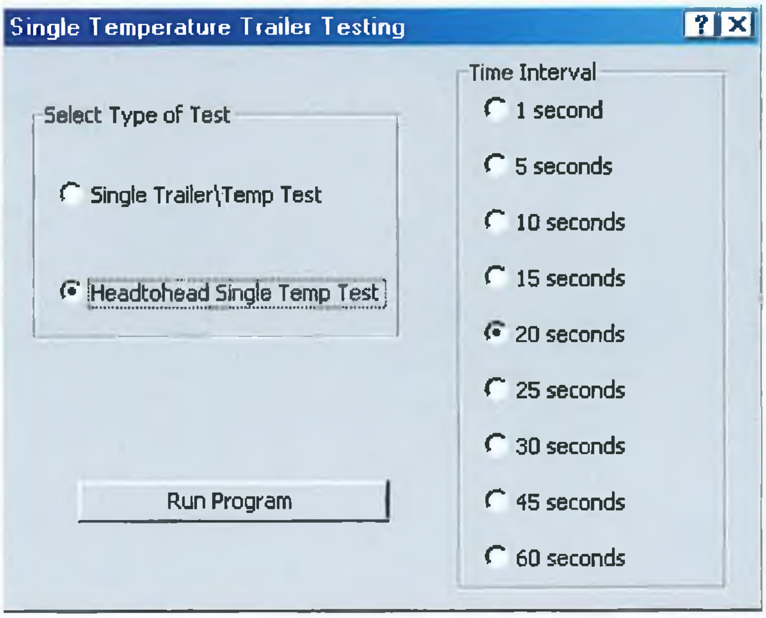

Figure 6.12 Visual Basic Interface 'Single Temp Test Options'

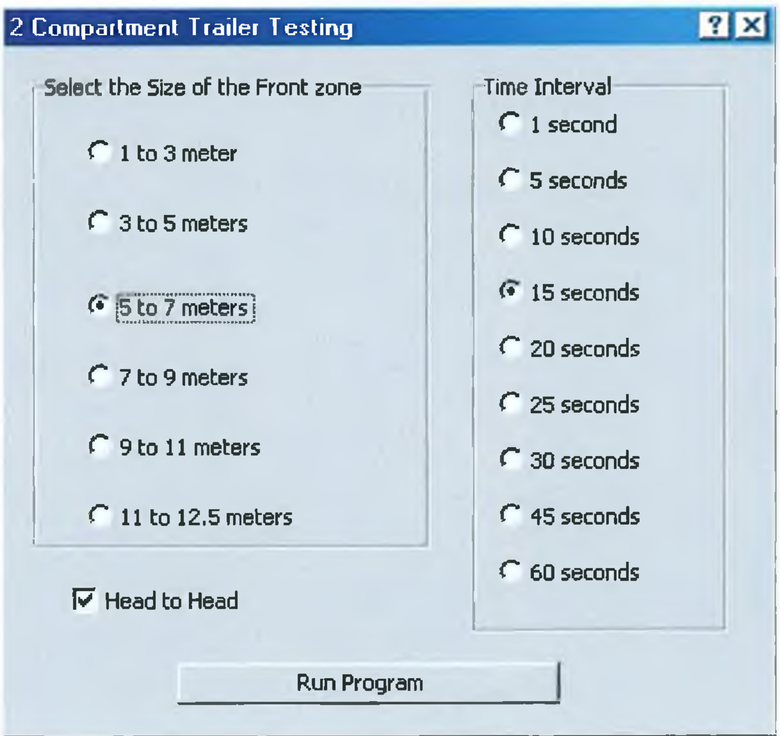

Figure 6.13 Two-Compartment Trailer Tests

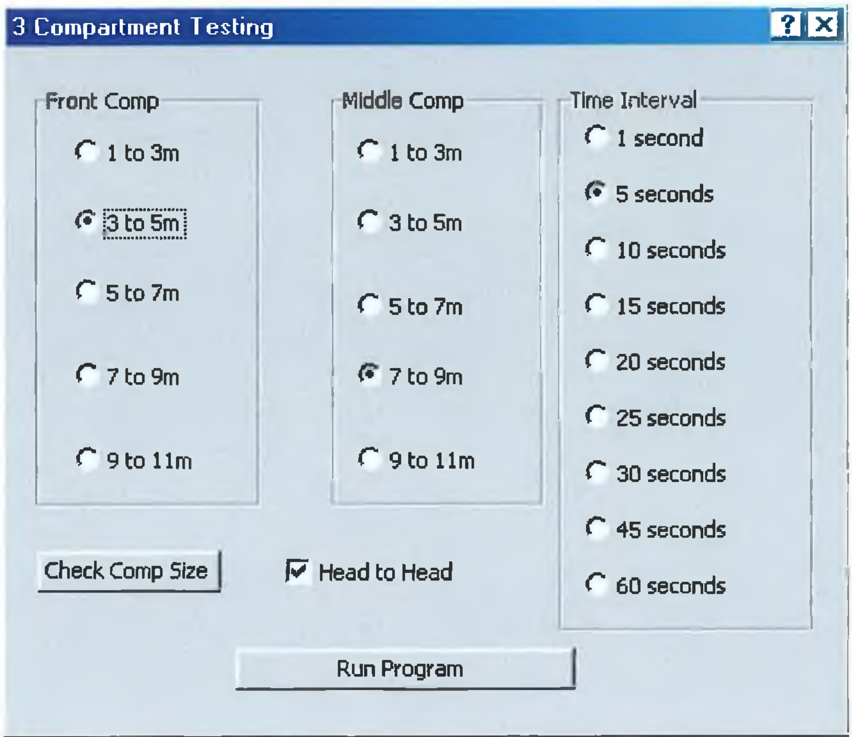

Figure 6.14 Three-Compartment Trailer Tests

Each dialog contains a 'Run Program' button, which can be selected when all other options have been chosen. A series of Macros related to the specific options chosen have been attached to this button. The program runs through the acquired data performing mathematical calculations and generating graphical representations typical to those shown in the following section. The whole procedure only takes a number of minutes to perform significantly reducing analysis time and eliminating the need for generating separate Macro programs for each standard test variation.

6.13 Data Presentation

Typical test results obtained can be seen from the following figures. These show results from a test carried out in the applications trailer and truck, and wind tunnel CIT systems. The first series of figures represent a multi-temperature test involving two refrigeration units. The trailer bodies were divided into 3 equi-spaced compartments, which required the use of 2 insulated bulkheads and two remote evaporator units. The compartment temperatures were set to –20^{0}C in the front, 3^{0}C in the middle and 12^{0}C in the rear compartment. It was a pull-down and maintain, cycle sentry test, which basically involved that the measurement of the units performance to adequately obtain and maintain the set temperatures. Cycle sentry refers to the operation mode of the unit, which programs the unit to switch off when it reaches its set temperature and automatically come back on when the temperature begins to vary from the set point. Figure 6.15 and 6.16 shows the graphical result of a Thermo King unit against its nearest competitors unit tested for a duration of 250 minutes. It illustrates the variation of temperature against time. The temperature is represented by the three lines, one coloured blue for the front compartment with a set-point of –20^{0}C, another coloured red for the middle compartment with a set-point of 3^{0}C and finally one coloured pink for the rear compartment with a set-point of 12^{0}C.

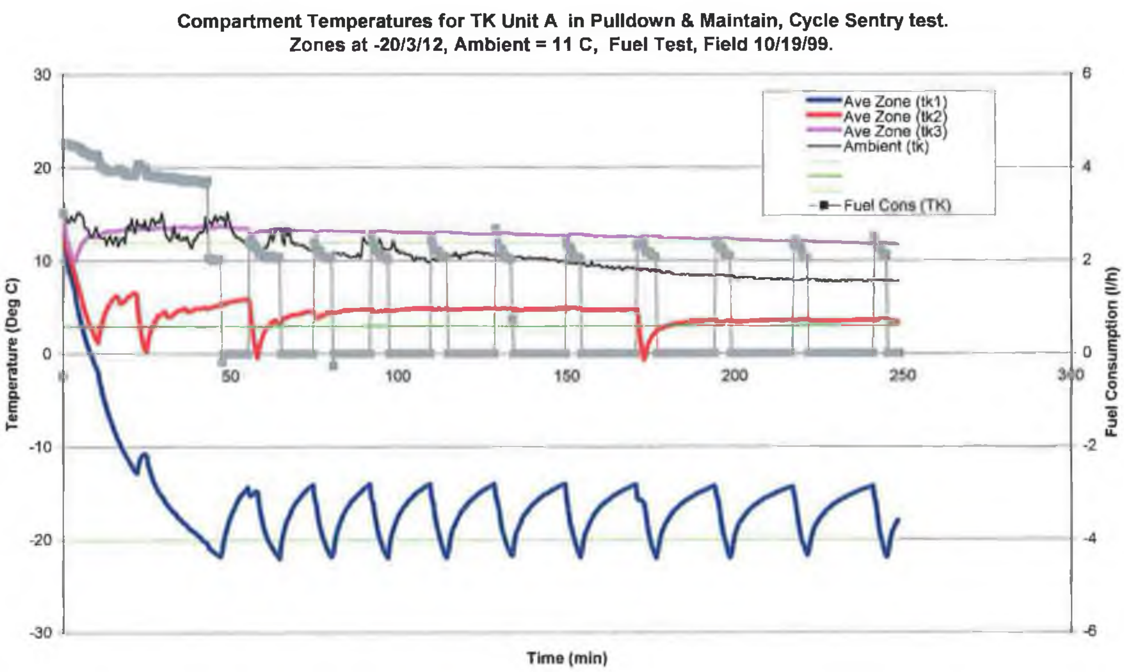

Figure 6.15 Graphical Result for Thermo King, Multi-Temp Trailer Test

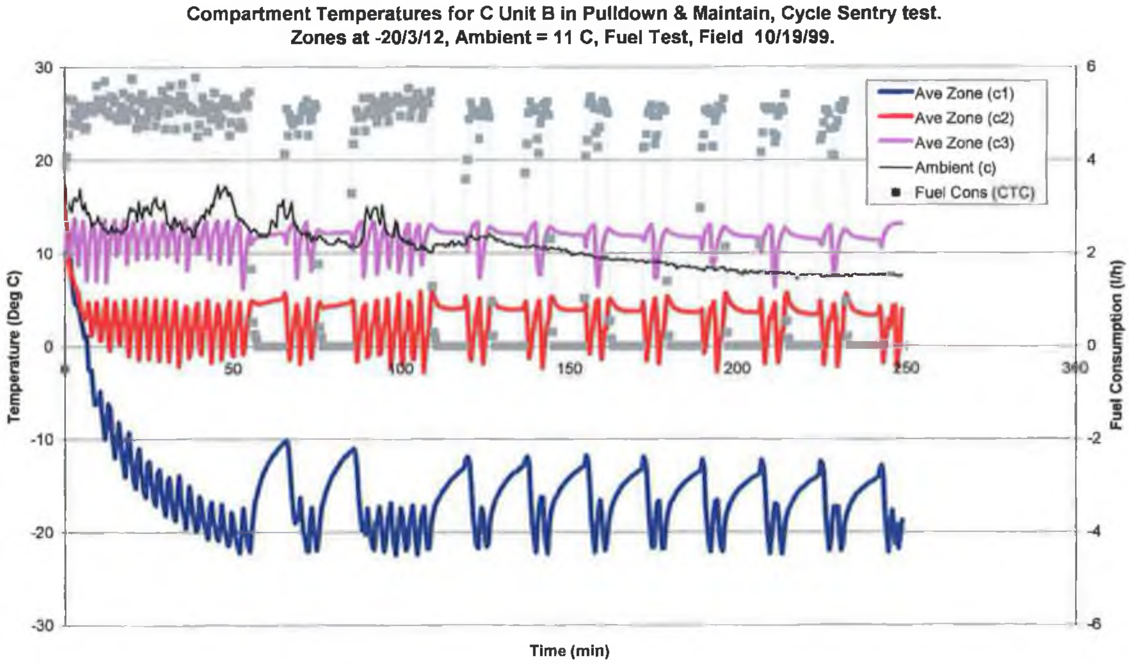

Figure 6.16 Graphical Result for the Competitors, Multi-Temp Trailer Test

An extra axis was added on the left-hand side to represent the fuel consumption rate throughout the test. This was represented on the graph by the presence of a series of grey coloured points. This enabled the identification of when the unit was either in high speed, low speed or switched off by cycle sentry operation.

The chart shown in figure 6.17 shows fuel consumption by itself. This particular test showed that for the test duration the Thermo King unit used 4.99 litres of fuel as compared to 12.38 litres used by the competitors unit.

Another common chart produced (figure 6.18) show a comparison of the temperature distribution throughout the trailer bodies. It shows a representation of the unit's power to provide cool air to all parts of the trailer body. There were many more charts produced to represent different characteristics of tests carried out but the ones shown here are the most commonly used and were generated automatically by the use of Excel Macros.

