THE UNIVERSITY OF ASTON IN BIRMINGHAM

THESIS TITLE

An Evaluation of Human Performance in a Risk Environment

Submitted by

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Summary

The work described in this thesis follows the research methodology of studying human performance with a machine system in action in the real world. Unfortunately proven methodologies for man-machine systems research do not exist. Nevertheless, by modifying the "Meister Taxonomy" a credible method was achieved for use with the man-machine system model selected for research.

The intent of the research was to observe and record the operators' performance whilst they operated a machine system element of the European Spacelab during its development and test program, i.e. their performance in terms of attention, recognition, decision making and responses to the warning system-signal stimuli presented by out-of-tolerance machine system conditions.

From the observed and evaluated data several aspects of human performance were found to be at odds with prior laboratory research, primarily because such research was fragmented. For example, although attention is the triggering mechanism of the perception process,the process per se depends upon stimuli detection, fields of view and the visual acuity of the operators themselves.

By comparison recognition is a more complex process. For example, with a simple machine system, recognition of signal-stimuli by an operator may be satisfied just by spatial location of the signal lamps. Whereas for complex machine systems operators may need to know not only what malfunction triggered the signal stimulus, but also what the cause of the malfunction was. Resolution would therefore depend on the memory storage capabilities of the operators knowledge of the machine system, which introduces subtleties on data storage (retention) and recall.

The observed and recorded research data once collated was used to produce operator performance profiles, indicating on these both the operators predicted and evaluated performance, in an attempt to determine which of the two methods is the more valid for this type of research.

Keywords: Human, Perception, Response, Performance, and Machine Systems.

Author Acknowledgements

My thanks are due to a number of people who made this thesis possible. Foremost amongst these is the management of Messerschmitt-Bolkow-Blohm (MBB) GmbH, Muenchen, West Germany, who gave me permission to use the 'Material Science Double Rack' (MSDR) for Spacelab as my research model. Principally Dr. F. Zimmermann (MSDR Project Manager) and Dr. H. Knoglinger (Head of Mission Assurance). Next are my colleagues of the MSDR 'Integration and Test Team' led by Hr. H-J. Schuran, the Team Manager, for without that help and co-operation nothing worthwhile would have been accomplished. Also my colleagues at the European Space Agency (ESA) whose support for my work has been a constant source of encouragement, especially Dr. H. Wessels, Mr. W. Nellessen, Dr. G. Mecke, Dr. C. Preyssl and Miss J. Irons. Finally, Dr. U. Merbold (ESA) Europe's first Payload Specialist Astronaut for his critique and suggestions on this work and recommendations for future research projects.

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1.0 INTRODUCTION

Over the last two to three decades extensive research covering different aspects of human performance has been carried out with various types of machines or systems. This wide range of research to study how humans and machine systems work together has generally been accomplished under controlled laboratory conditions at many different locations throughout the world. The outcome is that the theories emerging from the research are equally fragmented. Such research is however essential if all of those factors that constitute human performance are to be properly determined and understood. Thus, to understand how humans perform in the machine system environment means that a number of theories dealing with different aspects of human performance must be studied and, because no single theory exists that can explain human performance for the machine system environment in its entirety.

This thesis presents an evaluation of the performance of humans whilst operating a machine system in action in a real environment, specifically performance when operating a complex machine system, namely the "Materials Science Double Rack" (MSDR), to be used to perform scientific experiments in a low earth orbit (LEO) space environment.

This complex machine system, the MSDR (Material Science Double Rack), on completion of its two-year development cycle will form part of a manned orbiting space laboratory. The laboratory, or 'Spacelab' as it is known, is being developed by the European Space Agency as part of its space research programme. After successful acceptance testing, Spacelab is to be integrated into the NASA (National Aeronautics and Space Administration) 'Shuttle' (Space Transportation System) cargo bay at Kennedy Space Centre to provide the essential laboratory feature for the joint NASA/ESA venture. The European Spacelab Programme is described in detail in Chapter 2.

The author as the integration and test team 'mission assurance engineer' was given permission by Messerschmitt -Bolkow-Blohm GmbH (MBB) Muenchen, West Germany to use the MSDR as a research model for the study of human performance with the machine systems in action.

The opportunity to research human performance with machine systems in a practical, and indeed such an interesting environment rarely presents itself. However, with the advent of the MSDR a machine system became available which permitted research to be performed over a period of approximately two years, with the added advantage that during this period it would be manned by engineers from different disciplines and with differing levels of skill.

The purpose of the research was to observe and record human attention, recognition, decision making and response performance. Specifically, the performance of members of the 'integration and test team' whilst they were engaged in operating the MSDR. The intent was to use the data observed on attention and recognition to predict the probable response performance of the team members.

Such predictions would normally be compared against other existing research data and those theories that have been postulated. However, as stated earlier there is no one theory or combination of approaches describing human performance in a complex machine system environment. Thus comparison with other work and theories was not possible. This study was meant to be self-contained with findings relevant only to the practical issues of human performance in the tested environment. It may be hoped, however, that this work makes a useful contribution to current knowledge on human performance.

It was planned first to tabulate the raw observed data, next to predict future performance on the basis of the earlier observations and finally to compare the predicted and actual response performance. In addition it was intended to try and identify from the evaluated raw data on the team members those mechanisms that lead to human errors in the machine system environment. Ultimately, it is believed that this work on human performance will provide useful informative data for those payload specialists who will be engaged in operating the machine system element in the Spacelab environment. It is intended to provide a report on the findings of a payload specialist in the conclusions to this thesis. The findings of the payload specialist, based on his experience of functionally operating the MSDR in the space environment could provide insight into alternative areas of human performance that ought to be researched.

2.0 THE EUROPEAN SPACELAB PROGRAMME

Although space scientists in many disciplines have two decades or more of data from scientific and application satellites, one ambition remained unfulfilled. They have for a long time wished to tend and control their own experiments whilst in a space environment. At the same time scientists have also wanted to be able to retrieve and refurbish their experiment equipment and instruments, and to bring back specimens for further laboratory examination. However, it was not until the advent of the post-Apollo programme that such a notion could be given serious consideration.

With the decision by the government of the United States of America to concentrate on a reusable Space Transportation System (STS-Shuttle), it became a real proposition. Finally, through a joint venture between the USA and its "Western Partners", as the Western European countries who support the European Space Agency (ESA) are known, a laboratory for use in space (Spacelab) became a reality.

The ESA-Spacelab pressurized module concept consists of a combination of either one or two cylindrical elements, each 4 m in diameter and 2.7 m long. The module is closed at each end by conical sections called end cones.

One configuration, known as the 'short module', consists of one module segment - the core segment - and the forward and aft end cones. Two module segments - the core segment and the experiment segment - together with the end cones form the 'long module' configuration; this is the combined core and experiment segments which most people associate with the name 'Spacelab'. It is these two segments together, accessed via the Orbiter transfer tunnel, which form the pressurized, shirt-sleeve laboratory environment.

The interdependence of Spacelab and the Shuttle lies in the fact that Spacelab can only be used when flown in the Shuttle Cargo Bay where it can avail itself of the services the Shuttle Orbiter provides. For the Shuttle System concept a major milestone will be reached when together with Spacelab it provides a manned orbiting laboratory facility. This unique concept, namely the Space Transportation System (Shuttle) and Spacelab (long-module configuration) can be seen in Figure 2.1.

1980-1990

SPACELAB AND MICROGRAVITY

1983 marked the culmination of ten years work on the Spacelab programme with the highly successful ten-day mission which took place between 28 November and 8 December. The mission was a great success on two counts: firstly, it proved that Spacelab itself was an excellent facility as it met with flying colours all its operational requirements and secondly, it demonstrated that Spacelab is an ideal tool for space research. The scientific results obtained from the first mission in five major—and very different—disciplines were abundant. Spacelab-1 also marked the first flight into space of an ESA astronaut, Ulf Merbold.

Two "newcomers" to space science—Life and Material Sciences—grouped together under the general title of "Microgravity Sciences" have recently been added to the range of ESA programmes. Experimental work, using facilities specially developed for microgravity research, began in 1982 with a Sounding Rocket campaign, was pursued during the first Spacelab mission, and will continue on future Spacelab missions.

Another recent addition to ESA's activities is the development of a family of free-flying retrievable platforms. EURECA (for European Retrievable Carrier) will be launched from the Space Shuttle in October 1987 and be retrieved and brought back to Earth, again by the Shuttle, in June 1988. The first EURECA payload will be primarily devoted to microgravity research.

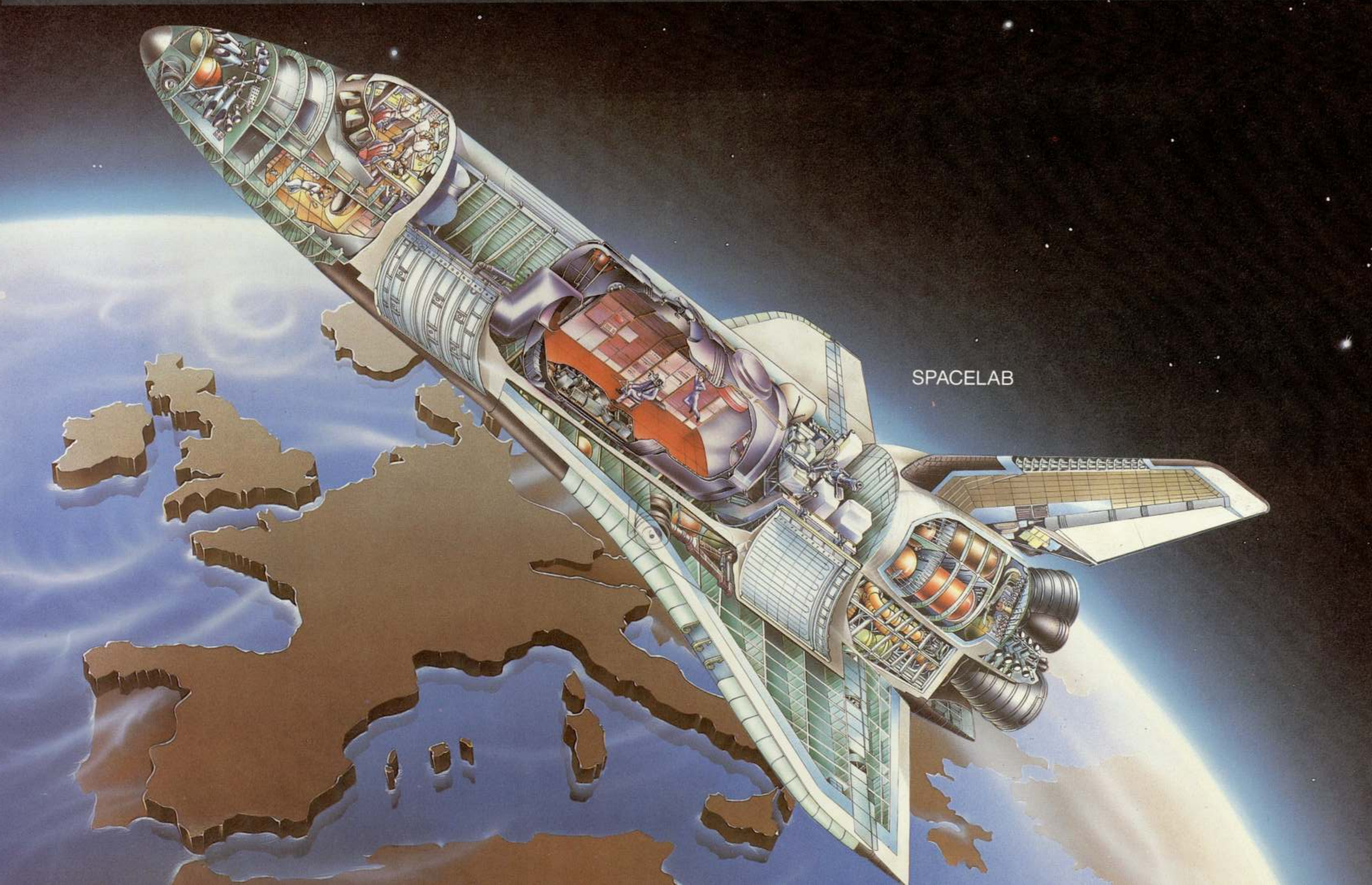

SPACELAB

Figure 2.1 : The Space Transportation System/Spacelab Flight Configuration.

Spacelab thus provides scientists with an answer to their ambitions, because in this module they can work in a comfortable environment whilst handling equipment and performing their experiments. Such real-time experimentation also enables the scientists to react to unforeseen developments or data as the experiments progress, accepting presented targets of opportunity, changing plans and even changing the direction of the research in a way which cannot be accomplished with remotely controlled payload experiments.

Upon completion of the mission profile (the time frame that the Shuttle System is in its 'Parking Orbit' and during which period the Spacelab experiments are performed) the Shuttle System returns to earth so that experiment equipment and instruments can be removed for refurbishment, and the Shuttle System readied for future missions.

Spacelab offers a flexibility which is unique because it enables several disciplines such as astronomy, physics, the life and material sciences, engineering, ocean and land sciences, etc., to be performed whilst the shuttle is in 'low earth orbit' (LEO).

Additionally, the Spacelab module affords scientists and engineers unparalleled views of earth and deep space, and immersion in the earth's magnetic and electric fields, whilst working in a microgravity environment.

For the 'First Spacelab Payload' (FSLP) the internal layout of the 'core' and 'experiment' segments are depicted in Figures 2.2 and 2.3, and were configured in this manner to permit the following five broad areas of investigation to be performed:

1. Atmospheric Physics and Earth Observations.
2. Space Plasma Physics.
3. Astronomy and Solar Physics.
4. Material Science and Technology.
5. Life Sciences.

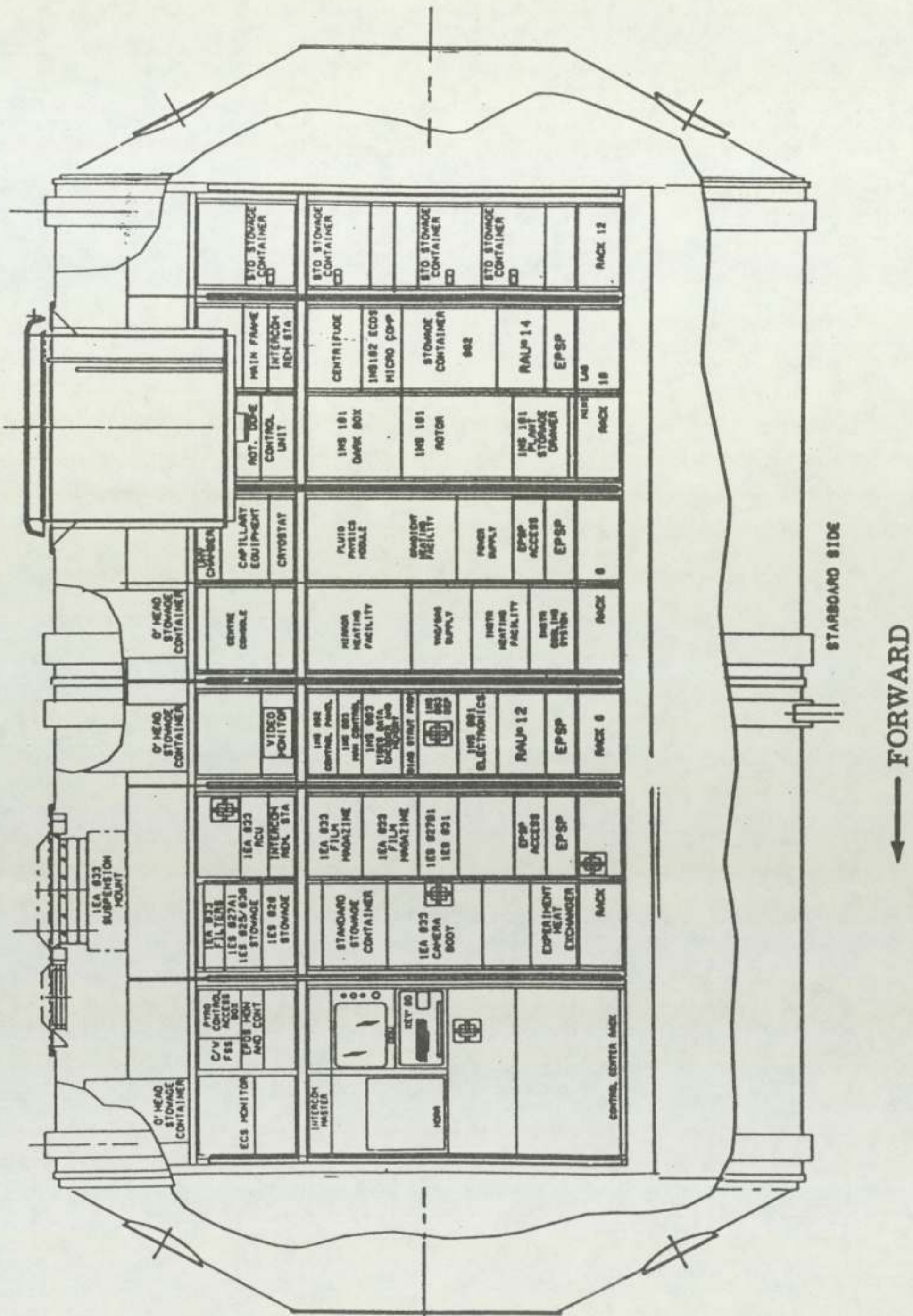


Figure 2.2 : Spacelab 1 Module, Starboard Side

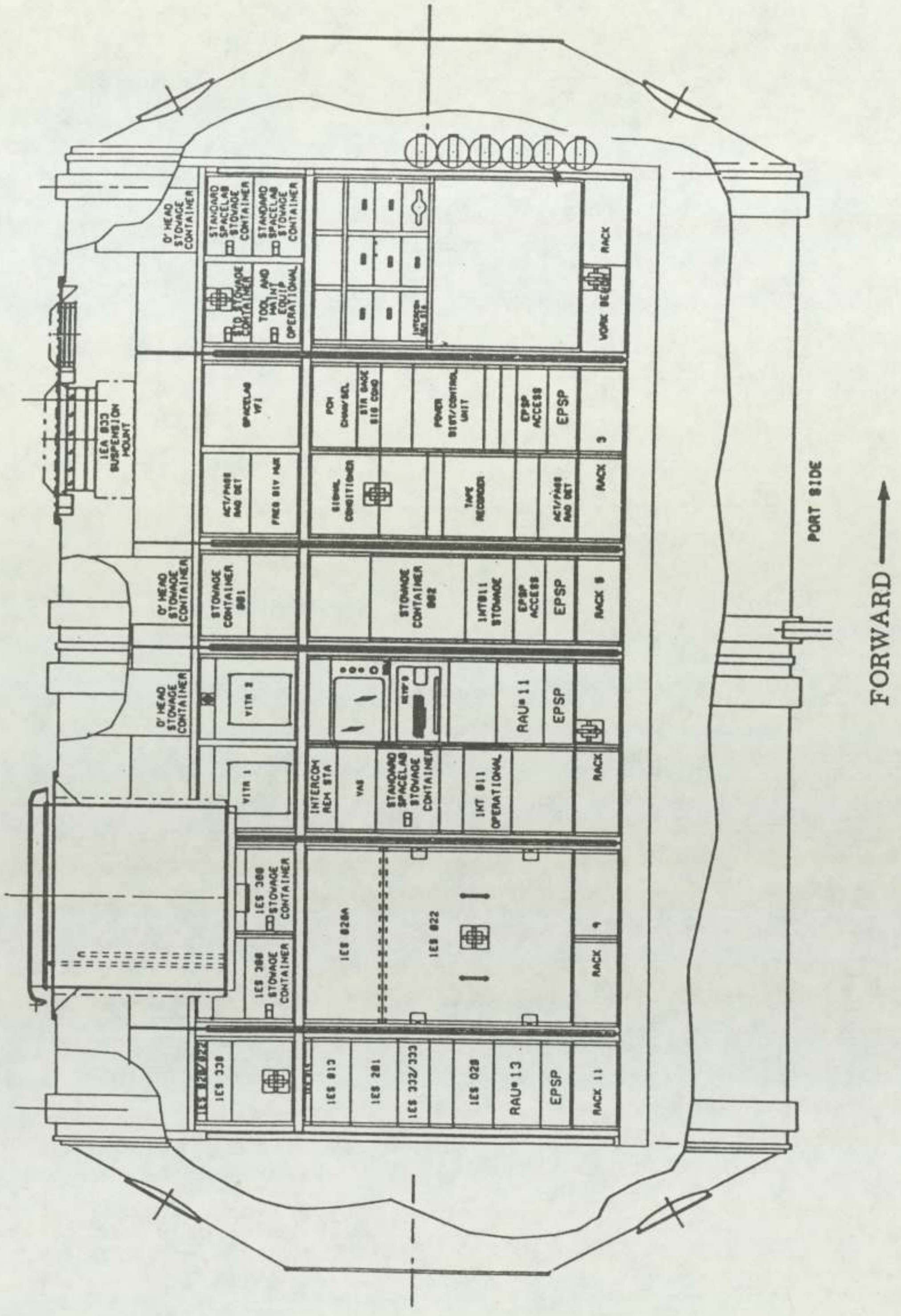


Figure 2.3 : Spacelab 1 Module, Port Side

To operate all the scientific equipments and instruments, the Spacelab systems, and the Shuttle Orbiter, a crew of six is needed. In addition to the Pilot and Commander of the Orbiter there are four scientists on board. Two of the scientists are 'mission specialists' who are astronauts, responsible for the management of Orbiter resources for Spacelab and the operation of Spacelab subsystems in support of the payloads.

The other two scientists, or 'payload specialists', are not astronauts but they still have to undergo space flight training so that they can be acclimatised to floating in microgravity conditions. The Spacelab module has been primarily designed to accommodate scientists and engineers who have received minimal space training.

It is the payload specialists who will operate the payload experiments on behalf of the investigators, and serve as test subjects for a number of biomedical experiments.

The 'Shuttle/Spacelab' combination will become a fully manned orbiting laboratory for use in low earth orbits. This will be the first time that scientists will have the opportunity to perform experiments in a retrievable microgravity environment.

Whilst it is possible to design, develop and test the Shuttle and Spacelab systems to ensure correctness of functions and to compensate for those failures that are most likely to occur, what cannot be readily predicted is the performance of those scientists when they interface with the wide range of equipments and instruments whilst in such an environment.

Launch of the 'Shuttle/Spacelab' combination was successfully accomplished on the 29th November 1983 and landed safely back at the Kennedy Space Centre nine days later.

3.0 THE MATERIAL SCIENCE DOUBLE RACK

The "German Microgravity Laboratory for Material Science and Space Processing Experiments" is one major piece of equipment which formed part of the 'first spacelab payload' and also a subsequent mission.

The following description is derived to a large extent from the paper by Zimmermann (1979).

In essence the design considerations were to produce a multi-purpose and multi-use facility which would enable material science and space processing of experiments to be performed in a microgravity environment. This 'microgravity laboratory' is located in the 'experiment' segment of Spacelab on the starboard side and, as shown in Figure 2.3, it occupies two racks which are identified as Double Rack No. 8.

The 'microgravity laboratory', usually referred to as either the "Material Science Double Rack" (MSDR) or the "Space Processing Laboratory" (SPL), consists of a variety of experiment facilities and common equipments to provide general support services, these are identified in Table 3.1.

Table 3.1 : Standard Interface to Spacelab

o DC POWER	22 - 32 V, 22 - 32 V } TOTAL PEAK 1885 W { 2 EPDB-OUTLETS 60 A EACH
o RAU INTERFACE	
PCM DATA LINE (2)	
PCM DATA CLOCK LINE (2)	
PCM DATA REQUEST (2)	
PCM CMD LINE	
PCM CMD CLOCK LINE	
FLEXIBLE INPUT LINE (2)	
UTC LINE	
UTC UPDATE LINE	
o AVIONICS AIR LOOP	FLOW RATE 160 kg/h TEMP. RANGE + 10 / + 30° C
o LIQUID COOLING SYSTEM	FLOW RATE 180 l/h TEMP. RANGE (PRIMARY SIDE) + 9 / + 25°C
o VACUUM SYSTEM (VENT LINE)	10^{-3} mbar, FLOW RATE 0.16 kg/sec (1.75l/sec)
o ESSENTIAL POWER	21 – 32V/ 36 W

3.1 MSDR Industrial Team.

The make-up of the 'MSDR Industrial Team' is shown in Figure 3.1, and is presented to show the range of European involvement for this major scientific space project. For this program the experiment facility/instrument developers were responsible for meeting not only the requirements of the experimenter community in terms of functional design but also all of the physical, functional and operational interfaces of the MSDR.

3.2 Experiment Facilities

The payload experiment facilities are intended to meet two main objectives:

1. During the 'first spacelab mission' in November 1983, to perform a number of significant pilot experiments in the fields of crystal growth, fluid physics and metallurgy, and, at the same time, to flight test the materials science hardware items developed, e.g., furnaces, process chambers, etc;

2. To make a significant contribution to the establishment of a materials science equipment pool, which will be an important feature in the planning of future missions.

Figure 3.2 is a front view of the MSDR showing the majority of the experiment facilities and common support equipments.

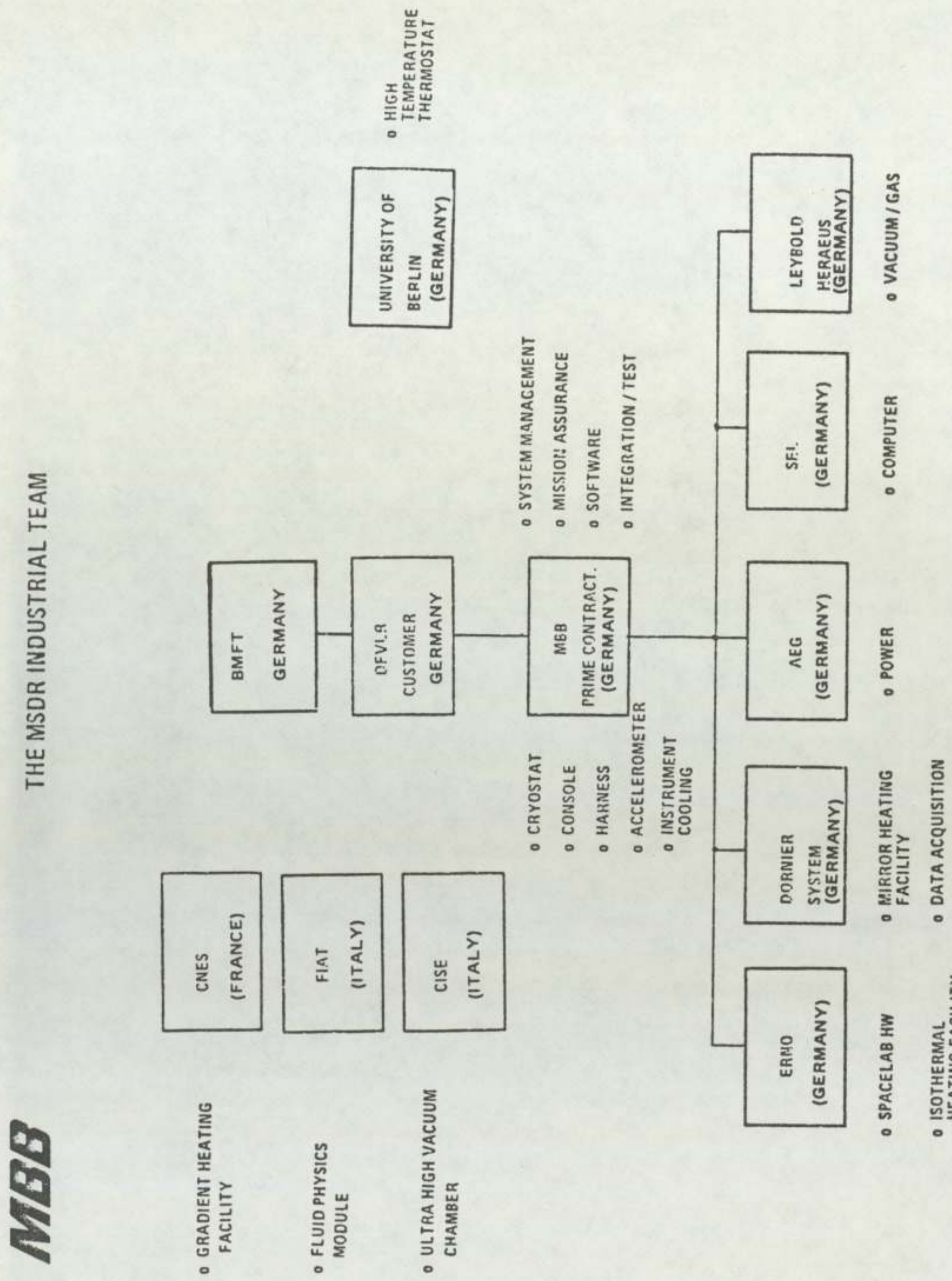


Figure 3.1 : The MSDR Industrial Team

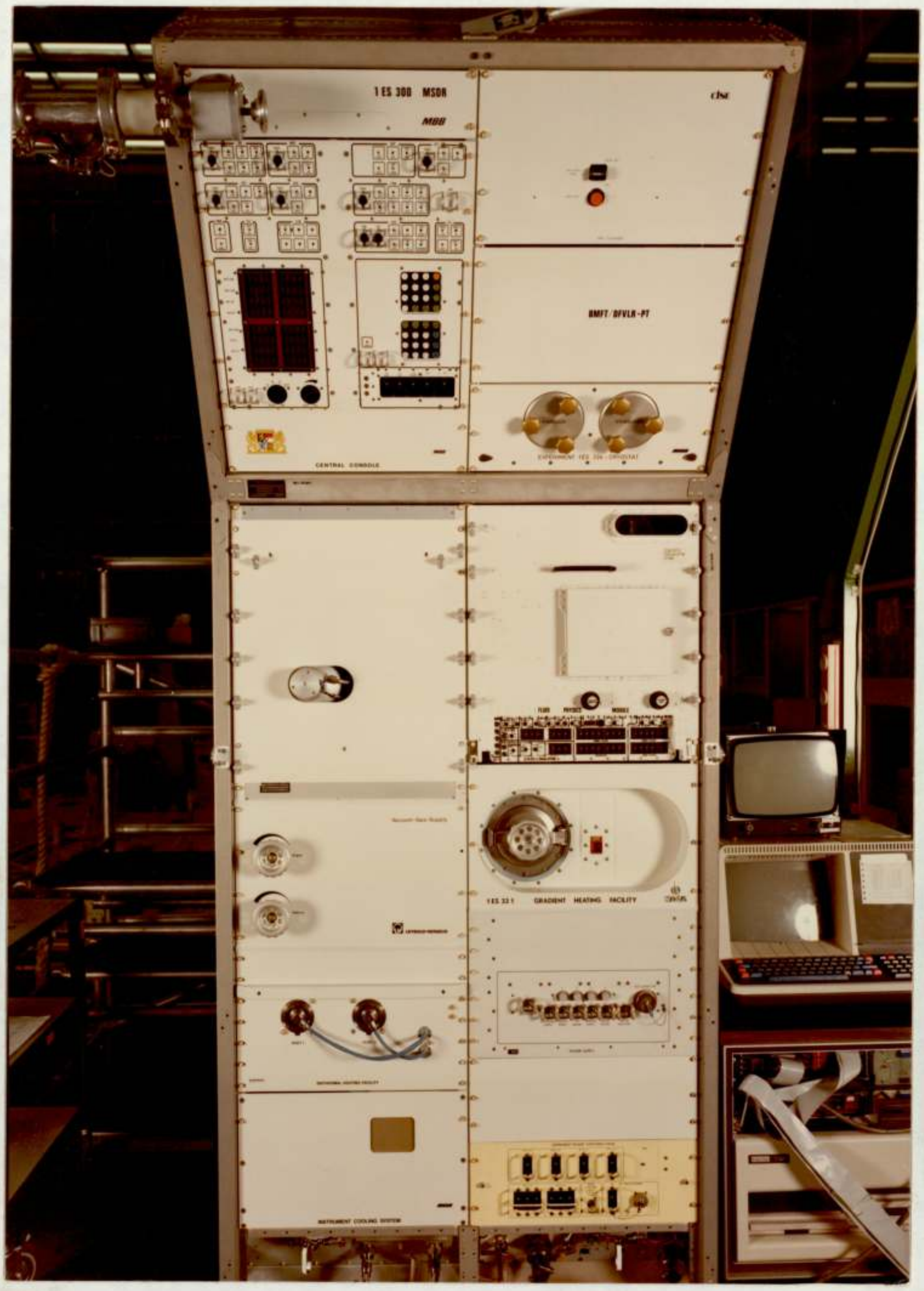


Figure 3.2 : Material Science Double Rack (Front)

There are 35 experiments planned most of which will be performed with the help of multi-user facilities such as furnaces, etc., six of these experiments are however performed using their own special equipment and may be viewed as being quasi-autonomous.

.2.1 Multi-user Facilities

The following defined equipments are those classified as multi-user facilities:

Isothermal Heating Facility (IHF)

This facility is to be used for different types of experiments, including solidification studies, diffusion fundamentals, casting of metals and composites, and the preparation of new and/or improved glasses and ceramics. The material to be investigated must be placed in cartridges which are inserted into the furnace. To allow the simultaneous heating and cooling of two different samples, a cooling and a heating chamber are provided.

The samples contained in the cartridges are attached to a sample holder which remains stationary during the entire experiment performance, whereas the cooling and heating chambers can be withdrawn to the rear of the chamber, rotated through 180° and then driven back over the cartridges.

The cartridge which was in the cooling chamber is now in the furnace chamber, therefore, ready for exchange, and the cartridge which was in the furnace chamber is now able to be subjected to the cool-down is now in the cooling chamber.

A controlled atmosphere of helium or vacuum is provided for the furnace chamber, and a helium or air atmosphere for the cooling chamber.

A view of the Isothermal Heating Facility heating and cooling chamber, motor drives and MSDR interfaces, is shown in Figure 3.3.

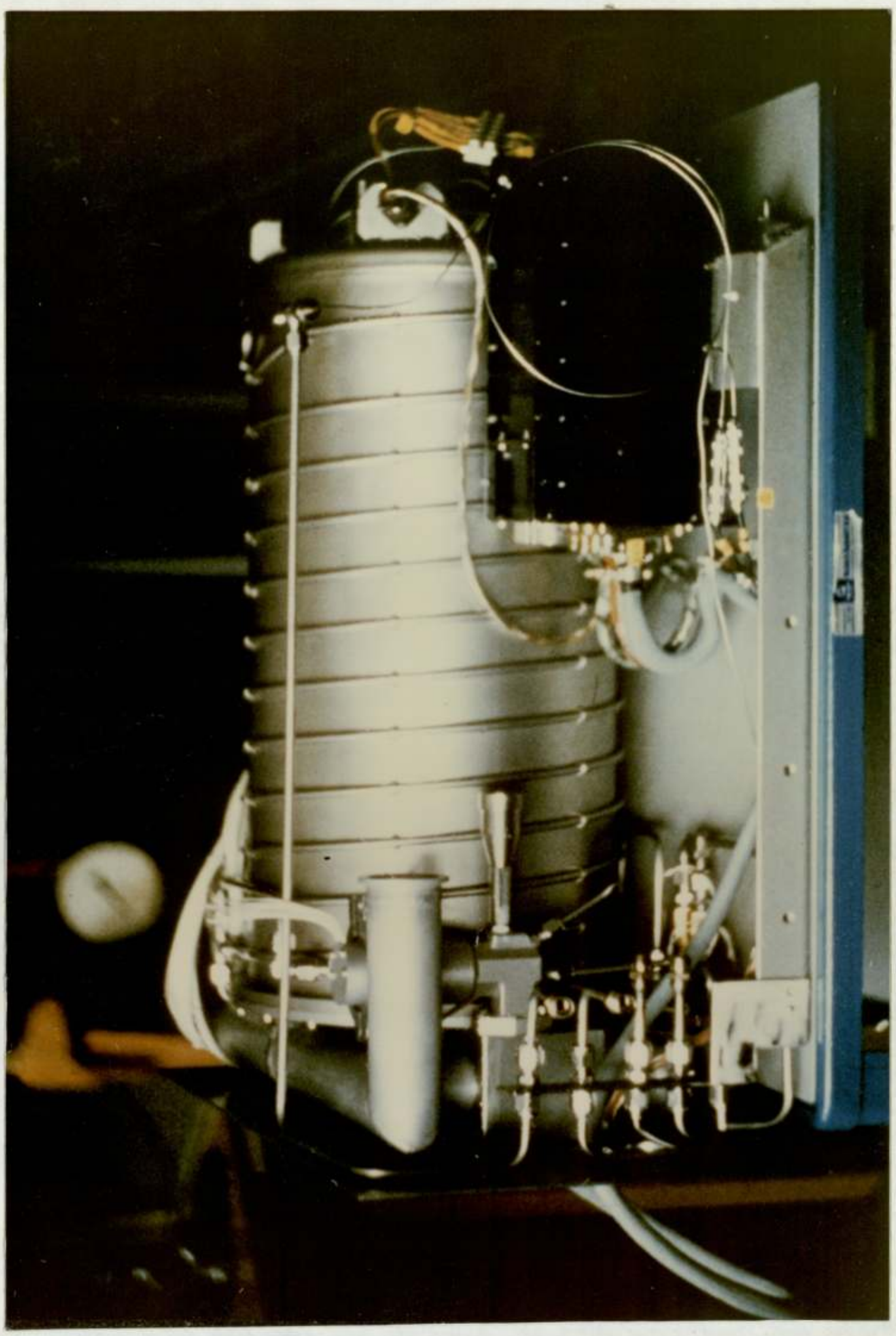


Figure 3.3 : The Isothermal Heating Facility

Gradient Heating Facility (GHF)

This facility is classified as a 'low temperature' equipment, i.e., maximum temperature < 1200^{o}C on the cartridges. Its functional purpose is to perform different types of experiments in crystal growth, unidirectional solidification of eutectics, etc.