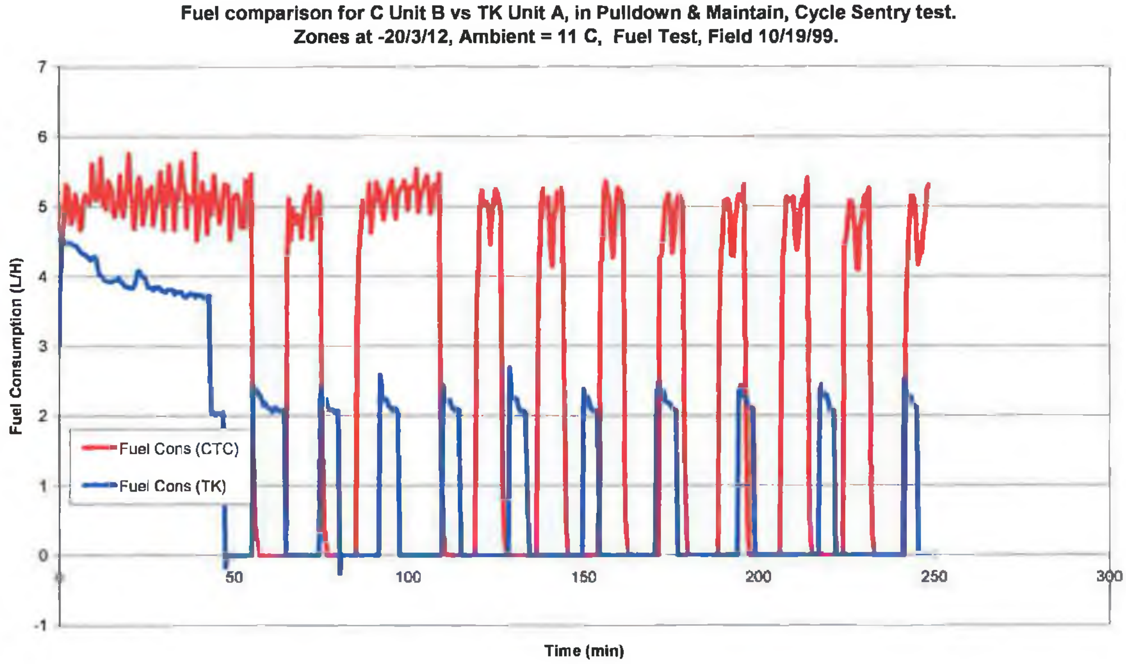

Figure 6.17 Comparison of Fuel Consumption

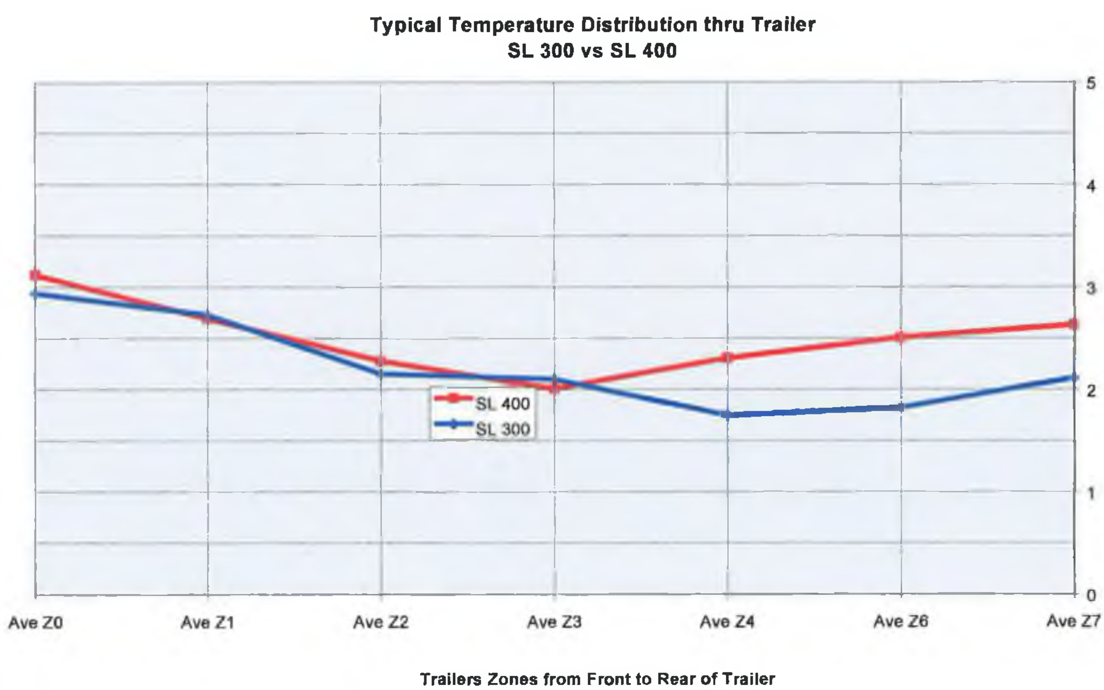

Figure 6.18 Temperature Distribution throughout Trailers

Ave Z7 in figure 6.18 above represents the average temperature of a set of sensors at the front of the trailers and Ave Z0 represents a set at the rear. This graph was constructed from a test completed on two single trailers, comparing two similar TK units.

In addition to the generation of graphical information a data sheet was also automatically produced so as the characteristics of the test could also be recorded. These characteristics included type of test, units types under test, set-points, test duration, total fuel consumed during test as well as the average fuel consumption rate, time to pull down, max min temperature within trailer/compartment and other characteristics related to specific tests performed.

Results obtained from the Wind tunnel testing system were not as complicated and could be represented by a single chart as shown in figure 6.19.

Figure 6.19 Graphical Results of a Wind Tunnel Test carried out on a Truck Unit

This graph shows the fan characteristic for the truck unit operating in low and high speed. This characteristic represents the airflow that the unit is capable of providing under different static loads. These static loads represent the loads being hauled in the truck body. Appendix B shows a standard report for the typical wind tunnel test.

6.14 Data Storage & Retrieval

All files on tests conducted in Thermo King Galway (R & D department) are stored using computer-based methods. This filing system consists of a series of folders stored on the local area network that can be accessed by personnel with adequate authority. Each test completed includes a test request, test report and all data files.

A test request lays out the details of the required test, which includes the purpose of the test, units for test, the name of the requester, the responsible engineers and technicians, test procedures and notes. The test report includes topics such as the requester, test set-up information, main results and the key metrics, analysis and conclusions. These along with the raw and analysed data files are all stored in folders as shown from figure 6.20. These folders are then named to give an indication of the test origin, test area and the units under test. They are named using the following protocol, Test request number – Location of test – Unit under test – General information. Table 6.4 illustrates the type of data used in naming these folders.

Test request number	Sequential number	Tr0001, Tr0002, Tr0003, Tr0004
Location of test	App	Applications trailer and truck testing
	Cal	Calorimeter testing
	WT	Wind tunnel testing
	End	Endurance test, reliability test
	Field	Tests carried out in the field
Unit under test	SL TCi, TS 600, SL 100 Vs SL 300, etc	
General information	Fuel Test, Defrost, etc	

Table 6.4 Protocol for Naming Test Folders

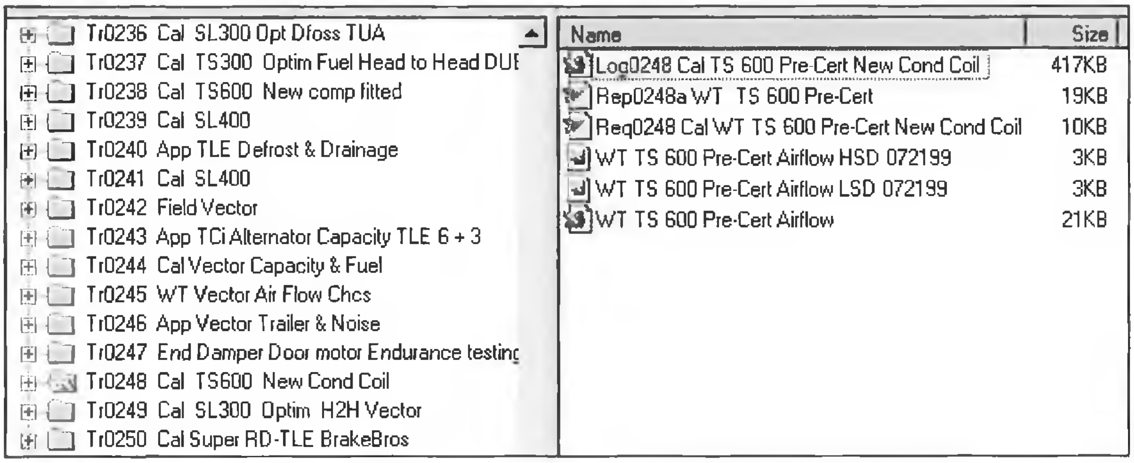

Figure 6.20 Example of file contents for Eng_Test folders.

The aim of this Eng_test computer-based folder directory is mainly to simplify test documentation and report writing, to make test information easier to locate, to promote consistent and standard documentation, to establish test requirements prior to the start of the test and to automate the reporting process for standard tests completed. This is consistent with the aims and objectives of a CIT environment, however improvements to the current method using a Group Technology (GT) type format would make the system more flexible and efficient.

Group Technology is not a new concept [68] (Burbidge, 1975) and can be defined "as bringing together and organising common concepts, principles, problems and tasks to improve productivity" [69] Greene and Sadowski, 1984). GT has also been described as "an extension of batch production in which the factory is organised with the aim of putting all the processes required for a particular product, or family of products, into one area" called a cell [70] (Freeman-Bell and Balkwill, 1996). The area of GT that this project is concerned with is based on a principle that the characteristics of a part can be represented in multi-digit code [71] (Bedworth, Henderson & Wolfe, 1991). An important part of GT is the use of a code, which acts like a library reference system and serves as an index to characteristics in testing, manufacturing, purchasing, resource planning and sales. It concentrates mainly on saving time, avoiding the production of duplicate items and facilities quick and easy information retrieval. [72] (Nancy Hyer & Urban Wemmerlov, 1984). In this case we are concerned with formatting a multi-digit code used to efficiently retrieve relevant test data.

Classification and coding is the key to a successful data storage and retrieval system. Many coding systems have been developed for GT, and selecting the best one for a particular application can prove to be difficult. Bedworth, Henderson and Wolfe have identified some factors that should be kept in mind at the selection stage which include objective, robustness, expandability, differentiation, automation, efficiency, cost and simplicity. Some of the more popular coding systems include the DCLASS and MICLASS coding systems. The MICLASS system is made up of two major sections the first one being a 12-digit code used to classify the engineering and manufacturing characteristics of a part, which can be seen from figure 6.21. The second section of a MICLASS code is optional and can contain up to 18 characters designed to meet the needs of a company.

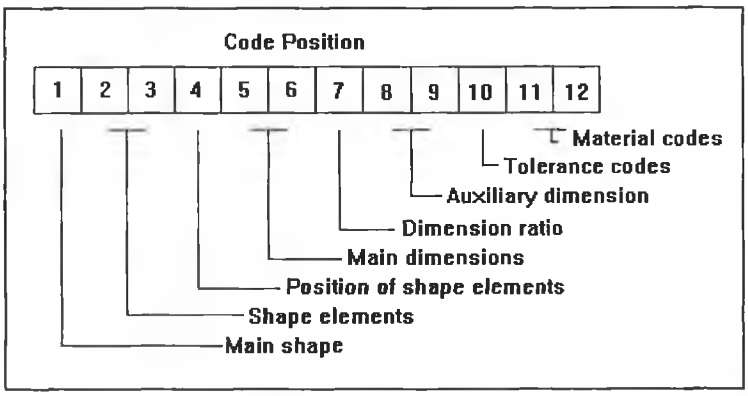

Figure 6.21 MICLASS Code Structure

The DCLASS or the design and classification information system was developed mainly for educational and research purposes. After many years in use an 8-digit code was developed. It consisted of 8-digits partitioned into 5 segments as shown in figure 6.22. The first segment was made up of 3-digits and described the basic shape, the next segment was for the form feature code. The third segment represented the overall size of the part whereas the forth segment denoted the precision of the part. The final segment (2-digits) was used to denote the material type.

This segment-based code would be an ideal template for developing a digitised code to aid in the storage and retrieval of the folders used for storing the various data files related to each test completed within the R & D department. These codes could then be used in conjunction with a Microsoft Access database program to retrieve test information. The generation of a segmented code along with a smart database program would accommodate a high degree of flexibility in that the users can search for information on any segment level.

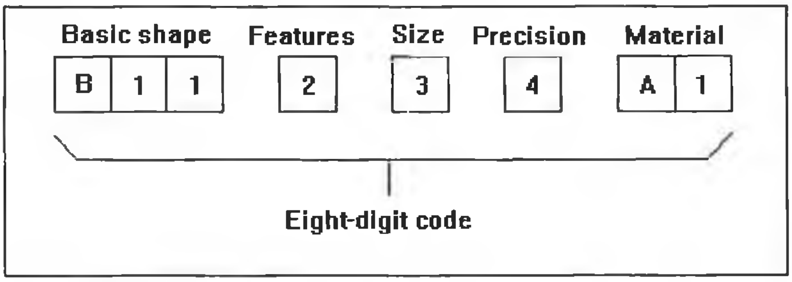

Figure 6.22 DCLASS part code segments

Take for example the code shown in figure 6.23. This code is made up of 22-digits separated into 8 segments. The first segment is 4-digits long for inserting the test request number. This segment would be very useful in cases where the test request number is known. In cases where the test request number is not known the user would have to rely on the remaining segments to locate the correct test information. The second segment calls for code to identify the location of the test referring the whether it was an applications (APP), calorimeter (CAL), wind tunnel (WTL) or field (FLD) test. The third and fourth segments require the initials of the technician and engineer responsible for the test. Next is a 3-digit segment for describing the type of unit tested before the date segment, which requires inputting the data that the test was performed in mm/dd/yy format. The final segment could be used to identify the type of test carried out as illustrated from table 6.5.

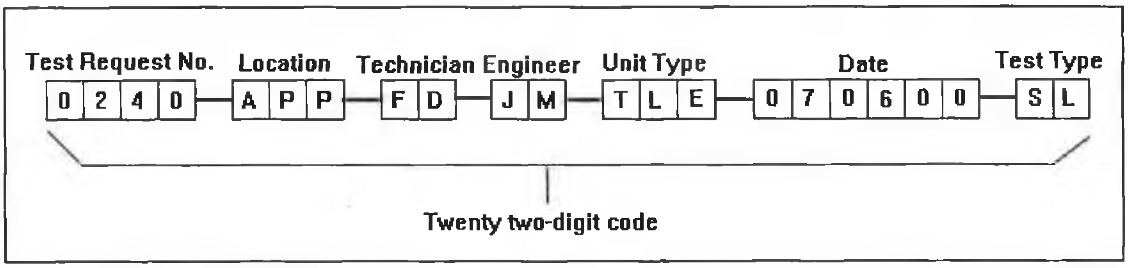

Figure 6.23 Eight Segment, Twenty Two-Digit Code for Test Folder Identification

Test Type	Identification Code
Single Trailer Tests	TL
Single Truck Tests	TK
Head to Head Trailer Tests	ST
Head to Head Truck Tests	MT
Head to Head Multi-Temp Trailer Tests	HT
Head to Head Multi-Temp Truck Tests	HK
Fuel Test	FT
Defrost Tests	DT

Table 6.5 Segment Code for Test Type

It must be remembered that the code should be concise and to the point. Long codes can become very tedious and time consuming to insert, especially if there are many tests to codify. GT would provide a means to structure and retrieve information on any test carried out in the testing environment.

6.15 Internet / Intranet Access

With regard to the test systems developed throughout the duration of this project Internet/Intranet accessibility was not implemented but it was suggested that integration with Internet technology could be accomplished easily due to the systems computer-based set-ups.

Test information could be viewed and retrieved by Internet users where ever and whenever required provided access was granted. As many tests completed are of a sensitive nature broadcasting information over an in-house Intranet within the company would provide tighter control on sensitive test information escaping the organisation. Employees could access information through the in-house Intranet incorporating the use of a data retrieval system as mentioned in the previous section. It would also be useful to inform employees of the advances being made in relation to product performance.

The Internet could be used to illustrate the amount of effort and consideration put in by the manufacturer to improve the product for the consumer in terms of increased product performance, realisation of fuel consumption savings, etc, thus increasing customer confidence. One area that Internet technology could benefit the organisation would be the live comparison of the Thermo King units against its nearest competitors units over the Internet. These types of tests have been completed in the presence of dealers and potential customers many times, illustrating the companies confidence in the products capabilities. The dealers and potential customers were greatly impressed that the company would stage live exhibitions comparing their units with the nearest competitors. This could be accomplished with the aid of a web/video-cam that has the ability to transfer moving images to the Internet in real-time. Images could be used to show real-time tests being completed in one window while illustrating real-time graphical results in another window.

In the development of a site for the CIT systems, web page design must be considered. The Web page appearance is one of the most important considerations in the development stage and incorporates such items as colours and backgrounds, images, page length, frames, sounds, etc. In relation to the colours and backgrounds, different monitors and computer systems display colours at different contrasts, therefore it is important to use colours that contrast well with one another. It must be highlighted that too much contrast can make the page difficult to read. The web is a visual medium so the use of images for illustration purposes is an excellent information tool. Most browsers, display images in both GIF or JPG format. Both of these formats use data compression, which basically means the file that contains the image is much smaller than the displayed image. The size of the images should be kept small so as the download time for the web page can be kept as short as possible. The page length must also be discussed. As a rule of thumb page lengths are usually kept to fewer than five scrolling screens. If the site requires more information hyperlinks in the form of next or previous page can be used. Sounds, Java, Java Script or ActiveX can also be added to a web page. They make the page more exciting and interactive for visitors.

Other useful tools that can be incorporated on a web page are return links, site maps, navigation bars and search capability options. A return link placed on a page allows the visitor to return back to the main or home page easily. Site maps are pages that displays the different documents or subject areas on the site where as a navigation bar is used to allow visitors to go from one page to another without constantly re-accessing a centralised menu or home page.

CHAPTER 7 DISCUSSION

7.1 Introduction

With the introduction of the various types of computer-based temperature, pressure and flow measurement instruments along with data acquisition hardware and software and communication devices/interfaces into the testing environment the benefits achieved were many with adaptability being of great significance to the overall endeavour. Adaptability was one of the major considerations dealt with from the design stage right through to the analysis of the various test data. Equipment selected was to be adaptable with not only several different transport refrigeration unit types but also several different test situations. System compatibility and conformity was also a major consideration and was acted upon by the use of similar instruments, software, data acquisition equipment, computer communication methods and test set-up methods throughout the various CIT systems.

7.2 Present Test Methods Vs. Traditional Methods

Traditional methods of measuring performance characteristics of the transport refrigeration units were somewhat outdated and lacked the precision and degree of data accuracy required in keeping up to date with new technologies and competitors. The precision and accuracy achieved with the introduction of computer methods far outweigh the traditional methods of measurement with computer-based instruments offering the most accurate data transfer rates possible.

Speed of testing must also be mentioned along with the speed at which the data can be collected and these were greatly increased with the introduction of computer methods. These factors play an important roll in the successful operation and control of the CIT systems. E.g. the test speed is important for achieving a high-test unit throughput mainly due to the quick and easy computer and computer-based instrumentation set-ups. The speed at which the data can be recorded refers to the logging speed of the data acquisition equipment, a common rule that is highlighted by many manufactures of data acquisition equipment is the relationship between data logging speed and data accuracy. The higher the speed the less accurate the data becomes. There is equipment available that can log data at very high speeds and still maintain an adequate degree of accuracy but these may prove to be more expensive. Another factor that affects the selection of an adequate logging speed is processing power and hard disk space available on the standard PC. It was discovered that when logging data at high speeds with up to 70 sensors connected to the system the computer was unable to handle the large amount of data being recorded indicating the requirement of a more powerful computer for higher speed applications. 99% of the testing carried out in Thermo King required a logging speed between 5 and 30 seconds, which did not affect the accuracy of the data or overload the standard PC.

With regard to traditional measurement systems control and operation of tests usually required personnel to be on site throughout the duration of the whole test to record the various data and to operate the various measurement instruments. Computer methods uses software packages to control the various instruments, log the data and can be set-up to indicate any problems that may occur throughout the duration of the test by initiating visual or audible alarms, sending an e-mail or making a mobile phone call to relay a pre-recorded message. Personnel can then benefit by not having to work in noisy, unhealthy environments allowing them to complete other important work while the test commences.

In relation to analysis of the test data significant advances have been made over traditional data analysis methods. One such area that has been dealt with in detail in chapter 6 is the automatic analysis of test data. Traditionally data was sorted/analysed on a spreadsheet and the various graphs and test results could be extracted from the information gathered. This was traditionally completed manually requiring a large amount of time to complete the required procedures. It is shown that with the integration of Excel Macros and Visual Basic tools complex data analysis procedures can be completed in a fraction of the manual analysis time with Visual Basic fronts promoting a user friendly environment.

To sum up CIT relies on an adequate data storage and retrieval system as a means of adequately storing the various test data and reports along with a method of easily retrieving specific data/reports through various optional classifications. i.e. test name, date of test, unit type, engineer responsible, etc. The present methods used to store the test data and reports identifies with a test request number (TR190), a test area identification code (app) and a unit name (sl300) for retrieval purposes. This method worked fine in the beginning but as the amount of tests performed grew, data became more difficult to locate thus realising the need for the development of a more efficient system.

Conclusions

Computer Integrated Testing is a concept that started to emerge at the beginning of the 1980's and with advances in technologies and software it is more justified now than ever before to have this incorporated to achieve efficiencies with respect to the testing function. As described in chapters 4 and 5 three-test systems were implemented during the project duration, which allowed for the opportunity to gain experience in CIT set-ups. These set-ups covered a wide range of tasks including data acquisition hardware set-ups, computer based instrumentation set-ups, application software template generation, PC and networking configurations and data analysis, presentation, storage and retrieval. Internet / Intranet incorporation with CIT systems was also discussed. Computer Integrated Testing has been described as a systems-level approach to managing large quantities and a broad range of testing. This is true but due to the inexpensive technology available on the market today smaller systems can be developed that offer significant advantages over the conventional test systems. CIT capitalises on the benefits that automation offers, but more to the point it integrates equipment management, maintenance, logistics, data management, cost control and personnel assignment in a structured environment. The key benefits to any CIT system being predictability, efficiency, and reliability.

By the coalition of the tools that CIT offers with state of the art systems technology and a comprehensive plan and design, the management of large volumes of test pieces can be accomplished efficiently and at a reduced cost. However the variety of options available can make the selection of computer integrated testing equipment difficult, but this difficulty can be eliminated by a good test plan and a detailed examination of the test requirements. It was found that in relation to selecting an adequate test system, purchasing from a proven supplier with good customer service and a proven record in maintaining regular hardware and software upgrades to incorporate new advancing technologies was the best option. PC-based DAQ technology has developed mainly due to recent technical advances in the areas of software capabilities, communication methods and devices, PC adaptable equipment and Internet technology. Networked CIT technology was examined and allows for wider ranges of control, monitoring, data analysis and presentation to be handled over local or wide area networks. The use of computer based instruments is a key factor in the success of CIT implementation, offering flexibility and adaptability as well as the fastest and most accurate data transfer rates possible.

CIT implementation involves the process of automating the testing function. Computer based instruments are used as opposed to traditional measurement instruments and can be connected directly to a PC, PC-based data acquisition unit or a stand-alone unit. The PC records the data, while simultaneously displaying it in raw, manipulated, graphical or pictorial form, allowing for instantaneous (real-time) interpretation of results. The benefits of successfully implementing a computer integrated test environment far outweigh the initial set-up costs. Expected benefits can include:

- Increased test throughput
- Increased efficiency
- Increased reliability
- Improved test quality
- Better data accuracy
- User friendly environment
- Less maintenance required
- Field testing is also possible with the correct CIT equipment
- Set-ups are quick
- Data management (interpretation, reduction, analysis, presentation) is easier and quicker
- Monitoring and test control can be handled from any networked workstation
- Real-time graphical and pictorial representations can be attained

- Real-time mathematical manipulation is possible
- Data transfer methods are greatly improved
- Computer based instruments ensure the fastest data transfer rates possible

New software packages are being developed that contain new, more advanced features, such as the new version of DASYLab developed by National Instruments, which now has a built in function that allows the user to program the software to send an e-mail or call a mobile phone following a predefined event. More recently the focus of the data acquisition equipment manufacturers is on the design and development of more adaptable systems, therefore companies can use the same systems for testing in many different environments incorporating the integration of any computer based instrument.

Another advantage that was discovered was the usefulness of Excel in the area of data analysis. As excel is offered with almost every PC sold today the need to purchase special analysis software is unnecessary, thus realising a significant cost savings. Excel offers the use of Macros for recording time consuming analysis procedures and also offers the option to build a Visual Basic front that promotes user friendly analysis operations. As described in chapter 6, one area of the project concentrated on the development of an analysis program in the Microsoft Excel environment to analyse the data recorded from the standard tests performed. It was developed using a Visual Basic front, which contained a number of options to choose from before running a set of Macros to analyse the data. The results generated were in the form of a series of graphical representations along with a data sheet highlighting important results.

In relation to the three industrial CIT systems implemented within the transport refrigeration industry during this project, they proved to be a success in terms of improving the company's performance. Performance was improved in relation to the company's products and through the design and testing of new products. Testing the performance of these products was an essential part of the design process, CIT offering the highest degree of efficiency, accuracy and reliability obtainable with today's resources.

The systems were developed for use by all personnel in the department, allowing for testing of product performance, capabilities, strengths, weaknesses, etc. It was set-up for adaptability, in that it could be easily adapted to any test requirement within reason. Software was the key to adaptability and the area that required most attention when changing test requirements.

The applications CIT system was designed to measure the overall performance characteristics of the transport refrigeration units. The set-up was relatively simple, but the number of possible test configurations introduced complexities in the area of data analysis. Tests therefore had to be standardised to maintain set procedures enabling data analysis to be automated. Room for test system expansion was accommodated so as extra test information could be achieved if the requirement arose. The hardware, software and instrumentation selected for the CIT system operates within the company's local area network or by control of one standalone laptop. This along with the portability of the data acquisition hardware and instrumentation made the system ideal for field testing applications. As mentioned in chapter 4 several field test ventures were performed with this system and were very successful.