The furnace consists of three chambers that allow cartridges to be heated by three heating elements which are independently controlled, so that a variety of temperature profiles, including isothermal, can be achieved.

Thermal insulation is provided by axial heat shields, a low conductivity radiation shield, multifoil insulation, and an outer protective shield. A vacuum and noble gas supply are provided to the facility, this allows quenching to be performed by purging the furnace with helium.

The Gradient Heating Facility is shown without its baseplate and front cover in Figure 3.4.

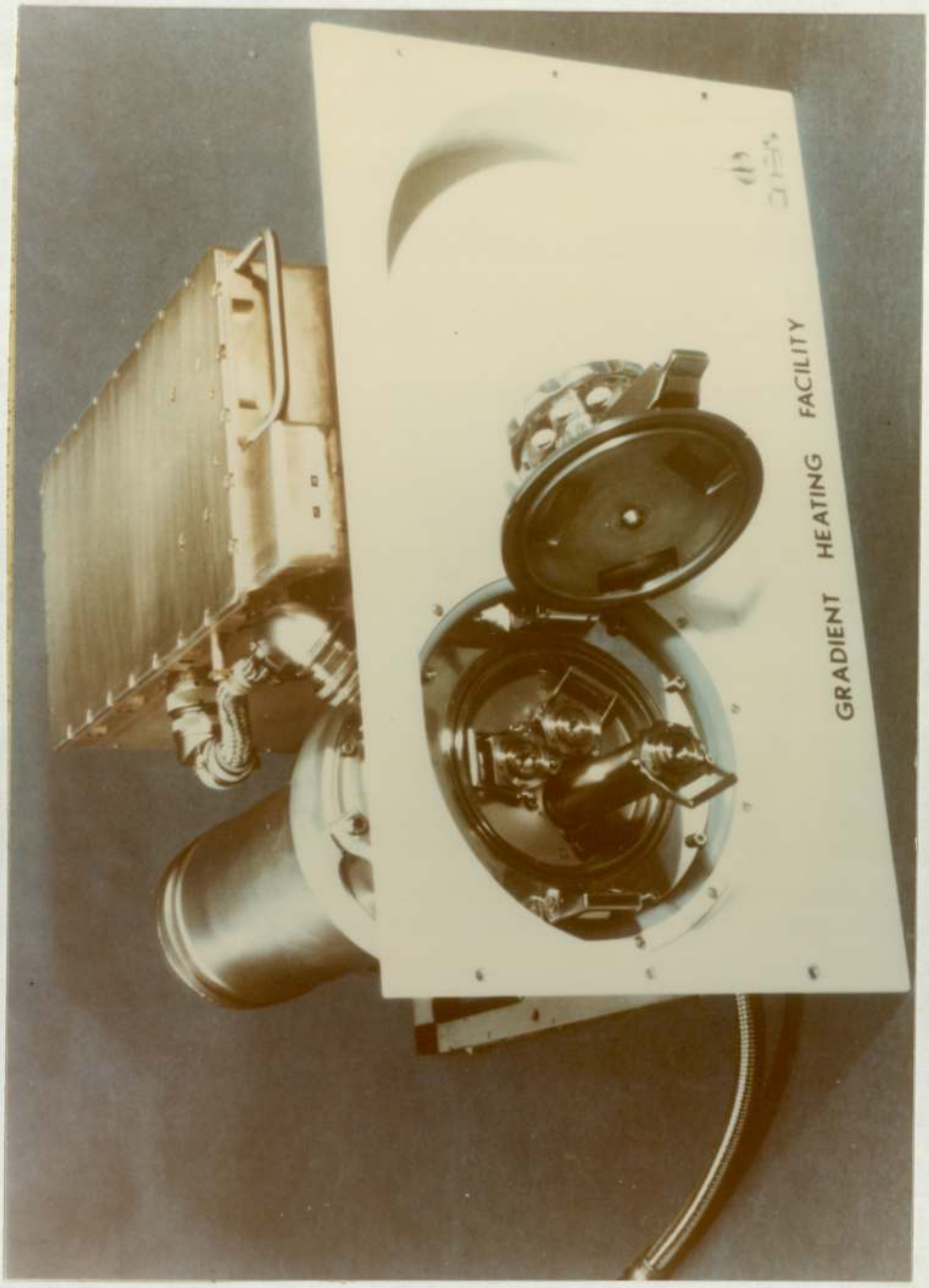


Figure 3.4 : The Gradient Heating Facility

Mirror Heating Facility (MHF)

This is an experimental facility which is particularly suitable for investigating crystal growth using the melt zone or travelling solvent methods. The facility consists of an optically heated zone furnace and ancillary devices, such as vertical and rotational drive mechanisms.

The key elements of the zone furnace are two ellipsoidal mirrors with coincident optical axes and a common focus. Halogen lamps acting as heat sources are located in the other two foci. The space for the samples (the melt zone) is located at the common focus. Samples are inserted into this location by two holders which are perpendicular to the optical axis. Two viewing ports are provided for optical monitoring and pyrometric temperature measurement and control.

Figure 3.5 shows the Mirror Heating Facility with the front cover open ready for cartridge loading.

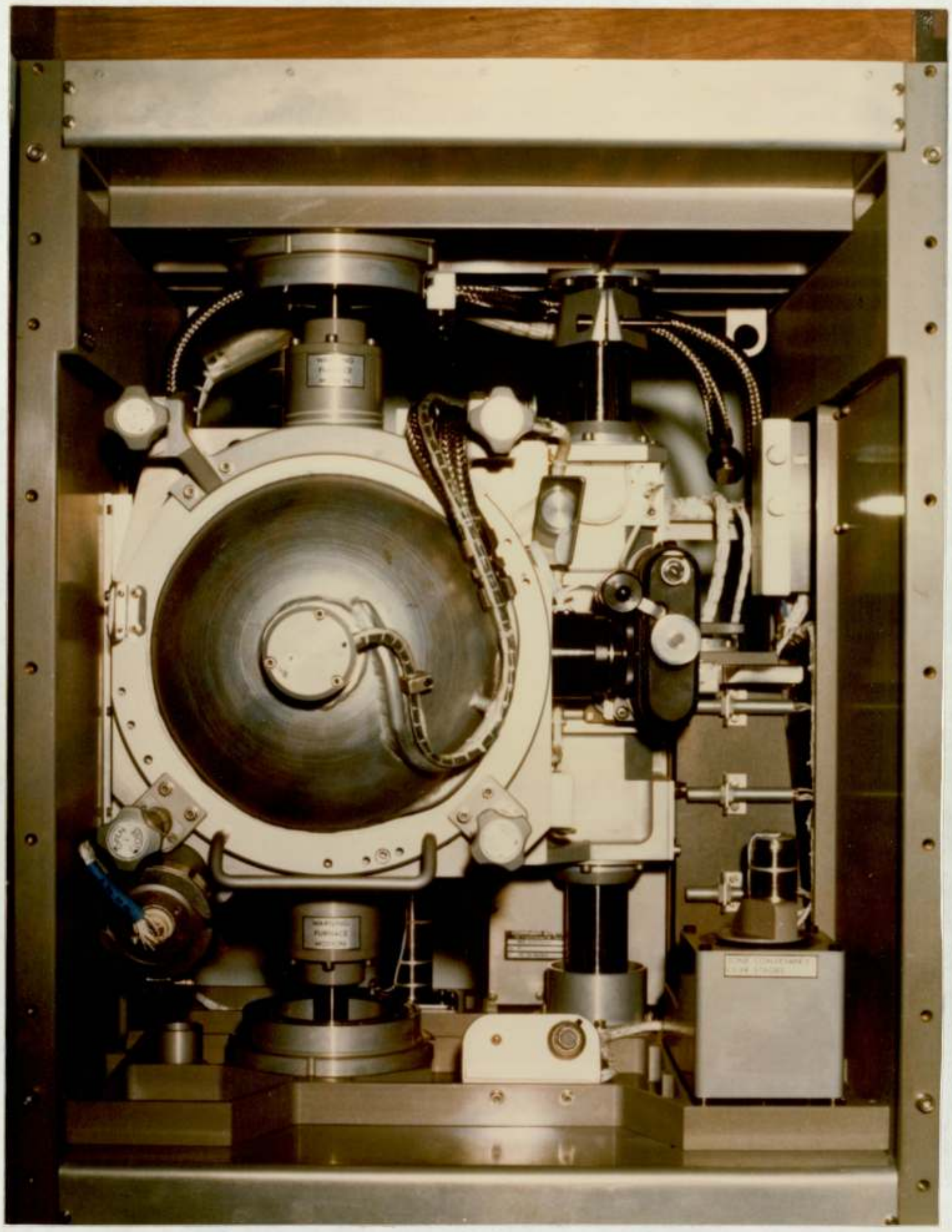


Figure 3.5 : The Mirror Heating Facility

Fluid Physics Module (FPM)

This module has been developed to serve a variety of scientific objectives in the field of fluid phenomena, i.e., fluid physics in its widest sense.

The module consists mainly of a structure fitted with two opposing discs which can be individually rotated at the same or different speeds, and in either direction. A 'floating zone' is then set up either on one of the discs or between the two.

There are also two 'auxiliary systems' which form an integral part of Fluid Physics Module, these are :

1. Visualization System - detects the shape and size of the floating zone as well as local speed of the operative fluid.

   For detecting the fluid motion range, a duplicate filming system has been adopted, i.e., one at right angles to the lighted meridian plane for recording the shape and speed in the meridian plane and one along the axis of rotation for recording speed in a plane at right angles to the axis.

2. Air-circulation and liquid-recovery system - Cleans out the test chamber if the floating zone is broken and also controls temperature and moisture inside the chamber.

The form and diameter of the end plates may be modified according to the experiment objectives, special containers may also be mounted and rotated, etc., with the help of the end plates. A variety of different fluids with or without tracers may be used for experimental purposes.

The experiment facility described above is shown in Figure 3.6.

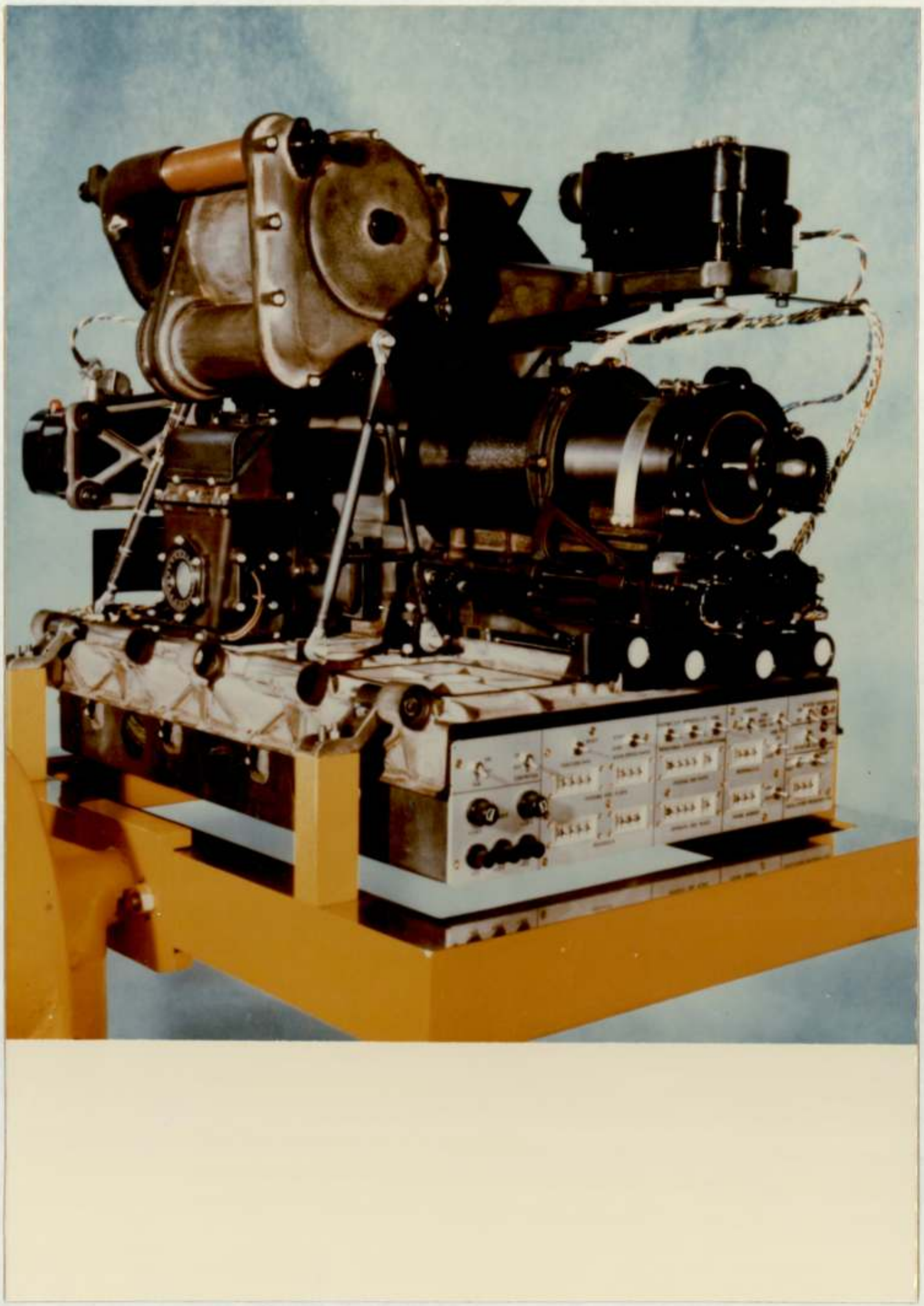


Figure 3.6 : The Fluid Physics Module

3.2.2 Quasi-Autonomous Facilities

The following equipments are those defined as quasi-autonomous facilities:

Cryostat (CRY)

The function of this facility is to investigate crystal growth by the diffusion of proteins in solutions. Two pairs of solutions are to be investigated, they are:

- Galactosidase in ammonium sulphate solution.
- Lysozyme in sodium chloride solution.

Figure 3.7 shows the Cryostat facility with its front cover plate fitted.

Figure 3.7 : The Cryostat Facility

The cryostat hardware consists of two chambers, one of these is the freezer unit, the other is the stabilizer unit. Both chambers will house a sample container which holds four different samples; 2 lysozyme, 2 galactosidase, with two different contact areas.

In order to prevent diffusion of proteins into solutions before starting the experiment, a buffer slide is fitted which divides the sample container into separate compartments.

The diffusion process is initiated by driving the buffer slides with a motor into a position which allows the phase materials and solutions to mix.

Ultra High Vacuum Chamber (UHV)

The UHV Chamber is a device designed to carry out investigation of the adhesion forces of metals in a microgravity environment. A high vacuum 10^{-10} torr is required in the chamber to counteract the chemical contribution to surface energies, this is achieved and maintained by an ionic pump.

The Ultra High Vacuum Chamber is shown in Figure 3.8.

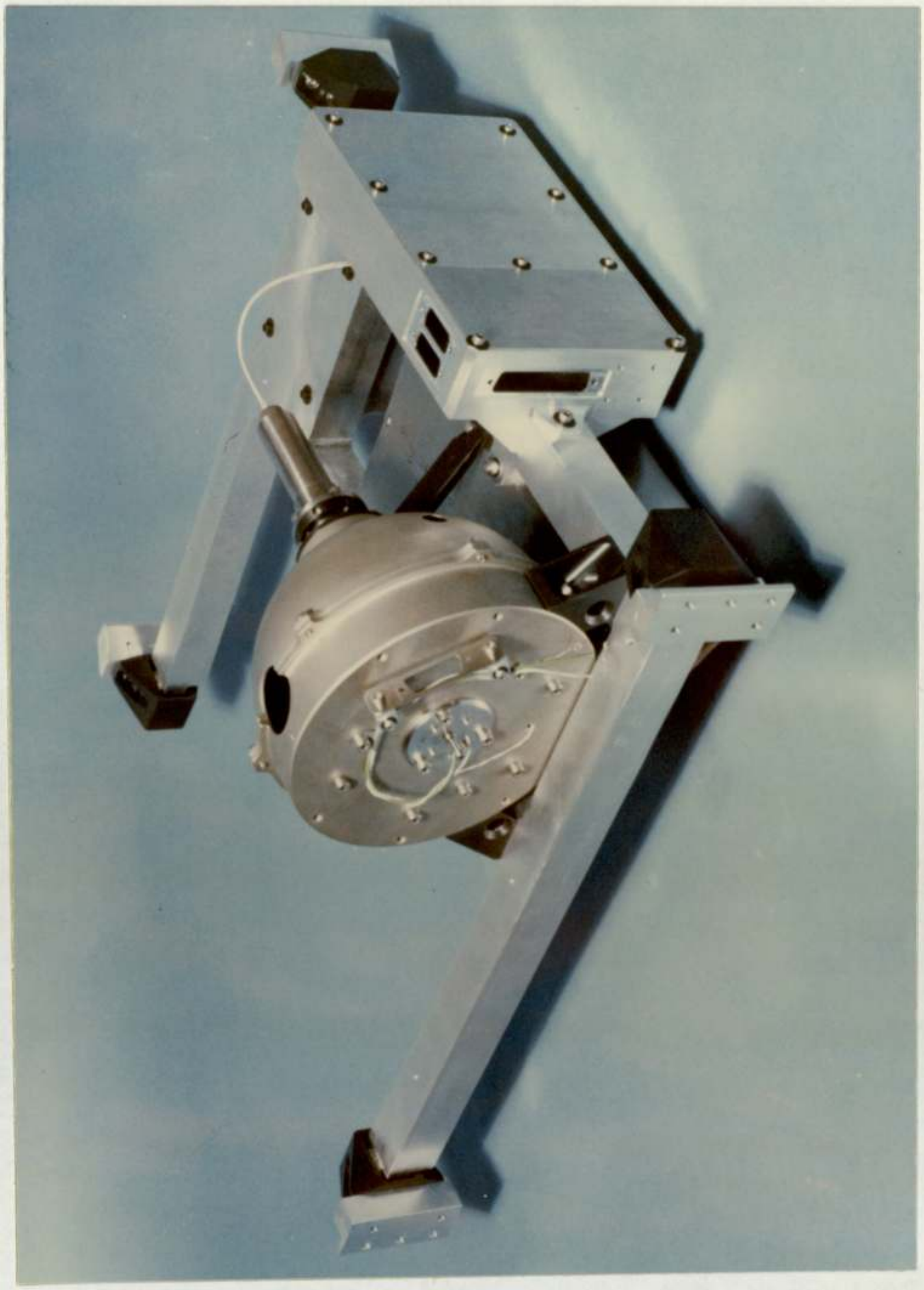


Figure 3.8 : The Ultra High Vacuum Chamber

The experiment is performed by accelerating a sphere (~3 mm outside diameter) with an electromagnetic activated hammer so that the sphere jumps back and forth against the target. A piezoelectric force transducer is used to measure the impact forces of the sphere on the target face.

High Temperature Thermostat (HTT)

The HTT, as shown in Figure 3.9, is designed to measure the diffusion and contact surface effects in the melting of tin. This device consists of 8 separate chambers each one housing its own individual cartridge. These are processed at different operating temperatures varying between 250 and 1600 ^{o}C.

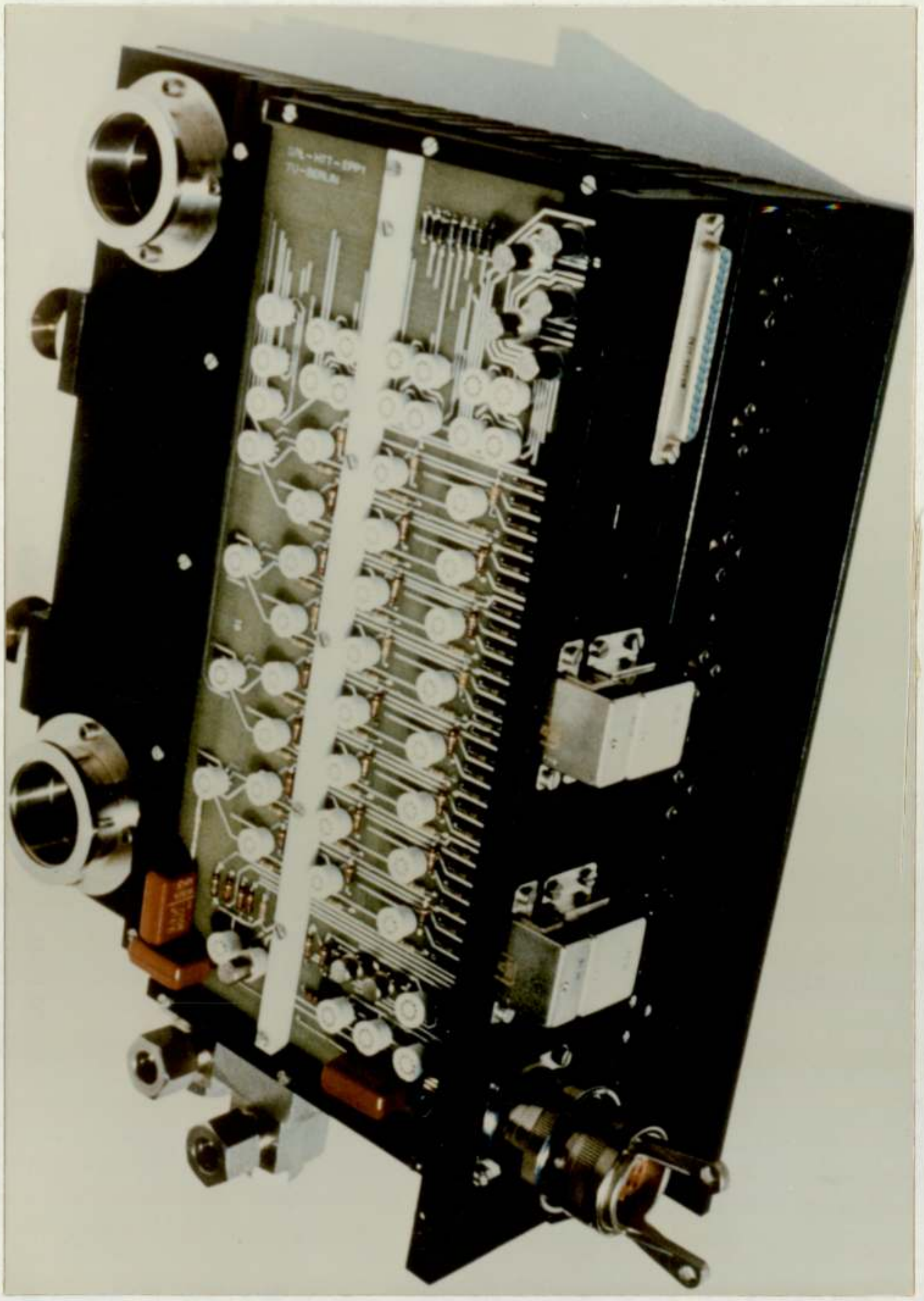


Figure 3.9 : The High Temperature Thermostat

The heating profile of the experiment samples is accomplished by filament windings which are internal to the cartridges the temperatures of these are monitored by three thermocouples which form an integral part of each HTT chamber.

The annealing time of the melted metals will range from between 1.5 and 10.2 hours with the cooling profile being achieved by staged power reduction in parallel with controlled injections of helium.

3.2.3 Common Support Equipment

None of the experimental facilities can fulfil its purpose without services. Whilst the support services are not used by all of the facilities they are common to most as shown by Table 3.2.

Those equipments which provide common support to the facilities are:

- Accelerometer
- Power Supply
- Vacuum & Gas System
- Instrument Cooling System
- Central Console

Table 3.2 : Allocation of MSDR-Elements to Common Equipment Services

SPL-ELEMENTS \ COMMON FUNCTIONS	STORAGE	VACUUM	GAS	WATER COOLING	AIR COOLING	FIXED VOLTAGES	VARIABLE VOLTAGES	DATA ACQUISITION	SOFTWARE CONTROL	S/L POWER BUS
ACCELEROMETER					●	●		●		
POWER SUPPLY				●	●			●		●
VACUUM / GAS					●	●	●	●	●	●
INSTRUMENT COOLING					●	●		●	●	●
CENTRAL CONSOLE					●	●		●		
ISOTHERMAL HEATING FAC	●	●	●	●	●	●	●	●	●	
MIRROR HEATING FAC	●	●	●	●	●	●	●	●	●	
CRYOSTAT	●			●	●	●		●	●	
HIGH TEMP. THERMOSTAT		●	●	●	●	●	●	●	●	
GRADIENT HEATING FAC	●	●	●	●	●			●	●	●
FLUID PHYSICS MODULE	●				●	●		●		
UHV-CHAMBER					●	●		●	●	

It will be these common support equipments of the MSDR which interface with those resources that are provided by Spacelab, as indicated in Table 3.2. The functional purposes to be served by these support equipments are :

The Accelerometer

Because it was not known before the first flight what quality of microgravity or levels of parasitic acceleration would be encountered in the Shuttle/Spacelab environment a dedicated accelerometer package was fitted into the MSDR.

The package was designed to measure all three axes within a frequency range of 100 Hz. However, to measure the peaks in such a range would mean an impracticably high sampling rate thus a peak detection circuit was incorporated to detect only the highest peaks received during a given interval of time.

Power Supply Unit (PSU)

The power supply unit was designed to convert the Spacelab unregulated main bus voltage of 22 to 32 Volts d.c. into secondary voltage outputs which were either at fixed or adjustable levels. This unit is shown in Figure 3.10.

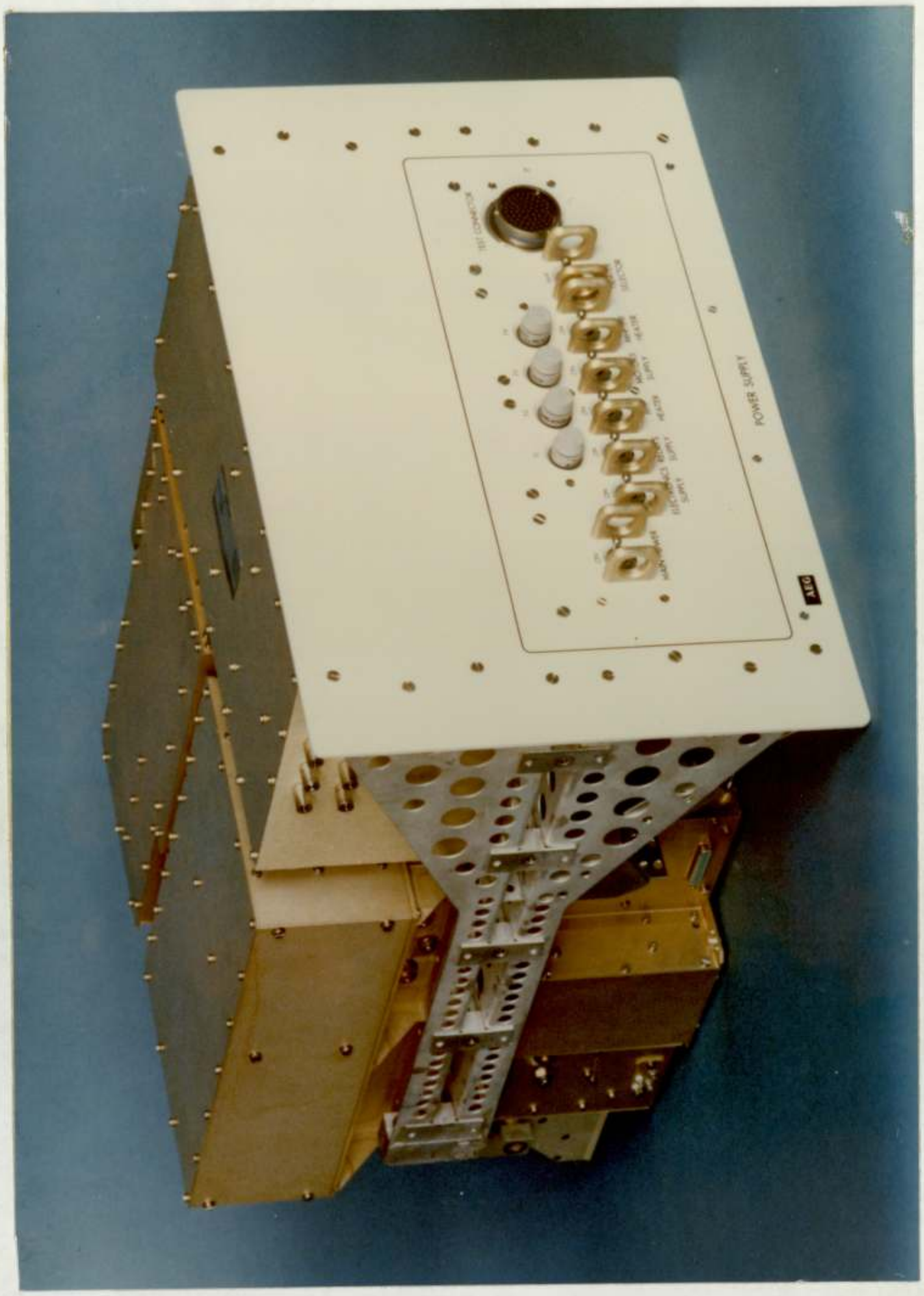


Figure 3.10 : The Power Supply Unit

The fixed voltages were to be used to supply electronics, motors and sensors, etc., whereas the adjustable voltages were used predominately for heater circuits.

All of the MSDR internal power lines are fuse protected, whereas protection of the Spacelab main busses to the MSDR is accomplished via circuit breakers.

Vacuum & Gas System (VGS)

The VGS includes a turbomolecular pump to enable the various furnaces to achieve high quality vacuum levels greater than 10^{7} mbar which is higher than currently foreseen via the Spacelab provided vent line.

The configuration layout of the VGS is shown in Figure 3.11.

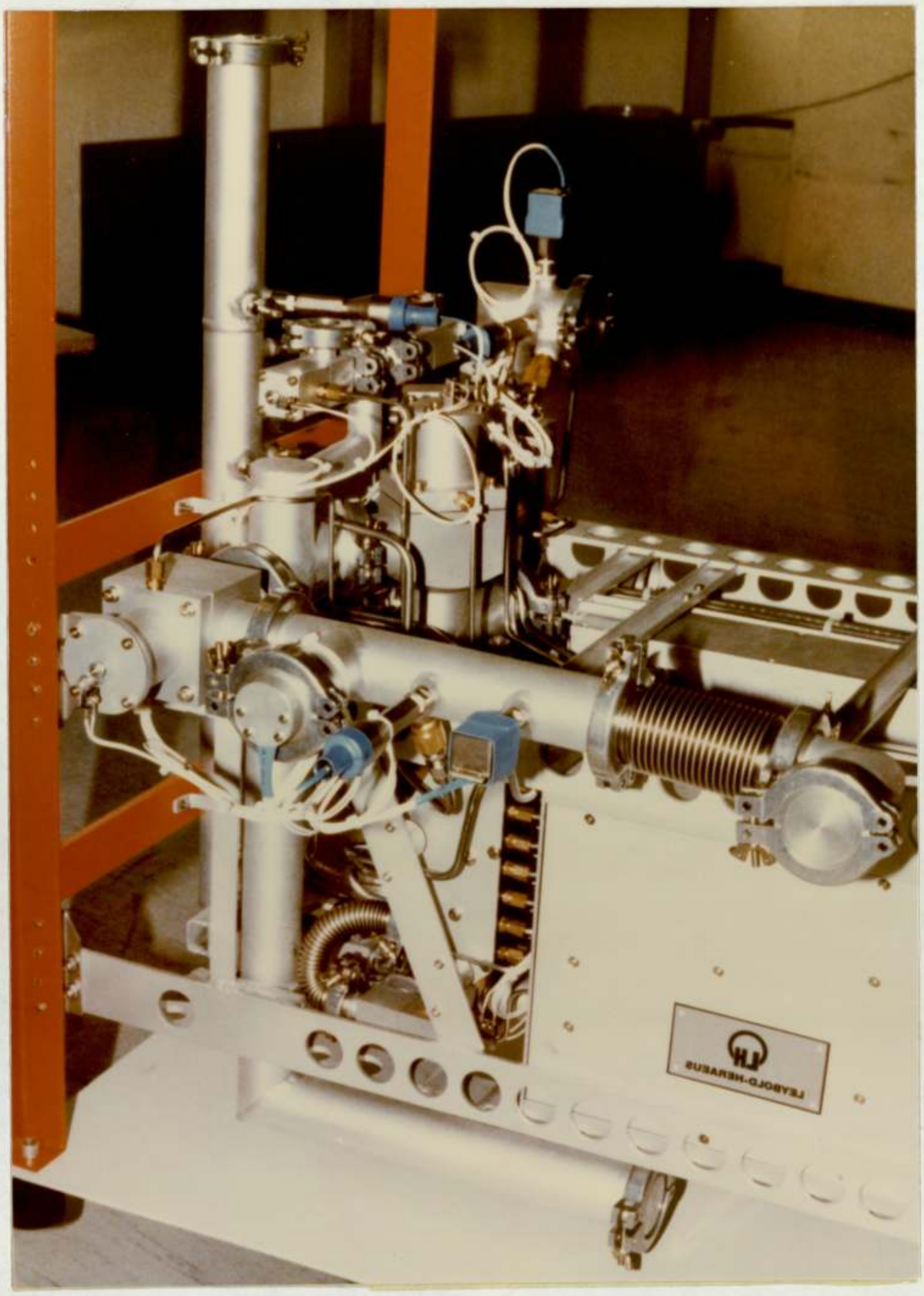


Figure 3.11 : The Vacuum and Gas System

The VGS also contains two gas bottles, each with a volume of 4 litres pressurized to 200 bar, one containing helium the other argon, which are planned to be used for the following functions:

- To flood furnaces in order to reduce sample cooling times.
- To provide certain experiments with an inert atmosphere.
- To provide a gas supply for the operation of electromagnetic valves throughout the MSDR.

Monitoring of furnace vacuum/pressures is performed by a three-stage measuring system which consists of the following elements:

- Piezovac - High Pressure 10 bar - 250 bar
- Piezovac - High Pressure 2 bar - 10 bar
- Piezovac - Low Pressure 10 mbar - 2 bar
- Thermovac - Prevacuum 10^2 mbar - 900 mbar
- Ionivac - High vacuum 10^6 mbar - 10^2 mbar

These elements of the VGS are shown in Figure 3.12.

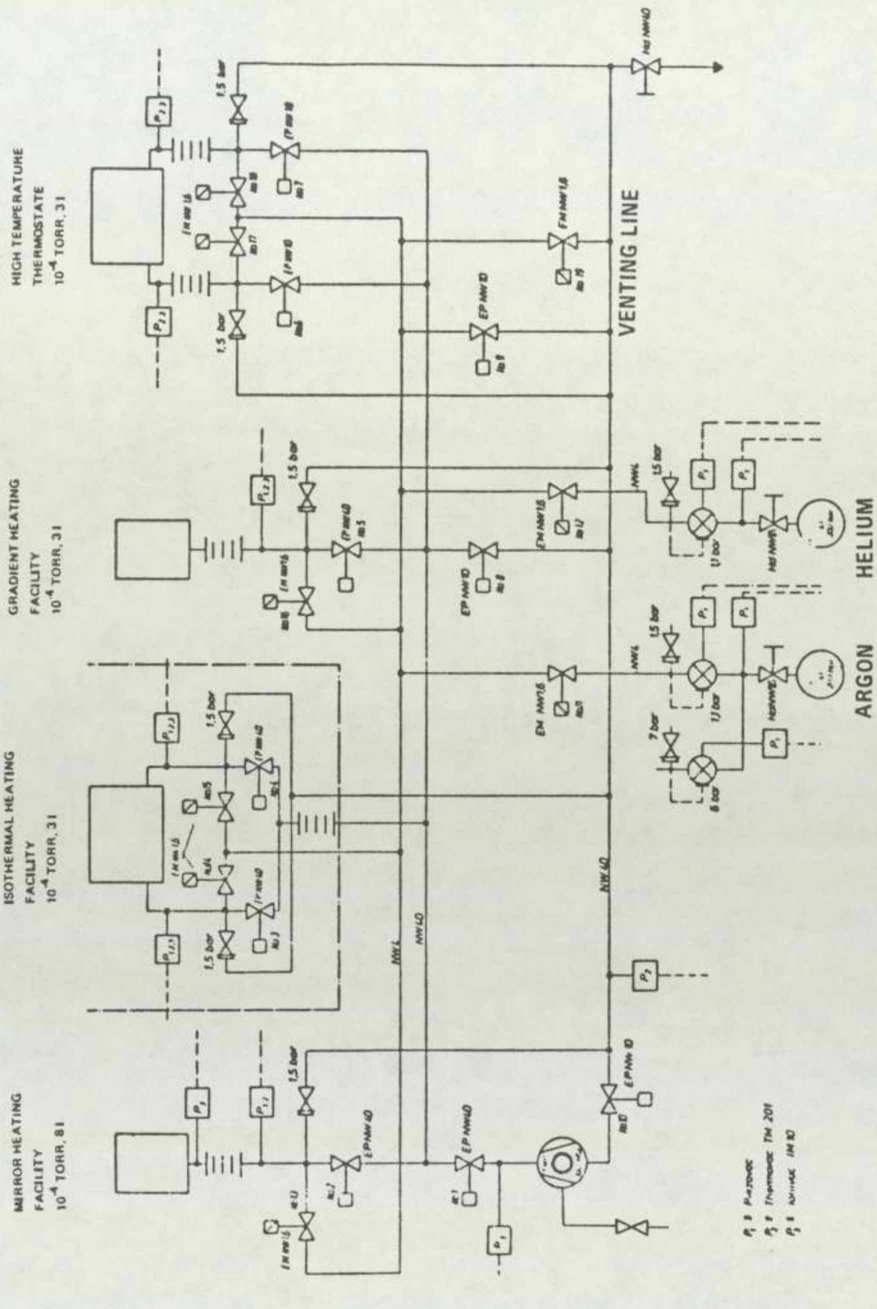


Figure 3.12 : Functional Schematic of the VGS

Instrument Cooling System (ICS)

The purpose of the ICS is to collect all of the heat dissipated within the MSDR and distribute it to the Spacelab 'environmental control system' (ECS) via:

- The Avionics Air Loop (AAL) of Spacelab.
- The Spacelab experiment heat exchanger (water loop).

Figure 3.13 shows the layout configuration of the Instrument Cooling System (Water Cooling).

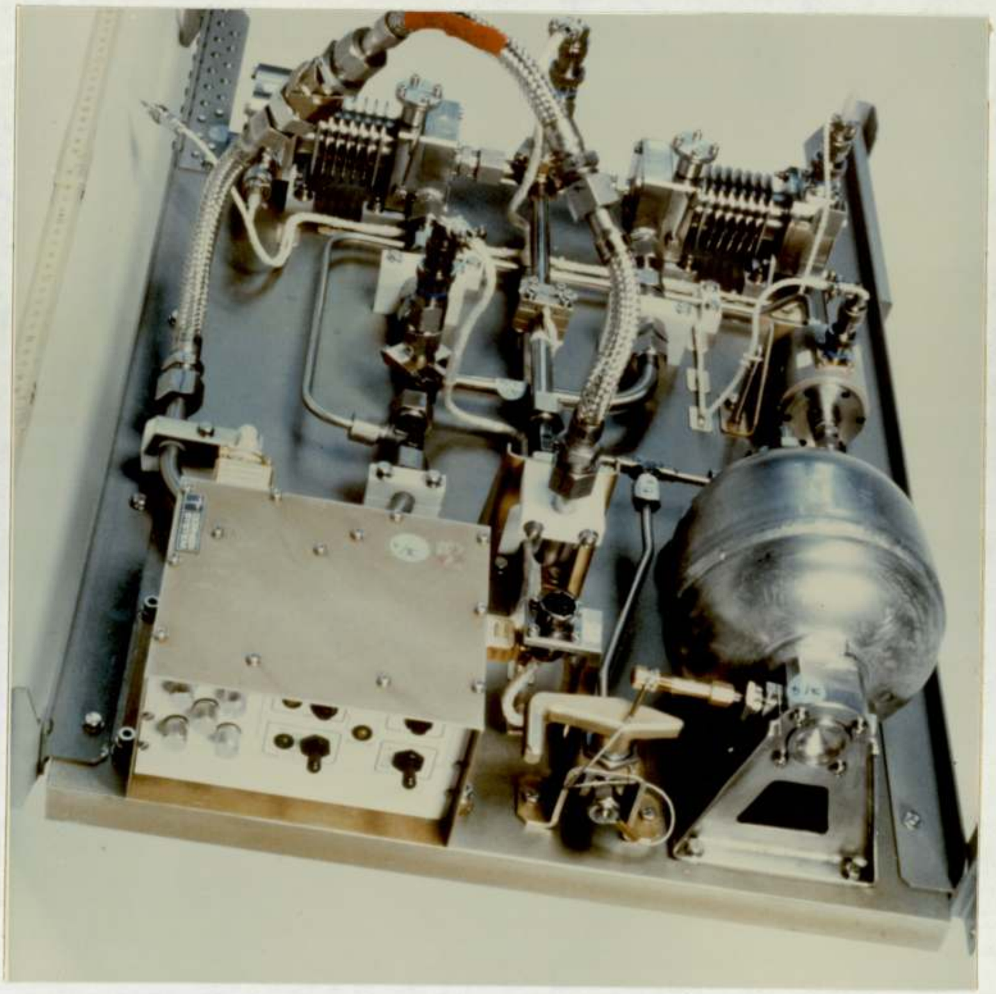


Figure 3.13 : The Instrument Cooling System (Water Cooling)

The 'avionics air loop' has been designed to fulfill the following criteria :

- Provide the interface between the double rack and the Spacelab avionics air loop.
- Utilize the ducted and surface cooling for various experiment facilities.
- Provide the primary cooling used for electronics boxes.

The following description of the 'water loop' indicates those requirements that had to be met:

- Provide a dedicated MSDR closed loop system.
- Provide dedicated furnace cooling for the experiment facilities.
- Provide 2 pumps with automatic switch over capability to a 'redundant' pump in the event of a 'prime' pump failure.
- Provide the redundant pump with power from both a main and essential bus with automatic actuation to 'essential bus' in the case of a 'main' bus failure.

Central Console

A 'central console' was a feature planned for the MSDR to enable the following purpose to be fulfilled:

- Firstly, to provide the payload specialist with a functional interface to the MSDR, thus allowing the effective monitoring and control of the system.
- In addition to managing the command and control functions of the MSDR it also provides for the acquisition of experiment facility and support equipment data.

The front panel of the Central Console is shown in Figure 3.14.

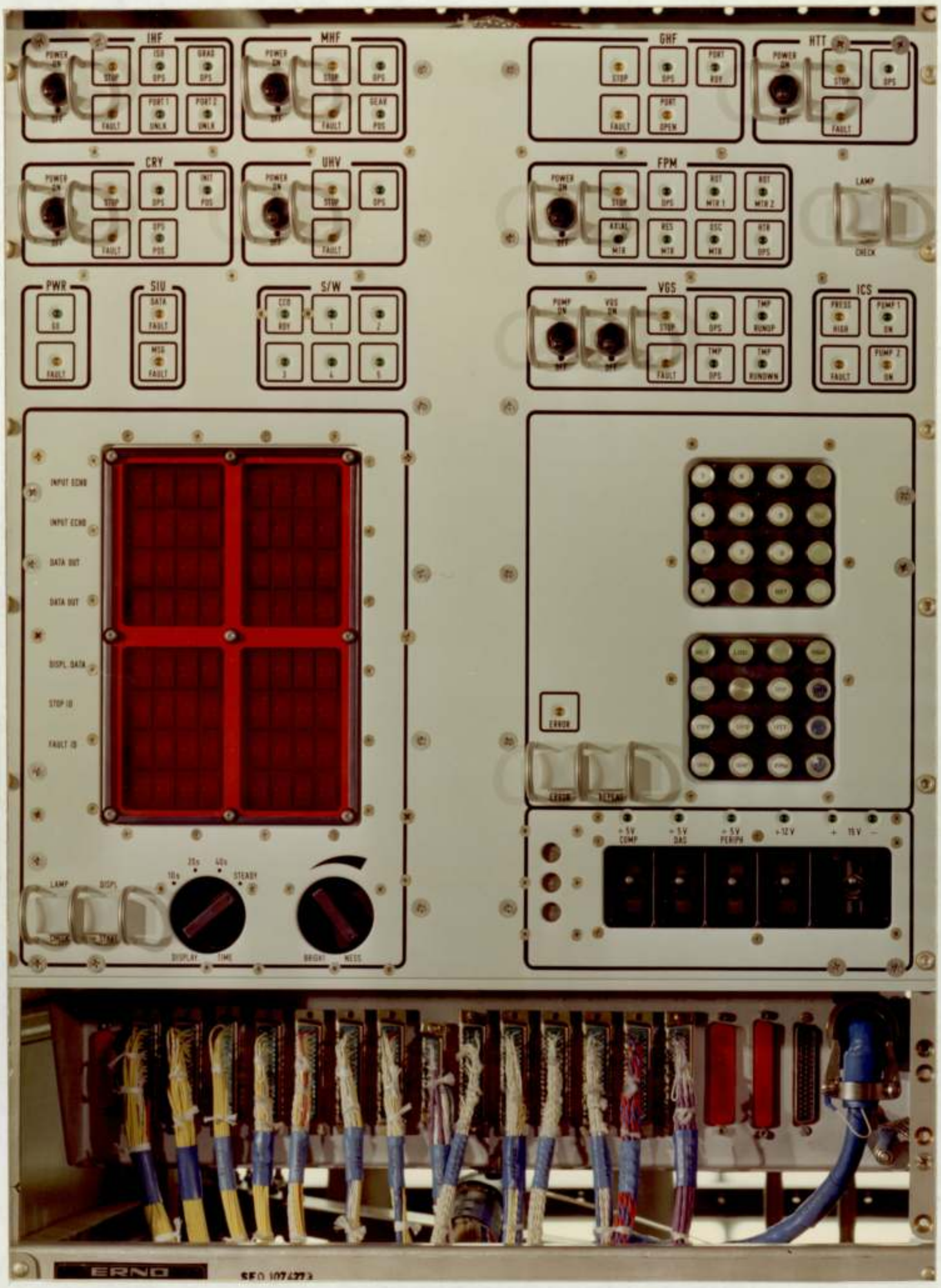


Figure 3.14 : The Central Console

This unit also provides the major communication interface to the Spacelab CDMS for loading the 'dedicated experiment programme' (DEP) from the Spacelab mass memory, and the transfer of data to the CDMS for monitoring or downlink to the ground.

3.2.4 **<u>Material Science Double Rack</u> (Rear)**

Those elements and element interfaces to the experiments described in this dissertation that should be discussed for purposes of clarity are those contained to the rear of the MSDR, and these are shown in Figure 3.15, and listed for convenience as follows:

- Spacelab Vent Line (Turbomolecular Pump)
- Avionics Air Loop (Air Ducts)
- ICS Pump Package and Coolant Pipes
- MSDR Harness
- Automatic Fire Suppression System.

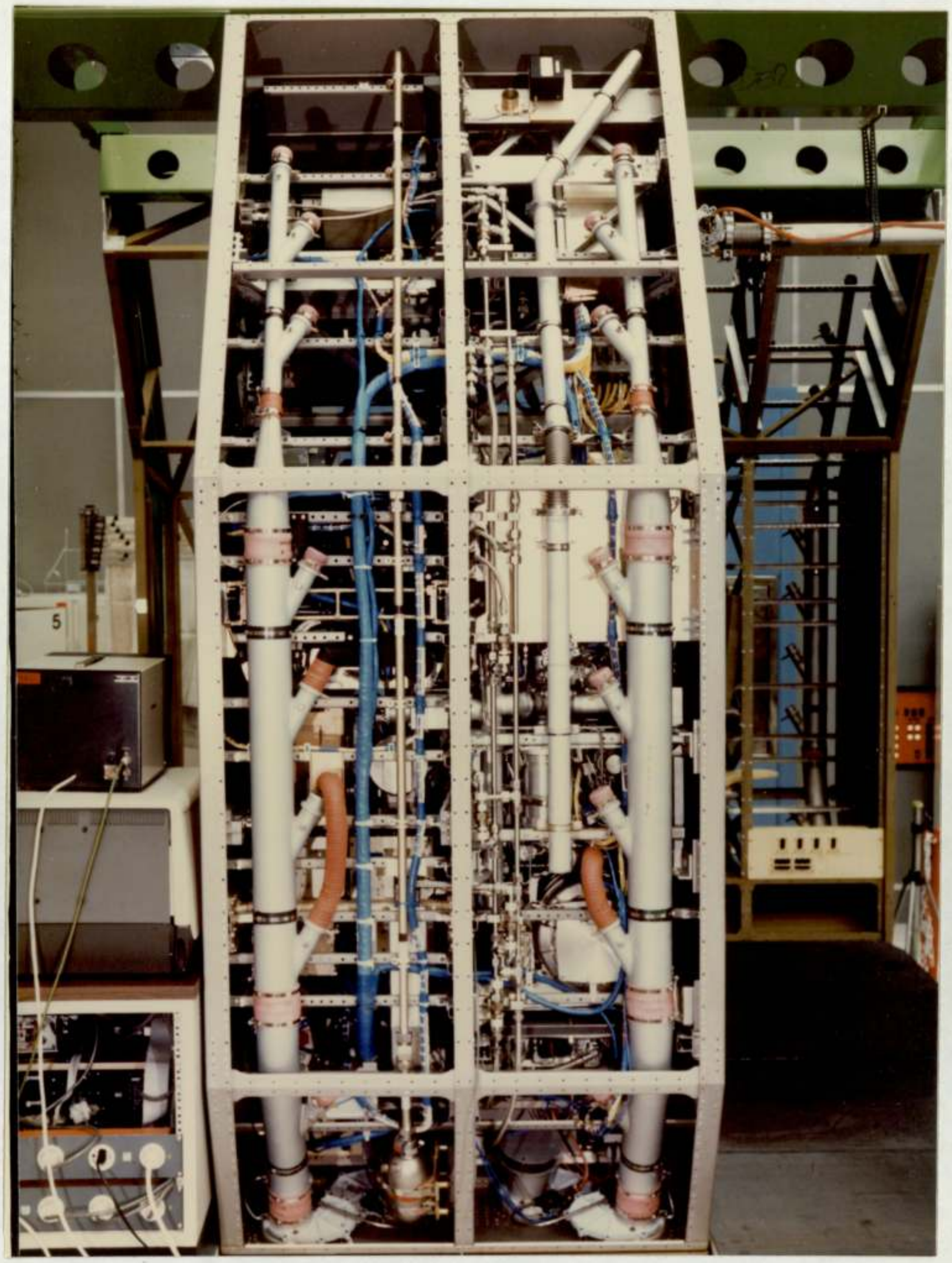


Figure 3.15 : The Material Science Double Rack (Rear)

Spacelab Vent Line (Turbomolecular Pump)

A number of the experiment facilities required high quality vacuum levels if they were to successfully perform the experiments and thus meet the investigators requirements. This meant that these facilities needed the support of the turbomolecular pump via the facility vent lines and coupled through a hand-operated control valve to the Spacelab vent line.

Avionics Air Loop (Air Ducts)

The 'avionics air loop' air ducts were designed to provide the interface connections between experiment facilities and common support equipments which required air cooling via the Spacelab air loop.

ICS Pump Package and Coolant Pipes

The pump package of the 'instrument cooling system' consisted of both a prime and a redundant pump plus a delta pressure switch. Both pumps are switched on until the required pressure is reached, and indicated by the delta pressure light on the front of the ICS panel, the redundant pump is then switched off.

It is the function of the prime pump to maintain pressure through the coolant lines of the facilities, the heat is then transferred to the Spacelab/Shuttle heat exchanger.

MSDR Harness

The harness design considerations clearly showed that it must consist of the following:

- A 'power' harness to carry the various voltage levels of the 'power supply unit' to the 'experiment facilities' and the 'common support equipments';
- A 'digital' harness to feed-back housekeeping data from temperature, vacuum and pressure sensors to the 'central console', and to transfer the data acquisition from the experiments into the Spacelab Command and Data Management System (CDMS).

Automatic Fire Suppression System

All of the racks in Spacelab are fitted with Fire Suppression Equipment. This is because the environment of Spacelab will probably have an enriched oxygen atmosphere of approximately 26% during its mission profile.

As fire is most likely to occur to the rear of the racks it may not be immediately noticed by either of the specialists. Therefore, detection and suppression of fire would need to be performed automatically.

4.0 MSDR OPERATING TASKS

The prime contractor responsible for the development, integration and testing of the machine system (MSDR) was Messerschmitt-Bolkow-Blohm GmbH, West Germany.

4.1 Manual Loading/Operating Tasks

The majority of the planned experiment facility and common support equipment development, and testing of the functional and operational modes of both the hardware and software element interfaces occurred between the beginning of April 1980 and the end of September 1981.

It is of course common practice with most complex man-machine systems to have a routine set-up/set-down procedure thus ensuring that the functional purpose of the machine can be accomplished and at the same time preclude the possibility of accidents. In this respect the MSDR was no different. However, what became apparent was that the MSDR set-up/set-down procedure had to be disciplined in approach due to two of the functional elements of the common support equipment, namely:

- loading of the 'dedicated experiment programme' (DEP) into the 'central console' (CCO); and,
- the run-up/run-down of the 'turbo-molecular pump' (TMP) for the 'vacuum and gas system (VGS).

The cause of concern in the first case was because any loss of programme during the loading sequence into the memory banks of the 'central console' could lead to unforeseen consequences during the operation of the experiment facilities. Unfortunately what cannot be predicted is what these consequences will be in a failure condition or when such a failure is likely to occur.

In the second case the result of inadvertent or accidental switch-off or loss of power would predictably lead to the rotor of the turbo-molecular pump dropping from its magnetic bearings onto its auxiliary bearings. Such an event could lead to destruction of the rotor blades, but in a worst case could lead to fragmentation of the stator and possible penetration of the Spacelab structural skin.

The operation chart which was established for the set-up/set-down of the common support equipment, and which needs to be performed by the 'payload specialists' is depicted in Figure 4.1.

The major physical interfaces which were encountered by the payload specialist during the set-up/set-down of the common support equipment are predominantly with the electrical and mechanical controls of the MSDR, as shown in Figure 3.2.

For example the first task indicated in Figure 4.1, is "Set-up Rack Air Cooling", it can be seen that at the very bottom of the double rack (Figure 3.2 refers) there are two white levers, rotation of these levers in the direction indicated by the arrows permits cooling air to flow through the various elements connected to the avionics air loop.

Activation of the "Electrical Power Distribution Boxes" (EPDBs) 2 and 3 by setting on switches 32 this would be performed by the 'mission specialist' in his role of allocating 'Shuttle' resources to the 'Spacelab' module.

All of the remaining tasks, with the exception of the VGS (Vacuum and Gas System), to be performed by the payload specialist are generally speaking no more than putting the switches into the required positions sequentially.

The VGS on the other hand requires that the operator opens the valves on the Argon and Helium gas bottles in order to enable the VGS and experiment facility electromagnetic valves to operate when required to do so.

These two hand valves are located on the left-hand side of the MSDR as indicated in Figure 3.2.

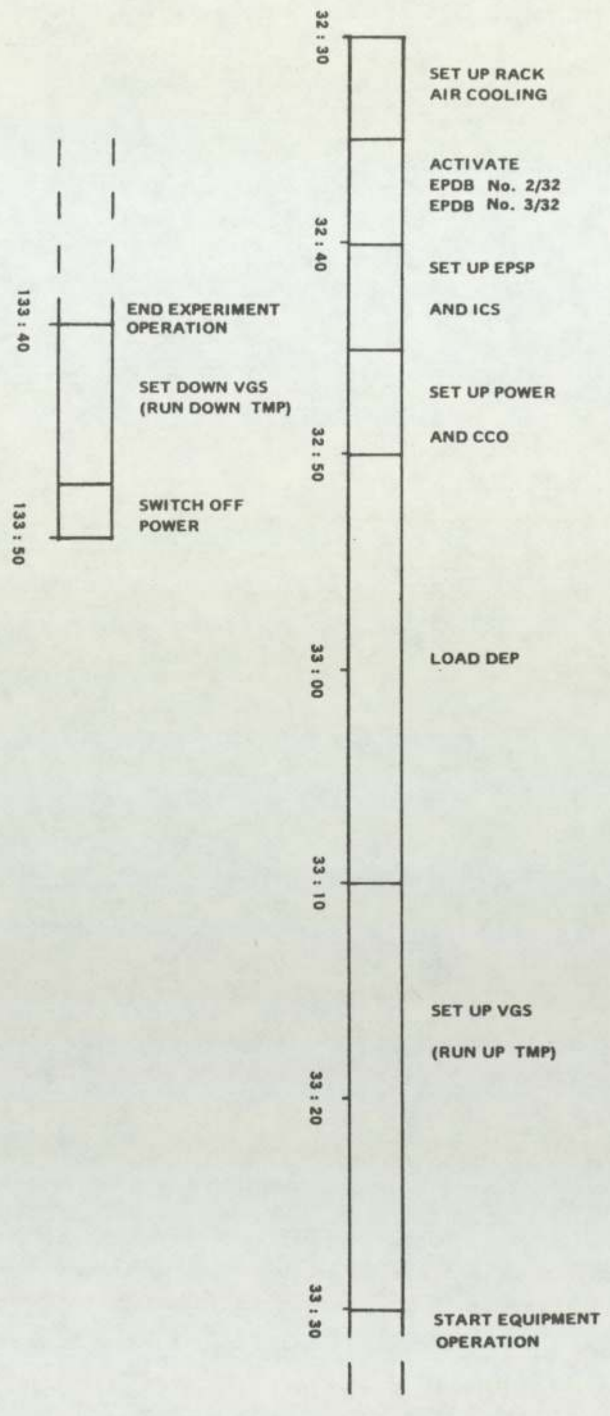


Figure 4.1 : The Set-up/Set-down of the MSDR Common Support Equipment

Only a relatively small number of the experiment facilities require a direct physical interface with the payload specialist, namely:

- Isothermal Heating Facility (IHF);
- Gradient Heating Facility (GHF);
- Mirror Heating Facility (MHF);
- Cryostat (Cry);
- Fluid Physics Module (FPM).

For the IHF and GHF the prime interface task is simply one of cartridge loading for the experiment profile, i.e., the time domain required to heat-up, maintain the temperature plateau, and effect the controlled cool-down of the cartridges and their exchange on completion of the profile.

This is also true for the MHF, with the added tasks that during the experiment profiles the furnace may be moved up and down over the sample cartridges, which can in addition be rotated at very low speeds.

At given points in the experiment profile the melt zones can be photographed by the payload specialist using the MHF-attached camera provided at the viewport.

For the Cryostat the payload specialist task is a relatively basic one of opening either the 'Freezer' or 'Stabilizer' chamber, inserting the appropriate sample container into the chamber, replacing the cover and securing it tightly with the three clamps.

The FPM operator tasks for the payload specialist consist primarily of loading the fluid into the test room and fitting the required discs to suit the experiment needs. Setting up of the fluid temperatures and the disc speeds, etc., is achieved via the front panel of the FPM itself.

It should be noted that all of the furnace type of experiment facilities are connected to the 'Spacelab' vent line via the vent line valve, this hand valve is located at the top left hand side of the MSDR as shown in Figure 3.2.

This vent line hand valve is opened by the operator prior to functional performance of the furnaces and is needed so that inert gases used for cooling or purging can be evacuated from the furnace chambers.

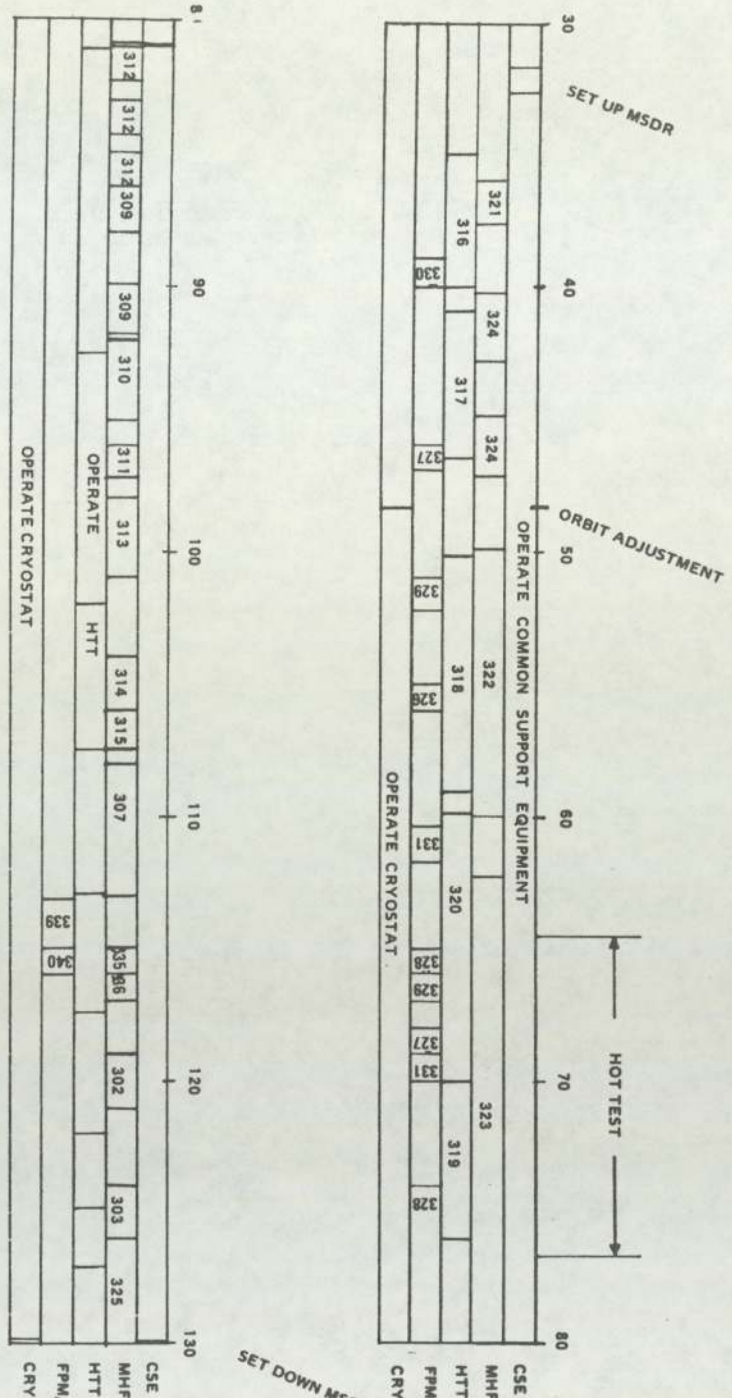


Figure 4.2 : MSDR Operational Timelining (Example)

For a more comprehensive description of the experiment facilities of the MSDR, reference should be made to the papers by Zimmermann (1979).

It should be noted that the sequence of operations planned for the various experiment facilities are not generally known until finalisation of the Spacelab Mission Profile which occurs only a few weeks prior to the Shuttle launch. Nevertheless, a probable experiment mission profile for the MSDR can be suggested as shown in the example given by Figure 4.2.

4.2 Functional Operating Tasks

The functional operation of the experiment facilities, after set-up of the common support equipment and the loading of the experiment samples, is accomplished by use of the MSDR Central Console which provides the following functional interfaces to the 'payload specialist':

- A Warning System with a field of 61 warning and status lamps;
- A Numeric Display (Visual Display); and,
- A Keyboard, which is operated to numerically identify:

81 Stop)
) Mode conditions of the MSDR
72 Fault)

The locations of the warning and status lamps, numeric display and keyboard are readily identifiable in Figure 4.3, which is a graphical view of the front panel of the MSDR Central Console.

The functional purpose of these units can be best appreciated by reviewing the sequence of actions which should be taken by an operator (payload specialist) when either one of the 8 "STOP" or 10 "FAULT" lamps are lit indicating an equipment or facility failure or malfunction.

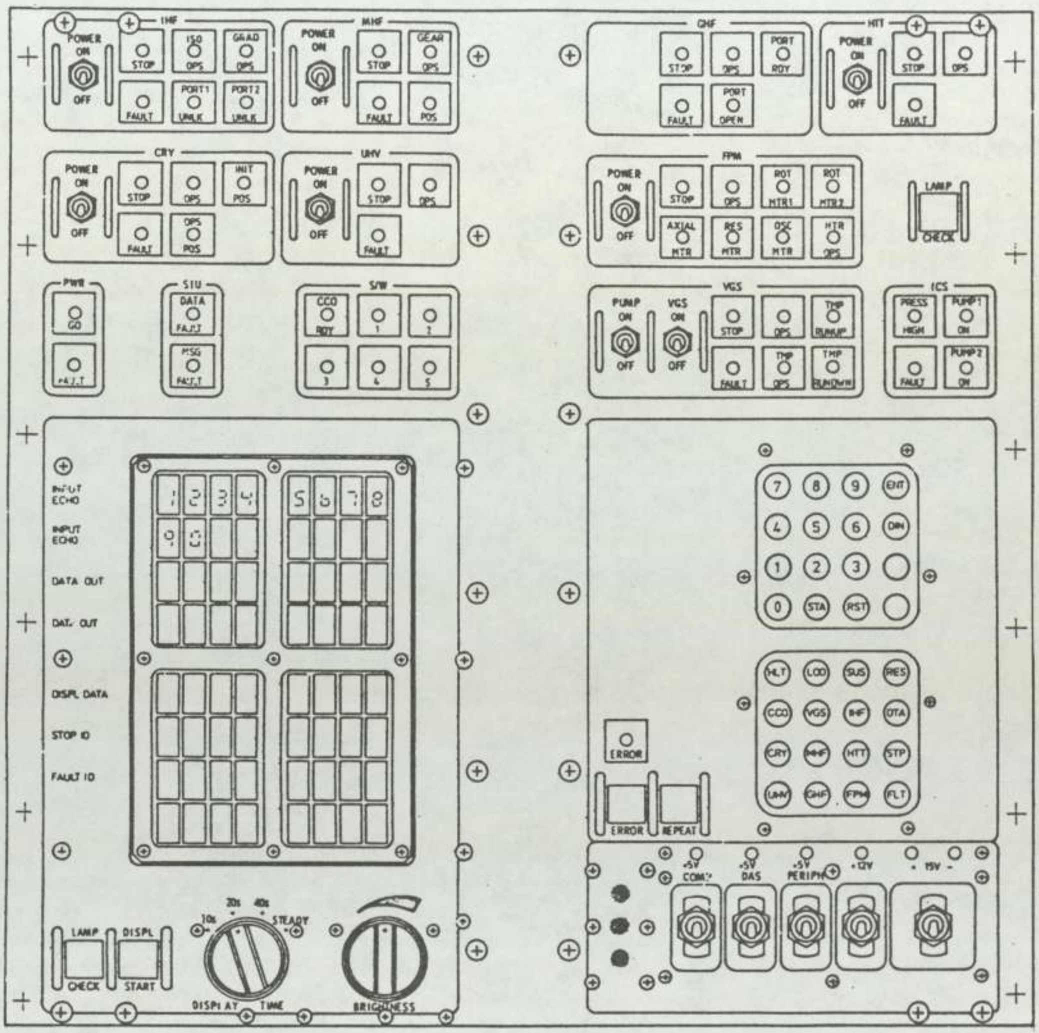
These response actions which need to be performed by the operator to set the MSDR from an out-of-tolerance condition back to its nominal functional state are shown in the "Operator/Warning System - Action Flow Chart", Figure 4.4.

To follow and understand the steps shown in Figure 4.4, reference should also be made to Figure 4.5 (front panel layout of the CCO) where all of the features addressed in the 'operator/warning system-action flow chart' are indicated.

In addition Table 4.1 identifies those prefix numbers that have been assigned to each element of the "Material Science Double Rack". It is this prefix number which allows quick access for the operator (payload specialist) if it is necessary to refer to the "Stop/Fault Identification Number List", contained in Appendix A.

Table 4.1 : MSDR Element Identification

MSDR Element Name	**Element Acronym**	**Element Prefix Number**
Vacuum & Gas System	VGS	0
Instrument Cooling System	ICS	7
Power Supply	PWR	7
Isothermal Heating Facility	IHF	1
Cryostat	CRY	2
Mirror Heating Facility	MHF	3
High Temperature Thermostat	HTT	4
Ultra High Vacuum Chamber	UHV	5
Gradient Heating Facility	GHF	6
Fluid Physics Module	FPM	7



CENTRAL CONSOLE

Figure 4.3 : Controls and Displays of the CCO

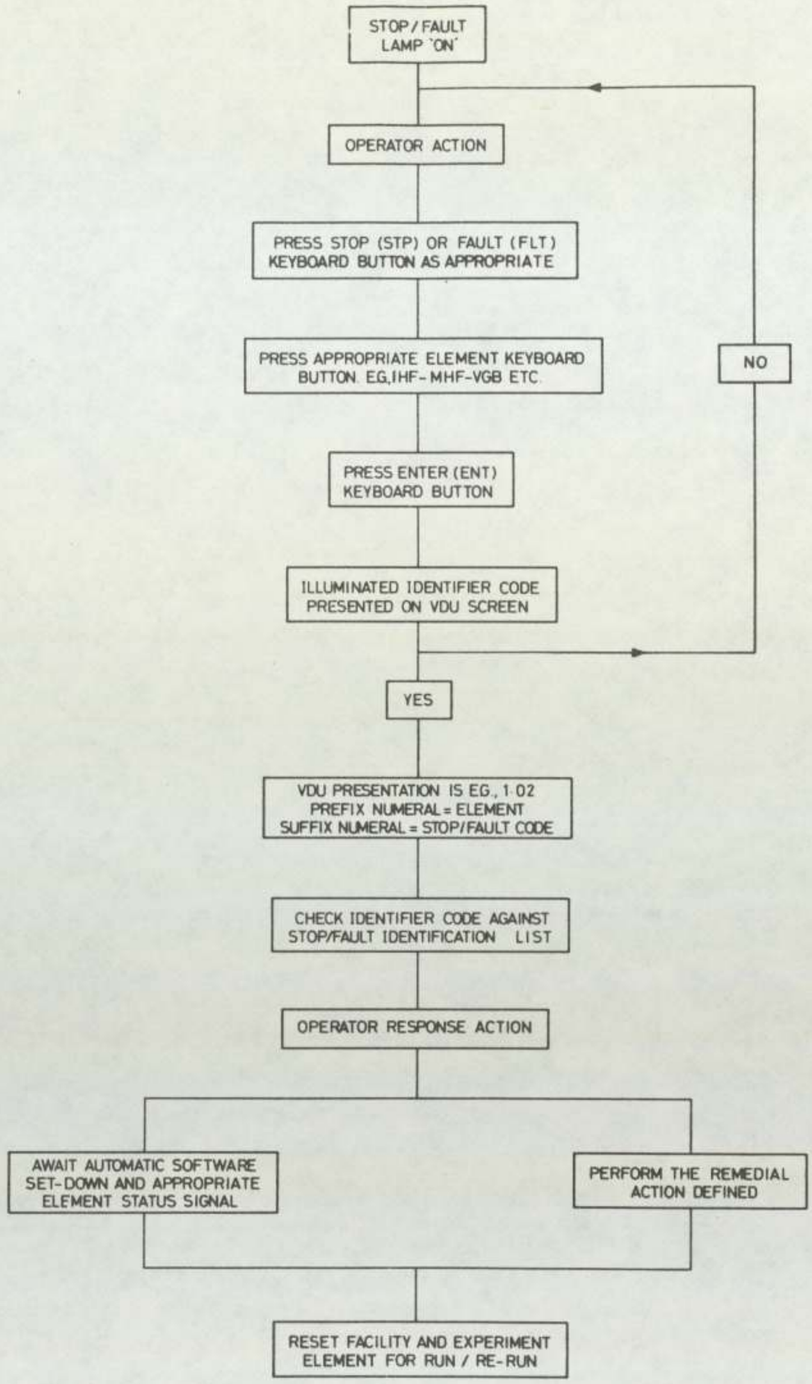


Figure 4.4 : Operator/Warning System Action Flow Chart

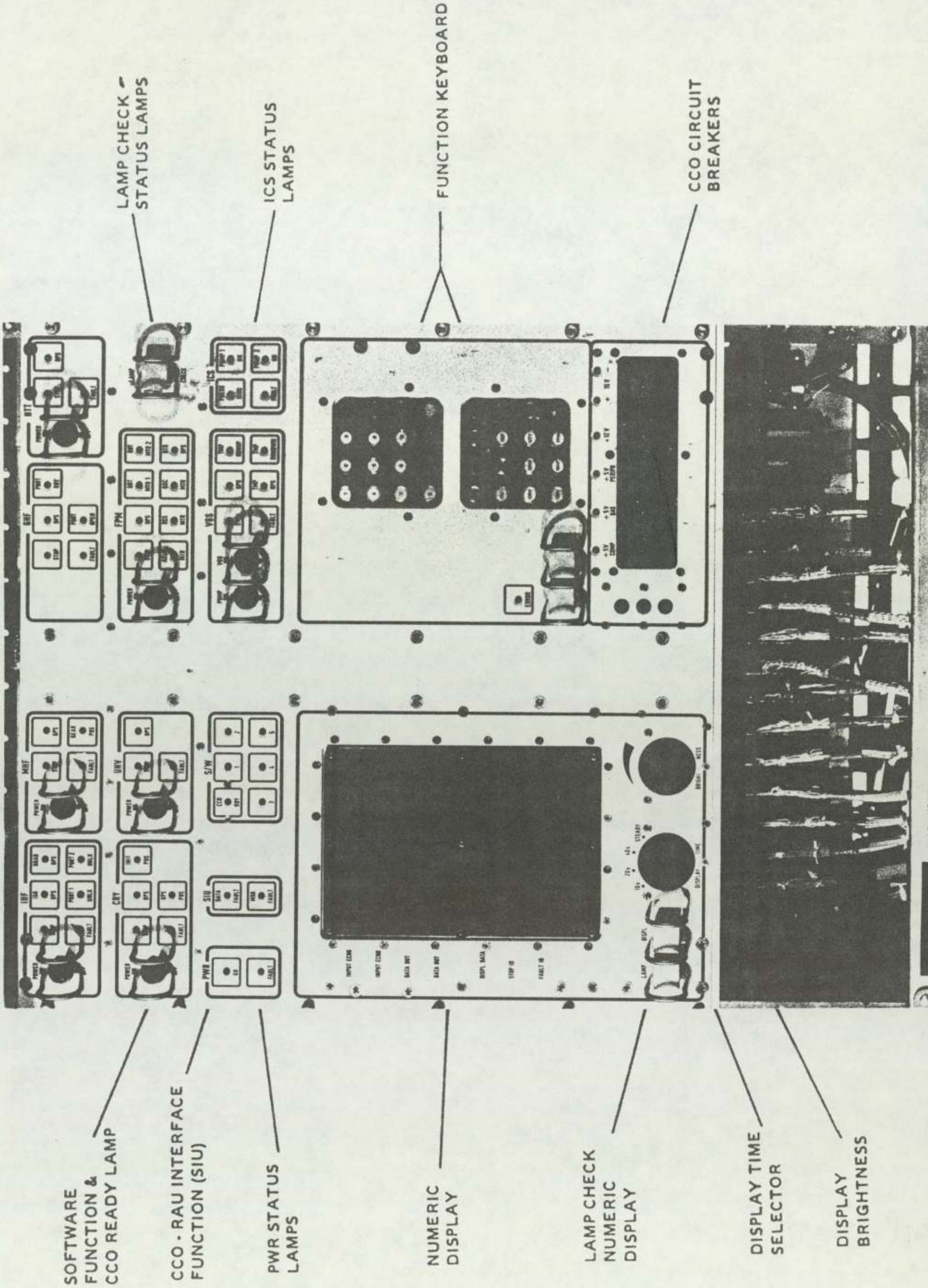


Figure 4.5 : Front Panel Layout of the CCO

The second part of the element identifier is the suffix number which is used to identify the stop or fault condition, and it is this list (Stop/Fault Identification Number List) which establishes for the operator what may be the probable cause of the stop or fault condition displayed. The list further identifies those stop conditions where there is automatic software set-down of the experiment facility or support equipment when such a condition is generated by an out of tolerance condition.