The Wind Tunnel CIT test system was specifically developed for measuring the volumetric air flow from the company's products. It was designed with the capability to measure the airflow of not only the host units, but also remote and competitor units. Both the hardware and software used in acquiring data and controlling the test procedure was similar to that used in the applications testing system. The measurement requirements for this system were somewhat different, therefore various pieces of new instrumentation had to be incorporated into the system. The software used for monitoring and controlling the system was set-up with a number of mathematical manipulations. The values measured from the instrumentation were viewed on the PC interface, these values represented specific measurement characteristics such as pressure, temperature and humidity. The measurements were then manipulated using mathematical methods to give real-time valuable information such as, the airflow in m^3/hr. This information was then combined with results from the applications testing system in the form of final reports on the units.

The calorimeter CIT system was set-up to test units under several different environmental temperature conditions (–29^{0}C to 50^{0}C). Three types of test scenario were proposed for the calorimeter and have been identified in chapter 5. The data acquisition hardware for this system consisted of a modular based DAQ set-up, each module consisting of 8 channels (FieldPoint). Hardware modules were mounted on lengths of DIN rail to complete the system. The hardware operates within the company's local area network but is not a portable system. The main advantage of this hardware is its modular structure. Modules can be added or removed as required without upsetting the system. The software supplied with the hardware included an Explorer for system configuration and for integrating the hardware with the application software of the user's choice. LabVIEW was selected as the application software for the system. This development environment was ideal for the application and was capable of representing the data from system instrumentation in any form required. Instrumentation incorporated into the system was similar to that used in the area of applications testing, therefore the instrumentation set-up stage was easily completed, as this was the last system implemented.

It was suggested that Group Technology principles be engaged to create an efficient data storage and retrieval system, which could be accomplished with the use of a digitised code consisting of 22 characters separated into 8 segment levels.

Similarly, though not implemented yet, it is imperative that appropriately designed

Internet/Intranet facilities be created to bring the data to the users whether they be company employees or customers.

The benefits that the company achieved with the introduction of computer integration was typical of the benefits mentioned above. But the real benefits are actually seeing how computer technology and the integration of computer technology with test systems can lead to massive advancements in the area of test in just a short time. This complements the state of the art CIM environment already in place in terms of the CAD/CAM/CAE set-ups used in Thermo King.

Recommendations

1. As mentioned in chapter 6 the need for a more adequate data storage and retrieval system is essential to the overall success of a totally integrated environment. Recommendation for further research into an improved data storage and retrieval system is required thus promoting the need for a follow on research project.

2. Also the development of Internet/Intranet facilities is recommended so as to get the information to the users when required. As much of the testing carried out in the research and development facility is of the sensitive nature certain security procedures would have to be initiated. The development of a Group Technology based digitised coding system has been suggested as a bases for developing a data storage and retrieval system. With the use of Internet technology and some type of digitised data storage and retrieval system specific test information could be viewed from anywhere in the world providing the users had access and the system could incorporate Group Technology for the purpose of adequately retrieving test information under several different test identification characteristics.

3. In regards to data analysis, automatic analysis procedures can be used to promote and create fast, user-friendly data analysis programs for any test situation. However more research and time is required in the program development stage and a major asset to the testing environment would be to develop a set of standard block type programs that could be added together or slightly modified to accommodate a wider range of test situations. It is important that these programs be written within the organisation so as the need to hire expensive experts or consultants can be eliminated.

4. Computer technology is advancing at enormous rates and with these advances comes more sophisticated computer compliant equipment, and software

technology, therefore future research into the development of more sophisticated computer integrated test systems is essential.

5. The introduction of CIT has benefited the company in Galway significantly in the area of research and development. Fundamentals of the system should be presented to other Thermo King facilities overseas to achieve corporate-wide integration.

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Trailer Test Procedure

Unit Set-up;
Ensure that the unit is supplied with battery, diesel supply and exhaust with extraction.

Trailer Test Set-up

- Weather the test required is for a single trailer single temperature test or for a head to head multi-temperature test the overall set-up procedures are basically identical.
- Each trailer is fitted with 35 type-T thermocouples which have an accuracy of ± 0.5% and can measure temperatures in the range of -200^{0}C to 350^{0}C. They should be placed at 1, 3, 5, 7, 9, 11 & 13 meters (in A & V formations as per figure 1A) from the front wall of the box.
- Each trailer also has 4 Type-T thermocouples on the evaporator return, evaporator discharge & ambient temperature which are all averaged to source.

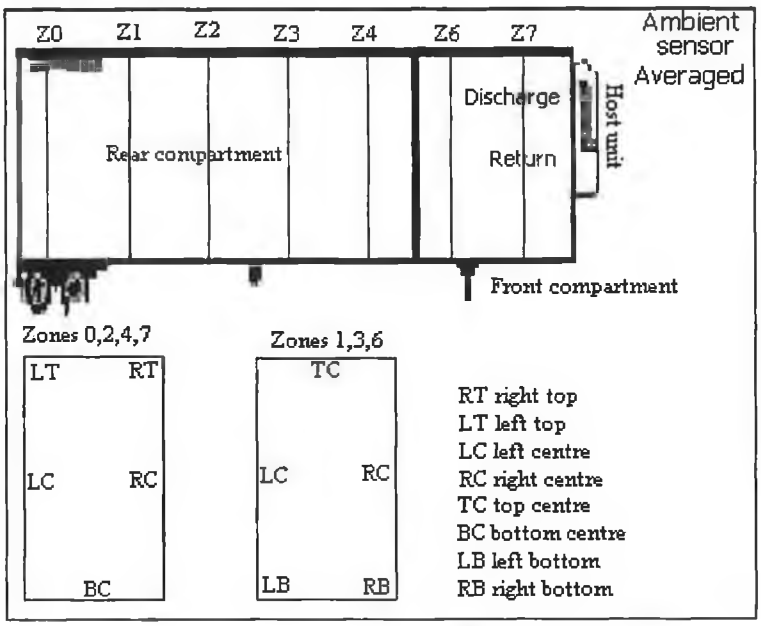

Figure 1A Trailer Thermocouple Sensor Layout

Figure 1A shows the layout of the sensors in the trailer, with every second zone having the sensors laid out in either a V or A section. There are 7 zones in all labelled 0, 1, 2, 3, 4, 6, and 7. The zone labelled 5 is only used for multi-temp testing and has a separate set of sensors for recording the temperature at the bulkhead.

- A Danfoss massflo 2100, flow meter should be connected to the unit being tested, it is used to measure instantaneous fuel consumption rate and total fuel consumed. (Contact technicians)

- Ensure that the correct date and time have been set on the units for testing.

PC & Data Acquisition

The use of a PC may be used in the testing area but is not essential, once the NetDAQ's are connected to the network any PC (with ThermoDAQ software) on the network can record a test. However it proves very helpful to have a PC close to the units so as any problems can be sorted out quickly during the set-up stage.

For trailer head to head testing 5 NetDAQ must be connected, either to separate network ports or to the hub locally. The temperature sensors are connected directly to the NetDAQ cartridges as shown in figure 2A. A shunt resister is connected in series with the circuit to convert the current output from the flow meter inverter to a voltage output.

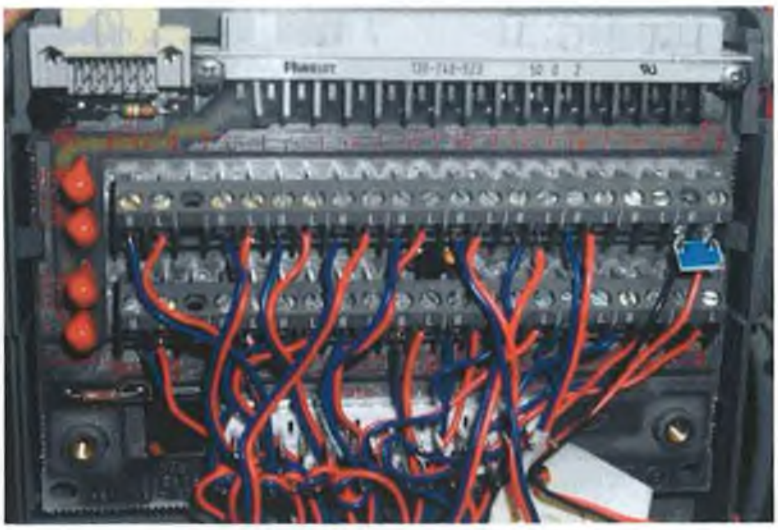

Figure 2A NetDAQ Cartridge

The flow meters (fig 3A) are connected directly back to the cartridge to measure the fuel consumption rate (with a shunt resister placed in series with the circuit). The total fuel can also be recorded by connecting the FREQ\PULSE1 terminals labelled “out” and “ - “ to the totalizer & ground terminals on the rear out the NetDAQ box. See figure 4A.

Figure 3A Flow Meter

Figure 4A Flow Meter Connections

Figure 4A shows the circuit board on the flow meter inverter. These connections are made to attain the signal from the sensor, which is fed back to the NetDAQ box so as to record the total fuel flow and the instantaneous flow rate. (Refer to inverter manual)

Table 1A identifies the sensors that are connected to each NetDAQ & the position of these sensors in the trailer. Column headings are described as follows:

Trailer 1 & Trailer 2

These are the names assigned to each trailer body.

Position

This refers to the sensor in the trailer. 0, 1, 2, 3, 4, 6, 7 are the names of the zones in the trailer box Zone 0 being at the rear of the trailer. They are equi-spaced within the trailer. Internal refers to sensors inside the box. External refers to sensors outside the box.

Label

Sensor Position Names

BC = BOTTOM CENTRE	TC = TOP CENTRE	LB = LEFT BOTTOM
RB = RIGHT BOTTOM	LC = LEFT CENTRE	RC = RIGHT CENTRE
LT = LEFT TOP	RT = RIGHT TOP	

E.g. label 7RT Refers to the sensor in the trailer at zone 7 (near the front of the trailer) on the top right hand-side of the trailer.

Sensor No.

This column refers to the NetDAQ channel that a particular sensor is connected to.

NetDAQ BCH

Each NetDAQ box has its own BCH number, which lets the user see which sensor is connected to which NetDAQ box. E.g. on trailer 2 we can see that sensor at position 2 label 2RT is connected back to NetDAQ box BCH 4.

Beginning a Test

To begin a test open the Thermo DAQ software & ensure that the PC recognises the NetDAQ boxes, then select the appropriate trailer template from F:\ Private \ Eng. Test \ ThermoDAQ \ Templates. Save this template under your selected test name. Make sure that the extraction system is switched on before turning on the units for test. Then on the ThermoDAQ software interface press upload. The software will now prompt for a time interval to acquire the data, which is left to the discression of the tester. When the program has been uploaded the record button on the interface is then pressed.

Analysing the Data

When all the data is recorded the file should be exported and saved using the following convention;

Test Area	(APP LTB)
Unit	(SL 300 Vs SL 400)
Type of Test & Setpoint	(PD 0C, PD&M -25C, CR -20C, CS -25C)
Date	3-8-99

E.g. 'APP LTB SL 300 Vs SL 400 PD -25C 3-8-99' and filed in f: \ Private \

Eng. Test \ under the appropriate Test request No.

- PD Pulldown
- PD&M Pulldown & maintain
- CR Continuous Run
- CS Cycle Sentry

When the data is recorded we can save the data file in CSV format, the data can then be viewed in Excel. Macros have been written to analyse the data and produce standard charts and data sheets indicating important characteristics and results. It sorts through the data selecting predetermined data for analysis and is located in f: \ Private \ Eng. Test \ Standards \ Standard Macros.

Writing Reports

The Trailer report should include the following sections;

Test Description
Test set-up
Test Results (including graphs)
Conclusions

This report should follow the form of 'Standard Trailer Head to Head Report Layout' in F;\ Private \ Eng. Test \ standards, as shown in Appendix C.

Trailer 1				Trailer 2			
Longitudinal position	**Label**	**Thermocouple No**	**NetDAQ BCH**	**Longitudinal position**	**Label**	**Thermocouple No**	**NetDAQ BCH**
0	0BC	1	2	0	0BC	1	4
0	0LT	2	2	0	0LT	2	4
0	0RT	3	2	0	0RT	3	4
0	0LC	4	2	0	0LC	4	4
0	0RC	5	2	0	0RC	5	4
1	1TC	6	2	1	1TC	6	4
1	1LB	7	2	1	1LB	7	4
1	1RB	8	2	1	1RB	8	4
1	1LC	9	2	1	1LC	9	4
1	1RC	10	2	1	1RC	10	4
2	2BC	11	2	2	2BC	11	4
2	2LT	12	2	2	2LT	12	4
2	2RT	13	2	2	2RT	13	4
2	2LC	14	2	2	2LC	14	4
2	2RC	15	2	2	2RC	15	4
3	3TC	16	2	3	3TC	16	4
3	3LB	17	2	3	3LB	17	4
3	3RB	18	2	3	3RB	18	4
3	3LC	19	2	3	3LC	19	4
3	3RC	20	2	3	3RC	20	4
4	4BC	1	3	4	4BC	1	5
4	4LT	2	3	4	4LT	2	5
4	4RT	3	3	4	4RT	3	5
4	4LC	4	3	4	4LC	4	5
4	4RC	5	3	4	4RC	5	5
6	6TC	6	3	6	6TC	6	5
6	6LB	7	3	6	6LB	7	5
6	6RB	8	3	6	6RB	8	5
6	6LC	9	3	6	6LC	9	5
6	6RC	10	3	6	6RC	10	5
7	7BC	11	3	7	7BC	11	5
7	7LT	12	3	7	7LT	12	5
7	7RT	13	3	7	7RT	13	5
7	7LC	14	3	7	7LC	14	5
7	7RC	15	3	7	7RC	15	5
External	Ambient	16	3	External	Ambient	16	5
Internal	Discharge	17	3	Internal	Discharge	17	5
Internal	Return	18	3	Internal	Return	18	5
		19	3			19	5
External	vol-flowl\h	20	3	External	vol-flowl\h	20	
Position	**Label**	**Digital Sensor No.**	**NetDAQ BCH**	**Position**	**Label**	**Digital Sensor No.**	**NetDAQ BCH**
External	Total fuel TRL1	TR(Totaliser)	3	External	Total Fuel TRL 2	TR (Totaliser)	5

Table 1A Sensor Listing

Truck Test Procedure

Unit Set-up;
Ensure that the unit is supplied with battery, diesel supply and exhaust with extraction.