This same list also indicates for a few instances possible remedial actions which should be taken by the operator for those fault conditions that are displayed by the MSDR warning system. However, in either case (stop or fault), the operators' final action must be to reset the facility and the appropriate element for its experimental run or re-run. It should be noted that the list only reflects those Stop/Fault conditions that were determined prior to any development and testing of the MSDR.

4.3 Division of Tasks

The MBB 'Integration and Test Team' consisted mainly of the following personnel:

- Integration and Test Manager
- Integration and Test Engineer
- System Engineer
- Software Engineer
- Mission Assurance Engineer

However, before any integration and test tasks could be established for the MSDR, other important and specific tasks had to be completed first; these are listed on the following pages.

Integration and Test Manager (I/TM):

Responsible for the planning, organisation, co-ordination and scheduling of MSDR Experiment Elements and Support Equipments with respect to their :

- Phased design reviews
- Phased safety reviews
- Qualification/Acceptance testing
- Delivery schedules to MBB

- Confidence checks prior to MSDR integration
- MSDR integration
- Experiment or Support Equipment checks of :
    a) Physical interface requirements
    b) Functional interface requirements
    c) Operational interface requirements
    d) System test requirements

In addition the planning, organisation, allocation and control of the necessary resources human or otherwise to ensure successful accomplishment of the above tasks.

Integration and Test Engineer (I/TE):

Responsible for the implementation and control of MSDR Experiment Elements and Support Equipment:

- Qualification tests
- Acceptance tests
- Confidence checks prior to MSDR integration
- Checks of Experiment or Support Equipment:
    a) Physical interfaces
    b) Functional interfaces
    c) Operational interfaces
    d) System tests

to ensure that they meet the requirements.

An additional parallel task to those listed above for the I/T Engineer was filling out and evaluating the test/check protocols. Also the compilation of these into test reports for the experiment/support equipment 'acceptance data packages' (ADPs).

System Engineers (SE)

System engineers were responsible for ensuring that the design and development of the experiment/support equipment met the requirements. That is those requirements which govern for example:

- Size of the Experiment/Support Equipment envelope - Mass, etc.
- Physical interfaces
- Functional interfaces
- Operational interfaces
- MSDR interfaces to Spacelab
- Experiment/Support Equipment nominal operation parameters/tolerances

These requirements were written into detailed specifications covering every facet of experiment/support equipment design. The specifications were imposed on the developers and their implementation controlled by the system engineer.

A further task of the system engineer was to ensure that developers test procedures/protocols fulfilled their functional purpose. That is with respect to the types, sequence and levels of testing to be performed to assure that experiment/support equipments could safely tolerate the STS/Spacelab launch/landing environments.

Software Engineer (S/WE)

The functional operation of the MSDR was dependent on numerous interrelated software programs. For example, experiment elements were driven by software from a Central Console (CCO). However, the experiment hardware could not function correctly without those services provided by the common support services, such services being:

- Instrument Cooling
- Power Supplies
- Vacuum and Gas Supplies
- Central Console - Status/Warning System

The production of these individual programs and their combination into a total MSDR system software program was the responsibility of the Software Engineer. This final program when fully proven with the MSDR hardware was used as an input for the spacelab mission scenario.

Mission Assurance Engineer (MA)

The term 'Mission Assurance Engineer' was coined to embrace the disciplines of 'Product Assurance' (PA) and in addition the discipline of 'System Safety'! Those tasks covered by the PA discipline are in the main:

- Reliability Engineering
- Quality Assurance Engineering

For the MSDR project the initial MA tasks were to ensure that experiment/support equipment developers were fully cognisant with the mandatory PA and safety requirements. To evaluate design concepts with the system engineer and advise developers of those recommendations that would enhance their design in terms of:

- Reliability (incorporation of redundancy strategies)
- Quality Assurance (material, piece part or processes review change recommendations, etc)
- Safety (review designs, make recommendations for fail-safe devices for safety critical functions).

Also liaison with the developers to define the:

- Experiment element or support equipment flight operations (Spacelab mission) and ground operations (Kennedy Space Centre pre and post launch activities)

for the safety data presentations at NASA Phased Safety Reviews.

In addition the review and approval with the I/T Engineer of all test/check procedures or protocols to ensure that there are no test or check steps that could bring either personnel or equipment into a potentially hazardous-mishap situation.

4.4 MSDR Integration and Test

The integration and test of the MSDR experiment elements and support equipments took place in the 'Cleanroom Facility' at MBB in Ottobrunn, West Germany. This integration and test program lasted for a period of almost two years because of the very complex nature of the machine system being developed for space application. Several years prior to the MSDR development, integration and testing phase personnel were selected and assigned to carry out those tasks defined in Section 4.3.

However, it should be noted that there were also many other engineers and technicians providing a wide range of support to the test team members.

Those tasks performed by the team members in essence may be described as follows:

1) Start day-log in the Logbook — MA
   a) Day and Date
   b) Time
   c) Personnel (team members) present
   d) Activity/Task to be performed
   e) Procedure: Name and Document Number
   f) Enter readings from Atmosphere Control Recorder
      (i) Ambient Temperature
      (ii) Ambient Pressure
      (iii) Humidity Level

2) Check all ancillary equipment: — I/TM-I/TE-MA
   Vacuum & Gas Support Equipment
   Power Supplies
   Cooling simulators, etc.

   Enter in Logbook — MA

3) Set-up of MSDR-Experiment Test — I/TM or I/TE
   a) Check that all MSDR switches are set to the 'off' position.
   b) Start ancillary support equipment
   c) Set-up MSDR support equipments
   d) Check experiment element is 'off'
   e) Open experiment sample door
   f) Check sample - code number
   g) Insert sample - close door
   h) Switch-on experiment (at CCO)
   i) Experiment fault lamp on CCO Panel 'on'
   j) Switch-off experiment (at CCO)
   k) Open experiment element door - remove sample
   l) Close experiment element door

   Enter in Logbook — MA

4) System engineer checks the experiment hardware — SE
   Software engineer checks CCO printout from off-line printer — S/WE
   Recheck of ancillary/simulation equipments — I/TM-I/TE

5) Team discussion: probable fault 'vent-line contamination' entered in Logbook — MA

6) Set-down MSDR — I/TE

Enter in Logbook — MA

7) Disconnect Vacuum pipes from MSDR/Spacelab ventline — I/TE-SE
Confirm contamination
Clean pipes - warm dry
Re-assemble vacuum pipes to MSDR/Spacelab ventline
Switch-on ancillary equipment

Enter in Logbook — MA

8) Repeat steps: 3a to 3h inclusive — I/TE

Enter in Logbook — MA

9) Test running - record voltage
current
temperature
pressure

Parameters in Test procedure. — I/TE

10) Vacuum and Gas System fault lamp on CCO Panel "ON"

11) Repeat step 3j

12) Repeat step 4

13) Repeat step 5. Team discussion: probable fault out-of-sequence software.
Entered in logbook. — MA

14) Repeat step 3h

15) Experiment Test continued
  a) Experiment status lamp on CCO Panel "ON"
  b) Experiment status lamp flashing-experiment ended
  c) Switch-off experiment
  d) Check printouts to verify touch temperature of sample
  e) Check CCO status
  f) Open experiment element door - remove sample
  g) Close experiment element door

Enter in Logbook — MA

16) I/TM decision: test re-run to be performed using alternative sample

Enter in Logbook MA

17) Attach CCO off-line printouts to test procedure MA

18) Obtain a new copy of Test Procedure I/TE

19) Restart test at step 1a.

What the much simplified test scenario is meant to show is that successful completion of any development, integration and test program for any complex machine system involves many skills and team effort. Therefore, any data gained or lessons learnt should be used as inputs for the correct and proper training of those operators who will be functionally controlling the machine system in its day to day operation.

5.0 MACHINE SYSTEM AND OPERATOR INDUCED ERRORS

As might be expected with any machine system that is extremely complex, a number of types of errors were observed and recorded during the development and testing of the MSDR.

These errors may be divided into two distinctive categories, namely:

- Machine system induced errors; and
- Operator induced errors.

5.1 Machine System Induced Errors

There is little data available on machine systems in terms of the type of errors that they may generate. The reason for this is that when something does go wrong it is usually attributed to the human elements in the man-machine system environment.

The lack of recorded and collated machine system error data has resulted in the situation explained by Norman (1983) in the following statement:

"Today, proper tools for design do not exist. Thus the designer who wishes to minimize error in his equipment has no standard reference to turn to for advice."

The consequence of this situation is that many machines being designed and built contain design induced errors and these in turn could lead to induced error on the part of the operator. This last statement excludes the range of human engineering data which is available. However, such data only provides a solution to part of the problem, perhaps because human engineering data tends to be more widely applied to government projects than to commercial ventures, possibly due to the project development cost constraints.

Nevertheless, we do know that when any machine system equipment that has been designed, developed and tested to stringent specifications, then any out-of-tolerance conditions that occur should only be those conditions caused by <u>real disturbances</u> of the <u>system</u> which exceed the set parameters of the system.

These real system disturbances (RSDs) are mostly predetermined in the design phase, but on occasion modified after the development and testing of the machine system, but before the final system test. In either case these RDSs are used to trigger a visual warning system - signal stimuli, to indicate to the operator that his intervention is necessary to correct the out-of-tolerance condition.

However, when the individual hardware elements were fully integrated into the MSDR configuration, out-of-tolerance machine system-warning signals were generated that were not caused by real disturbances of the system. Such warning system signals being generated by either 'normal fluctuations of the parameters' (NFPs) or by 'out-of-sequence software' (OSS) conditions.

In essence an NFP occurs when any one of a number of controlled functions does not react in the manner prescribed for every case. An example of this situation was the control of MSDR furnace temperature profiles where sensors provide temperature data to the 'central console' (CCO). The CCO computer uses these sensor inputs to control the temperatures by regulating the furnace power consumption. Meanwhile, however, the MSDR Instrument Cooling System (ICS) is still absorbing the excess heat being dissipated, so its own temperature continues to increase until it trips the ICS upper limit parameter setting. In such an event a warning system signal was generated thus indicating an 'ICS Over temperature' condition which did not really exist. This was because although the furnace was being powered down to lower the temperature it was still dissipating heat to the MSDR-ICS, which reacted after and more slowly to controlled changes in the furnace temperature.

Out-of-sequence software generally occurred due to either 'timing errors' or 'coding errors' in the MSDR Software Programs. In the first case it was simply one of the software trying to control a hardware function at the incorrect time, such as too early or too late. For the second case it was where the software was trying to command, for example,the 'switch-off' of a hardware function that was not set to the 'on' position, or conversely trying to command the 'switch-on' of a function already set to the 'on' position. In either case there could not be a 'command executed' response signal to the CCO computer. For such cases the CCO computer flagged either a 'STOP' or a 'FAULT' signal indicating an MSDR out-of-tolerance condition which again did not really exist.

These out-of-sequence software conditions arose because the software programs for each of the individual experiment facilities and support equipments had to be amalgamated to form the total MSDR System Software Program. The result of this amalgamation of the individual software programs was that 'timing errors' were introduced and 'coding errors' created in the MSDR System Software Program. It should be noted that this was not an unexpected situation. However, the full extent of such errors could not be fully anticipated or prevented prior to the full system testing.

5.2 Operator Induced Errors

The most simple form of operator induced errors observed and recorded were generally associated with the set-up of the MSDR for various test sequences. The following list indicates the most common operator errors:

- Failing to mate or re-mate electrical connectors;
- Forgetting to operate a switch in the set-up/set-down of the MSDR;
- Forgetting to open gas bottles (Vacuum and Gas Systems);
- Forgetting to open 'Spacelab' vent-line;
- Failing to set up MSDR simulators correctly, e.g.:

  a) Power Supply,
  b) Space Vacuum Pump,
  c) ICS Heat Exchanger;

- Failing to set both ICS water pump switches to the 'on' position (no delta 'P' reached). To achieve the required water pressure in the instrument cooling system it was necessary to switch both water circulation pumps to the 'ON' position. Once the required pressure in the system was reached a delta pressure switch initiated a signal light. Perception of this signal by the operator should result in 'pump 2' being switched to the 'OFF' position, where the 'OFF' position is in effect a 'standby' mode and is automatically switched back to the 'ON' position in the event of either a 'pump 1' failure or loss of main power;
- Forgetting to switch off the ICS standby pump when the delta 'P' indicator lamp was illuminated (see above).

5.3 The Consequence of Errors

In principle the only warning system-signal stimuli that should be presented to the operator are those generated by a real system disturbance. However, during development and testing of the MSDR both machine system induced errors (NFPs) and operator induced errors (OSS) were found to be capable of generating warning system-signal stimuli.

The fact that the signal-stimulus presented to an operator can be generated by a 'true' or 'false' machine condition places the operator in a precarious position because for the majority of cases the operator has no option but to judge them all as true.

The effects that may well result out of this state can be expressed by means of Table 5.1:

Table 5.1 : Response Truth Table

Machine Condition	Operator Responses		
	X (correct)	Y (incorrect)	Z (None)
True	1	0	0
True	0	1	0
True	0	0	1
False	0	0	1
False	0	1	0
False	1	0	0
<u>Note:</u> In some cases no action may be the correct action			

This suggests that signal stimuli presented to the operator, generated by either fluctuation of the machine system parameters or out-of-sequence software, could lead to further operator induced errors, with the caveat that such errors might indeed place the operator at risk.

5.4 Study of Errors by Operators

Published work clearly indicates that the man-machine system environment is not the perfect partnership that it ought to be. Davis (1958) and Rolfe (1977) tell us that this is because the human and the machine systems they operate appear to be in conflict. Such appearances readily lead us to assume that the apparent conflict may be attributed to two prime factors:

- The first is concerned with those inter-relationships which should exist between the human and a machine system, for whilst such relationships are seldom trouble free, they seem to be becoming more problem prone rather than less so.

- Next is the factor of interdependence; a factor that we have come to automatically expect as existing between the human and his machine system. Unfortunately this dependence between man and his machine system is becoming less obvious, and indeed where it does exist the links are somewhat tenuous.

The above is especially true at a time when the majority of the functional operations of many machines and machine systems are performed semi-autonomously. This trend towards semi-autonomous equipments was highlighted in those previous texts that described the various elements of the MSDR.

The implication is that the operator's (payload specialist's) role in several instances may be viewed as one which is quasi-passive. The outcome of this only becomes 'open and obvious' when there is a breakdown in the human-machine system dependence inter-relationships and is usually reflected in the form of errors. It is these errors which can, and often do, lead to the occurrence of accidents or mishaps sometimes with serious consequences.

In addition to the practical importance of studying human performance in the operation of the 'material science double rack', it was also an interesting machine system model with which to study errors by operators. Primarily, because it permitted in the first instance the opportunity to observe operator performance in a realistic machine system environment over a period of almost two years. Next, as stated earlier, the MSDR was to be manned during its development, integration and test by personnel from different disciplines each with varying levels of skill.

It was this study of human performance and those errors made by operators which forms the theme of this thesis.

6.0 LITERATURE REVIEW

6.1 Human Performance in Accident Causation

The most obvious consequences arising out of operator error in the machine system environment may be to hazard his own or others safety, especially if the hazard leads to an accident which results in loss of life or serious injury.

The subject area of accident causation has been addressed by Robinson (1977), notably by the following statement made with respect to accidents in man-machine systems:

"Progress in reducing accidents has been materially impeded by two problems:

1. the motivation attitude toward the human, as opposed to the performance limitation view; and,

2. the lack of human performance theory, models and data applicable to accident causation."

"The first problem is finally receiving due attention, Swain (1974) is a leader here".

"Safety professionals are beginning to understand the lack of effectiveness in the "be more careful" approach. Increased awareness of the error in the motivational approach, however, places increased demand on the solution of the second problem - the lack of adequate relevant human performance information".

Whilst this statement by Robinson, op cit., may be correct for skilled operators in the complex machine system environment, it would be wrong to suggest that such a statement would necessarily hold true for the traditional craftsman/operator with less complex equipment or machine systems.

6.2 Human Performance Theory

The statement by Robinson, op cit, to the effect that there is a lack of human performance theory, models, and data applicable to accident causation is also misleading. This is because ample psychophysical research on human performance in the machine system environment has been performed in the past; although the purpose of such research was not directly aimed at accident causation theory.

This research also tended to be fragmented because it primarily concentrated on individual aspects of the human or machine system thus isolating only those features of interest to the investigator. Such an approach has, on occasion, failed to take into account the inter-relationship and interdependence that exist in man's internal processes which are constantly being mediated by the environment.

This suggests that if the results obtained from such specific but individualistic psychological research are reviewed it should be possible to determine what the causal factors might be that lead the human to err. For example, any insight gained as to how breakdowns occur when man tries to process information from its perception through to a subsequent response may identify some underlying mechanism that is inherent in all humans. The "Man-Machine System Loop" from Meister (1971) shown in Figure 6.1, presents in simple form the machine system interfaces that will be experienced by the payload specialist whilst operating the MSDR in the Spacelab module. It may also be readily noted from Figure 6.1, that a breakdown of any of those functions shown, especially by the human component, could result in errors being generated with the probable consequence that an accident may occur.

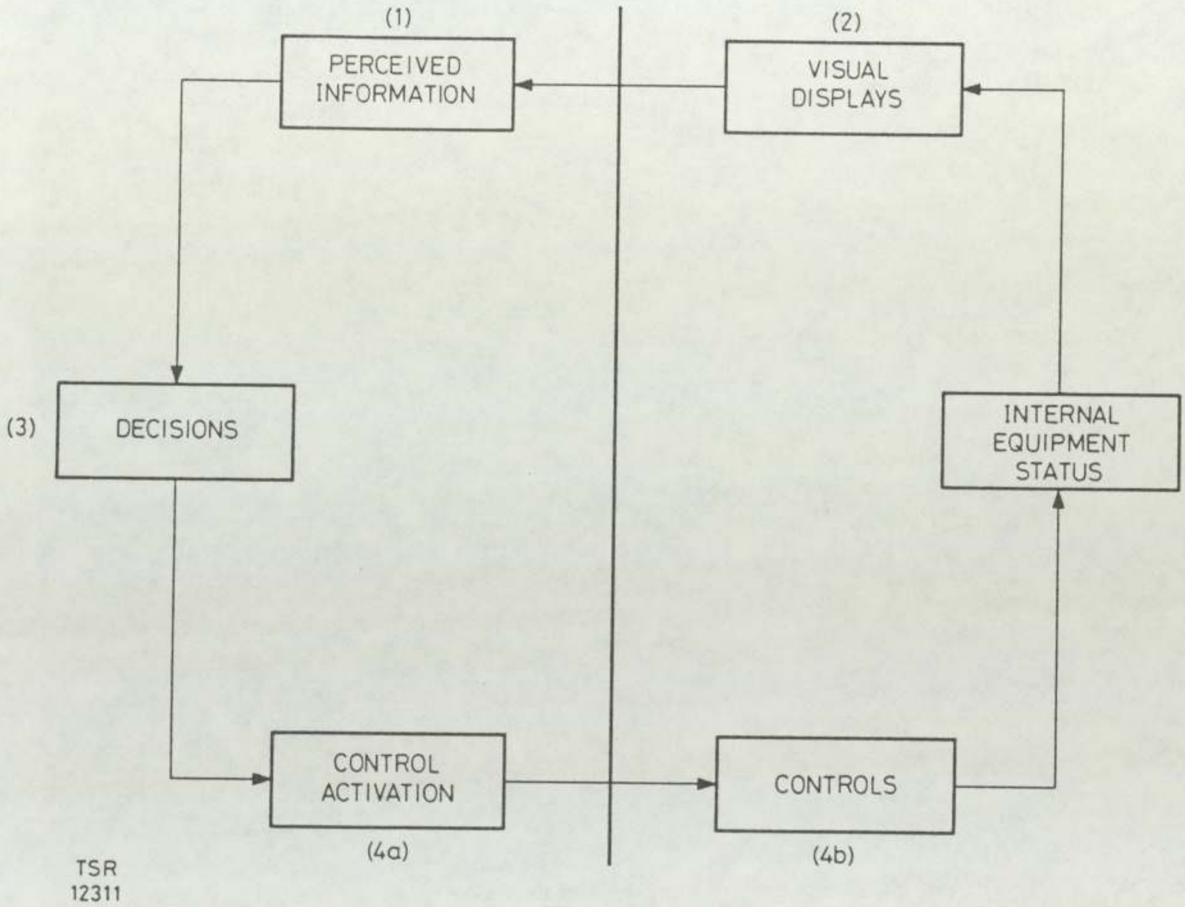


Figure 6.1 : The Man-Machine System Loop. Meister (1971)

This concept of viewing man and the machine system as a closed-loop configuration is explained by Meister, op. cit., as follows :

"This concept says in effect that there is a closed-loop relationship between the human and his equipment. The operator receives information (1) from the equipment via displays (2), makes certain decisions (3), involving that information and operates controls (4), to affect equipment status (5). The equipment in turn provides information about its changed status to the operator (1), and so the cycle continues until one turns either the machine or the operator off."

What the above description of the man-machine closed-loop configuration by Meister, op. cit., suggests is that Figure 6.1 should be modified to clearly identify those aspects of the man-machine system that need to be reviewed, and which may need to be revisited during the evaluation of the research data.

What Figure 6.2 now identifies is those subject areas where literature ought to be reviewed in support of this thesis, such as:

- Warning Systems
- Human Perception
- Human Information Processing
- Human Response Performance

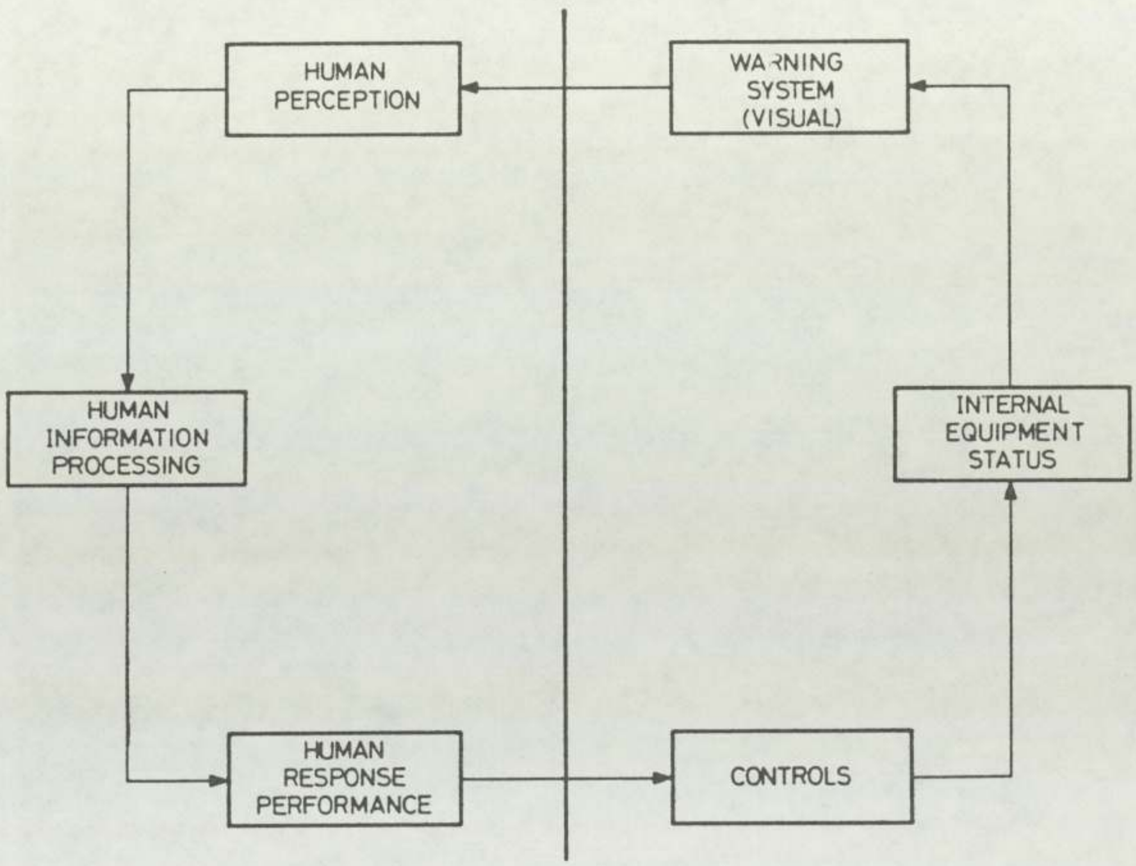


Figure 6.2 : The Modified Man-Machine System Loop.

6.2.1 Human Information Processing

One of the more recent developments in psychology is the emergence of the field of "information processing". This term is borrowed from the "information sciences" which include computer programming, systems analysis, and the mathematical theory of communication. To a very large extent this branch of psychology combines the associated concerns of both perception and cognition.

The advent of the computer has enhanced the general understanding of how organisms receive information (perception) and how they process it further before acting on it (cognition). The computer concept offers psychologists a tangible model from which theories about the operation of the humans mental processes may be developed. In principle computer programs may be considered as exhibiting many close parallels with the human thinking process, e.g., a computer program instructs a machine to execute certain procedures, or to combine information according to specified rules, or to either store certain information or to retrieve other alternative information.

However, despite certain similarities it cannot be stated that the human being acts like a computer. Unlike humans, "intelligent programs" are unemotional, inflexible, and cannot be distracted. According to Stewart (1982):

"Human information processing has been studied and investigated extensively within the field of experimental psychology, particularly in the areas of human memory and cognitive psychology.

Understanding the conceptual bases of human information processing is important for any student of human behaviour. It is especially necessary for those who utilise humans as system components."

The whole subject area of human information processing has received much more attention over the last two decades. This is predominately because when the mechanism is known as to how and why humans process information in the ways they do, then those problems in either machine system design, robotics, or the cause of accidents may be solved or much simplified.

The outcome of the emphasis given to this subject of concern is evidenced by the range and variety of data available to which reference may be made. The following outline represents what is believed to be not only a realistic combination of the available data but also a credible model of human information processing.

6.2.2 A Human Information Processing Model

The concept of viewing man as a processor of information was first postulated by Broadbent (1958) in his "Single Channel Information Processor Theory", and is illustrated in Figure 6.3.

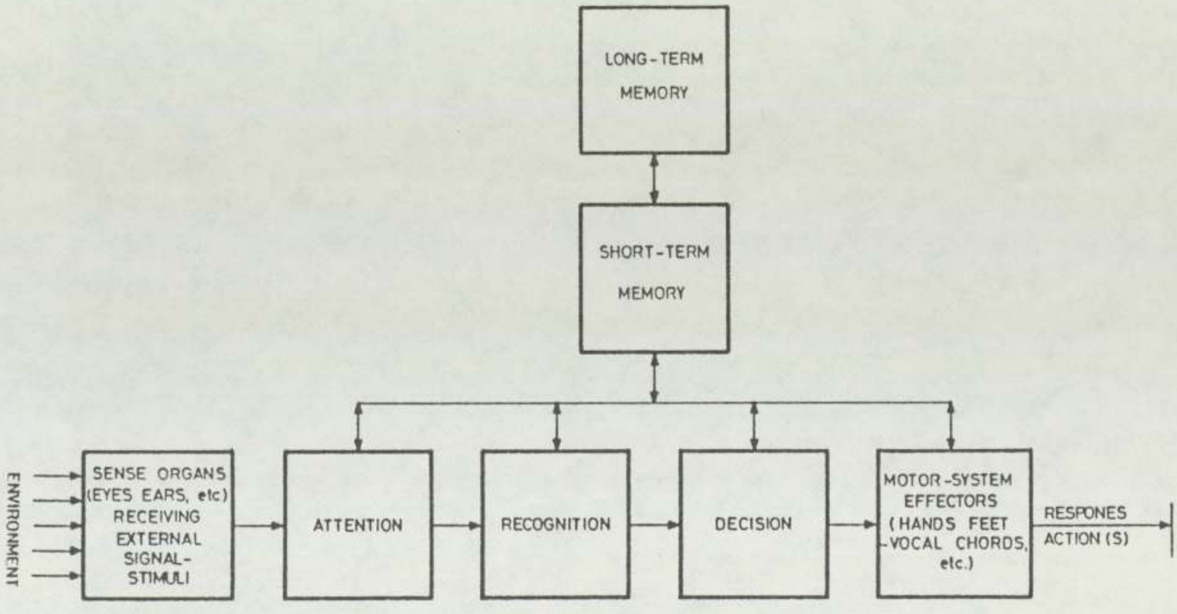


Figure 6.3 : The Single Channel Information Processing Model. Broadbent (1958)

The model of human information processing shown in Figure 6.4, is a modified version which includes those contributions made by subsequent researchers in the field, notably: Smith (1968), Sternberg (1969), Welford (1976) and Wickens (1984).

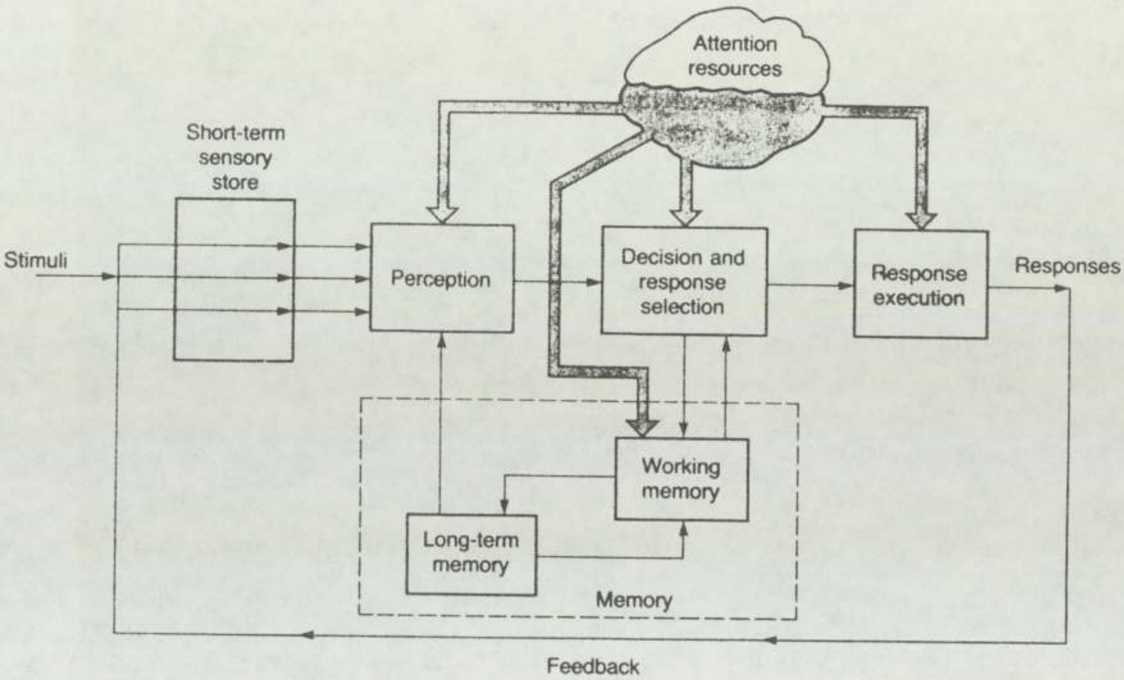


Figure 6.4 : A Model of Human Information Processing. Wickens (1984)

The processing of information by a human can be defined as an active perceptual and cognitive process that is analogous in many ways to computer processing system.

Kantowitz (1982) explains this as follows:

"It is the flow and transformation of information within a human."

In general terms the human is seen as an active seeker of information who is therefore constantly receiving, processing and acting upon the stimuli presented by the surrounding environment. This means that human information models are nothing more than conceptual representations of cognitive behaviour which attempt to show what perceptual and cognitive processes are likely to occur and when, how and why these activities interact.

As such these conceptual models are often used by researchers upon which to state their theoretical assumptions when attempting to define human limitations or capabilities.

Unfortunately, this single channel information processing concept tends to be misapplied, as stated by Hunt (1979):

> "The 'computer analogy' is frequently misunderstood to mean that our brains must follow the style of processing of physical computers; binary operation, passive memory systems and serial computation.
>
> This is an error. The analogy only maintains that it is useful to think about thought by applying the same concepts to human reasoning that we would apply to any physical information processing system."

To appreciate this concept of human information processing more fully, it is necessary to briefly review those elements shown in Figure 6.4, beginning with sensory processing.

6.2.3 Sensory Processing

The processing of perceived environmental stimuli by the humans sensory receptors, i.e., the eyes, ears, nose, mouth and skin, is the most important stage in the processing of information.

For example in the visual world a single glance creates an iconic image which usually lasts for only a few milliseconds. Storage of this iconic image is therefore dependent on a series of successive glances where each one is representative of a small section of the perceived object.

6.2.4 <u>Sensory Stores</u>

In human information processing the first (memory) store(s) are called the sensory store(s), by their very nature they are perceptual and thought to operate at the subconscious level.

The sensory stores generally alluded to are the visual or iconic store(s) which receives informative data from the eye(s) and the auditory or echoic store which receives informative data from the ear(s).

Research by Sperling (1960), Darwin, Turvey and Crowder (1972) provides experimental evidence which not only supports their existence, but also the distinctions between these sensory stores. Both iconic and echoic stores are considered to be only brief repositories of perceptual information, and are capable of holding some four or five items for a period of 10 to 20 milliseconds, Loftus and Loftus (1979); this is generally termed the span of apprehension.

6.2.5 Perceptual Encoding

The reasons the span of apprehension is so short is because the sensory detail from the perceived stimulus is subject to rapid decay. Nevertheless, this fleeting experience does provide an abundance of informative detail which, when processed by the neural system of the brain, is combined with other experiences and this can lead to recognition of the perceived object.

For example, momentary glances provide colour, texture, density, movement and shape. However, when the perceived stimulus has been encoded, by comparing and examining the perceived stimulus with either current detail in the working memory (short-term memory store) or the rehearsed and learned data in the long-term memory store, detail which is surplus to the perceptual encoding process is discarded.

On 'sensory information' Stewart, op cit, offers the following explanation:

"A large amount of visual and auditory information is perceived by the human from his immediate environment, however, the raw sensory data serves no useful purpose unless it has meaning.

It is believed that the processes of pattern recognition and attention achieve this and in so doing permits the transfer of this information into the next store - which is the short-term (memory) store."

6.2.6 Memory Stores

Memory can be divided into two different systems. One system contains all information that is presently active. This is short-term memory. Generally speaking, there is a limited amount of information available in this system as the capacity for immediate processing is quite limited.

Short-term memory is an important feature of information processing theory because it is this system that relates a current piece of information to previously stored material. Short-term memory can be used to update the information in long-term memory, which includes all memory that is not currently active. Items in short-term memory have a very brief span if they are not sustained by active attention (a process called "rehearsal").

Psychologists have theorized that the short-term memory is supported by a continuous electrical process in the brain, while long-term memory involves an actual change in the physical properties of the brain cells. Material that is in long-term memory can be brought into active memory and will not be lost even if it is interrupted. However, it appears that the capacity of the active system is still limited to a brief period of recall even if it is recalling material from long-term memory.

This limited capacity of active memory is thought to be the reason why people have difficulties in problem solving.

.2.6.1 **Short-Term Memory Store**

Experimental research by Loftus and Loftus, op cit, (involving free recall examples and plotting the results in serial position curves) does support the existence of both short and long-term (memory) storage. Brown and Herrnstein, op cit, explain short and long-term (memory) storage in the following manner:

"What one knows at any one moment seems to fall naturally into classes - the happenings of the moment, and what one really knows."

The 'happenings of the moment', are explained by James (1890), as follows:

"Let me sum up, now, by saying that we are constantly conscious of a certain duration - the specious present - varying in length from a few seconds to probably not more than a minute, and that this duration (with its content perceived as having one part earlier and the other part later) is the origin of time."

The above explanation does in fact describe short-term memory, from the aspects of time duration, where the original information stimuli received via the sensory organs are still subject to change.

This change is due to either the influence of other external stimuli from the environment, e.g. Noise equals Abstraction (refer to Figure 6.4), or downgraded due to internal disturbances, i.e. distraction. However, irrespective of the cause - internal or external - faintness of stimuli information in the short-term (memory) store, reflects the decay of a process which was active only a minute or so earlier.

The short-term memory receives information data from both the sensory and long-term (memory) stores, and according to Bransford (1979) is capable of storing that data for up to fifteen seconds. Short-term memory is a transient store where the contents are subject to rapid change unless they are rehearsed. Verbal or mental rehearsal permits the human to retain information in the short-term memory store for longer periods of time between 15 and 60 seconds, or to transfer it to the long-term memory store.

The capacity of the short-term memory store has been determined by Miller (1956) as being seven plus or minus two (7 +/- 2) items, however, the data content of this store is not dependent on item number because it is possible through chunking to increase the amount of content stored.

ANACAPA Sciences, Inc., (1981) explain 'chunking' as follows:

"Chunking is a subjective organisation that incorporates information from several items into one chunk, e.g. when trying to recall a list of 12 letters, chunking them into four familiar acronyms, IBM-FBI-PHD-TWA, facilitates retention."

Objective measurements of the information content of each chunk is done by determining the number of bits needed to encode or understand the content of the chunk.

Bits - short for binary digits - are used by researchers to measure information; a bit is the amount of information available to a human when one of two likely alternatives is chosen.

There is an exponential relationship between bits and the amounts of information, which has been defined by Abrahamson (1963), and expressed mathematically by the equation :

$$H = \mathrm{Log}_2 K$$

Where:
H = the amount of information received, and
K = the number of equal alternatives and probabilities.

This means that if a human being is presented with eight equally likely alternatives then a choice will yield three bits of information; and sixteen alternatives = four bits, and so on. The relationship may also be expressed that as the number of bits increase, so the amount of uncertainty decreases.

However, the implication still remains that if the human short-term (memory) store is overloaded due to excess information, then there will be a breakdown in the humans ability to learn and understand.

Chunking of information does help to avoid this and also gives the human a greater available store, thus increasing his capacity to process information. On short-term memory capacity, Stewart, op. cit., states:

"There are individual differences in the short-term memory store capacity (i.e. some are able to incorporate greater amounts of information into one chunk than others), but the number of items remain at 7 +/- 2."

It is the rehearsal and organisation of information which enables its transfer from short-term to long-term memory.

2.6.2 Long-Term Memory Store

This transfer of data is explained by Brown and Herrnstein, op. cit., who state:

"In the transition from short to long-term memory storage the material is re-worked, coded, clustered, grouped, or analyzed into structural features."

The long-term (memory) store, is the so-called permanent memory which is presumed to hold all the sensory and semantic information necessary for human beings to think.

It is this permanent (or conventional) memory that holds all the humans knowledge of the world, states Stewart, op. cit., where:

"Information is encoded and held here and can be retrieved through the process of recognition and recall."

There are numerous papers and abstracts on the subject of retrieval, Atkinson and Shiffrin (1970), Brown and Herrnstein, op. cit., and others, however, for the purposes of this thesis, the following extract was chosen.

From Atkinson and Shiffren, op. cit.:

"The retrieval of information from long-term (memory) storage is considerably more complicated. So much information is contained in the long-term store that the major problem is to find access to some small sub-set of the information that contains the desired image, just as one must find a particular book in a library before it can be scanned for the desired information."

Decay of information from the long-term (memory) store, or forgetting, Underwood (1964), Ceraso (1967), et al., is believed to occur due to interference and failures in the recall process.

Two types of interference are suggested by Stewart, op. cit., and these are clarified as follows:

"Proactive" : when information processed before receiving an item to remember affects the recall of that item, and :

"Retroactive" : when information processed after receiving an item to remember affects its recall.

6.2.7 Decision Making and Response Selection

Once the perceived stimulus has been perceptually encoded the human is faced with making a decision, in essence such decision making offers three possibilities, namely:

- Immediate selection of the required response; or
- Hold the encoded data in the working memory until needed to elicit the response required; or

- Rehearse and learn the encoded data and transfer it into long-term memory until recalled to elicit the required response.

To be able to reach any of these decisions implies that the human has had to go through some form of mental exercise which may be termed as problem solving. Figure 6.5 shows a credible model that may be likened to those mental processes which anyone might have to perform in order to make a decision. It also offers a reasonable alternative to the generally held idea that all decision making via memory operates on the basis of association, habit strength, or competing responses.

Selection of the required response is also a function of decision making and in the machine system environment has recourse to the proper response by various optional methods.

These options have been well discussed by Welford (1976) and Goodstein and Rasmussen (1960), they are responses which result from:

- Skill-based behaviour
- Rule-based behaviour
- Knowledge-based behaviour

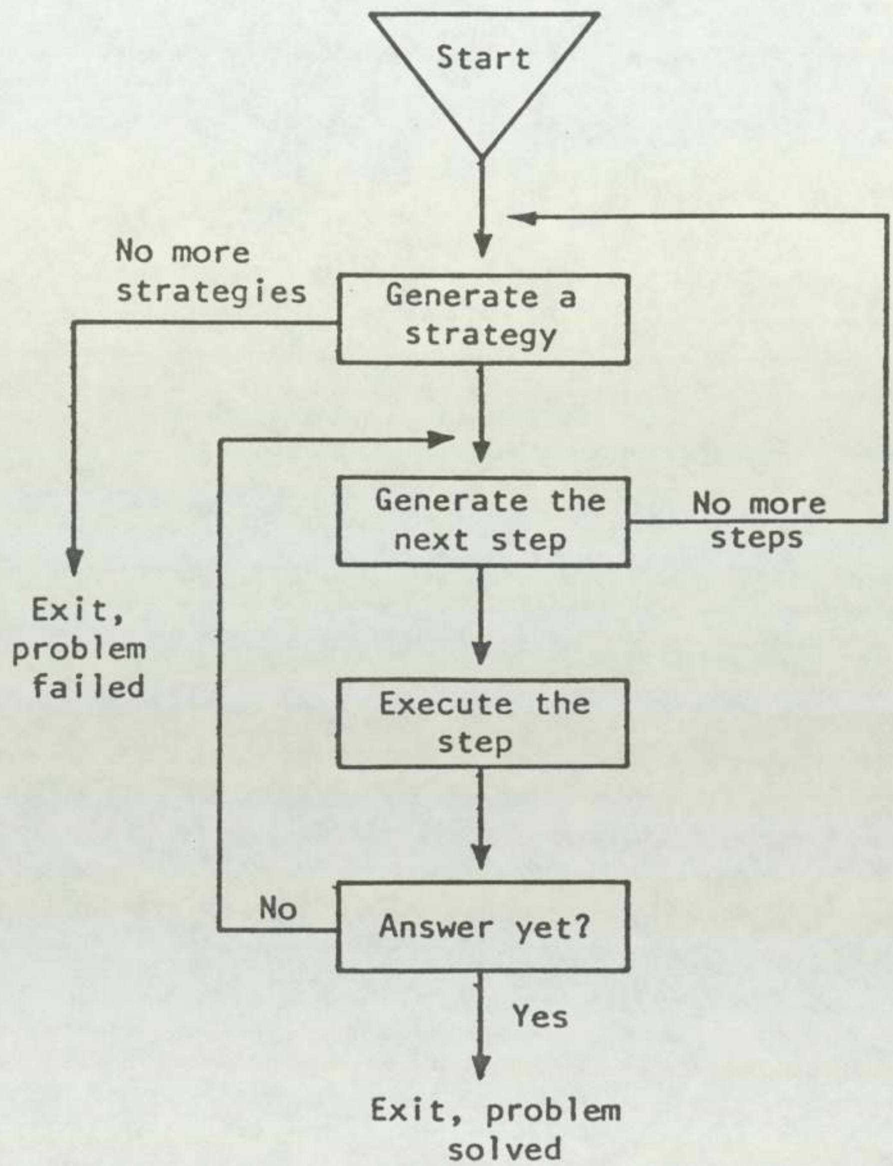


Figure 6.5 : The Computer Program Executive Routine

The three options are explained in greater detail by

Goodstein and Rasmussen, op. cit., as follows:

Skill-based (automatic sensory-motor) behaviour - immediate examples from everyday are riding a bicycle, typing, playing a musical instrument. This type of behaviour occurs typically as the consequence of a consciously expressed intention (ride, type) which is thereafter executed as a subconscious smooth and highly integrated sequence of movements synchronized to certain key features extracted from the 'surroundings'. The result of highly trained performance, for this type of behaviour is relevant in the present context for many tracking and control tasks as well as for manual manipulations in connection with familiar tools and equipment.

Rule-based behaviour - rules take the form of either prescribed (written) work instruction or as remembered procedures from earlier successful applications. Thus, this type of behaviour occurs in situations which arise and are recognised as belonging to the set of previously foreseen or predetermined situations. Rule-based behaviour is typical in the control of complex and/or lengthy activities which form part of relatively familiar job activities.

Ideally, at least in the eyes of management and regulatory authorities, prescribed rule-based behaviour is/should be both task-dependent and operator-dependent.

Knowledge-based behaviour - this type of behaviour becomes actual (as a last resort) when skills and rules are neither available nor adequate and the situation therefore calls for problem solving and perhaps improvisation. Elements of data processing thus include observing, identifying, deciding and planning and these involve causal and functional reasoning based on a knowledge of the functional properties of the system including the potential means for and effects of making corrective changes in order to counter an undesirable state or trend."

Having decided what type of behaviour option is necessary, which to a certain extent is governed by the type of man-machine system model environment, all that is now required is to translate this into the proper operator responses and thus perform those operations which will rectify the out-of-tolerance condition and re-establish the status quo.

6.2.8 Closed-Loop Feedback Control

In setting an out-of-tolerance machine system back to its proper status, it is essential that the operator monitors the effect that his executed response has on the machine system. This process is a continuous closed-loop feedback process, shown by Figure 6.2, and is essential if the machine system is to be controlled correctly.

As such the feedback, to the operator response, is through either the human's visual, auditory, or tactile senses, etc.

6.2.9 <u>Attention</u>

The majority of the stages in information processing are dependent on attention if they are to function effectively. However, as a resource it has limited capacity in terms of availability.

The following paragraphs explain the underlying concepts of attention, beginning with James, op. cit., who tells us:

> "Everyone knows what attention is. It is the taking possession by the mind, in clear and vivid form, of one out of what seem several simultaneously possible objects or trains of thought. Focalisation, concentration, of consciousness are of its essence. It implies withdrawal from some things in order to deal effectively with others, and is a condition which has a real opposite in the confused, dazed, scatter-brained state which in French is called 'distraction' and 'Zerstreutheit' in German."

This is of particular interest when considered in parallel with the aspects of attention discussed by Goodstein and Rassmussen, op. cit., who suggest:

> "That the field of attention can be likened to photographic "zooming", where the amount of system coverage and location of specific detail is variable and depends on the desired field or span of attention, which in turn depends on the current level of activity."

The paradox is that in selecting our focal point of attention the zooming effect becomes inverted.

An alternative model to describe this phenomena that is often used by psychologists, Wickens,et al., is the so-called 'searchlight' effect.

The shaded portion, in Figure 6.6, indicates those areas where noise from the environment has the effect of causing abstraction to the focal point of attention and hence interferes with active information processing, this of course excludes any consideration at this time of operator self-induced distractions.

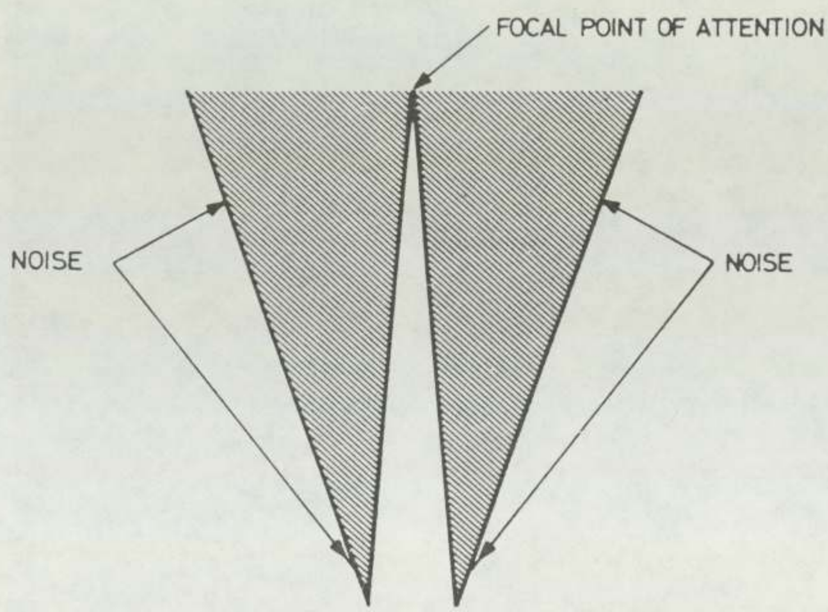


Figure 6.6 : The Focal Point of Attention

The 'withdrawal' from some things in order to deal effectively with others as stated above by James, op. cit., also needs to be considered in parallel with the area of selective attention.

Brown and Herrnstein, op. cit., state that it is customary since the paper by Broadbent, op. cit., "to speak metaphorically of a central "filter" that operates to select, from the always multifarious stimuli impinging on an organism's sensory receptors, just those "channels" that are relevant to some task at hand, totally tuning out all others." Brown and Herrnstein, op. cit., go on to say:

"that the basic necessity for positing a filter or selective mechanism is the human severely limited capacity at the levels of consciousness and memory storage."

Man is unable to attend to everything at once, to respond at once. If we consider this in terms of 'Information Processing Theory' the human mind may be likened to a communication channel with a sharply limited central processing capacity.

Figure 6.7 is a diagram drawn by Treisman (1964) to represent the 'filter theory of attention', postulated by Broadbent, op. cit.

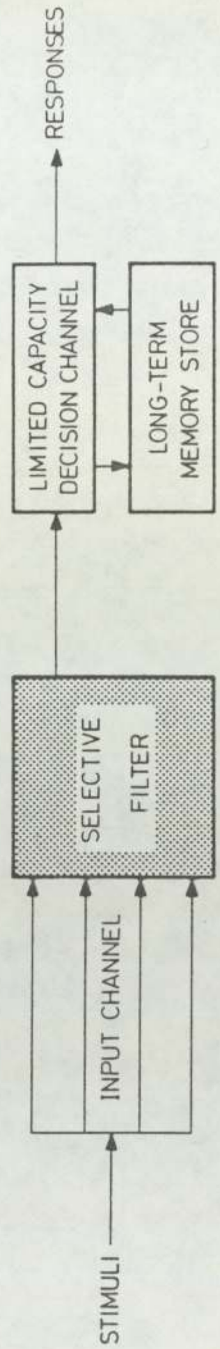


Figure 6.7 : The Filter Theory of Attention. Treisman (1964)

The human mind is treated in Figure 6.7 as an information handling system, therefore, the figure as such, can only be a flow chart representing the orders and relations of those processes that are believed to take place. The implication, as shown, is that more potential stimuli impinge on the organism at anytime than it can process. So only a selection is transmitted for higher level processing by a unit of limited capacity, and only stimuli processed by the higher level unit can enter long-term memory.

In this respect, Steinbuch, op. cit., has summarised the estimated reduction of information that occurs due to filtering, from the initial reception of stimuli by the sense organs through the intermediate stages of processing to final access into permanent storage-memory as shown in Table 6.1.

Table 6.1 : Information Reduction (Steinbuch 1962)

Process	**Maximum flow of information (bit/s)**
Sensory Reception	1,000,000,000
Nerve Connections	3,000,000
Consciousness	16
Permanent Storage	0.7

To complete this section on the subject of attention it is necessary to return to James, op. cit., who states:

"The things to which we attend are said to interest us. Our interest in them is supposed to be the cause of our attending."

This tends to infer that the filtering which occurs during the attention process is to some extent governed by external or internal interest(s) which though different for each human, is a peculiarity common to all, in other words, the selective attention of an operator may be pre-conditioned by his selective interests.

6.3 Warning System/Signals

The two main types of warning signals presented to the human in the machine system environment are either auditory or visual. What has to be appreciated is that whilst they are both excellent methods for advising a human of a particular condition or specific situation requiring a response, each type has limitations in their practical applications.

It is these limitations which can preclude the use of one warning signal system in favour of the other. The simplest explanation of this somewhat paradoxical situation is to be found if consideration is given to such places as iron and steel foundries, stamping works, etc., where the noise levels are so high as to make audible warning system signals almost null and void. Because the auditory system of many operators have been assailed by high levels of noise for such a long time that their hearing is either damaged or impaired.

In the following literature review of warning system - signals the tendency has been to concentrate on those signal types which are visual rather than auditory.

The reason for this is because in the majority of cases visual signal - systems appear to be the preferred choice of designers. Particularly for those complex machine systems which require a wide range of status, monitoring and warning system - signals to indicate the condition of the machine system during its functional operation. Therefore, it was essential to establish what the functions and limitations of visual warning signal/systems might be. Also to further define those underlying problems which are seen to arise because of them.

To this end, twenty-one papers on warning signals and thirty-nine papers on alarm signals were reviewed. However, only eight and ten papers respectively could be considered as applicable to the areas of prime concern. Most of the papers reviewed provided extensive detail with respect to the functional purpose of the types of signals used in warning systems. In addition the papers also explained the obvious advantages and disadvantages of auditory/visual types of signals when used for specific purpose warning systems, e.g. emergency or contingency warning systems.

From Singleton (1972) we learn that :

"The object for which any man-machine system is designed will be achieved only if all its components are matched to each other, and interact in ways appropriate to their common purpose".

This suggests that if the warning system-signal does not attract the operators attention then the components referred to by Singleton, op. cit., do not match, as intended.

This would seem to imply that it is the effectiveness of warning systems to present signal information to an operator which requires the emphasis, and would therefore, appear to be dependent on the following inter-related elements :

- The detectability of warning system signals (information stimuli), and
- The visual capability of the human (operator, signal detection, human perception).

6.3.1 <u>The Detectability of Warning System-Signals</u>

Those factors which can influence the detectability of a machine warning system signal (information stimulus) light (status, monitoring or warning) are primarily the following :

- Size-Luminance and Exposure Time (Graham and Margaria, 1935, also Teichner and Krebs 1972).

also the :

- Colour (Reynolds, et al. 1972)

as well as the :

- Flash Rate of Lights (Woodson and Conover, 1964, and Markowitz 1971).

The colour and flash rate requirements for lights are stated in the Military Standard "Human Engineering Design Criteria for Military Systems, Equipment and Facilities" Mil. Std. 1472B.

This specifies in the section on visual displays, that :

"YELLOW shall be used to advise an operator that a condition exists which is marginal. YELLOW shall also be used to alert the operator to situations where caution, re-check, or unexpected delay is necessary."

and :

"GREEN shall be used to indicate that the monitored equipment is in tolerance or a condition is satisfactory, and that it is alright to proceed (e.g. "go-ahead", "in tolerance", "ready", "function activated", "power on", etc)."

It also specifies :

"FLASHING LIGHTS - The use of flashing lights shall be minimized. Flashing lights may be used when it is necessary to call an operators attention to some condition requiring action. The flash rate shall be within 3-5 flashes per second with approximately equal amounts of ON and OFF time."

Likewise by reference to British Standard 4099: Part 1:1976, specification for "Colours of Indicator Lights, Push Buttons, Annunciators and Digital Readouts", it can be seen that there is complete accord with the above Military Standard with respect to the purpose and function of "YELLOW" and "GREEN" lights in warning systems.

Within the same British Standard (Part 1) there is also agreement on the 'use of flashing light' which is stated as follows :

"A steady light is normally used for indicator lights and for illuminated pushbuttons. For further distinction or information and especially to give additional emphasis, flashing lights may be used for the following purposes :

a) to attract further attention;

b) to request immediate action;

c) to indicate a discrepancy between a commanded state and the actual state of the related equipment;

d) to indicate a change in progress (flashing during a transition period). If, for information of a different priority, flashing lights with different flashing frequencies are used, the rapidly flashing light should be used for the higher priority information".

The flash rates recommended by this standard are contained in Part 2 and are listed as follows:

Rapidly Flashing Signals :

"Rapidly flashing signals shall flash at a reasonable constant rate of 110 +/- 30 flashes per minute and shall have an ON/OFF time ratio between 4:1 and 1:1. Such signals shall be used to indicate that high priority action is required or that a change of state has occurred or that a discrepancy exists between a commanded state and a related state.

An even higher flashing rate, such as 300 flashes per minute, may be specified in certain instances, e.g. for discrepancy controllers, to distinguish between discrepancies arising from an automatic trip and preselected trip".

Slowly Flashing Signals :

"Slowly flashing signals shall flash at a reasonably constant rate of 20 +/- 5 flashes per minute and shall have an ON/OFF time ratio between 2.2:1 and 1:1. Such signals shall be used to indicate a lower priority state of change or a discrepancy between a commanded state and a related actual state, or to attract attention with no particular priority."

The aspects of warning system-signal lights quoted from the above standards, i.e. Mil-Std-1472B and BS4099 (parts 1 & 2) were included to highlight a point of interest. That is the slight but significant variance between the flash rate stated in Mil-Std-1472B, i.e. 3-5 flashes per second with approximately equal amounts of ON and OFF time, and the flash rate recommended for attracting attention stated by Woodson and Conover, op. cit., which is in the order of 3 to 10 flashes per second (with a duration of at least 0.05 seconds).

It should also be noted however, that the high flash rate recommended by British Standard 4099 concurs exactly with the upper range of the flash rate stated in Mil. Std. 1427B.

What is surprising is that the British Standard suggests three different flash rates:

- Slowly flashing signals = 20 +/- 5 per minute
- Rapidly flashing signals = 110 +/- 30 per minute
- High flash rate signals = 300 per minute

Any speculation made on the limitations of visual warning systems in the literature review took the view that most failures could be attributed to limitations of the warning system itself, Meister, op. cit., Munns (1971).

However, as stated by McCormick (1976):

"Flashing or steady state lights are used for various purposes including the following:

as indication of warning (as on highways); as identification of aircraft at night; as navigation aids and beacons; and to attract attention, such as to certain locations on an instrument panel.

There apparently has been little research relating to such signals, but we can infer some general principles from our knowledge of human sensory and perceptual processes that might be helpful."

From Figure 6.1 it is clear that the prime human interface with the machine system is with the visual display of that system. Therefore, flashing or steady state lights, as stated by McCormick, op. cit., play an important role in the man-machine interface relationship, because not only are they used to give a warning indication of an out-of-tolerance machine system condition, but the same warning light must also attract the operator's attention.

6.3.2 Human Perception

It was readily established by reviewing a fairly wide range of literature related to the visual capabilities of a human, e.g. Brown and Herrnstein (1975), Lindsay and Norman (1972), and Taylor (1973), et al., that the importance of the human visual system has been well recognised. Therefore, the necessity for the human to have an intact visual system whilst performing critical tasks, during his interactions with a machine system, has also become increasingly evident.

The most important sensory input the human receives, either interfacing with the machine system during involved functional activities - tasks, or whilst interfacing with his environment in general, is visual.

From the research carried out by Steinbuch, op. cit., it has been established that the human's sensory receptors have to cope with approximately 10^8 bits of information data from the environment alone. However, Steinbuch, op. cit., indicates by his table (refer to Section 6.2.9) that this figure is much reduced by the conscious mental processes of the human. Nevertheless, this should not be construed to mean that the human can now cope with a lower level of 16 bits of informative data because this is not so. Firstly, all of the informative data being processed by the human's visual system is being constantly mediated by his environment and, finally, it is believed that the selective attention of the human will reduce the 16 bits to only those of interest and concern.

To understand the visual capabilities of humans requires review of the following inter-related factors :

- The fields of view of the human
- The visual performance of the human

6.3.3 The Fields of View of the Human

Visibility as a term has been used in a number of ways, e.g. by meteorologists in evaluating seeing conditions in the atmosphere, by aircraft designers to describe the pilots field of view, and others.

Used in its purely technical sense, visibility really refers to the total process of seeing and so reflects the interaction between the human visual system (described earlier) and the physical environment.

Visibility, therefore, relates to the properties of the visual stimulus (an object seen against a background, illuminated in some specific way) the paths of sight (optical transmission will obviously differ between air, or water, or through some intervening element such as a window or optical device) and the visual performance capabilities of the human observer.

Figure 6.8 illustrates the optimum 'lines of sight' of a human, however, the optimum shown is that normally given for those operators seated in front of a console display panel, i.e. where the man-machine system relationship is a fixed one.

Figure 6.9 illustrates the "vertical and horizontal visual field" of the human, and these together with the 'lines of sight' mentioned in the last paragraph, form two of the known constituents in the so called paths of sight.

A general treatment of the topic may be found in the papers of Duntley, et al., (1964), and Blackwell, (1974).

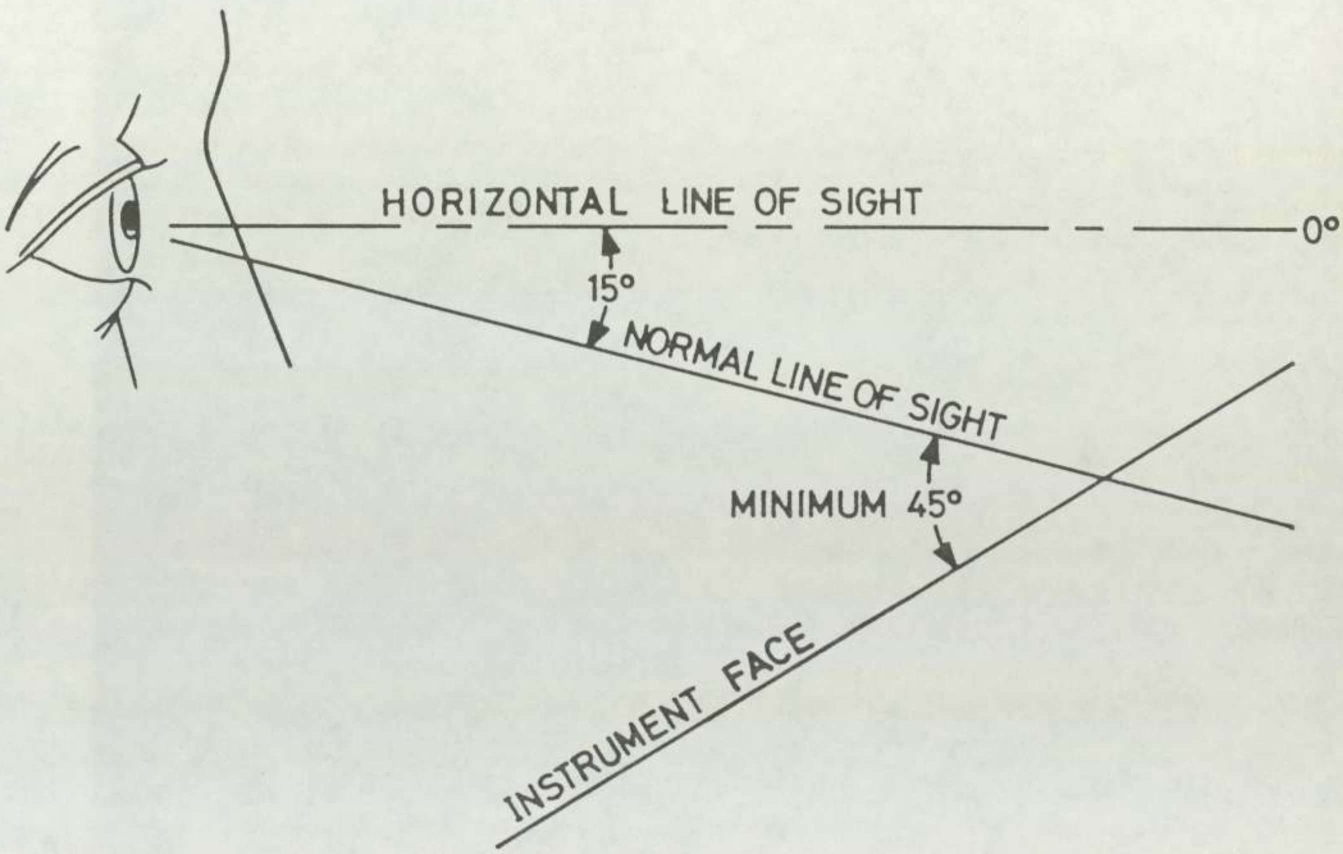


Figure 6.8 : Lines of Sight

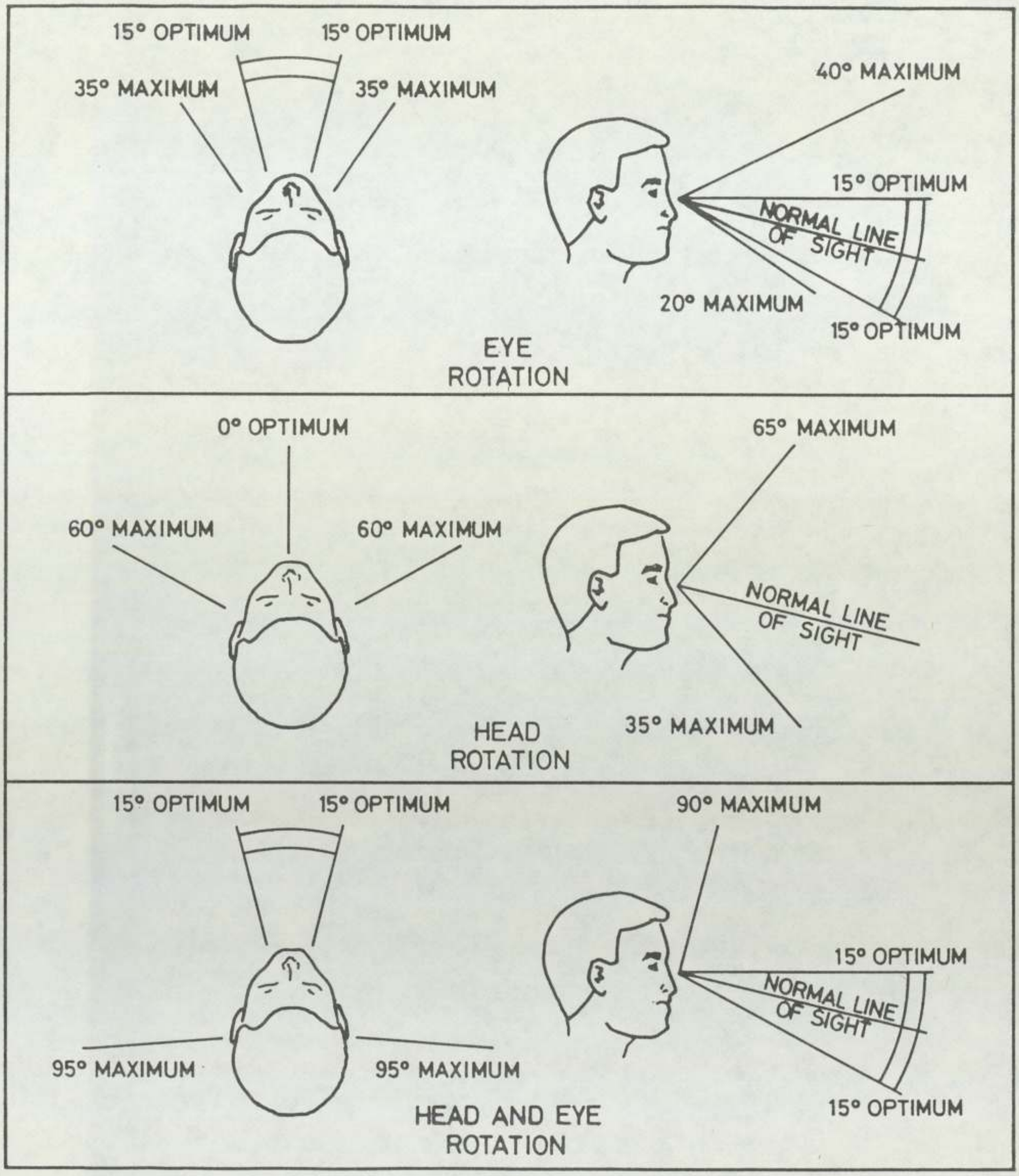


Figure 6.9 : Vertical and Horizontal Visual Field

6.3.4 **The Visual Performance of the Human**

Papers and abstracts on the visual performance of the human abound. However, the most succinct explanation is provided by Taylor op. cit.:

Visual Performance

"Normal visual performance involves a number of interdependent discriminations which are made in response to factors in the visual environment and mediated by the structure of the visual system.

Principal among these discriminations are the appreciation of detail (visual acuity), contrast, colour, form, distance, movement and certain temporal aspects of the object of regard."

"The limiting capabilities of the human observer have been extensively investigated in all of these areas, usually in laboratory studies which isolate the function of interest.

It must be recognised, therefore, that the data does not take into account the interactions between functions which are known to occur. Rather, they should be taken as indicative of the limiting case, modifiable for better or worse in accordance with other factors."

Visual Acuity

On visual acuity, Taylor, op. cit., offers the following explanation:

"There are many definitions of the term 'visual acuity', all, however, incorporate the notion of the resolution of detail.

A variety of test patterns has been used to measure acuity, from the simple dots to twin stars, gratings, checker-boards, and letters ... [refer to Figure 6.10] ... It is unfortunate that no general agreement as to the choice of a test has been reached, and that results from the different patterns are at odds."

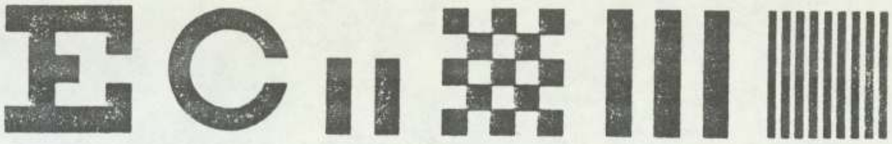


Figure 6.10 : Acuity Test Patterns

About Figure 6.10, McCormick, op. cit., explains it is to show:

"Illustrations of various types of targets used in visual acuity tests and experiments. The features to be differentiated in targets a.b.c.d. and e, are all the same size and would, therefore, subtend the same visual angle at the eye.