Truck Test Set-up

- Each truck test performed requires the same basic set-up.
- 2 truck bodies are required each measuring 7 meters in length.
- Each Truck body is fitted with 20 type-T thermocouples which have an accuracy of ± 0.5% and can measure temperatures in the range of -200^{0}C to 350^{0}C. They should be placed at 1, 3, 5, & 7 meters (in A & V formations as per figure 5A) from the front wall of the box.
- Each Truck body also has 4 Type-T thermocouples on the evaporator return, evaporator discharge & ambient temperature, which are all, averaged to source.

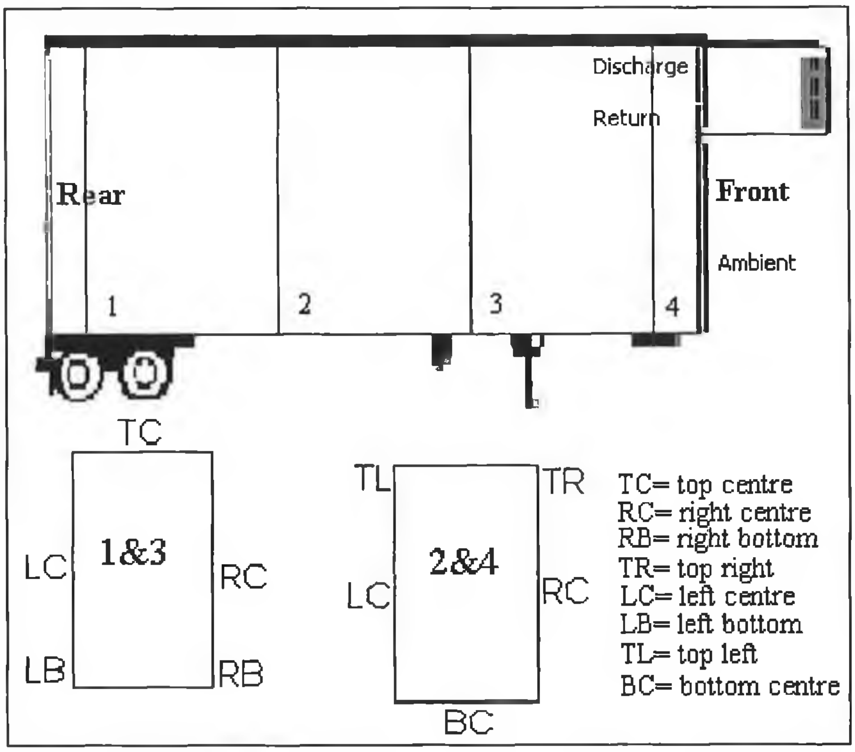

Figure 5A Truck Thermocouple Sensor Layout

Figure 5A shows the layout of the sensors in the Truck, with every second zone having the sensors laid out in either a V or A section. There are 4 zones in all labelled 1, 2, 3, & 4.

- A Danfoss massflo 2100, flow meter should be connected to the unit being tested, it is used to measure instantaneous fuel consumption rate and total fuel consumed. (Contact technicians)
- Ensure that the correct date and time have been set on the units before testing.

PC & Data Acquisition

The use of a PC may be used in the testing area but is not essential, once the NetDAQ's are connected to the network any PC (with ThermoDAQ software) on that network can record a test. However it proves very helpful to have a PC close to the units so as any problems can be sorted out quickly during the set-up stage.

For Truck head to head testing 3 NetDAQ must be connected, either to separate network ports or to the hub locally. The temperature sensors are connected directly to the NetDAQ cartridges as seen in figure 6A. A shunt resister is connected in series with the circuit to convert the current output from the flow meter inverter to a voltage output.

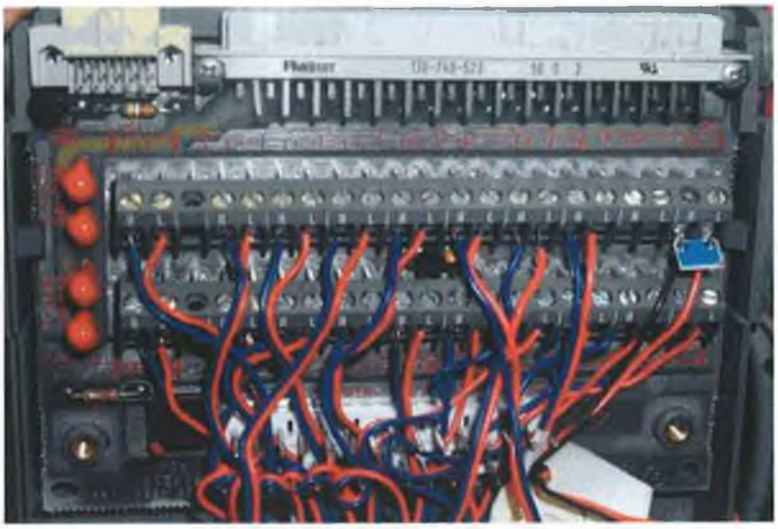

Figure 6A NetDAQ Cartridge

The table 2A below identifies the sensors that are connected to each NetDAQ & the position of these sensors in the Truck. Column headings are described as follows:

Truck 1 & Truck 2

These are the names assigned to each Truck body.

Position

This refers to the sensor in the Truck. 1, 2, 3, 4 are the names of the zones in the Truck box Zone 1being at the rear of the Truck. They are equi-spaced within the Truck. Internal refers to sensors inside the box. External refers to sensors outside the box.

Label

Sensor Position Names

BC = BOTTOM CENTRE	TC = TOP CENTRE	LB = LEFT BOTTOM
RB = RIGHT BOTTOM	LC = LEFT CENTRE	RC = RIGHT CENTRE
LT = LEFT TOP	RT = RIGHT TOP	

E.g. label 4TR refers to the sensor in the Truck at zone 4(near the front of the Truck) on the top right hand-side of the Truck.

Sensor No.

This column refers to the NetDAQ channel that a particular sensor is connected to. These can be modified if required.

NetDAQ BCH

Each NetDAQ box has its own BCH number, which lets us see which sensor is connected to which NetDAQ box. E.g. on Truck 2 we can see that sensor at position 2 label 2RT is connected back to NetDAQ *box BCH 7.*

Beginning a Test

To begin a test open the Thermo DAQ software & ensure that the PC recognises the NetDAQ boxes, then select the appropriate Truck template from F:\ Private \ Eng. Test \ ThermoDAQ \ Templates. Save this template under your selected test name. Make sure that the extraction system is switched on before turning on the units for test. Then on the ThermoDAQ software interface press upload. The software will now prompt for a time interval to acquire the data, which is left to the discression of the tester. When the program has been uploaded the record button on the interface is then pressed.

Analysing the Data

When all the data is recorded the file should be exported and saved using the following convention;

Test Area	(APP R&D)
Unit	(TS 300 Vs Supra 744)
Type of Test & Setpoint	(PD 0C, PD&M -25C, CR -20C, CS -25C)
Date	3-8-99

E.g. 'APP R&D TS 300 Vs Supra 744 PD -25C 3-8-99' and filed in f: \

Private \ Eng. Test \ under the appropriate Test request No.

- PD -Pulldown
- PD&M -Pulldown & maintain
- CR - Continuous Run
- CS - Cycle Sentry

When the data is recorded we can save the data file in CSV format, the data can then be viewed in Excel. Macros have been written to analyse the data and produce standard charts and data sheets indicating important characteristics and results. It sorts through the data selecting predetermined data for analysis and is located in f: \ Private \ Eng. Test \ Standards \ Standard Macros.

Writing Reports

The Truck head to head report should include the following sections;

Test Description
Test set-up
Test Results (including graphs)
Conclusions

This report should follow the form of 'Standard Truck Head to Head Report Layout' in F;\ private \ Eng. test \ standards. See appendix C.

The flow meters (fig 7A) are connected directly back to the cartridge to measure the fuel consumption rate (with a shunt resister placed in series with the circuit). The total fuel can also be recorded by connecting the FREQ\PULSE1 terminals labelled "out" and " - " to the totalizer & ground terminals on the rear out the NetDAQ box. See figure 8A

Figure 7A Flow Meter

Figure 8A Flow Meter Connections

Figure 8A shows the circuit board on the flowmeter here the connections are made to attain the signal from the sensor, which is fed back to the NetDAQ box so as to record total fuel flow and the instantaneous flow rate.

Truck 1 Truck 2

Longitudinal position	Label	Thermocouple No	NetDA Q BCH	Longitudinal position	Label	Thermocouple No	NetDAQ BCH
1	1TC	1	1	1	1TC	1	7
1	1LB	2	1	1	1LB	2	7
1	1RB	3	1	1	1RB	3	7
1	1LC	4	1	1	1LC	4	7
1	1RC	5	1	1	1RC	5	7
2	2BC	6	1	2	2BC	6	7
2	2LT	7	1	2	2LT	7	7
2	2RT	8	1	2	2RT	8	7
2	2LC	9	1	2	2LC	9	7
2	2RC	10	1	2	2RC	10	7
3	3TC	11	1	3	3TC	11	7
3	3LB	12	1	3	3LB	12	7
3	3RB	13	1	3	3RB	13	7
3	3LC	14	1	3	3LC	14	7
3	3RC	15	1	3	3RC	15	7
4	4BC	16	1	4	4BC	16	7
4	4LT	17	1	4	4LT	17	7
4	4RT	18	1	4	4RT	18	7
4	4LC	19	1	4	4LC	19	7
4	4RC	20	1	4	4RC	20	7
External	Ambient	1	8	External	Ambient	5	8
Internal	Discharge	2	8	Internal	Discharge	6	8
Internal	Return	3	8	Internal	Return	7	8
External	vol-flowl\h	4	8	External	vol-flowl\h	8	8
Position	**Label**	**Digital Sensor No.**	**NetDA Q BCH**	**Position**	**Label**	**Digital Sensor No.**	**NetDAQ BCH**
External	Total fuel TRK1	TR(Totaliser)	1	External	Total Fuel TRK 2	TR (Totaliser)	7

Table 2A Sensor Listing

Wind Tunnel Test Procedure

Unit Set-up;

1. Ensure that unit is supplied with battery, diesel supply & exhaust with extraction fan. If in the case of a remote evaporator, a power supply must be connected to the fans. Also in the case of an SL 300 with the new fan a motor must be attached.

Wind Tunnel Set-up;

2. Connect the main 3-phase plug to a socket with the ELCB disconnected. (Contact Billy/John Quinn)
3. Connect the fan motor plugs to the sockets on the inverter. (fig 9A) (Ensure that the inverter is off before plugging in/out any fans).
4. Connect the wind tunnel hydraulic hoist to a single-phase socket.

Figure 9A Shows Fan motor plugs connected on to the inverter.

Figure 10A Shows the front panel of the inverter

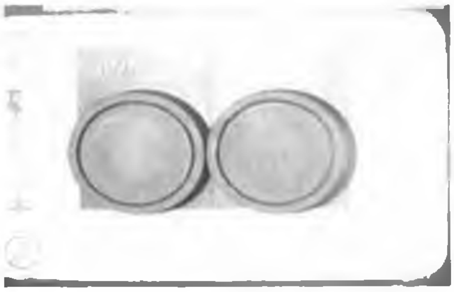

Figure 11A Controls for Hydraulic Hoist

Determining the Template Size and No. Of Nozzles

5. A nozzle plate is supplied for;
   Remote Evaporator/ Truck size airflow 3500 m^3/hr 6 Nozzle Plate
   Trailer size airflow 6000 m^3/hr 3 Nozzle Plate

6. The appropriate plate must be installed on the wind tunnel.

7. In order to select the correct template and no. Of nozzles open Microsoft Excel. Open file C:\Program Files\ThermoDAQ\Wind Tunnel Data. Appendix D

8. Macro should automatically run. If not then press the "smiley button" on tool bar.

9. Select unit type from drop down menu in dialog box. If not present, then click "unit type not present" button. Now select the estimated range of operation i.e. is the maximum airflow in the region of a truck/remote evaporator or in the region of a trailer. This will now give you an indication of the no. of nozzles to leave open by equating the no. of nozzles to an airflow range. See table 3A.