With target .a. the subject is to identify each letter; with c, e, and f, he is to identify the orientation (such as vertical or horizontal); and with .b. he is to identify any of four orientations. With target .d. he is to identify one checkerboard target from three others with small squares."

Therefore, from the informative data provided in the preceding texts on human perception, it is fairly obvious that where warning systems-signals stimuli only impinges on the periphery of the human eye, i.e. on the borders of an operators lines of sight, then accurate, definitive resolution of the detail (visual acuity) of the stimuli information presented, becomes less likely and understandably so.

7.0 **Human Performance Research and Theories**

An extensive range of literature covering such subject areas as:

- Perception of Danger
- Skilled performance and Stress
- Ergonomics and Air Safety
- Information Input and Response Time
- Pattern Recognition and Display Characteristics
- Control-Display-Subject Interactions and Perceptions on a Complex Perceptual Motor Task
- The Relevance of Vigilance Research to Aerospace Monitoring Tasks
- Methods of Predicting Human Reliability in Man-Machine Systems
- Human Errors and Transport Accidents
- Engineering Psychology and Human Performance

plus many others were reviewed to establish which theories and supportive data could be considered as applicable to the research presented here.

7.1 Research Methods

Wickens,op cit.,states that there are in principle five categories of research methodologies employed by scientists and engineers, and these can be placed on a continuum from high to low realism:

- Observation of systems in action in the real world
- Field studies of fully developed systems
- Studies of simulated systems
- Laboratory experiments
- Mathematical models

A review of the different literature was not very encouraging for two specific reasons: first of these is that no research papers could be found on human performance with systems in action in the 'real world'. Next, whilst all of the research literature addressed human performance in differing contexts, in general, the research studies performed were at the lower end of the realism scale.

Indeed, with one or two notable exceptions, none of the research literature directly addressed either human or machine system induced errors.

The majority of researchers tended to emphasize the limitations of the human as a component in the performance of many tasks related to functional operations of a machine system. What is curious, is the same researchers gave no mention to any limitations on the part of either the simulated systems, or the laboratory equipment, or machine system elements used for their studies.

In addition also missing from the research data was any identification, or explanation, of failure mechanisms or causal factors that might contribute to limitations in performance by the human. This does exclude those discussions on the 'open and obvious' causal factors which can modify or degrade the humans performance, such as: fatigue, stress, workload or personality conflicts, etc.

The MSDR was an ideal candidate for study (as discussed in Section 5.4) because it offered an opportunity to observe a system in action in a real working environment, especially if the following distinctive features are also taken into account:

1) The machine system model would be subjected to hardware/software development and development testing for a period of about two years.

2) During the development and testing of the model it would be staffed by personnel from a range of different disciplines with varying levels of skill.

3) Development and testing of the model meant that not only true signal stimuli would be generated, but also false signal stimuli. Thus providing a good opportunity to measure operator perception and response performance for real system disturbances (RSD), as well as for those disturbances caused by either normal fluctuations of the parameters (NFP) or out-of-sequence software (OSS).

It is these two last factors, (normal fluctuations of the parameters and out-of-sequence software) that might be the contributory causal mechanisms leading to the creation of a risk environment, therefore, an important research consideration.

The research methodology selected, loc. cit., (Chapter 8.0) was chosen because it permitted the following salient features to be investigated and analysed:

- Human performance with a machine system in action in the real world.

- Machine system performance in terms of signal generation(RSD,NFP or OSS).

- Human error causal factors and their underlying mechanisms.

7.2 Spacelab/Shuttle Test Program

It should be noted that the Spacelab/Shuttle project was based on an interactive integration and test program. For example each element of the MSDR had been designed, developed and tested by the equipment or facility developer, however, it was not until these elements were fully integrated into the MSDR and interfaced with the common support equipments that the MSDR could be tested as a complete system. Similarly Spacelab itself could only be considered complete when all of the racks had been integrated and tested using Spacelab provided resources. This program only ended when the Spacelab module and the Shuttle (STS) became a fully operational entity.

7.3 Research Theory

The review of the literature clearly showed human performance to consist of three distinctive stages, perception, information processing and response, and a credible model incorporating these stages was constructed. What was not readily apparent is that there is no single theory available that totally embraces every aspect of human performance.

Instead there are a number of theories which together in combination can give account of the various aspects that constitute the human perceptual, processing and response performance capabilities.

In developing a theory for the research of human performance with the MSDR, specific considerations had to be constantly borne in mind. Paramount amongst these was that there could not be any manipulation of the machine system variables to observe what the subjective responses might be from the various members of the team. Next, was the fact the team members did not receive any specific training prior to their involvement with the integration, development and testing of the MSDR and its elements. The rationale being that they were qualified and experienced engineers, therefore, had the requisite skills to perform those tasks allotted to them.

The research needed to re-assess the functions of perception, information processing and response performance, this time however, in a real world environment. This was necessary because although various aspects such as attention, recognition and decision making, etc, had been well investigated during other psychophysical research, such individual experiments were primarily conducted to isolate only factors of interest to the experimenter.

This approach did tend to obscure other factors of equal importance, and when performed often ignore the fact that perception, information processing and response performance are all a part of one continuous process made up of many interrelated and interdependent psychological and physiological factors.

The theory being developed was based on comparing those differences found between:

- An evaluation of the team members performance from the observed and recorded research data.

- Predicted team member performance probabilities using the same observed and recorded research data.

The intention was to build human performance profiles for each member of the team; this being accomplished by using the observed and recorded research data on attention and recognition to predict each team member's probable response performance. That was his performance for every warning system-signal stimuli generated by out-of-tolerance conditions of the machine system, real or otherwise, to which he attended and subsequently recognised.

Then, as soon as the observed and recorded data for attention, recognition and response performance for each team member has been evaluated, this information would also be included on each individual team member's prediction profile.

By simple comparison between the predicted and evaluated human performance data for each team member obvious differences were established. These differences for recognition and response being highlighted on each team members prediction profile. The purpose in carrying out such a comparison between predicted versus evaluated human performance data was to define which of the two methods are the more accurate for use in future human performance research with machine systems.

8.0 Research Methodology

Experimental research was undertaken during the period from April 1980 until September 1981 to study human performance in a real time machine system environment. The reason for performing this type of research was prompted because prior studies of human performance were inappropriate and fragmented. That is to say, in general, they only dealt with individual aspects of the whole process of human performance, whereas the performance of any task, even the most simple, by a human is dependent on many interrelated mental activities, such as perception, information processing and decision making and finally psychomotor output responses.

The comments in the previous paragraph suggest that the research methodology selected must be capable of achieving realism. That is, the results on human performance during the development and integration testing of the experiment elements and support equipments should be obtained under realistic conditions. However, any study of human performance in real time conditions generally means there is less control of the experiment variables. This was also true for the MSDR because during its functional operation it did not permit manipulation of any of the machine system element variables to allow controlled observation of subjective responses.

An additional consideration was that the results from such real time experiments, in contrast to those obtained from laboratory simulated experiments, do not appear to be relevant to anything other than the MSDR itself.

If the results inevitably lack general applicability as a candidate to human performance data this should be balanced by their validity to payload specialist training.

However, for reasons of practicality, the research could not be performed in the actual environment which would be experienced by the payload specialist whilst performing his tasks during the real Spacelab mission. For example Spacelab experiences a microgravity environment once the Shuttle reaches its parking orbit. Manifestly such conditions could not be reproduced for the development, integration and testing of the MSDR in the ground environment.

However, the majority of the other Spacelab environmental conditions could be met, for example, the Spacelab interior lighting was designed to be at levels of 200 to 300 lumens/m^2. This level of lighting is the same level to be found in any modern office block, and was easily met in the MBB cleanroom facility. Similarly, Spacelab was to be kept at a shirt-sleeve environment, that is an ambient temperature of 22 ^oC with a maximum allowable temperature of 30 ^oC. The above temperatures for Spacelab were exactly the same as those maintained in the MBB cleanroom facility.

In addition a further requirement was also specified for operator touch temperatures which should not be greater than 45 ^oC and not less than 4 ^oC.

These temperatures levels were achieved by means of the MSDR test equipment monitors in the first instance. Towards the end of the MSDR development and test program they were accomplished by the experiment elements using the central console computer.

A further consideration was to ensure that noise levels of less than 55 dB(A) for Spacelab were maintained. However, this could not be achieved initially because several other program activities were being performed concurrently, e.g., Solar array strobe tests (Intelsat), R.F. signal generation (Exosat), etc., thus creating spurious noise levels.

Finally, payload specialist task sharing activities could not be predicted because the total experiment complement for Spacelab was not known at the time of the experiment. Therefore, task sharing effects could not be considered during the research period, however these effects were known after the first mission and are discussed in the conclusions to this thesis.

8.1 Research Approach

To establish the most effective research approach for the man-machine system model selected, various methodologies were examined to find the one most suitable.

From the various methodologies reviewed, the "Human Performance Prediction" methodology, designated the "Meister Taxonomy" by Finley, et al. (1970) was the one selected for the research, though not in its entirety. The reason for modifying any taxonomy is made apparent by Meister, op. cit., with the following statement:

"It is not that any one taxonomic method is superior to another, or that universal truth is contained in one taxonomy and universal error in another. It is a fact that despite all pretensions to the contrary, no taxonomy has inherent truth in it, a taxonomy is a convention on which all concerned will agree as representing an acceptable way of denoting things. Although they would deny it if it were called to their attention, previous workers have talked of a taxonomy as if there were only one; and if that were developed, it would solve all their problems. This is unacceptable. There are simply a number of possible taxonomies for different purposes, leading to different consequences and outputs. Above all the value of a taxonomy lies in what it permits one to do with the taxonomic outputs."

The methodology to be used during the research is a modified version of the "Personnel Behaviour Taxonomy: Descriptive Level 2 - Tasks" from "Meister Taxonomy".

The methodology described in Section 8.2 identifies those operator tasks which need to be observed and recorded to establish operator's performance via the machine system models visual display system. As well as their subsequent response performance upon recognition of the signal stimuli presented.

8.2 MSDR Research Methodology

1. Perform control-display operations.

A) Activate MSDR controls as part of the set-up sequence - perform appropriate control action in accordance with display indications:

(i) routine programmed procedures (e.g., MSDR set-up and checkout).

(ii) routine variable events (e.g., temperature/pressure corrections).

(iii) emergency condition - corrections.

Note: The operator's behaviour will involve, but not be completely restricted to, discrete perceptual motor activity. The observed operator(s) perceptual activities to be recorded and evaluated.

B) Activate MSDR experiment controls.

Note: This activation can only occur after proper set-up and checkout of MSDR support elements, e.g., power, cooling and vacuum & gas subsystems, i.e., ensure that there are no set-up failures indicated on the visual display.

C) Monitor display indications

(i) record changes in status indications (observe operator's response to changes).

Compare displayed status with required system status, for correctness of indication.

(ii) compensation activities, determination and adjustment of experiment level indications (this is a form of hardware/software calibration to ensure that the experiment profile is achievable.

2. Record data received

A) From the visual displays.

B) From the operators observations.

Note: A) is an inherent function during test activities, whereas B) is less common, yet is probably one of the most important aspects to be recorded, especially as it may reflect any anomalies that the operator might have observed during the performance of some functional operation of the machine system.

3. Decision making

A) In the functional operation of a machine system an operator is constantly involved in deciding between two or more:

(i) hypotheses (e.g., is the fault or status signal due to a real system disturbance or has it been caused by a fluctuation of the system parameters).

(ii) discrete alternatives (e.g., the modes of operating the various elements of a machine system).

(iii) general strategies.

B) Analyse alternatives (e.g., different ways of troubleshooting a machine system element, or which method to use to solve a problem) such as a hardware fix or a software change.

C) Analyse and interpret data.

D) Anticipate/predict events (e.g., that the generation of the next stop, fault or status signal stimulus will be due to the same causal factors as those previously generated).

E) Hypothesize causal relationships (e.g., that two events are related).

F) Verify that a hypothesis is correct by reference to available data (e.g., confirm by reference to test data acquisition printouts).

G) Troubleshoot malfunctioning support and experiment elements of the machine system model.

Note: As the machine system model selected is being developed for the "Spacelab 1" mission profile means that operator(s) decisions will be related to the developed and programmed mission event profile.

Discrete alternatives refer to those alternatives for the operation of the machine system, e.g., two ways of accomplishing set-down of the machine system, either by the programmed mission software or by operator interrupt via the central console. General strategies refer to a series of hypotheses or alternatives extended in time.

Interview techniques for the interrogation of operators was seen as an essential pre-requisite for those occasions when the following types of anomaly occurred during the test of the machine system model, and would be essential if there was to be any attempt in understanding the underlying causal factors in the operators reasoning, e.g.,

a) where an operator's response to a signal-stimulus was passive, when it should have been active, or vice-versa.

b) where hardware/software trouble shooting is performed to determine which of these either singly, sequentially or in combination, have been the cause of parameter fluctuations, which in turn has led to the generation of a false signal in the warning system of the machine system model.

The data recording proforma shown in Figure 8.1 has been specifically designed to fulfil the requirements of the research methodology and at the same time enable ease in the recording of observed operator actions - reactions to the signal stimuli presented by the warning system during functional operation of the machine system model.

The proforma used is both relatively simple and self explanatory indicating as it does those areas of operator response performance which should be observed and recorded if the capabilities or limitations of individual team members are to be determined with regard to the warning system-signal stimuli presented.

Similarly, the capabilities or limitations of the machine system model warning system to generate signal stimuli which will elicit the correct human operator response performance also needed to be determined by data observed and recorded.

A complete description of the format and the rationale for the selection of the data to be recorded, collated and evaluated is contained in Appendix E.

Date: Time:
Personnel Present:
Experiment Element:
Support Elements:
Test:
Observations:

I D Attention by:

Recognised Y N by:

Identified with list by:

Evaluated Y N Problem H S

NFP Y N Human Error Y N

Date: Time:
Personnel Present:
Experiment Element:
Support Elements:
Test:
Observations:

I D Attention by:

Recognised Y N by:

Identified with list by:

Evaluated Y N Problem H S

NFP Y N Human Error Y N

Date: Time:
Personnel Present:
Experiment Element:
Support Elements:
Test:
Observations:

I D Attention by:

Recognised Y N by:

Identified with list by:

Evaluated Y N Problem H S

NFP Y N Human Error Y N

Date: Time:
Personnel Present:
Experiment Element:
Support Elements:
Test:
Observations:

I D Attention by:

Recognised Y N by:

Identified with list by:

Evaluated Y N Problem H S

NFP Y N Human Error Y N

Figure 8.1 : Data Recording Proforma

9.0 RESULTS OF INVESTIGATION

9.1 Introduction

From the beginning of January 1980 to the end of September 1981, the period of the experimental study, over 500 observations were made and recorded on operator attention, recognition, etc. with the machine system model. However, the number chosen for analysis had to be reduced to 255 observations for the following reasons:

1) In 51 cases the data recording proformas were incomplete, i.e., relevant and important data was missing. In these cases the author/observer was obliged to conduct his own tasks and was unable to devote full attention to the performance of others.

2) A further 82 proformas were deleted because they reflected only the results of the software checks that automatically illuminated the 'STOP' and 'FAULT' lamps sequentially for every credible failure mode programmed.

3) Another 27 were deleted because the off-line computer printouts were either incomplete or did not match the information on the data recording proformas.

   This situation raised doubts as to the validity of the data that was recorded because it could not be checked after the event, so left little alternative but to remove them from the database to be used for the predictions and evaluation of human performance.

4) Development activities of the MSDR entailed many changes to both support and experiment element hardware/software. These changes gave rise to hardware/software anomalies which in turn generated false signal stimuli to the members of the team.

   These false signals did lead to the wrong conclusions via the decision making processes of the team members involved at the time, therefore, these signals and the responses they elicited were considered as null and void. This action removed a further 39 data recording proformas from the research database.

5) There were also 33 anomalies recorded on the proformas that were excluded because the reasons given by the various team members for their probable cause could not be verified. A simple example of this was where an operator made the correct response to the signal presented and yet less than a minute later when the same signal reappeared it elicited no response whatsoever. The operators explanation for his failure to respond was that he did not believe it to be a true signal!

6) Finally, in a further 13 instances recorded, the operators' reasons for not responding to the signal presented was that although they recognised the signal they were more interested in trying to understand the underlying cause for the signals quick reappearance. Unfortunately such statements by operators cannot be verified, so this data was also removed from the records.

9.2 Research Data Evaluation

All of those essential aspects relating to operator attention, recognition, decision making and response, etc., as defined in the "MSDR Research Methodology", loc cit. (Section 8.2), that had been observed were recorded on the research "Data Recording Proforma" (refer to Figure 8.1).

These recordings for the various set-up and test sequences of the MSDR during its development phase have been tabulated and are to be found in the appendices, that is, with the exception of the tables for attention and recognition.

The tabulated data which relates specifically to operator attention and recognition has, in addition, been statistically evaluated and the results of these are contained in Appendix B for "attention", and Section 9.4 for "recognition".

It should be noted that the data on attention was evaluated primarily for the following reasons:

Firstly, determination of each persons level of attentiveness during the research phase was necessary as these figures would be needed in conjunction with the figures for their recognition capabilities to further determine what the levels of response for each person should be, for comparison against their actual performance.

Next, because the MSDR was functionally operated on board the "Spacelab 1" mission (and will be on subsequent missions) by a "Payload Specialist", it is important to know if poor attention was due to limitations on the part of the operator, or inadequacies on the MSDR Central Console to capture an operators attention to some condition requiring action.

9.3 Operator Attention

9.3.1 Operator Attention - Results

It was presumed that the credible operator actions - reactions to any warning system-signal stimuli generated could only be one of the following:

- Immediate attention
- Delayed attention (typically a delay between the appearance of a signal and the operator's response of more than one second)
- Failure to attend

It may be noted that the "delay" is measured from the moment that the observer first notes the appearance of the signal, thus the results may exaggerate the number of occasions when the operator attended immediately.

From James, op cit., we learn that:

"There is no such thing as voluntary attention sustained for more than a few seconds at a time."

It may be presumed from this statement that such breaks in a human's attention (concentration) are the main contributory factor leading to so-called delayed attention responses to signal stimuli.

Table 9.1., shown on the subsequent pages, reflects the collated data for operator attention observed during the research. The box headings at the top of the tables are meant to be self-explanatory, indicating from left to right as follows:

- Data Sheet Number; was used to indicate the number of the entry made on the 'Data Recording Proformas', loc cit., Figure 8.1.

- Date; this box was used to show the date on which the observations were made.

- The abbreviations I/TE-S/WE-SE and I/TM were given in full in Section 4.3, loc cit., whereas the abbreviation CE which has not been previously mentioned stands simply for 'Customer Engineer'.

- Remarks; this box heading simply indicates that this column may be used for any notations of importance.

It may be noted by reference to the 'data recording proformas' that several of the data sheet numbers recorded also have an alphabetical suffix attached. This suffix was added for those conditions where the signal stimulus appeared twice in a row, but for different reasons.

Finally the legend selected to present the collated data was chosen for ease in recording and is explained as follows:

*) This symbol was used to denote the 'immediate attention' of the team member.

D) This letter was chosen to represent the team members' 'delayed attention'.

O) The 'O' figure was selected to show the team members' 'failure to attend'.

-) A dash (-) was used to show that the team member was absent for a particular test sequence being observed.

The data on attention for each member of the team that was observed and recorded during the period of research are contained in Table 9.1 shown on the following pages. By reference to this table the attention, delayed attention and failures to attend for each team member is readily visible when the legend is applied.

Table 9.1 : Recorded Data for Operator Attention

Data Sheet No.	Date	I/TE	S/WE	SE	CE	I/TM	Remarks
1	03.04.80	D	0	-			
2	23.07.80	0	D	D			
3	23.07.80	*	0	*			
4	23.07.80	D	0	D			
5	23.07.80	*	0	0			
6	09.10.80	0	0	*			* MA intervention
7	09.10.80	*	0	-			
8	09.10.80	*	*	0			
9	09.10.80	D	D	D			
10	09.10.80	*	*	*			
11a	09.10.80	D	D	D			
11b	09.10.80	D	D	D			
12	10.10.80	D	0	-			
13a	10.10.80	*	*	-			
13b	10.10.80	*	*	-			
14a	10.10.80	*	*	*			
14b	10.10.80	*	*	*			
15	11.10.80	*	*	0			
16	13.10.80	0	0	0			* As above
17	13.10.80	D	-	-			
18	13.10.80	*	-	-			
19	04.11.80	D	D	D			
20	12.11.80	*	*	*			
21	12.01.81	0	D	-			
22	13.01.81	D	D	-			
23	13.01.81	*	-	-			
24	13.01.81	*	*	-			
25	15.01.81	0	D	-			
26	15.01.81	D	0	-			
27	15.01.81	D	0	-			
28	15.01.81	*	*	-			
29	15.01.81	D	0	-			
30	15.01.81	D	0	-			
31	16.01.81	0	*	-			
32	16.01.81	*	0	-			
33	16.01.81	D	D	-			
34a	16.01.81	*	*	-			
34b	16.01.81	*	*	-			
35	16.01.81	*	*	-			
36	16.01.81	D	D	-			
37a	16.01.81	*	*	-			
37b	16.01.81	*	*	-			
38a	16.01.81	*	*	-			
38b	16.01.81	*	*	-			
39	16.01.81	*	*	-			
40	17.01.81	*	*	*			
41	20.02.81	*	*	-			
42	20.02.81	*	*	-			
43	20.02.81	*	*	-			
44	20.02.81	*	*	-			

Table 9.1 : Recorded Data for Operator Attention (cont'd)

Data Sheet No.	Date	I/TE	S/WE	SE	CE	I/TM	Remarks
45	20.02.81	*	*	-			
46	20.02.81	*	*	-			
47	27.04.81	*	*	*			
48	30.04.81	D	D	D			
48b	30.04.81	D	D	D	-	-	
49	30.04.81	D	D	D	-	-	
50a	30.04.81	*	*	*	-	-	
50b	30.04.81	*	*	*	-	-	
51	30.04.81	D	D	D	-	-	
51a	04.05.81	D	D	D	-	-	
52b	04.05.81	D	D	D	-	-	
53a	04.05.81	*	*	*	-	-	
53b	04.05.81	*	*	*	-	-	
54a	04.05.81	*	*	*	-	-	
54b	04.05.81	*	*	*	-	-	
55a	05.05.81	D	D	D	-	-	
55b	05.05.81	D	D	D	-	-	
56	05.05.81	D	D	D	-	-	
57	05.05.81	*	0	0	-	-	
58	05.05.81	*	0	0	-	-	
59a	05.05.81	0	*	*	-	-	
59b	05.05.81	*	0	0	-	-	
60	06.05.81	*	*	*	-	-	
61	06.05.81	D	D	D	-	-	
62	06.05.81	*	*	*	-	-	
63	06.05.81	D	D	D	-	-	
64	06.05.81	*	*	0	-	-	
65	06.05.81	*	*	*	-	-	
66	07.05.81	*	0	0	-	-	
67	07.05.81	*	0	0	-	-	
68	07.05.81	*	*	*	-	-	
69	07.05.81	*	0	0	-	-	
70	07.05.81	D	D	D	-	-	
70	07.05.81	D	D	D	D[2]	-	
72	07.05.81	*	*	*	*	-	
73	07.05.81	*	*	*	*	-	
74	07.05.81	D	D	D	D	-	
75	07.05.81	D	D	D	D	-	
76	07.05.81	*	*	*	*	-	
77	07.05.81	*	*	*	*	-	
78	07.05.81	D	D	D	D	-	
79	07.05.81	*	0	0	0	-	
80	07.05.81	*	*	0	0	-	
81	07.05.81	*	*	0	0	-	
82	07.05.81	D	D	D	D	-	
83	07.05.81	D	D	D	D	-	
84	07.05.81	*	*	*	*	-	
85	07.05.81	*	*	*	0	-	
86	07.05.81	0	0	D	D	-	
87	07.05.81	0	0	*	*	-	

Table 9.1 : Recorded Data for Operator Attention (cont'd)

Data Sheet No.	Date	I/TE	S/WE	SE	CE	I/TM	Remarks
88	07.05.81	D	0	0	0	-	
89	07.05.81	D	D	D	D	-	
90	07.05.81	*	*	*	*	-	
91	07.05.81	*	0	*	0	-	
92	07.05.81	*	0	*	*	-	
93	08.05.81	*	*	*	*	-	
94	08.05.81	0	*	0	*	-	
95	08.05.81	*	*	*	*	-	
96	08.05.81	0	*	*	*1	-	
97	08.05.81	*	*	0	0	-	
98	08.05.81	*	*	*	*	-	
99	08.05.81	0	0	*	*	-	
100	08.05.81	*	*	*	0	-	
101	08.05.81	*	*	*	*	-	
102	08.05.81	*	*	*	*	-	
103	08.05.81	*	*	*	*	-	
104	09.05.81	*	0	*	-	-	
105	09.05.81	*	*	0	-	-	
106	09.05.81	0	D	D	-	-	
107	09.05.81	*(S) D(F)	*(S) D(F)	*(S) D(F)	-	-	
108	09.05.81	*	0	*	-	-	
109	09.05.81	*	*	*	-	-	
110	09.05.81	D	D	D	-	-	
111	09.05.81	*	*	0	-	-	
112	09.05.81	0	0	0	-	*	
113	09.05.81	*	*	*	-	*	
114	09.05.81	*	0	*	-	0	
115	09.05.81	*	0	*	-	*	
116	09.05.81	0	0	0	-	0	* MA Intervention
117	09.05.81	*	0	0	-	-	
118	09.05.81	*	*	*	-	-	
119	09.05.81	D	D	D	-	-	
120	09.05.81	0	0	*	-	-	
121	09.05.81	*	0	0	-	-	
122	09.05.81	*	*	*	-	-	
123	09.05.81	*	*	0	-	-	SE was at rear of rack
124	09.05.81	0	*	0	-	-	
125	09.05.81	D	D	D	-	-	
126	09.05.81	*	*	*	-	-	
127	09.05.81	*	0	0	-	-	
128	09.05.81	*	*	*	-	-	
129	09.05.81	0	*	*	-	-	
130	09.05.81	D	0	0	-	-	
131	15.05.81	*	*	0	-	-	
132	15.05.81	*	0	0	-	-	
133	15.05.81	D	D	D	-	-	
134	15.05.81	*	0	0	-	-	
135	15.05.81	D	D	D	-	-	
136	15.05.81	*	0	0	-	-	

Table 9.1 : Recorded Data for Operator Attention (cont'd)

ata heet o.	Date	I/TE	S/WE	SE	CE	I/TM	Remarks
137	15.05.81	*	*	*	-	-	
138	15.05.81	*	0	0	-	-	
139	15.05.81	*	*	0	0	-	
140	15.05.81	0	0		D1	-	
141	15.05.81	D	D	D	D	-	
142	15.05.81	*	*	*	*	-	
143	15.05.81	*	*	*	*	-	
144	15.05.81	0	0	*	0	-	
145	15.05.81	*	0	0	0	-	
146	15.05.81	*	0	0	0	-	
147	15.05.81	D	D	D	D	-	
148	15.05.81	D	D	D	D	-	
149	15.05.81	D	D	D	D	-	
150	15.05.81	*	0	0	0	-	
151	15.05.81	D	D	D	-	-	
152	15.05.81	*	*	*	-	-	
153	15.05.81	*	*	*	-	-	
154	15.05.81	*	*	*	-	-	
155	15.05.81	*	*	*	-	-	
156	15.05.81	*	*	*	-	-	
157	15.05.81	*	*	*	-	-	
158	15.05.81	*	*	*	-	-	
159	15.05.81	D	0	D	-	-	
160	15.05.81	*	*	*	-	-	
161	15.05.81	0	*	0	-	-	
162	15.05.81	D	D	D	-	-	
163	15.05.81	D	D	D	-	-	
164	15.05.81	S	S	S	-	-	S = Simulated Signal
165	15.05.81	*	*	*	-	-	
166	16.05.81	*2	*2	*4	*2	*1	* MA Team = 12
167	16.05.81	*2	*2	*4	*2	*1	
168	16.05.81	*MHF	*VGS	0	0	*VGS	
169	16.05.81	0	0	0	0	*	
170	16.05.81	*	0	0	0	*	
171	16.05.81	*	*	*	*	*	
172	16.05.81	*	*	*	*	*	
173	16.05.81	D	D	D	D	D	
174	19.05.81	0	0	0	0	0	* MA Intervention
175	21.05.81	0	0	0	0	*	
176	21.05.81	*	*	*	*	*	
177a	21.05.81	*	*	*	*	*	HTT
177b	21.05.81	*	*	*	*	*	YES
178a	21.05.81	*	*	*	*	*	
178b	21.05.81	*	*	*	*	*	
179	21.05.81	*	*	*	*	*	
180	21.05.81	*	*	*	*	*	
181	21.05.81	*	*	*	*	*	
182a	21.05.81	*	*	*	*	*	
182b	21.05.81	*	*	*	*	*	
183	21.05.81	*	*	*	*	*	

Table 9.1 : Recorded Data for Operator Attention (cont'd)

ta eet .	Date	I/TE	S/WE	SE	CE	I/TM	Remarks
84a	21.05.81	*	*	*	*	*	
84b	21.05.81	*	*	*	*	*	
85	22.05.81	0	0	*	0	0	
86	22.05.81	*	*	*	*	*	
87	22.05.81	*	*	*	*	*	
88	22.05.81	D	D	D	D	D	
89	22.05.81	D	D	D	D	D	
90	22.05.81	D	D	D	D	D	
91	22.05.81	*	*	*	*	*	
92	22.05.81	*	*	*	*	*	
93	22.05.81	D	0	0	0	0	
94	12.06.81	*	*	*	*	*	
95	12.06.81	0	0	0	0	*	
96a	12.06.81	D	D	D	D	D	
96b	12.06.81	0	0	*	0	0	
97	12.06.81	*	*	*	*	*	
98	26.06.81	*	*	*	*	*	
99a	24.07.81	*	*	*	*	*	
99b	24.07.81	*	*	*	*	*	
00a	24.07.81	*	*	*	*	*	
00b	24.07.81	*	*	*	*	*	
01	24.07.81	*	*	*	*	*	
02	27.07.81	0	0	0	0	0	MA Intervention
03	27.07.81	0	0	0	0	0	MA Intervention
04	27.07.81	D	D	D	D	D	
05	27.07.81	D	0	D	0	0	
06	27.07.81	*	*	*	*	*	
07	29.07.81	D	D	D	D	D	
08	29.07.81	*	*	*	*	*	
09	04.08.81	D	D	D	0	0	
10	04.08.81	D	D	D	D	D	
11	23.09.81	*	*	*	*AE6	*	AE = Acceptance Engineers
12	23.09.81	D	D	D	D	D	Also includes Customer Engi- neers
213a	24.09.81	*	*	*	*	*	
213b	24.09.81	*	*	*	*	*	
214	24.09.81	*	*	*	*	*	
215	24.09.81	*	*	*	*	*	
216	24.09.81	*	*	*	*	*	
217	25.09.81	D	D	D	D	D	
218b	25.09.81	D	D	D	D	D	
219	25.09.81	0	0	0	0	*	
220	25.09.81	0	*	0	0	*	
221	25.09.81	0	*	0	0	*	
222a	25.09.81	0	*	0	0	*	
222b	25.09.81	0	*	0	0	*	
223	25.09.81	0	*	0	0	*	
224	25.09.81	*	*	*	*	*	
225a	25.09.81	0	*	0	0	*	

Table 9.1 : Recorded Data for Operator Attention (cont'd)

ata heet o.	Date	I/TE	S/WE	SE	CE	I/TM	Remarks
225b	25.09.81	0	D	0	0	D	
225c	25.09.81	0	D	0	0	D	
226	25.09.81	0	0	0	0	*	
227	25.09.81	0	*	0	0	*	
228	25.09.81	*	*	*	*	*	
229	25.09.81	0	*	0	0	*	
230	25.09.81	*	*	*	*	*	
231	25.09.81	0	0	0	0	*	

9.3.2 Operator Attention - Predictions

Tabulating the data for operator attention simplified the task of extracting the relevant data for each operator's immediate attention as shown below:

Summary Table: Observed Operator Attention (Immediate)

Team Member "Discipline"	Total No. of Trials	Immediate Responses	Immediate Attention Probabilities
Integration and Test Engineer	255	149	0.58
Software Engineer	251	132	0.53
System Engineer	220	106	0.48
Custom Engineer	122	59	0.48
Integration and Test Manager	82	59	0.71

From this tabulated data it was a straightforward exercise to extract the required figures to predict the probabilities of each team member in terms of their immediate attention to a warning system-signal stimuli. These figures were also calculated because they would be needed to perform the necessary comparison between the predicted and evaluated performance of the various team members.

It was further decided to calculate the probabilities for those delays in attention exhibited by the various team members so as to assess the consequences of such delays on their overall performance.

The calculations made for delayed attention are as follows:

Summary Table: Observed Operator Attention (Delayed)

Team Member "Discipline"	**Remaining No. of trials**	**Delayed Responses**	**Delayed Attention Probabilities**
Integration and Test Engineer	106	69	0.65
Software Engineer	119	57	0.48
System Engineer	114	55	0.48
Customer Engineer	63	25	0.40
Integration and Test Manager	23	13	0.56

9.3.3 Operator Attention - Discussion

The results of the statistical evaluations for operator attention using the "Binomial Theorem" are contained in Appendix B.

These statistical evaluations were performed on the assumption that probably four members of each team member discipline would be needed if attention were to be assured. In this manner it was possible to determine what the manning levels for each discipline should really be to ensure attention to any warning system-signal stimuli generated by an out-of-tolerance machine system condition.

From examination of the probability figures calculated for the following disciplines it can be readily seen that any one engineer,irrespective of discipline, would be sufficient if attention to the signal stimuli presented was to be reasonably assured:

-	Integration and Test Engineer (I/TE)	0.97
-	Software Engineer (S/WE)	0.95
-	System Engineer (SE)	0.93
-	Customer Engineer (CE)	0.93

During the experimental study the machine system model was always manned by the 'integration and test engineer' and for most of the time supported by engineers from the other disciplines involved.

Customer engineers were the exception because they were generally only present for the 'final acceptance testing' of the experimental element for which they were responsible.

In the section on 'operator attention-predictions' it may be noted that the probabilities for immediate attention of three team members (S/WE, SE and CE) do not differ widely. Likewise, by review of the probabilities for delayed attention it is seen that for two members of the team (S/WE and SE) the probability figures are almost identical to their figures for immediate attention. The widest dispersion between the figures for immediate and delayed attention of any significance lie between the 'integration and test manager' (I/TM) 'integration and test engineer' (I/TE) and the remaining members of the team.

Both the 'integration and test engineer' and the 'integration and test manager' (I/TM) achieved high success rates for immediate attention to the warning system - signal stimuli presented during those trials attended.

The I/TE and I/TM also had the highest probability figures for delayed attention which in certain circumstances could be construed as poor attendance by them to the tasks in hand. This construction might have been held to be true if the experimental study had placed its emphasis on operator reaction-response times to warning system - signal stimuli presented by a machine system malfunction or failure.

However, for all of the disciplines considered and evaluated, these figures for delay may also be used to logically argue that they were not total failures. Therefore, the delayed attention data should be added to the figures for immediate attention and compared with those figures where there was a failure to attend.

For example, if we add the immediate and delayed attention figures for the 'integration and test engineer' together and compare those figures with those where were failures to attend then the figures for attention are 0.854 and for failure to attend 0.145.

These figures now suggest a high level of attentiveness on the part of the 'integration and test engineer' and from this it may also be inferred that all of the team members displayed fairly high levels of attentiveness during the experimental study.

Alternatively, it may also be argued that the operators perceptual awareness was triggered by those immediate reactions of the other team members in close proximity to himself. That is when they responded to a machine system, warning system-signal stimulus requiring attention, in this instance his delayed responses may be viewed as being caused by his delayed attention.

Such delays in attention are generally believed to be caused by distractions internal to the human. However, whilst such distractions on the part of the human are known to exist, the mechanisms which lead to their occurrence are not fully understood. This implies that whilst delayed attention should be considered in the following texts it should not be used to formulate any assumptions on human performance because the background data cannot be substantiated.

9.3.4 Operator Attention - Theory

For human perception to occur means that there must be an allocation of the human's resources of attention.However, the true nature of attention, as with many perceptual processes, is unknown though its measure has been taken and theorized by a number of researchers.

For example, it was believed that the "Theory of Signal Detection" would prove to be useful in evaluating research data on attention. However, as stated by Wickens, op cit., the 'theory of signal detection' serves its purpose best when applied to those circumstances in which detection of a signal itself represents a source of uncertainty, or a potential bottleneck in the humans performance.

As such the theory would appear to be more beneficial where it is necessary to detect signals or events that are near the threshold of the humans perception, especially where there are difficulties in discriminating between two states: a signal is present or it is absent. The 'theory of signal detection' was ruled out for use with this particular research because signal detection or signal discrimination was not viewed as a problem with the MSDR warning system.

That is to say that there were no obvious perceptual threshold problems related to the MSDR warning system, in terms of the signal stimuli generated by out-of-tolerance machine system conditions.

Selective attention which forms an inherent part of the 'single channel processor theory' mooted by Broadbent, op cit., was also reviewed as a possible method for use in evaluating the research data. The various aspects of 'selective attention' via the postulated theories of Senders (1964) Sheriden (1972) Moray (1976) Sheriden & Rouse (1971), et al., have also been well discussed by Wickens, op cit. However, whilst these theories on visual and auditory information selection by humans was extremely informative, its applicability for use in evaluating the research data was considered to be doubtful, primarily because the database of the research was obtained by observation of humans whilst they were functionally operating a machine system in action in the real world, as opposed to those studies using controlled experiments where the variables could be manipulated and where successful completion of a task by a subject was rewarded.

Attention without any doubt is a resource which has to be allocated by the human, however, such allocation is conditional, as remarked by James, op cit., 'we attend to those things which are of interest to us, our interest in them is the cause of our attending'.

9.4 Operator Recognition

9.4.1 Operator Recognition - Results

Identification and/or recognition of the warning system-signal presented to the human is an essential prerequisite if the decision and response making process is to subsequently occur. Just as attention must first take place before there can be any identification or recognition process.

On occasion there was a need for the operators to refer to the 'Fault/Stop Identification List' (Appendix A) it was therefore considered prudent to list those times when the operators had cause to use the list. The recordings made of identification in this context are shown by the tables in Appendix C.

Statistical evaluation of the collected and collated data on recognition or identification per se, provides no more useful data than that which can be readily calculated from either the tables in Appendix C or Table 9.2.

The box headings given at the top of Table 9.2 are exactly the same as those given on Table 9.1. Therefore, those rationales used for Table 9.1 equally apply to all tables that contain the observed and recorded research data that has been collated.

Finally, the legends selected to represent the data on the above tables are listed and defined on the front page of each table.

Signal Stimuli-Causal Factors which are listed in the tables contained in Appendix D are the only exception to the above explanation given for the tables, however by reference to these tables it is very clear to see what the box headings are meant to imply. In addition the legend used throughout on these particular tables are included on the front page and is self-explanatory.

Table 9.2 : Recorded Data on Operator Recognition

Data Sheet No.	Date	I/TE	S/WE	SE	CE	I/TM	Remarks
1	03.04.80	0	Y	-	-	-	
2	23.07.80	0	Y	Y	-	-	
3	23.07.80	Y	Y	0	-	-	
4	23.07.80	0	Y	0	-	-	
5	23.07.80	0	0	Y	-	-	
6	09.10.80	0	Y	0	-	-	
7	09.10.80	Y	0	-	-	-	
8	09.10.80	0	0	Y	-	-	
9	09.10.80	Y	0	0	-	-	Y = Recognition
10	09.10.80	Y	Y	Y	-	-	0 = No Recognition
11a	09.10.80	0	0	0	-	-	X = Not Possible
11b	09.10.80	Y	0	0	-	-	
12	10.10.80	Y	Y	-	-	-	
13a	10.10.80	Y	Y	-	-	-	
13b	10.10.80	0	0	-	-	-	
14a	10.10.80	Y	Y	0	-	-	
14b	10.10.80	0	0	0	-	-	
15	11.10.80	0	0	0	-	-	
16	13.10.80	0	0	0	-	-	
17	13.10.80	0	-	-	-	-	
18	13.10.80	Y	-	-	-	-	
19	04.11.80	0	0	0	-	-	
20	12.11.80	Y	Y	Y	-	-	
21	12.01.81	Y	0	-	-	-	
22	13.01.81	X	X	-	-	-	
23	13.01.81	0	0	-	-	-	
24	13.01.81	0	0	-	-	-	
25	15.01.81	Y	0	-	-	-	
26	15.01.81	0	0	-	-	-	
27	15.01.81	Y	P	-	-	-	
28	15.01.81	Y	0	-	-	-	
29	15.01.81	Y	0	-	-	-	
30	15.01.81	Y	0	-	-	-	
31	16.01.81	Y	0	-	-	-	
32	16.01.81	Y	0	-	-	-	
33	16.01.81	0	0	-	-	-	
34a	16.01.81	Y	Y	-	-	-	
34b	16.01.81	0	0	-	-	-	
35	16.01.81	Y	Y	-	-	-	
36	16.01.81	Y	Y	-	-	-	
37a	16.01.81	Y	Y	-	-	-	
37b	16.01.81	0	0	-	-	-	
38a	16.01.81	0	0	-	-	-	
38b	16.01.81	Y	Y	-	-	-	
39	16.01.81	Y	Y	-	-	-	
40	17.01.81	0	0	0	-	-	
41	20.02.81	Y	Y	-	-	-	
42	20.02.81	Y	Y	-	-	-	
43	20.02.81	0	0	-	-	-	
44	20.02.81	0	0	-	-	-	

Table 9.2 : Recorded Data on Operator Recognition (cont'd)

Data Sheet No.	Date	I/TE	S/WE	SE	CE	I/TM	Remarks
45	20.02.81	Y	Y	-	-	-	
46	20.02.81	Y	Y	-	-	-	
47	27.04.81	0	0	0	-	-	
48a	30.04.81	Y	Y	Y	-	-	
48b	30.04.81	Y	0	0	-	-	
49	30.04.81	0	0	0	-	-	
50a	30.04.81	Y	Y	0	-	-	
50b	30.04.81	Y	Y	0	-	-	
51	30.04.81	Y	Y	Y	-	-	
52a	04.05.81	Y	Y	0	-	-	
52b	04.05.81	0	0	0	-	-	
53a	04.05.81	0	0	0	-	-	
53b	04.05.81	Y	0	0	-	-	
54a	04.05.81	Y	Y	Y	-	-	
54b	04.05.81	Y	Y	0	-	-	
55a	05.05.81	Y	Y	0	-	-	
55b	05.05.81	0	0	0	-	-	
56	05.05.81	Y	0	0	-	-	
57	05.05.81	Y(P)	0	0	-	-	
58	05.05.81	0	0	0	-	-	
59a	05.05.81	0	Y	0	-	-	
59b	05.05.81	0	Y	0	-	-	
60	06.05.81	Y(P)	0	0	-	-	
61	06.05.81	0	0	0	-	-	
62	06.05.81	Y	0	0	-	-	
63	06.05.81	0	0	Y	-	-	
64	06.05.81	Y	Y	0	-	-	
65	06.05.81	Y(P)	0	Y	-	-	
66	07.05.81	Y	0	0	-	-	
67	07.05.81	Y	0	Y	-	-	
68	07.05.81	Y	Y	Y	-	-	
69	07.05.81	Y	0	Y	-	-	
70	07.05.81	Y	Y	0	-	-	
71	07.05.81	Y	Y	Y	Y	-	
72	07.05.81	Y	Y	Y	Y	-	
73	07.05.81	Y	Y	Y	Y	-	
74	07.05.81	Y	0	0	0	-	
75	07.05.81	Y	Y	Y	Y	-	
76	07.05.81	Y	Y	Y	Y	-	
77	07.05.81	Y	0	Y	Y	-	
78	07.05.81	Y(P)	0	0	0	-	
79	07.05.81	0	0	0	0	-	
80	07.05.81	0	Y	0	0	-	
81	07.05.81	Y	Y	0	0	-	
82	07.05.81	Y	0	0	0	-	
83	07.05.81	Y	Y	0	0	-	
84	07.05.81	0	0	0	0	-	
85	07.05.81	Y	Y	0	0	-	Stop signal
86	07.05.81	Y	Y	0	0	-	
87	07.05.81	Y	Y	0	0	-	

Table 9.2 : Recorded Data on Operator Recognition (cont'd)

Data Sheet No.	Date	I/TE	S/WE	SE	CE	I/TM	Remarks
88	07.05.81	X	X	X	X	-	
89	07.05.81	Y	Y(P)	0	0	-	
90	07.05.81	0	0	Y	0	-	
91	07.05.81	Y	Y	Y	Y	-	
92	07.05.81	Y	Y	Y	0	-	Stop signal
93	08.05.81	Y	Y	Y	0	-	
94	08.05.81	Y	Y	0	0	-	
95	08.05.81	Y	Y	Y	Y	-	
96	08.05.81	Y(P)	0	0	0	-	
97	08.05.81	0	0	0	0	-	
98	08.05.81	Y	Y	Y	0	-	
99	08.05.81	0	Y	0	0	-	
100	08.05.81	Y	Y	Y	0	-	
101	08.05.81	Y	Y	Y	Y	-	Stop signal
102	08.05.81	Y	Y	Y	Y	-	
103	08.05.81	Y	Y	Y	Y	-	
104	09.05.81	0	0	Y(P)	0	-	
105	09.05.81	0	Y	0	0	-	
106	09.05.81	0	0	Y	0	-	ICS signal
107	09.05.81	Y	Y	Y	-	-	
108	09.05.81	Y(P)	0	0	-	-	
109	09.05.81	Y	Y	Y	-	-	
110	09.05.81	0	0	0	-	-	
111	09.05.81	Y	0	0	-	-	Stop signal
112	09.05.81	Y	Y	0	-	0	
113	09.05.81	Y	Y	Y	-	Y	
114	09.05.81	Y	Y	Y	-	0	
115	09.05.81	Y	Y	0	-	0	
116	09.05.81	Y	0	0	-	-	
117	09.05.81	Y	Y	Y	-	-	Fault signal
118	09.05.81	Y	Y	Y	-	-	
119	09.05.81	Y	Y	Y	-	-	PWR signal
120	09.05.81	Y	0	Y	-	-	
121	09.05.81	Y	Y	Y	-	-	
122	09.05.81	Y	Y	Y	-	-	
123	09.05.81	Y	Y	0	-	-	
124	09.05.81	Y	Y	Y	-	-	
125	09.05.81	Y	Y	Y	-	-	
126	09.05.81	Y	Y	Y	-	-	
127	09.05.81	Y	Y	Y	-	-	
128	09.05.81	Y	Y	Y	-	-	
129	09.05.81	Y	Y	Y	-	-	
130	09.05.81	0	0	0	-	-	
131	15.05.81	0	0	0	-	-	
132	15.05.81	0	0	0	-	-	
133	15.05.81	Y(P)	0	0	-	-	
134	15.05.81	0	0	0	-	-	
135	15.05.81	0	0	0	-	-	
136	15.05.81	Y	0	0	-	-	

Table 9.2 : Recorded Data on Operator Recognition (cont'd)

Data Sheet No.	Date	I/TE	S/WE	SE	CE	I/TM	Remarks
137	15.05.81	Y	Y	Y	-	-	
138	15.05.81	X	X	X	-	-	
139	15.05.81	Y	Y	0	0	-	
140	15.05.81	Y	Y	Y	0	-	
141	15.05.81	Y	Y	Y	Y	-	
142	15.05.81	Y	Y	Y	Y	-	
143	15.05.81	Y	Y	Y	Y	-	
144	15.05.81	0	0	0	0	-	
145	15.05.81	0	0	0	0	-	
146	15.05.81	0	0	0	0	-	
147	15.05.81	Y	Y	0	0	-	
148	15.05.81	0	Y	Y	0	-	
149	15.05.81	Y	Y	0	0	-	
150	15.05.81	0	0	0	0	-	
151	15.05.81	Y	Y	Y	Y	-	
152	15.05.81	Y	Y	Y	Y	-	
153	15.05.81	Y	Y	Y	Y	-	
154	15.05.81	Y	Y	Y	Y	-	
155	15.05.81	Y	Y	Y	Y	-	
156	15.05.81	Y	Y	Y	Y	-	
157	15.05.81	Y	Y	Y	Y	-	
158	15.05.81	0	0	0	0	-	
159	15.05.81	Y	Y	Y	Y	-	
160	15.05.81	Y	0	0	0	-	
161	15.05.81	0	0	Y	0	-	
162	15.05.81	0	0	0	0	-	
163	15.05.81	0	0	0	0	-	
164	15.05.81	S	S	S	S	-	S = Simulated Signal
165	15.05.81	Y	Y	Y	Y	-	
166	16.05.81	0(2)	Y(2)	0(4)	Y(2)	0(1)	MSDR Team (+ MA)
167	16.05.81	Y	Y	Y	0	Y	
168	16.05.81	Y	Y	0	0	Y	
169	16.05.81	Y(P)	0	Y(P)	0	0	
170	16.05.81	Y	0	0	0	0	
171	16.05.81	0	0	Y(1)	0	0	
172	16.05.81	0	0	0	0	0	MA Recognition only
173	16.05.81	0	0	0	0	0	
174	19.05.81	0	Y	Y(1)	0	0	
175	21.05.81	0	0	0	0	0	
176	21.05.81	Y	0	Y	Y	Y	
177a	21.05.81	0	0	0	0	0	
177b	21.05.81	0	0	0	0	0	
178a	21.05.81	0	0	0	0	0	
178b	21.05.81	0	Y(1)	0	0	0	
179	21.05.81	Y	0	Y(1)	0	0	
180	21.05.81	0	Y(1)	0	0	0	
181	22.05.81	0	0	Y(1)	0	Y	
182a	22.05.81	Y	Y	Y	Y	Y	
182b	22.05.81	0	0	0	0	0	
183	22.05.81	Y(1)	0	0	0	Y	

Table 9.2 : Recorded Data on Operator Recognition (cont'd)

Data Sheet No.	Date	I/TE	S/WE	SE	CE	I/TM	Remarks
184a	22.05.81	0	Y	0	0	0	
184b	22.05.81	Y(1)	Y(1)	0	0	Y	
185	22.05.81	0	0	Y(1)	0	Y	
186	22.05.81	0	Y(1)	0	0	Y	
187	22.05.81	0	0	Y(1)	0	0	
188	22.05.81	0	Y(1)	0	0	0	
189	22.05.81	0	0	0	0	0	
190	22.05.81	0	0	0	0	0	
191	22.05.81	Y	Y	Y	Y	Y	
192	22.05.81	Y	Y	Y	Y	Y	
193	22.05.81	0(1)	Y	Y	Y	Y	
194	12.06.81	Y(1)	0	Y(2)	0	0	
195	12.06.81	Y(1)	0	0	0	Y	
196a	12.06.81	0	Y(1)	0	0	Y	
196b	12.06.81	0	0	Y(1)	0	Y	
197	12.06.81	Y(1)	0	Y(1)	0	Y	
198	26.06.81	0	Y	Y(1)	0	Y	
199a	24.07.81	Y	0	0	0	0	
199b	24.07.81	Y	Y	Y	Y	Y	
200a	24.07.81	Y(1)	0	0	0	Y	
200b	24.07.81	0	0	Y	0	0	
201	24.07.81	0	Y	0	0	0	
202	27.07.81	0	0	0	0	0	
203	27.07.81	0	0	0	0	0	
204	27.07.81	0	0	0	0	Y	
205	27.07.81	0	0	0	0	Y	
206	27.07.81	Y	Y	Y	Y	Y	
207	29.07.81	Y(1)	0	0	0	0	
208	29.07.81	Y	Y	Y	Y	Y	
209	04.08.81	Y(1)	Y(1)	0	0	0	
210	04.08.81	0	0	0	0	0	
211	23.09.81	Y(1)	Y(1)	0(1)	AE0 (6)	0(1)	Team = 10 + MAE = Acceptance
212	23.09.81	0	0	0	0	0	Recognition was a simplified task for the I/TE-SE and AE personnel, as they were using a VDU which showed all of the machine system model parameter changes as they were occuring, therefore could anticipate probable results, whereas the I/TM & S/WE personnel were working directly from the signal presented.
213a	24.09.81	0	0	0	0	0	
213b	24.09.81	Y	Y	Y	Y	Y	
214	24.09.81	Y	Y	Y	Y	Y	
215	24.09.81	Y	Y	Y	Y	Y	
216	24.09.81	0	0	0	0	0	
217	25.09.81	0	0	0	0	0	
218	25.09.81	0	0	0	0	0	
219	25.09.81	0	Y	0	0	0	
220	25.09.81	0	Y	0	0	Y	
221	25.09.81	0	Y	0	0	Y	
222a	25.09.81	Y	0	Y	Y(1)	0	
222b	25.09.81	0	Y	0	0	Y	
223	25.09.81	Y	0	Y	Y	0	
224	25.09.81	Y	Y	Y	Y	Y	
225a	25.09.81	0	Y	0	0	Y	

Table 9.2 : Recorded Data on Operator Recognition (cont'd)

Data Sheet No.	Date	I/TE	S/WE	SE	CE	I/TM	Remarks
225b	25.09.81	Y	0	Y	Y	0	Recognition was a simplified task for the I/TE-SE and AE personnel, as they were using a VDU which showed all of the machine system model parameter changes as they were occuring, therefore could anticipate probable results, whereas the I/TM & S/WE personnel were working directly from the signal presented.
225c	25.09.81	Y	0	Y	Y	0	
226	25.09.81	0	Y(D)	0	0	Y	
227	25.09.81	0	Y	0	0	Y	
228	25.09.81	Y	Y	Y	Y	Y	
229	25.09.81	0	Y	0	0	Y	
230	25.09.81	Y	Y	Y	Y	Y	
231	25.09.81	0	Y	0	0	Y	
							MAE = Mission Assurance Engineer
							AE = Acceptance (Customer) Engineer

9.4.2 Operator Recognition - Predictions

If the data on identification and recognition are to be evaluated to establish what the subsequent operator decision and response probabilities might be, then "Bayes Theorem" can be used to make such predictions. "Bayes" rule or theorem is useful in computing the probabilities of various hypotheses for those different events where at least one of which is known to have occurred and therefore should result in a subsequent event.

For example we may assume that the event of attention by operators to a warning system-signal stimulus has a high probability of leading them to the event of signal stimulus recognition. Therefore, we need to be able to predict the probabilities that the event of recognition will lead the same operators to a subsequent decision and response event which is successful.

By definition : P(ai) is the a priori likelihood of all possible and mutually exclusive states "ai". Since these probabilities are exhaustive, P(ai)=1.

Those probabilities which are assumed to be related to the actual ai that exist, are denoted as P(c/ai) i.e., the probability of "c" given "ai".

$$P(ai/c) = \frac{P(ai)\ P(c/ai)}{P(ai)\ P(c/ai)} \quad \text{Bayes theorem.}$$

The evaluated figures for the 'integration and test engineers' recognition of the warning system-signal stimuli presented is 0.576, therefore, the figure for no recognition is 1 - 0.576 = 0.424.

P(recognition) = 0.576
P(no recognition) = 0.424

However, as already stated recognition of the warning system-signal stimulus presented can only occur if there is attention on the part of the operator in the first place, therefore, using the figures already evaluated:

P(attention/predicted attention) = 0.583 : 0.984 = 0.593.

It should be noted that the figure 0.984 is the predicted figure for both delayed and immediate attention of the 'integration and test engineer' and the rationale for its use was that delayed attention may also lead to the process of recognition.

P(attention/attention predicted) =

$$\frac{P(\text{recognition})P(\text{attention predicted/attention})}{P(\text{recognition})P(\text{attention predicted/attention}) + P(\text{no recognition})P(\text{attention predicted/no recognition})}$$

$$P = \frac{(0.576)\ (0.593)}{(0.576)(0.593)+(0.424)(0.593)} =$$

$$\frac{(0.341)}{(0.341)+(0.251)} = \frac{0.341}{0.592} = \underline{\underline{0.576}}$$

and P (no attention/attention predicted) =

0.416 + 0.984 = 0.422

$$= \frac{(0.424)(0.422)}{(0.576)(0.593)+(0.424)(0.422)} = \frac{0.178}{0.339+0.178} =$$

$$\frac{0.178}{0.517} = \underline{\underline{0.344}}$$

Whilst attention to a warning system-signal stimulus is the first important step in the human information processor theory. Attention per se does not, indeed cannot, ensure that decision and the subsequent decision response will actually occur.

As shown by use of "Bayes Theorem" in the above example the main controlling function is clearly seen to be the recognition process. Because without it there can be no decision response output even through the operators attention has been captured by the warning system-signal stimuli!

The situation appears to improve if the observed and recorded recognition and identification figures are also combined, as shown by the following results:

$$P(ai/c) = \frac{P(ai)P(c/ai)}{P(ai)P(c/ai)}$$

P(recognition + identification) = 147 + 80 : 250 = 0.890

P(no recognition or identification) = 1-0.890 = 0.110

P(total attention/attention predicted) = 0.854:0.984
= 0.867

$$P = \frac{(0.890)(0.867)}{(0.890)(0.867) + (0.110)(0.867)} = \frac{0.771}{0.771 + 0.095} =$$

$$\frac{0.771}{0.866} = \underline{\underline{0.890}}$$

And P(no attention/attention predicted) = 0.146:0.984
= 0.148

$$P = \frac{(0.110)(0.148)}{(0.890)(0.867) + (0.110)(0.148)} = \frac{0.016}{0.771 + 0.016}$$

$$\frac{0.016}{0.787} = \underline{\underline{0.020}}$$

9.4.3 Operator Recognition - Discussion

The statistical evaluations made using "Bayes Theorem", in the previous section (Section 9.4.2.) only show those figures for the 'integration and test engineer'. Similar evaluations were also made for the other members of the team in order to predict their probable response performance, and these are discussed later in Chapter 10.

From the evaluated data for the 'integration and test engineer' there appeared to be a significant improvement where the observed and recorded recognition and identification data were combined; that is 0.890 as opposed to the original figure of 0.576 which was calculated for recognition alone. What seems to be an improvement is unfortunately misleading, the reasons for this are because the figures tend to be mentally compared with what is believed to be a straight forward process. Such assumptions are generally founded on the 'single channel processor theory' mooted by Broadbent, op cit., which is misleading because, as shown by Figure 9.1, there are several alternative paths which provide options in the processing of information by humans.

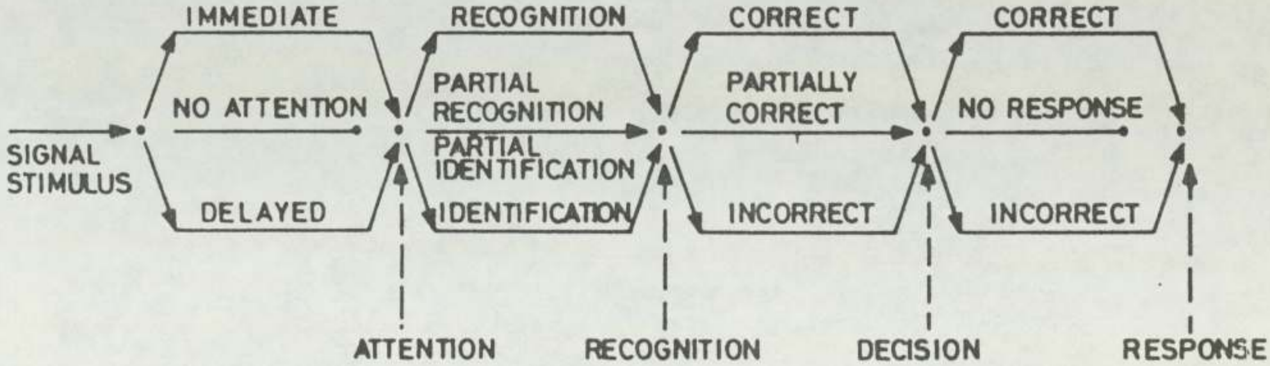


Figure 9.1 : Human Information Processing - Optional Routing

If consideration is given to Figure 9.1, it can be seen that the optimal path is the one uppermost in the figure, because it clearly identifies immediate attention - total recognition - correct decision and correct response.

From the calculations made such routing is primarily dependent upon immediate attention and total recognition of the warning system-signal stimuli presented to the operator. With the assumption being made at this point that this will lead to both a correct decision and a correct response.

Such an assumption however,is based on the premise that there will be total recognition of a signal stimulus by the operator, which may not be the case.

For example, if a warning system-signal stimulus presented to an operator was 'warning light number 3' then recognition in the first instance is one of spatial location and lamp colour. That is the warning light occupies position number 3 in the row of lamps and is red in colour.

This would suggest that recognition at this stage is only partially completed. Which in turn could further imply that if there is to be total recognition of the signal stimulus perceived then the cause underlying the generation of the signal also needs to be known by the operator.

Such causal factors when known are presumed to lie in the long-term memory store (fact memory). Or if recall has occurred within the last minute or so, then due to such recency, should still be in the short-term memory store (working memory), therefore, still available for immediate access.

This means that the above quoted warning system-signal stimulus could be satisfied by the underlying causal factor "Cooling Line 9 Over-temperature Condition".i.e., 'warning light number 3' was generated by a 'cooling line 9 over-temperature' condition.

Therefore, assumptions based on the premise that recognition of the signal stimulus, in or of itself, will automatically lead the operator to making the correct decision and hence response cannot be held to be true for every case.

What is apparent from Figure 9.1 is that while the resource of attention is the mechanism that activates the recognition (memory) process, it is the recognition process (either in total or partially) that activates the next stage in information processing; namely decision making. As such decision making is dependant not only on the resources of attention but memory as well it is, therefore, subject to the same frailties as the process of recognition.

9.4.4 Operator Recognition - Theory

The process of recognition has not been researched as widely as one would suppose. Most research, we learn from Wickens, op. cit., using the 'theory of signal detection' has been performed in the area of 'eye-witness testimony', this research being performed by, notably, Buckhout (1974); Ellison and Buckhout (1981); Wells, Lindsay and Ferguson (1979). For theory on the process of recognition, refer to the work of Miller (1962). In essence, Miller, op cit., informs us that recognition is contingent on the amount of informative data the human has to process. That is to say, the human can recognise more clearly when only one or two possibilities exist; but can be obscured when it is one of an extremely large number.

The situation may be summed up by referring to the work of Abrahamson, op cit., loc. cit. (Chapter 6) where it was pointed out that as the number of bits of information increase so do the numbers of likely alternatives!

However, what cannot be said in regard to recognition is that as the number of bits increase then the number of uncertainties will decrease.

9.5 Operator Decision Making - Discussion

It was stated within the Chapter entitled "Decision Making" that an operator has recourse, after recognition of the signal stimulus presented, to three options namely:

- Skill-based behaviour.
- Rule-based behaviour.
- Knowledge-based behaviour.

and it is these options which are accessed via the decision making process.

Operator decision making also requires the function of memory as part of the human's processing of information. A process activated by a signal stimulus which has captured the operators attention followed by their perception and recognition of the warning system-signal stimulus intent.

Decision making is only directly measurable in terms of operator response. However, such measurements only tell us that the operator has, or has not, responded to the signal stimulus presented. What it does not tell us is how decision making can and should enable an operator to select one of the response options such that it allows the operator to set the machine system out-of-tolerance condition back to the status quo.

However, as suggested earlier, loc cit., (Section 6.2.7), decision making may also be viewed as a form of problem solving. In support of this assumption the "Computer Program-Executive Routine", Figure 6.5, was included.

For example, on receipt of a warning system-signal stimulus such as 'warning light number 3', the operator would need to generate a strategy, as such a strategy is needed, to solve the problem reflected by 'warning light number 3', but caused by an out-of-tolerance machine system condition.

It is possible that the strategy may be immediately satisfied by selecting the required action from a set of prescribed rules, therefore the implementation of this action should correct the out-of-tolerance machine system condition.

Alternatively, due to the recency of a previous strategy recalled from the long term memory store (fact memory), the strategy is still in the short term memory store, implying that its implementation should also solve the problem by setting the machine system back to its proper status.

On the other hand, the strategy that may be required could demand a search through the long term memory store of the operator before the execute step can be performed. This search should, for the warning lamp quoted above, result in the recall of, for example, 'cooling line 9 over-temperature condition' which should permit the operator to restore the status quo.

Knowing the underlying cause of the signal stimulus generated may be essential if the operator is to set a complex machine system back to its correct status.

Nevertheless, irrespective of the response behaviour selected, rules or knowledge, the ultimate psychomotor response would essentially be one of 'skill' based behaviour which may, for the complex man machine system, also require a search through the long-term memory store (skill memory) in order to recall the correct sequence of the psychomotor responses required.

It should be noted that in the routine set-up/set-down procedures of the MSDR machine system the majority of the tasks that needed to be performed by the team members were predominately 'skill-based behaviour' responses.

The above explanation on the role of decision making in the processing of information by humans has excluded in-depth discussions on rule-based behaviour. This is because whilst rule-based behaviour still requires the allocation of attention resources, and the identification of the appropriate rule, they are not dependent on the facets of memory, except for the selection of the psychomotor response from the long-term memory store (skill memory).

Finally, skill-based responses are generally found to be more widely used in the working environment of operators or craftsman where they are using and interfacing with fairly simple equipment or machines on a regular day to day basis.

9.6 Human and Machine System Errors

All of those failures or errors in performance either by the human or the machine system that were observed during the research period were also listed and collated. This was performed for the following reasons, i.e. it is essential to know what types of failures or errors may occur and with what frequency.

Such records should permit these failures or errors to be evaluated to determine what the consequences might be if they occur, and how the possible effects may be either compensated for or mitigated in some way so that both human and machine system performance can be improved and accidents prevented. The listed data on human and machine system errors is contained in Appendix D.

9.7 Machine System Errors

The normal fluctuations of the machine system parameters which occurred were extremely high, i.e. 94 NFP events out of 255 trials were established by evaluation at the time of their occurrence. However, whilst most of these could be rationalised as to their probable cause after the event, they could not have been anticipated by the operator during the event except in the 'open and obvious' cases.

As remarked throughout the MSDR was subject to development and test, therefore to understand the significance of the data collected the data itself needs to be divided into three distinct parts.

The first of these covers the period from 3rd April 1980 to the 15th May 1981, and may be viewed as the development and test phase of the machine system. During this period there were 178 observations made and recorded out of which 62 were NFP events = 35%.

However, during the next period from 16th May to 4th August 1981, inclusive, the machine system model (MSDR) was subjected to full system testing, i.e. with minimal simulation support, and out of the 52 trials observed and recorded 16 were NFP events < 31%, a small but nevertheless significant improvement.

For the last period from 23rd to the 25th September 1981, inclusive, the MSDR was connected to Spacelab provided facilities (ERNO Bremen) and out of 25 trials observed and recorded 13 NFP events occurred = 52%, which is a statistically significant increase.

The difference between the three phases can be explained as follows: during all phases of testing of the machine system model there were many occurrences where warning system-signal stimuli was presented to the operators to which they correctly responded.

However, quite a number of these responses were to NFPs, such allocation only being given to those hardware anomalies which could not be accounted for as part of the machine system model normal functional operation, this being established by review of the test protocols and the software test data acquisition printouts.

NFP conditions were brought about in a number of ways. For example, all of the heating facilities were controlled by software to ensure that the heat-up, plateau and cool-down phases met the experiment requirements. The cool-down profile was maintained by using both the facility heaters and helium gas (from the vacuum and gas system) intermittently, until the profile was complete. Software then operated the ventline valve so that the contaminated gas could be removed, on completion of this the valve was closed. The facility was then flooded with argon gas to equalise internal to external pressure (ambient) and to ensure touch temperatures were less than 45 ^{o}C, (for operator protection) before opening the facility.

During the 'Spacelab' mission the ventline would be directly accessed via control valves to (deep) space (pure vacuum). Whereas, in the test facilities the machine system model ventline was connected to a heavy duty vacuum pump to simulate space vacuum.

However, the vacuum levels achieved at best were in the order of 10^{-3} torr which meant that the contaminants were not totally removed and the ventline itself became contaminated. The effects of these conditions were reflected back into the system with the result that they enabled the generation of warning signals.

A further type of problem encountered was due to out-of-sequence software (OSS). This was continuously investigated throughout the programme of testing, and could only be attributed to some form of computer hardware/software mismatch condition and in almost every instance could not be reproduced despite repetitive testing.

During the initial phase many attempts were made to remove - or at least reduce - the NFP and OSS conditions to an acceptable level and to this end a good deal of progress was made.

The improvements made to the machine system model as a whole can be readily appreciated when analysis is made of the reduced number of NFPs observed and recorded during the second phase, i.e. the MSDR System Tests.

Phase 3 gave initial cause for concern because the machine system model had been transported from MBB (Munich) to ERNO (Bremen) so that the MSDR could be tested using 'Spacelab' provided facilities. However, owing to the contamination levels found in the environment which affected the machine system model parameters the inevitable result was an abnormally high number of NFP events.

9.8 Human Error - Evaluation

Out of the 255 trials monitored during the period of research, 38 operator-induced errors (as listed in Section 5.2) were observed and recorded, which was certainly less than had been anticipated, and quite surprising considering the length of time that the MSDR was undergoing development testing.

Throughout the proceeding texts on 'human information processing' and 'human response performance' etc., the general census of opinion was that human limitations (which includes human error) are the underlying cause of most, if not all, problems relating to machine systems.

However, it was also established how the performance of the human is affected by many factors, e.g., fatigue-stress abstractions and distractions, etc., which might lead to errors being induced by the operator during their functional operation of a machine system.

Unfortunately, what seems to be missing is the form of the mechanism which permits these errors on the part of the operator to occur in the first place.

A 'mechanism of human error' is suggested by Norman, op. cit., and is summarised as follows:

"Human errors yield some insight into the psychological mechanisms that are involved. The highest level specification of a desired action is <u>intention</u>, such intention may result from conscious decision making or from subconscious processing. An error in the intention is called a <u>mistake</u>.

An error in carrying out the intention is called a <u>slip</u>.

Both classes of error are important; each gives rise to different forms of difficulty with different underlying principles and suggested solutions."

Of particular interest is the fact that the majority of the human errors recorded during the research were software based, i.e. errors created when changes were made to the software programs during the development and test of the various MSDR elements. These types of errors would according to Norman, op cit, be classed as descriptive errors: ambiguous or incomplete specification of the intention, i.e., mistake.

The remainder of the human errors were associated with operator set-up of the MSDR for experimental test runs, for example, forgetting to mate connectors, or operate switches, etc. Such errors according to the classification given by Norman, op cit, would be faulty activation of schema: forgetting an intention, i.e. slip. The types of mistakes and slips described by Norman, op. cit., are shown in diagrammatic form in Figure 9.2.

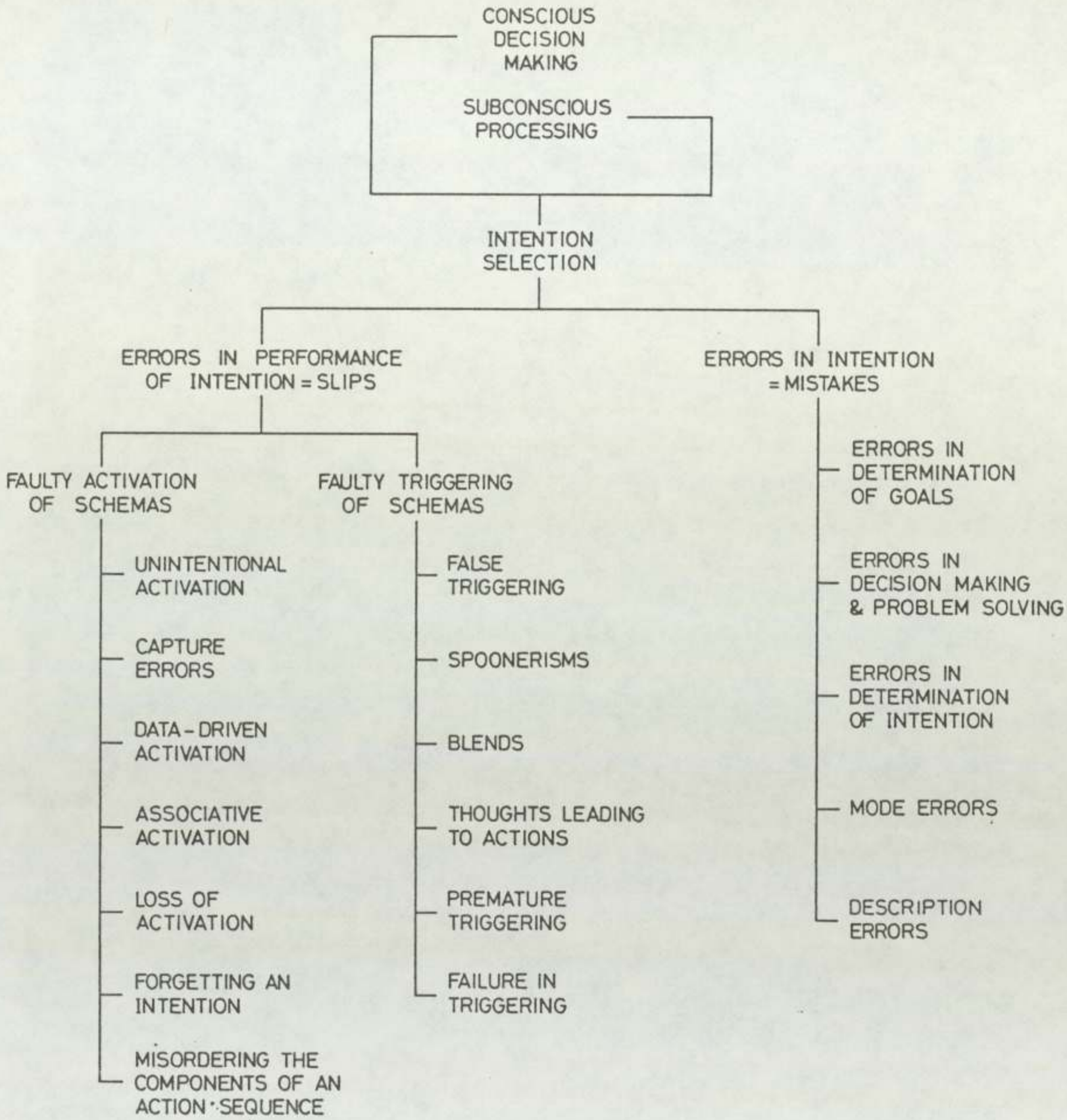


Figure 9.2 : Intention Selection/Performance Errors

9.9 Human Engineering

Those principles of human engineering related to visual warning systems, specifically the detectability of the signals, loc cit., (Section 6.3.1), that were applied to the design of the machine system research model (MSDR) were in general excellent, there were, however, two anomalies which do need to be discussed.