Template Size	No. of Nozzles	Airflow Range (m^3/h)
Small	1	350 to 620
	2	700 to 1250
	3	1000 to 1850
	4	1400 to 2500
	5	1800 to 3100
	6	2135 to 3700
Large	1	1300 to 2250
	2	2500 to 4500
	3	3800 to 6800

Table 3A Airflow Range

10. If the unit type is present, then note down the information. (i.e. the correct template, the maximum static pressure and the no. of nozzles to leave open)

11. Set up the wind tunnel with the correct template.

12. Close off nozzles as required with the aluminium blanks provided.

13. If when the unit and the wind tunnel are started, the frequency goes to 55Hz then another nozzle must be opened or the template changed. If the frequency goes to 20Hz another nozzle must be closed or the template changed.

PC and Data Acquisition Set-up;

Before a test may be started the ThermoDAQ template must be opened and updated.

14. Open the ThermoDAQ software.

15. Open worksheet. If you are using the small nozzle template open WT Truck/Remote Evap Template. If you are using the large nozzle template open WT Trailer Template. These are both in C:\Program Files\ThermoDAQ

16. Enter the nozzle no. on the ThermoDAQ worksheet.

17. Press the "Upload" button on the toolbar.

Setting Required Set-Point and Running Test

The point of the test is to acquire a fan characteristic for the particular unit. This involves measuring the volumetric airflow for various pressures. This is done by setting the desired pressure on the inverter.

18. To record an operating point the setpoint must be set on the inverter. This is done by entering the 'extended menu' on the inverter panel, scrolling across using the right scroll key to 'Applic functions' then using the up or down scroll keys to find 'Setpoint 1' (418). This should be set for the target static pressure (operating point). This value is set by pressing the change data key on the inverter, then using the up and down scroll keys to change the value, when done press OK. There is an offset of -12 Pa. Press Autostart after doing this for the first time.

19. Initially set it for 0 Pa.

20. Wait for the static pressure at fan outlet to settle. Then press the snapshot button on the tool bar in the ThermoDAQ software. This records one reading for the static pressure setting. This is done twice for each setting.

21. The compensation fans allow fine control of the fan outlet static pressure,

compensating for pressure drop in the measurement system. The fan frequency ranges from 20 to 55 Hz. In order to take a measurement the frequency must be within this range. The damper allows for coarse control of the airflow.

22. The compensation fans may be used to keep the readings within range as follows
    - If the frequency is at 20 Hz the damper should be closed off.
    - If the frequency is at 55 Hz the damper should be opened
    - or the nozzle template is not the correct size.

23. Then change the static pressure setting. For example take readings at 0, 50, 100, 150, 200, 250 and 300 Pa. The fan airflow reading will decrease. The maximum static pressure at which you can take a reading depends on the fan you are testing. If the unit type was present in the Excel sheet then the maximum static pressure is known. Otherwise the maximum static pressure achievable is at the minimum airflow achievable which will be around 300m^3/h. Generally the maximum achievable static pressure is approximately 300 for a trailer unit. The wind tunnel is used to plot fan characteristics, i.e. the static pressure against the volumetric airflow.

24. When you are finished recording data then press the tabular button on the toolbar. A table with all the recorded information will pop up. At the bottom of this there is a button named "export". Press this button. Now a save file as box will pop up. Select the C:\msoffice\excel\wind tunnel results. Now name the file using the following convention:

Test Area	Wind Tunnel (WT)
Unit	(TS 600, SL 300)
Test Purpose	(Prototype blower HSD), Pre-certification LSD)
Date	21^{st} July 1999

25. The wind tunnel report should include the following sections;
    Test Description
    Test set-up
    Test Results (including graphs)
    Conclusions
    This report should follow the form of 'Standard Wind Tunnel Report Layout' in F;\private\eng_test\standards.

Controlling the Compensation Fans on the Wind Tunnel
This involves changing the control from remote to local on the inverter. The Hand/Off/Auto switch should be changed to hand. Then within the extended menu the parameter "203 reference site" changed to local. Then the frequency may be set rather than the outlet static pressure.

Determining Modes of Operation

There are several modes of operation on both a host unit and a remote evaporator. Sometimes it is of interest during testing to be able to determine the mode in which the unit is operating. This is of particular importance in defrost testing when it is essential to know when the host or remote evaporator is in defrost. It can be difficult to identify whether the host or remote evaporator is in defrost by examining the temperatures within the refrigeration circuit (recorded by the NetDAQs and ThermoDAQ software). It can be determined by looking at the controller display but this is not always convenient, as the information is not recorded for future reference.

These operating modes can be recorded in a manner similar to the temperatures and fuel consumption. The NetDAQs have to be used in a manner that records the operating mode and then communicates with the software, which then records the information. When the operating mode changes (for example when the remote evaporator starts to go into heat, the hot gas solenoid is energised) the information needs to be recorded. This is done by recording a change in the voltage output from the controller relays. A relay must be used to connect the NetDAQ and the component supply as the compensation voltage from the NetDAQ disturbs the unit operation. Within the NetDAQ itself the digital I/O channels are used to determine a change in voltage which signifies a change in operating mode. These wires are then connected into the relay as shown in figure 12A.

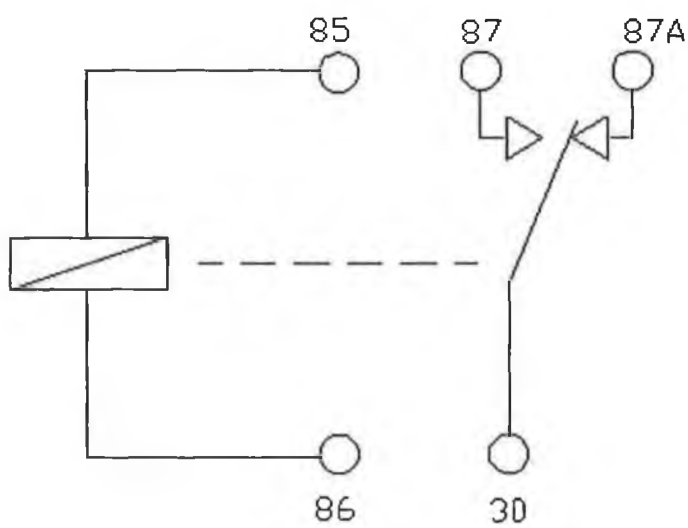

Figure 10A Relay Wiring Diagram

85 Component Supply
86 Ground or controller circuit
87 Ground
30 NetDAQ

In the software a digital sensor is set up corresponding to each wire (component supply). Digital sensor D0521 corresponds to digital I/O channel 0 and so on (where the 5 refers to the BCN No. of the NetDAQ being used). These are either on or off depending on the voltage signal received at the NetDAQ. The "off position or 0" is signified by a low voltage which according to the NetDAQ manual has to be below 0.8V.

Standard Trailer Head to Head Report layout

Test Title Trailer Head to Head Temperature Distribution & Fuel Consumption Test.

Purpose Assessment of Pulldown & Temperature Maintance Preformance of SL 400 Vs SL 300

Requester
Responsible Engineer A. Ryan, J. Mannion
Responsible Technicians F. Devaney.

Date **7/1999**

Unit Trl. 1 **SL 400**

Unit S / N **0595TA2813**

Unit Trl. 2 **SL 300**

Unit S / N **0395DQ241**

Test Set-Up

Test Area Location;

- Large Trailer Bay

For each trailer body;

- 35 T-type TCs located inside the body at 7 zones at 1, 3, 5, 7, 9, 11 &13 m from the front wall. Arranged alternately in A & V formations.
- 4 T-type TCs on evaporator return, averaged at source.
- 4 T-type TCs on evaporator discharge, averaged at source.
- 4 T-type TCs for ambient temperature, averaged at source.
- Danfoss MassFlo 2100, flowmeter measuring instantaneous fuel consumption rate and total fuel consumed.
- 2 NetDAQ are required for each trailer body and ideally should be connected into the network via a hub.
- 1PC for recording and monitoring the information received from the NetDAQ's

NetDAQ used BCN 2 IP Address 168.92.46.42
BCN 3 IP Address 168.92.46.43
BCN 4 IP Address 168.92.46.44
BCN 5 IP Address 168.92.46.45

Thermo Daq Template F:\ Private\ Eng. Test \ ThermoDAQ \ Templates \ Standard Trailer head to head
Data Files F:\ Private\ Eng. Test \ TR

Test Results

Tests carried out

Test No:	Name:	Duration:
1	App LTB 300v400 PD-25C 11-3-99	8hr 19min
2	App LTB 300v400 PD&M 0C 12-3-99	5hr 1min
3	App LTB 300v400 PD-25C 15-3-99	8hr 17min
4	App LTB -25^{0}C SL300 Cycle 16-3-99Sentry	7hr 26min

For a standard test 4 charts are produced as follows

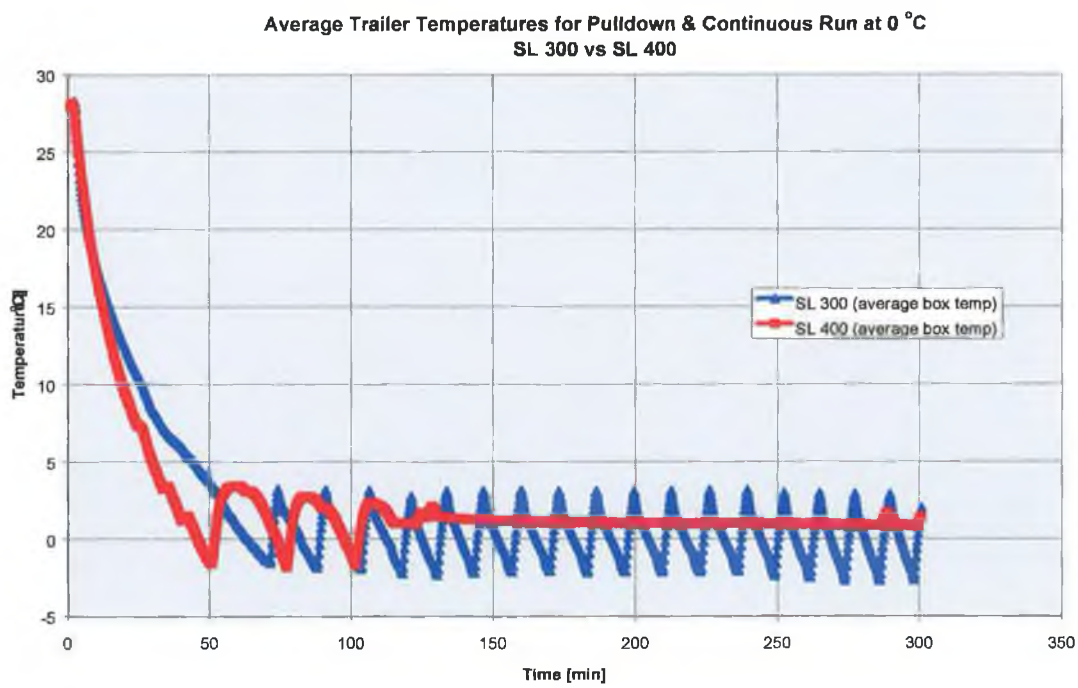

Figure 1B Comparison of Average Box Temperatures

Figure 1B shows a direct comparison of the average box temperatures. It shows us that the sl400 reached setpoint approximately 17 to 18 minutes faster than the sl300. The sl400 cycled around the set point for a short time before levelling off just above the set point holding the temperature at an even temperature throughout the remainder of the test. The sl300 cycled between approximately -3 to +3.5 throughout the remainder of the test.

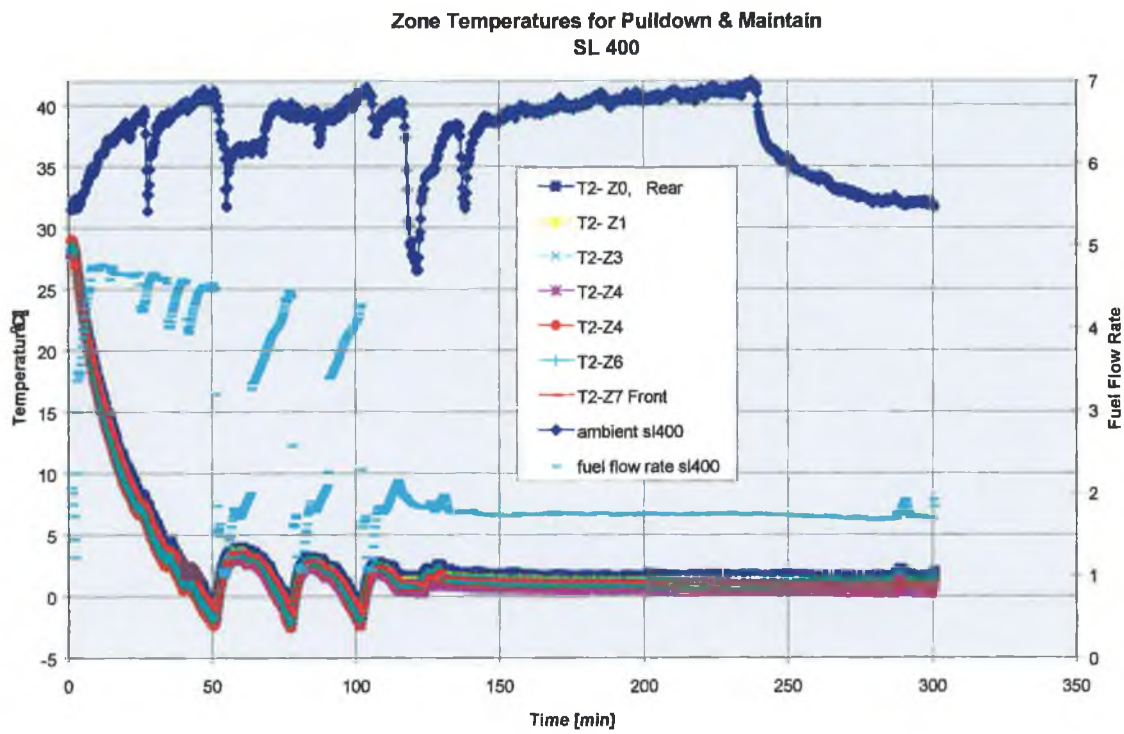

Figure 2B Comparison of Zone Temperatures for Trailer 1

Figures 2B and 3B show the average zone temperatures which are situated throughout the trailer (zone 0 to the rear & zone 7 to the front). For each one we can see that the average zone temperatures are very close to each other indicating that the temperature is consistent throughout the trailer. The ambient temperature for both trailers are very similar with a significant drop occurring between 100 &150 min maybe due to the door of the large trailer bay being opened for a short period.

However if we compare the fuel flow rates there is a major difference when the units reach there setpoint, the sl400 goes into low speed and remains in low speed for the remainder of the test. Whereas the sl300 cycles between high and low speed, thus using a more fuel.

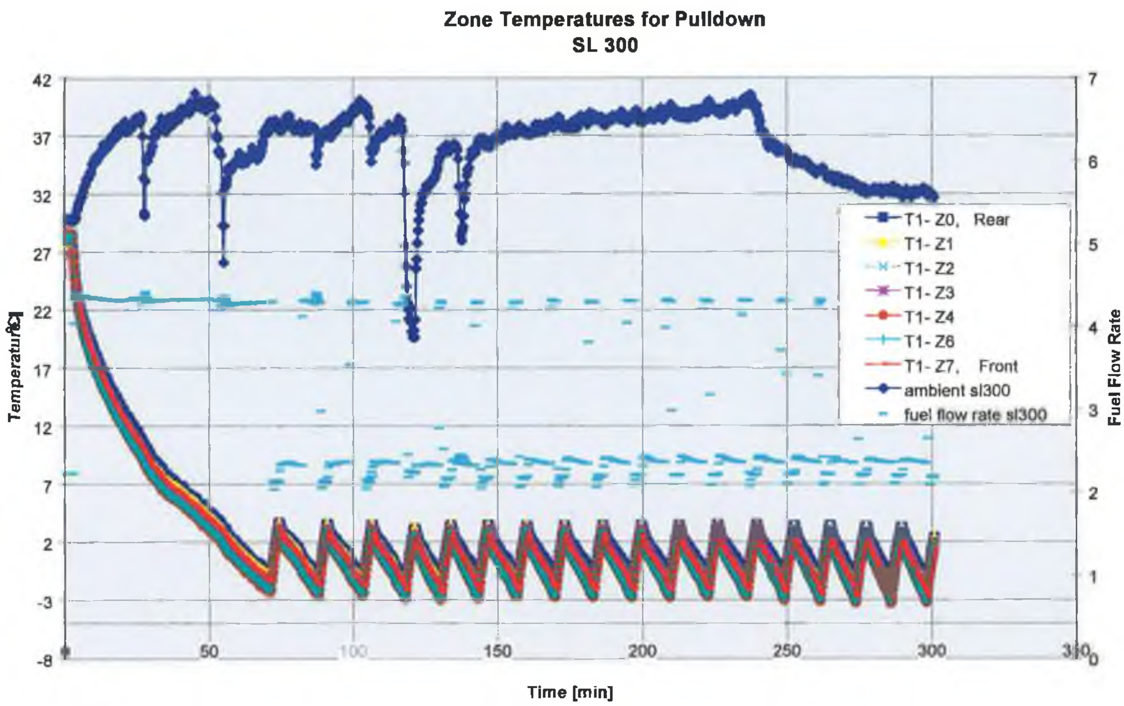

Figure 3B Comparison of Zone Temperatures for Trailer 2

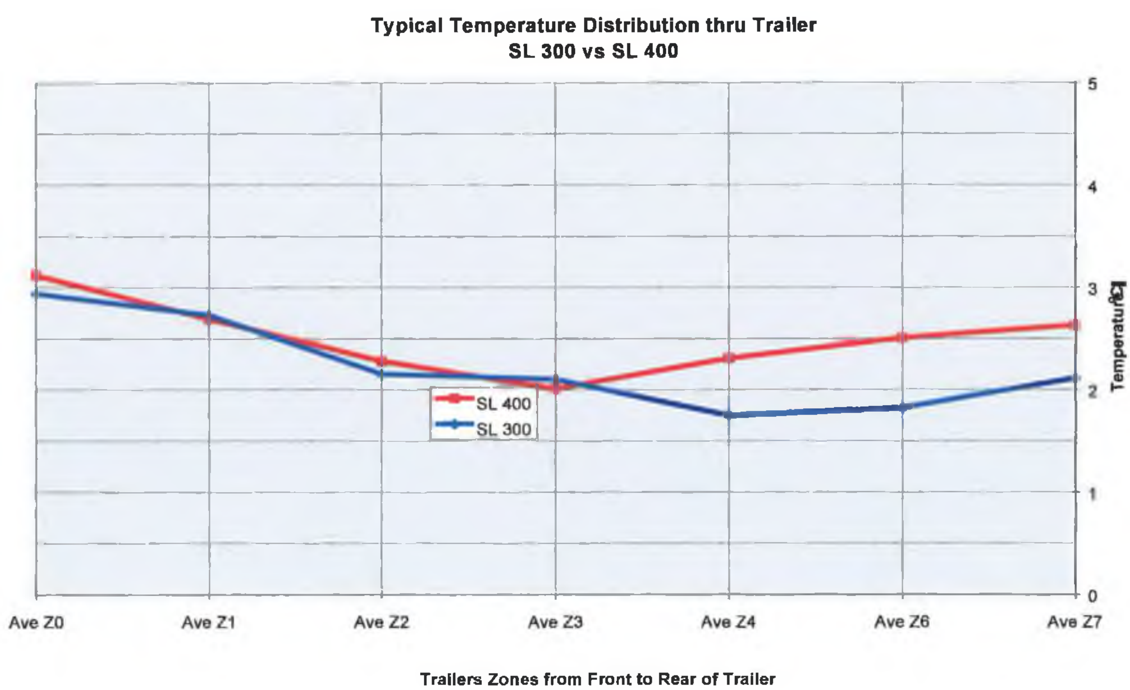

Figure 4B Comparison of Temperature Distribution

Figure 4B shows the temperature distribution throughout the trailers. Results show that the temperature for the sl300 varied by approximately 1.1^{0}C and for the sl400 1.25^{0}C.

Conclusion

- SL 400 pulled down from approximately 30 to 0^{0}C in 46minutes, 17.5 minutes before SL 300.
- For the pull down section of the test the fuel consumption rate for the SL 400 was more than that of the SL 300 put because the SL 400 pulled down faster it used 26.03% less fuel than the SL300.
- For the test as a whole the SL 400 used 22.88% less fuel than the SL 300.
- The temperature distribution throughout the trailers was similar for both units, the temperature holding to within 1.25^{0}C throughout the trailer.
- The SL 400 holds the temperature at a constant value after reaching setpoint, whereas the SL 300 operates by heating and cooling the unit cycling around the setpoint and changing from high speed to low speed operation.

Standard Truck Head to Head Report Layout

Test Title Truck Head to Head Temperature Distribution & Fuel Consumption Test.

Purpose Assessment of Pulldown & Temperature Maintance Preformance of TS 300 Vs Supra 744

Requester
Responsible Engineer A. Ryan, J. Mannion
Responsible Technicians F. Devaney.

Date 7/1999

Unit Trl. 1 TS 300

Unit S / N

Unit Trl. 2 Supra 744

Unit S / N

Test Set-Up

Test Area Location;

- APP R&D

For each Truck body;

- 20 T-type TCs located inside the body at 4 zones at 1, 3, 5, & 7 meters from the front wall. Arranged alternately in A & V formations.
- 4 T-type TCs on evaporator return, averaged at source.
- 4 T-type TCs on evaporator discharge, averaged at source.
- 4 T-type TCs for ambient temperature, averaged at source.
- Danfoss MassFlo 2100, flowmeter measuring instantaneous fuel consumption rate and total fuel consumed.
- 3 NetDAQ are required for the two Truck body and ideally should be connected into the network via a hub.
- 1PC for recording and monitoring the information received from the NetDAQ's

NetDAQ used	BCN 1 IP Address 168.92.46.41 BCN 7 IP Address 168.92.46.47 BCN 8 IP Address 168.92.46.48

Thermo Daq Template F:\ Private\ Eng. Test \ ThermoDAQ \ Templates \ Standard
Truck head to head
Data Files F:\ Private\ Eng. Test \ TR

Common Test Analysis

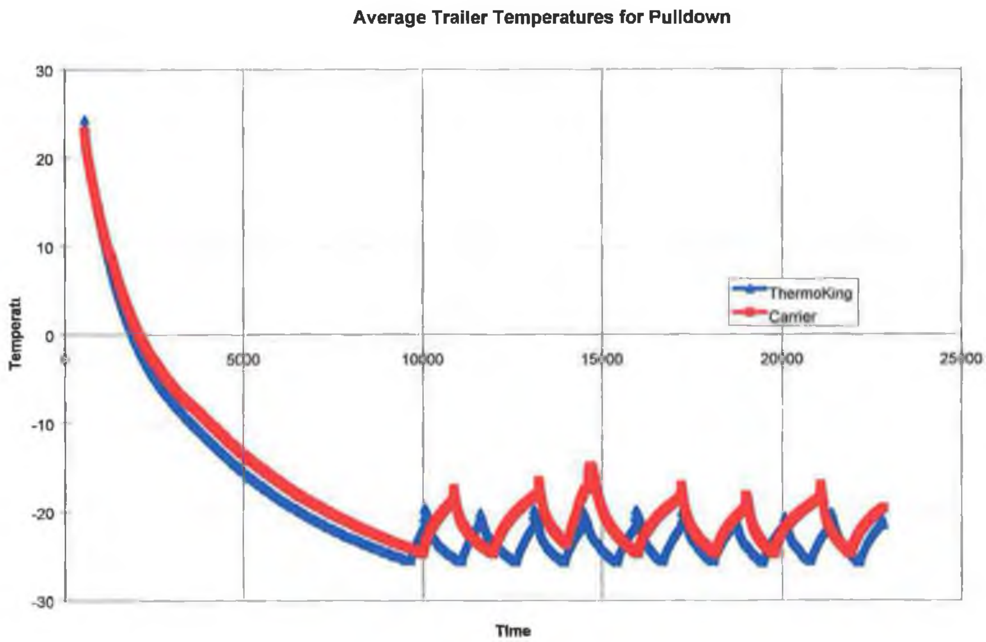

Figure 5B Average truck body temperature during test.

Note; For pulldown test, only pulldown portion of test is shown for each unit.

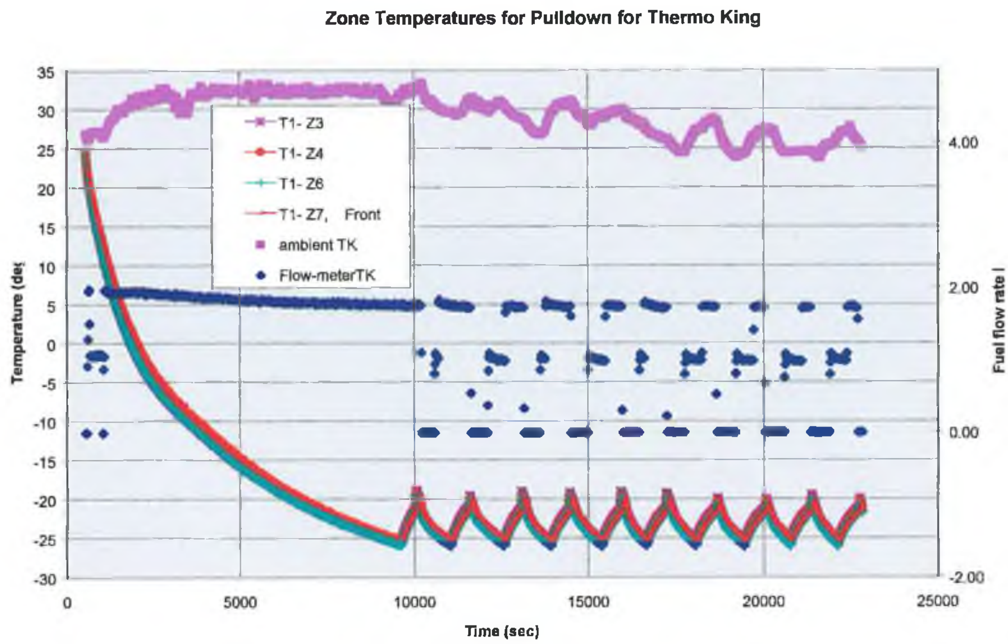

Figure 6B Zone temperatures, ambient & fuel consumption rate for truck 1

Note; For pulldown test, only the portion of the test where both are in pulldown is shown to enable direct time based comparison.

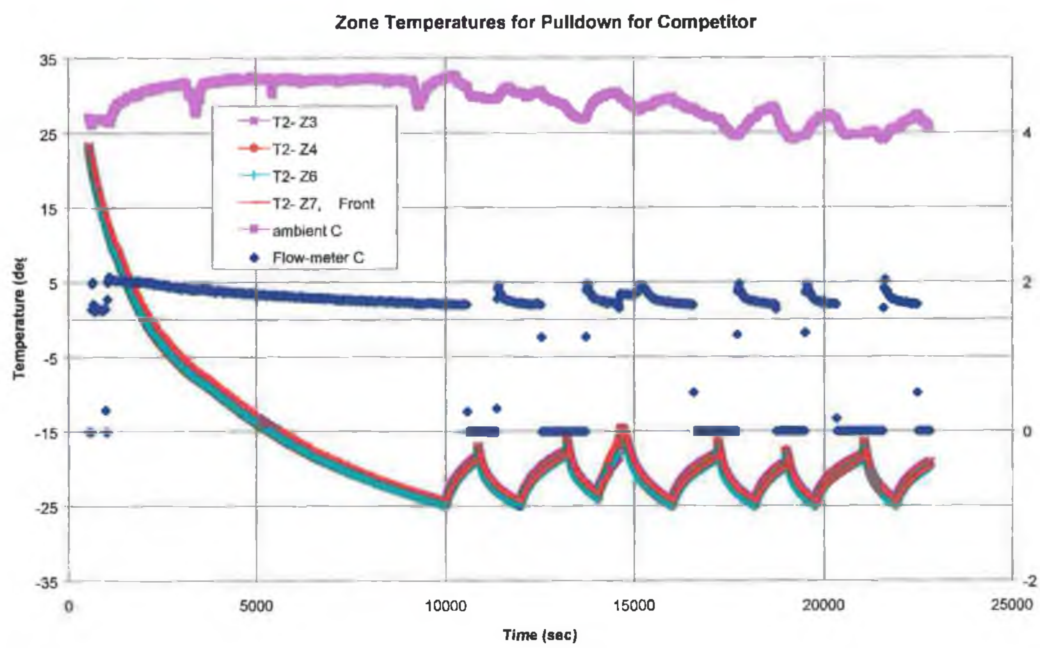

Figure 7B Zone temperatures, ambient & fuel consumption rate for truck 2

Note; For pulldown test, only the portion of the test where both are in pulldown is shown to enable direct time based comparison.

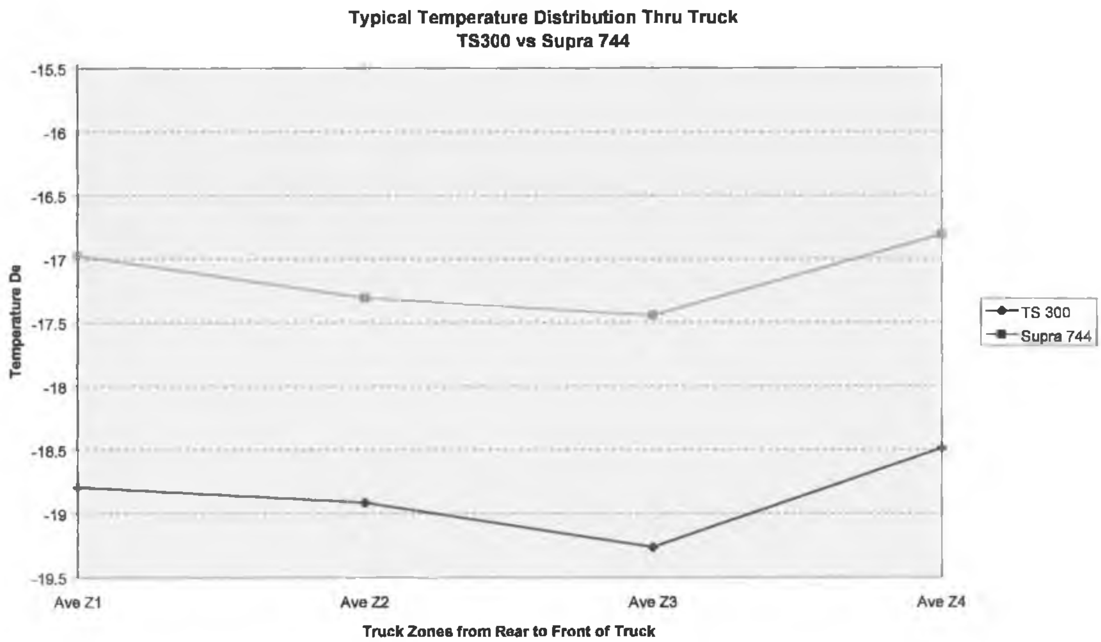

Figure 8B Typical zone temperatures for truck bodies indicating temperature distribution during test.

Standard Test Report (Wind Tunnel) Airflow

Test Title TS 600 Airflow Preciertifcation Test.

Purpose Test airflow of TS 600 in high speed and low speed to ensure it gets the airflow required during ATP testing.

Requester A. Ryan, M. Tullemans, S Eberly.
Responsible Engineer A. Ryan, J. Mannion
Responsible Technicians F. Devaney.

Date 7/1998

Unit TS 600

Unit S / N 1289S79678

Test Set-Up

Test Area Location Workshop
Wind Tunnel Template Truck
Nozzle Template Truck/Remote Evap.
Nozzles Used 6

Thermo Daq Template Wind Tunnel 2
Data Files WT TS 600 Pre-Certification Airflow HSD 072199. csv
WT TS 600 Pre-Certification Airflow LSD 072199. csv
WT TS 600 Pre-Cert Airflow. xls

Fan Set-Up;
Mechanical/Electrical Fans Mechanical
Voltage Supply N/A
Grills All European grill requirements.

Test Results

Test 1, High Speed Diesel

Diff Press on Nozzles	Fan I/L Temperature	Fan O/L Static Pressue	Motor Volts	Motor Amps	Fan Speed	Flow (m3/hr)	Flow (cfm)
226.985	20.3824	-1.37387				3275.22	1927.91
226.985	20.3824	-1.37387				3275.22	1927.91
197.103	20.0904	50.3919				3042.34	1790.83
163.694	19.7742	100.668				2766.05	1628.2
136.81	19.6582	150.543				2528.78	1488.53

Test 2, Low Speed Diesel

Diff Press on Nozzles	Fan I/L Temperature	Fan O/L Static Pressure	Motor Volts	Motor Amps	Fan Speed	Flow (m3/hr)	Flow (cfm)
26.4873	19.7011	139.582				1107.47	651.9
38.2434	19.9071	99.7717				1329.77	782.752
62.7116	20.0115	48.5801				1703.37	1002.67
88.4202	19.9189	-1.1936				2025.56	1192.32

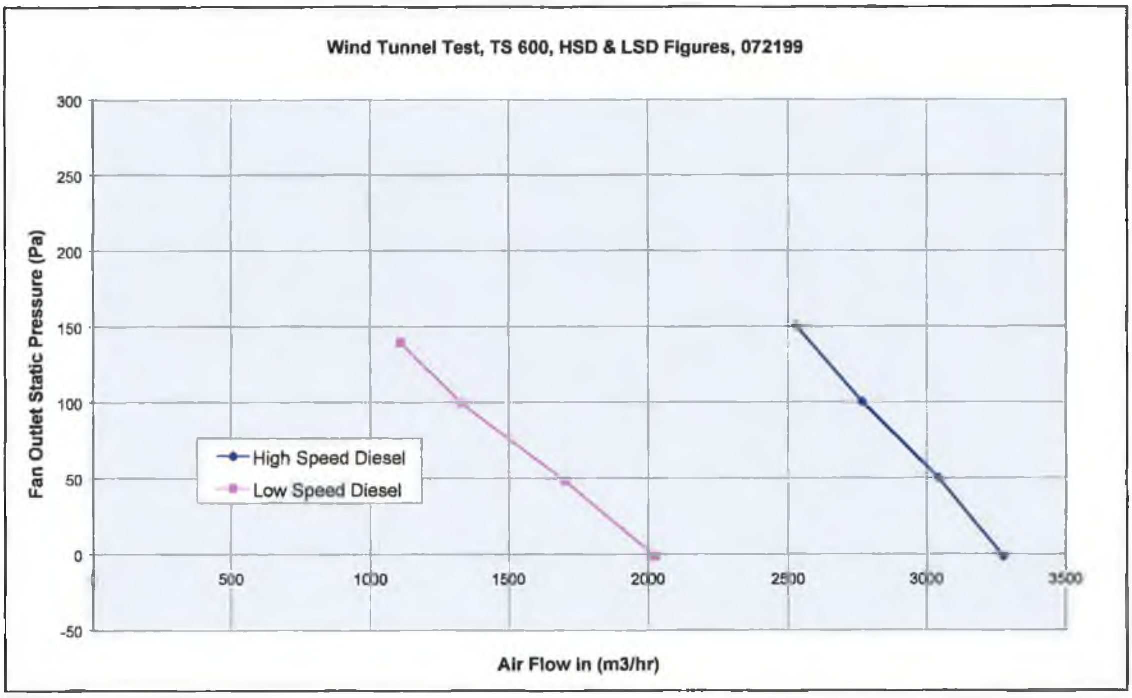

Figure 9B Static Pressure VS. Flow Rate to show Fan Characteristics

Conclusion

- High-speed diesel figures at 0 static pressure for the TS 600 show airflow is 3275 m^3/hr.
- This is 2% greater than the required airflow of 3200 m^3/hr laid down as product specification.
- This airflow is, however, 13% less than the high-speed diesel figure for the XDS tested in CRT. The difference in figures may be due to grill arrangement or differences in the evaporators.
- Low Speed Diesel figures were also about 19% lower than those tested in CRT in 1998

Wind Tunnel Nozzle Selection

Figures 1C and 2C show information to aid in the selection of the correct number and size of nozzles to use when testing airflow on the Wind Tunnel. Personnel in the department can access this information when performing a test promoting the extensive use of this apparatus by all personal.

	A	B	C	H	I	J	K
1	Unit Type	Airflow (m^3/h)	Airflow (m^3/s)	Template Size	Max No. of Nozzles	Min No. of Nozzles	Max Static Pressure
2	SL 300	5500	1.53	Large	3	1	
3	SL 330	5500	1.53	Large	3	1	
4	SL 200	4800	1.33	Large	3	1	915
5	SL 100	4000	1.11	Large	3	1	850
6	SB-III SLE	5470	1.52	Large	3	1	
7	RD-II SR	3060	0.85	Small	5	1	315
8	KD-II SR	2720	0.76	Small	5	1	366
9	MD-II SR	2720	0.76	Small	4	1	285
10	UMD-II MA:	2040	0.57	Small	3	1	
11	SDZ	1700	0.47	Small	3	1	515
12	CD	1800	0.50	Small	3	1	157

Figure 1C Excel Sheet Containing Data on the selection of No. Of Nozzles & Plate

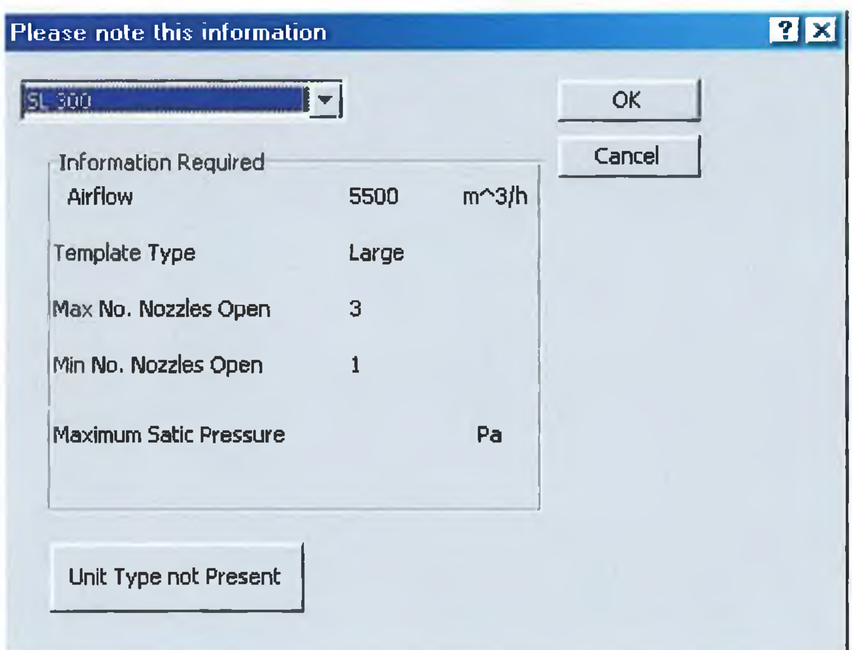

Figure 2C Automatic Pop-up Dialog to aid in the Selection of Nozzles