Firstly by reference to Figures 3.14 and 4.3 it will be noted that 'switch protection guards' have been fitted to both the left- and right-hand sides of all switches in the status and warning lamp fields of the CCO. These are of the square hoop type and serve the function of preventing any inadvertent switch operations by personnel and are a recommended requirement of the previously mentioned military standard (Mil. Std. 1472B).

Unfortunately, whilst the switch guards serve their intended purpose admirably, the guards presented an unexpected problem in a way that had not been foreseen. The assumption made during the design phase of the machine system model (MSDR) status and warning system, was that the operator (payload specialist) would have foot restraints, thus enabling him to stand directly in front of the machine system model, during the operational modes of the experimental facilities.

However, during the space mission profile the payload specialist may have to perform other tasks over and above those related to the MSDR experiments.

Therefore, as discovered during MSDR Element and Integrated Systems Test, any operator moving approximately 0.5 metres from position X, as shown in Figure 9.3, in the direction indicated, loses his view of most of the 'STOP' and 'FAULT' lamps. This is because they are obliterated from their line of sight by the right-hand switch protection guards, a condition which does not occur to quite the same extent in the Y direction due to the switches being located to the left of the grouped lamp field.

This was not viewed as a critical situation, primarily because the mission profile for the payload specialist would ensure that task time sharing would be limited, particularly for those experimental facilities with critical operating modes which demand constant attention.

Nevertheless the above example does serve to illustrate how the human engineering solution to the problem of inadvertent or accidental switch operation by personnel, has in fact resulted in a situation which hitherto had not been considered.

Finally, in order to achieve the optimum design, certain imposed design limitations had to be taken into account, e.g. due to microgravity conditions which will prevail during the 'Spacelab' mission, one of the design considerations was to ensure that all elements (experiment facilities and support equipment) were contained within the envelopes of the racks, i.e., they should not violate the freedom of the Spacelab centre aisle.

This meant that the normal concept of a console at which the operator sits with the 61 warning and status lamps, visual display unit and associated keyboard configured at an angle of 45° (as shown by Figures 3.2 and 9.3) and by building the central console into this part of the structure, the warning and status-signal stimuli was kept in the visual field of the operator, thus achieving the optimum design feasible under such circumstances.

It was therefore concluded that the human engineering aspects of the 'material science double rack' warning system design had been fulfilled to the greatest extent practicable considering the constraints imposed and the current status of the human engineering art.

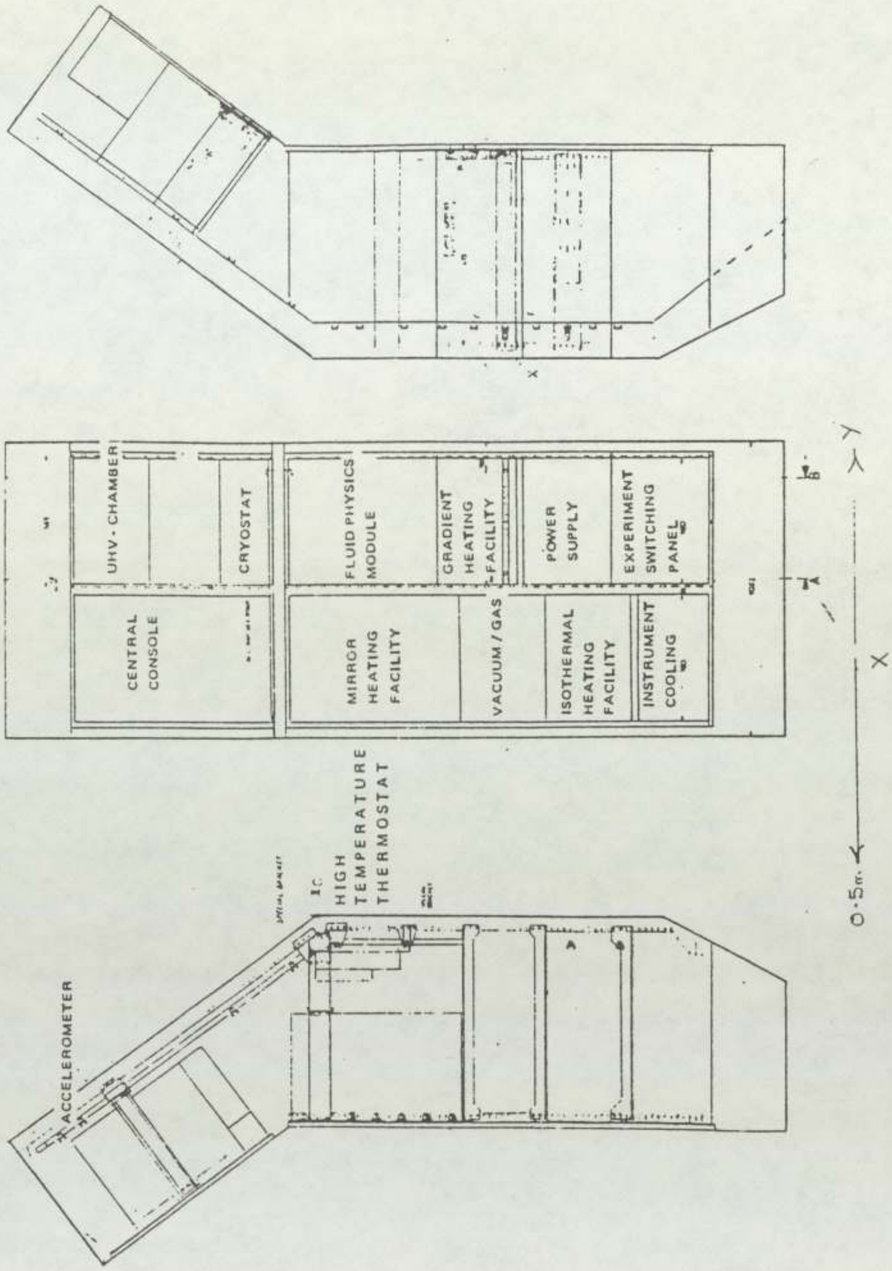


Figure 9.3 : Physical Accommodation of the SPL

10.0 OPERATOR PERFORMANCE

10.1 Predicted versus Evaluated Operator Performance

The following figures (Figures 10.1 to 10.4 inclusive) were constructed to enable comparison to be made between the figures arrived at by statistical methods and those figures which were directly extracted from the observed, recorded and collated data obtained during the research.

To permit a comparison to be made it was essential to show as part of the human perception-information processing and response performance of each individual member, those 'real system disturbances' (RSD) of the machine system model as well as those 'normal fluctuations of the parameters' (NFP) and 'out-of-sequence software' (OSS) conditions which actually occurred.

The actual figures for those NFP, OSS and RSD conditions that were recorded and subsequently verified (via computer printouts) may be identified by referring to any of the figures, specifically under the heading 'number of trials'.

The 'integration and test engineer' (I/TE) attended 255 trials during the period of research, the number of anomalies recorded during these trials, were as follows:

- 90 NFPs
- 69 OSSs
- 96 RSDs

The 'integration and test engineers' score for immediate attention was 149 out of the 255 trials attended, and accounted for the following number of anomalies:

- 53 NFPs
- 40 OSSs
- 56 RSDs

Delayed attention figures were not included on the team members profiles for those reasons already given in Section 9.3.1.

By reference to Figure 10.1 it may be noted that the probabilities for recognition of signal stimuli presented by out-of-tolerance machine system conditions have also been included. From the predictions made and shown on the profile the 'integration and test engineer' would have only been successful 87 times and not the 147 times that were actually recorded and verified by interviews with the team member concerned. Nevertheless, these predicted figures do create a theoretical loss of 60 recognition possibilities by this engineer.

A similar disparity between the figures (predicted and evaluated) may also be noted by referring to the last two blocks on Figure 10.1 that is 'conscious decision making'. These figures arose because the 'integration and test engineer' consciously decided that 99 of the out-of-tolerance conditions were due to NFP, OSS or RSD causal factors. This figure, however, contradicts the probability figure of 87 that had been predicted.

It was confirmed, by 'interview techniques' that what occurred when there was an out-of-tolerance machine system condition where the team member could not readily fix a label, e.g., NFP, OSS or RSD, then the team members analogically inferred what they believed to be the cause of the machine system condition as well as the most suitable response action to rectify that condition.

It is therefore these analogical inferences made by the team member which produced the response to those out-of-tolerance conditions which might otherwise have been lost. Which in the case of the 'integration and test engineer' would have accounted for a theoretical loss of 48 out of the 147 responses that he made, either individually or jointly with the other team members. Where analogical reasoning could, or did, not produce an adequate solution,presumably due to a lack of knowledge in the team members memory store about a particular anomaly, then the team member had little recourse but to perform troubleshooting of the hardware/software elements of the machine system. Then effect the appropriate remedial action after mentally evaluating the results of their investigations.

There were several machine system malfunctions or anomalies which were also investigated (though not in the strict sense) by the team members after the event, and was viewed as a form of self-check by the team members themselves to confirm that they had made the correct response.

It is of interest to note that this invariably occurred after partial recognition or identification of a signal stimulus by the team member.

From examination of the team members profiles it can noted that the I/TE, S/WE and SE all would have had very high theoretical losses for recognition, that is from the statistical probability calculations made, for example:

Team Member	Observed Recognition	Predicted Recognition	Theoretical Recognition Loss
I/TE	147	87	60
S/WE	132	69	63
SE	93	45	48

From the same profiles it can be seen that these self same team members terms also had high theoretical losses in terms of their response performance, for example:

Team Member	Observed Performance	Predicted Performance	Theoretical Performance Loss
I/TE	147	99	48
S/WE	132	108	24
SE	93	50	43

It should be noted that the ultimate operator responses are the culmination of the decision making process using both the functions of memory and the recognition process.

The probability predictions shown on the 'integration and test manager' (I/TM) profile appear to be more realistic, because the theoretical loss of recognition and response performance capabilities is much lower. That is until it is noted that out of a possible 255 trials the 'integration and test manager' only attended 82 of them.

From the above figures it may be inferred that the use of probability predictions in the evaluation of human performance can be misleading.

Indeed it could be interpreted from such probability predictions that the team members were very limited in terms of their overall performance with the machine system model the 'material science double rack'. Whereas, in reality their performance was quite exceptional especially when it is remembered that the 'material science double rack' was in fact being developed as a piece of space hardware over a two year period.

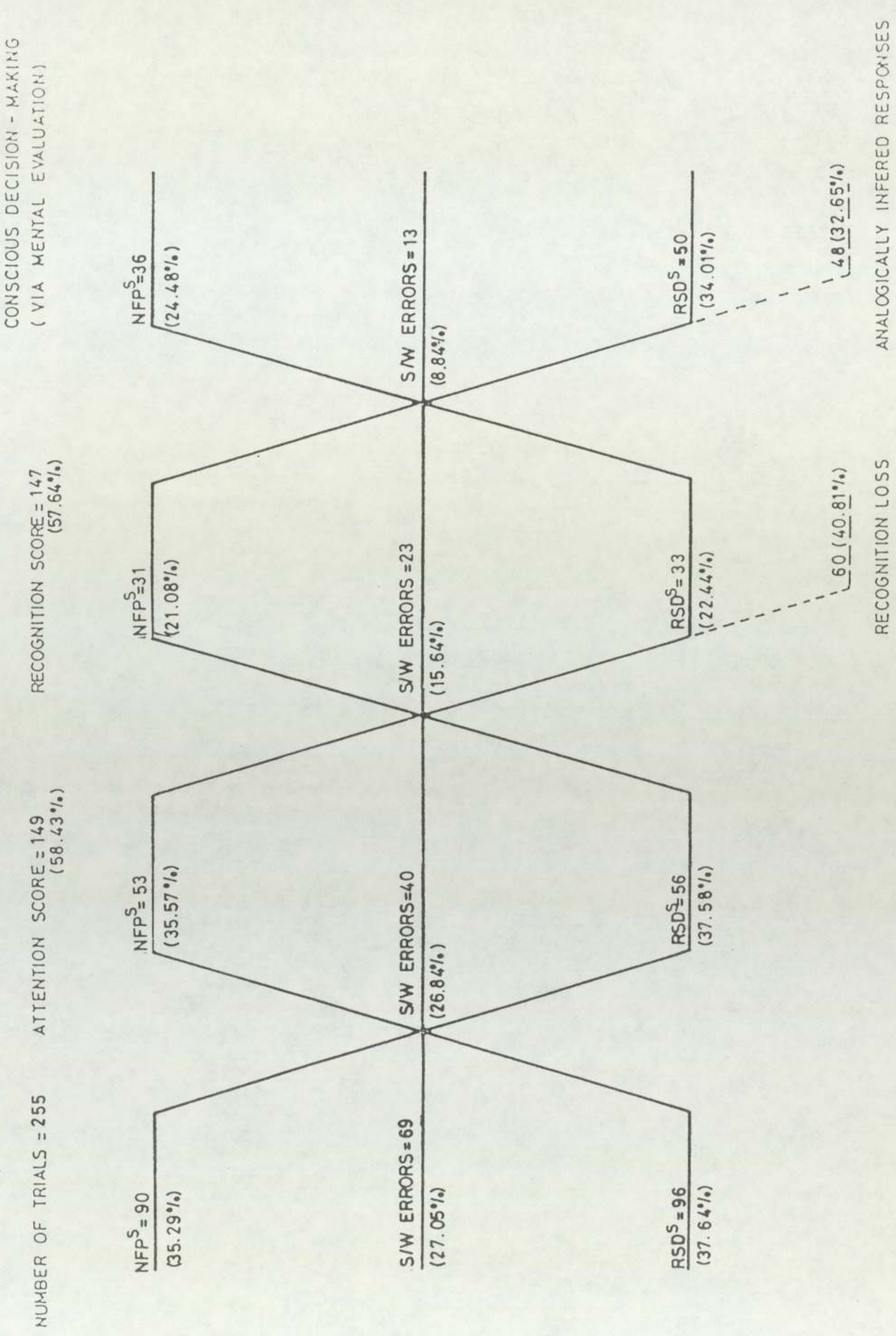


Figure 10.1 : I/TE Perception and Information Processing Analysis

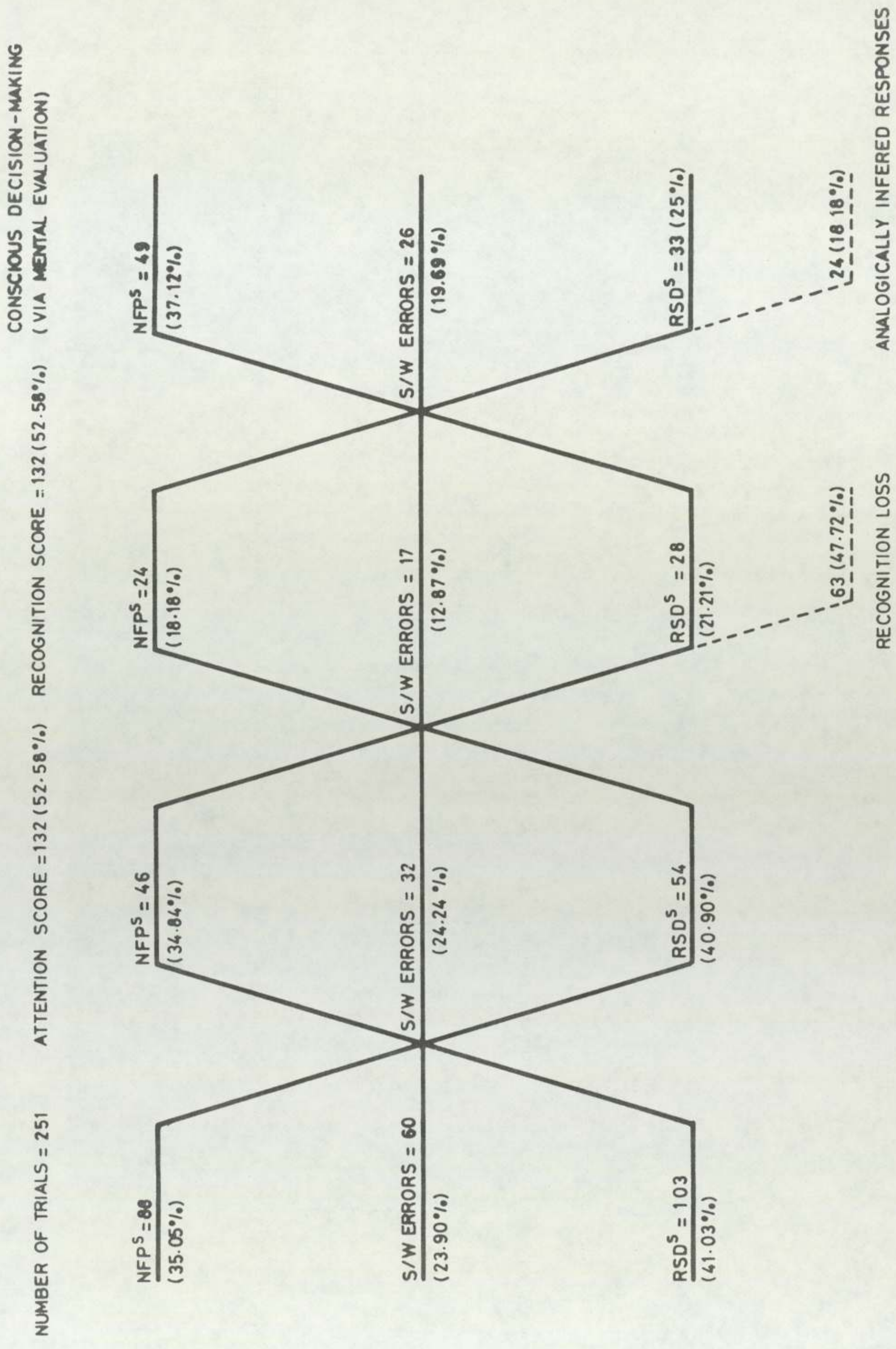


Figure 10.2 : S/WE Perception and Information Processing Analysis

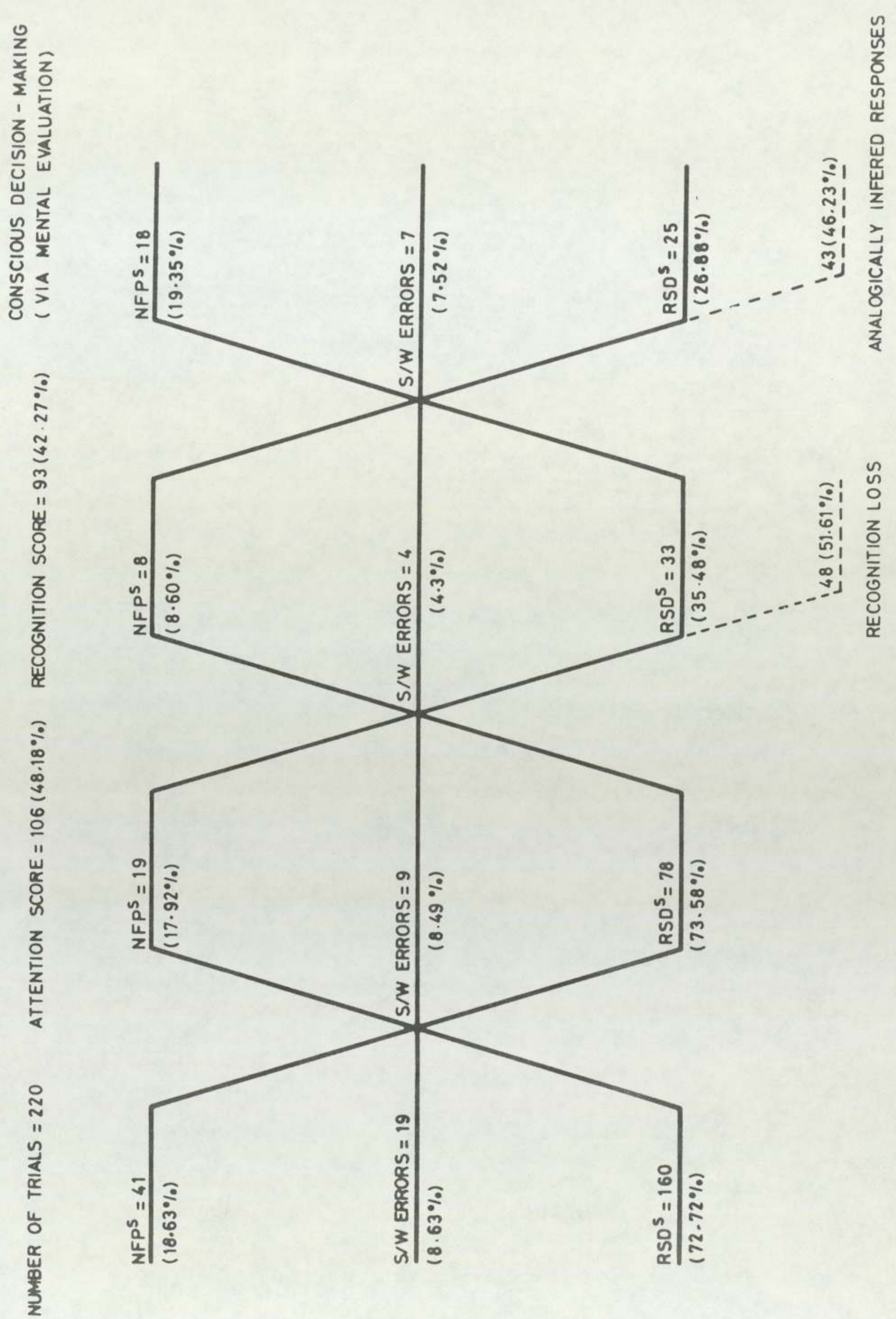


Figure 10.3 : SE Perception and Information Processing Analysis

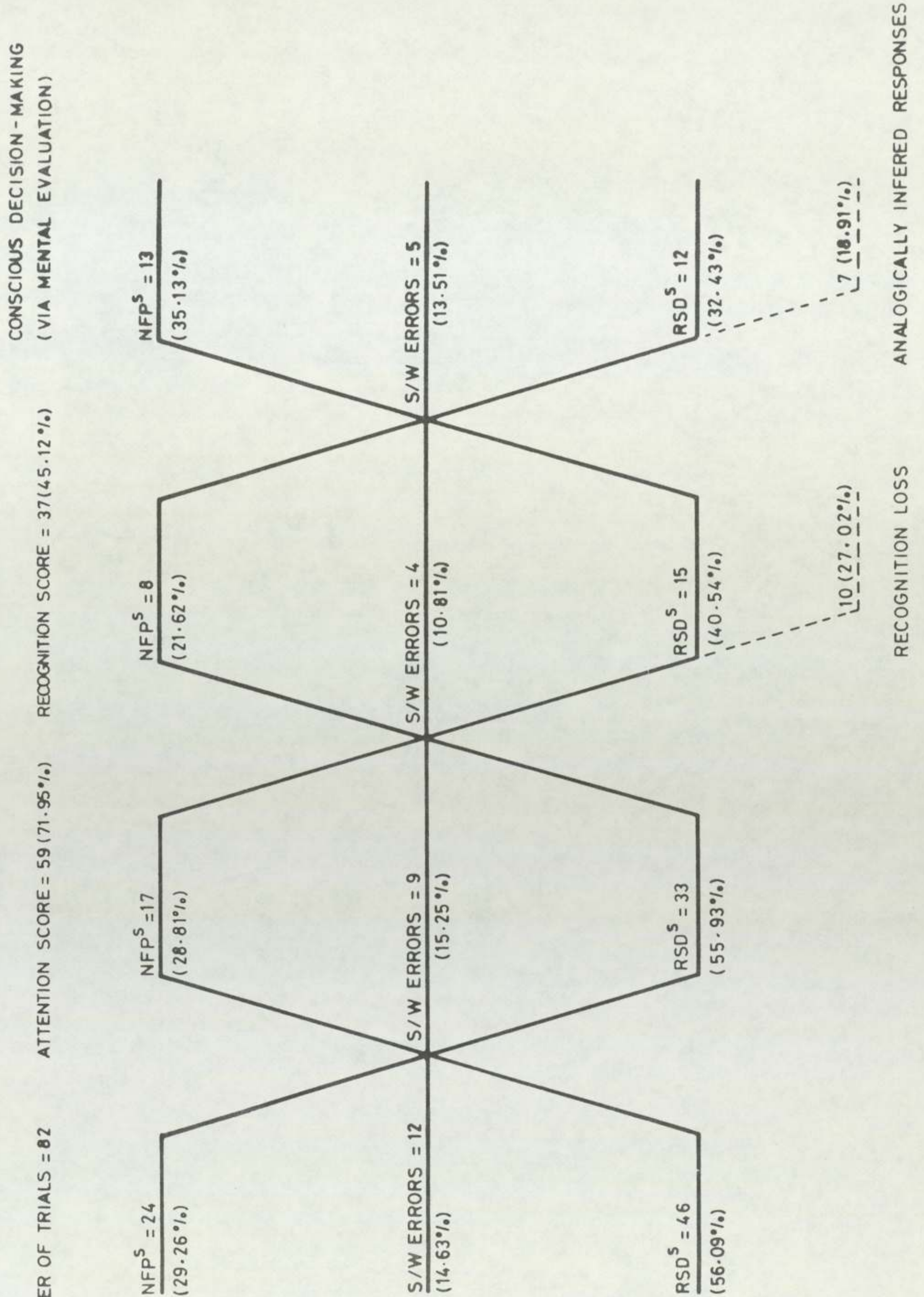


Figure 10.4 : I/TM Perception and Information Processing Analysis

11.0 CONCLUSIONS

The conclusions to the work contained in this thesis are given under the following five main headings:

- Research Approach.
- Results of Research.
- Research Theory.
- "Spacelab Payload Specialists Report"
- Research Recommendations.

11.1 Research Approach

A methodology for determining the performance of human operators was devised incorporating inter alia the following novel features:

1) A machine system which was to be subjected to extensive development and testing for approximately 18 months.

2) During the development and test of this machine system it would be manned by engineers from different disciplines and with varying levels of skill.

3) Provided a remarkable opportunity to observe the engineers actions-reactions to machine system generated parameter fluctuations and out-of-tolerance software signals as opposed to real disturbances whilst they were functionally operating the machine system.

4) Permitted human perception, information processing and subsequent response performance to be observed and recorded with a machine system in action in real life.

11.2 Results of Research

From the results of the evaluations made of the study data on human perception, information processing and response performance the following can be postulated:

1) The recognition of warning system-signal stimuli does not automatically follow the perception of such signal stimuli by an operator.

2) The recognition of a warning system-signal stimulus does not necessarily mean that there will be an automatic decision made resulting in a response output on the part of an operator.

3) Delayed attention to warning system-signal stimuli elicited more in terms of recognition and subsequent response actions than immediate attention.

4) Skill memory appears to play a major role when an operator is making his response to rectify an out-of-tolerance machine system condition.

5) Fact memory appears to be a crucial feature in human information processing, especially where an operator is unsure of the the appropriate decision to make, in order to select the correct response to rectify the out-of-tolerance machine system condition.

11.3 Research Theory

It became apparent very early on in the research that there was no single theory in existence which totally embraced all of those aspects covered by the term human performance. That is where the term is used to encompass human perception, the processing of information and the subsequent responses made in a machine system environment.

To determine whether or not a theory could be developed, it was decided to use the research data of the team members performance with the MSDR in action in two ways.

Firstly, the observed, recorded and collated research results for attention and recognition were used to predict the team members decision making and response performance probabilities for those trials in which they participated.

This data on attention, recognition and the predictions made for decision making and response were then used to construct performance profiles for each member of the team. In addition the data on attention for each team member was divided on the profiles to take into account those different causal factors, e.g., RSD, NFP or OSS conditions, that generated the warning system-signal stimulus presented to the team members.

Finally, the observed and recorded research data for the team members decision making and response performance were then evaluated, and those differences between the evaluated and the predicted data were then added to the team members profiles.

From a review of the profiles constructed it would appear that the observed decision making and response performance of the team members was much better than those that had been predicted.

However, these results are somewhat misleading because the response performance though generally performed by one team member, in many instances were the outcome of team effort. For example, one team member's actions were the trigger mechanism that activated the others. This means that some team members may have been credited with response performance to a machine system out-of-tolerance condition to which they were not properly "entitled".

In a similar way decision making by the team members may have been made with hindsight. For example, when the team members were interviewed to establish exactly how they had arrived at their decisions, the answers given by them may have been conditioned by those responses made by the other members of the team.

This suggests that it would be imprudent to discuss developing theories for observed human performance with machine systems in action in the real world at this time.

Nevertheless, whilst such results are disappointing it may also be argued that the results of the research still have something to offer. For example, whilst many of the responses made by the team members may have been influenced by the actions of the others, it cannot be held to be true for all of the response observations made and recorded.

Therefore, if the figures on the team members profiles for decision making (theoretical recognition loss) and response performance (analogically inferred) are reduced by 50 to 60%, then these new figures for the observed team members performance still show better results than those that were predicted. This therefore implies that a theory could be developed, but requires more sophisticated interview and research techniques to be developed if the study of both humans and machine systems in action in the real world are to be more meaningful.

It was also anticipated that from the research performed additional data on the mechanisms of human error would be forthcoming. Reluctantly, it has to be admitted that most of those human errors observed could be rationalised using the current theories on the subject; that is they were either mistakes (ambiguous or incomplete specification of an intention) or slips (forgetting an intention).

The only observation on human error worthy of mention was the curious fact that an operator could set-up the MSDR correctly early in the morning; whereas, the same operator failed to set-up the MSDR correctly after lunch, by failing to set two switches to the 'on' position. All that was elicited from the operator by interview was that he forgot because he was thinking of something else.

This tendency by the team members to pay attention to those things of interest to them, as opposed to the task in hand, appeared to be due more to internal distractions than any other reason. However, whilst this did not lead to the creation of a risk environment, had the MSDR only been operated by one person and not a team, there is every reason to believe that a risk situation could have developed.

11.4 **"Spacelab" Payload Specialist Report**

Written and submitted by Dr. U. Merbold.

The Materials Science Double Rack (MSDR) was the scientific instrument flown on the first Spacelab mission which was used more than any other; almost half of the 72 experiments selected for flight were conducted in the MSDR. The facility contained three furnaces - the Isothermal Heating Facility (IHF), the Gradient Heating Facility (GHF) and the Mirror Heating Facility (MHF) - all capable of processing materials at temperatures well above 1000 ^{o}C. The High Temperature Thermostat (HTT) provided highly-controlled and uniform temperature fields of similar magnitude for studying the diffusion mechanism in molten metals. With the Fluid Physics Module (FPM) a powerful instrument was added for the investigation of liquids under microgravity conditions.

In addition to the scientific instruments, the MSDR contained a number of common facilities such as the Instrument Cooling System (ICS), the Vacuum Gas System (VGS) and the Central Console (CCO) which all provided various support.

The interface between the facilities of the MSDR and the Scientist-Astronaut was the CCO. It consists of different switches, a large number of status lamps, a display system and a keyboard. Its main element is its dedicated processor which drives all the lamps and displays. In addition, its memory contains all the software for process control and data acquisition. Normally, control is achieved in a closed loop; the guiding philosophy being to relieve the astronaut, consequently repetitive operations such as the evacuation of furnaces are performed by the dedicated processor by automated routines.

Sufficient transparency is provided to the astronaut by status lights and the possibility of displaying information at the CCO either as part of the automated routine or at the astronaut's request via the keyboard. The lights, for instance, give the astronaut important information on whether a furnace has reached its operational state or whether it is still in the heat-up phase.

The actual temperature values can be viewed interactively by the astronaut who has to display the content of the relevant address within the data acquisition frame. The information is then presented to him as octal numbers. With the help of a manual this number can be transformed into engineering units - in this example into a temperature. The resolution of the engineering data is more than adequate but the conversion from octal numbers into physical units is time-consuming and a cause of frequent error. Obviously a display format in engineering or scientific units instead of octal numbers would be highly desirable but, in principle, all data was accessible on board. This is also true for the status information - such as whether a valve is closed or open.

It turned out that transparency to the astronaut was essential for mission success.

Another helpful routine provided by the CCO is fault detection. If conditions of facilities deviate from the nominal situation, the affected facility is made safe and a yellow stop light is lit. If the situation is not critical a fault light is lit (yellow as well) and the process is not terminated but continues under these conditions. The lights which indicate nominal conditions are green lights.

Whenever the lights started flashing, the astronaut was (nominally) called for interaction or help - for instance to exchange a processed sample for the next raw material.

In case of faults and stops an error message on the central display unit of the Spacelab and an audible signal were generated. In addition, the CCO allows the astronaut to display the fault or stop code which gives him detailed information about what has gone wrong. A malfunction procedure for each fault and error code allows the astronaut to correct the problem.

Another feature of the CCO is the ability to patch software in flight. One key on the keyboard allows any register in the memory to be addressed, another key overrides its content in the format of octal numbers; a tremendous amount of flexibility results from this. For instance, process parameters such as temperatures or heating rates and times can easily be adjusted if the need arises. Truly interactive science becomes a reality since a second run of the same process can take the results of the first run into account.

In conclusion, it has to be said that the MSDR was the workhorse of the first Spacelab mission and two years later, on the D1 mission, it fully satisfied our expectations. However, limitations of the data acquisition and control system which resulted from tight funding were painfully noticeable. They could only be overcome by intensive training (learning to convert octal numbers into engineering units). The possibility of patching software allowed the commanding of facilities and the optimization of materials science processes although this was authorised by ground instruction only. On the D1 mission the MSDR performance proved again the soundness of its design, both in hardware and software. On the two flights, close to 100 material science investigations were conducted in about two weeks of operation time in orbit.

There is no question that there is sufficient growth potential in the MSDR to fly it on future missions. It is recommended that the CCO be improved in order to facilitate the man-machine interface. All parameters acquired in the data frame should be displayed in engineering units. In some cases a functional diagram could be displayed; the VGS, for instance, could be shown in this format with all valve positions showing the actual status, e.g., like a mimic display. Perhaps the display could itself be interactive so that the astronaut could use a mouse to address the pressure transducer in whose reading he is interested. The pressure value should then be displayed in plain engineering units. Perhaps closed loop control could be achieved in the same way; by means of a command key the status of a selected valve could be changed.

With better data, system error detection and correction could also be improved. Instead of a flashing stop or fault light, which then necessitates the display of the error code by CCO entries, an error message could be displayed automatically which should contain sufficient information and detail to prompt the astronaut to take the proper corrective action.

11.5 Research Recommendations

The opportunity to perform research where it is possible to observe people engaged in the day to day operation of a complex machine system was most revealing, particularly with respect to the varying levels of knowledge and skills that are exhibited by people from different disciplines when they are engaged in the functional operation of such a machine system.

From the research contained here it is now apparent that if a similar research project were to be undertaken then certain changes would need to be introduced.

The proposed recommendations for future research may be listed as follows:

1) The "Meister Taxonomy" which was modified for this research is an ideal tool; however, to be implemented to its best advantage it needs more than one person to perform the research if the methodology is to be applied effectively.

   This is because one person watching a number of other people in the performance of tasks can himself make errors; not only in what he thinks he saw, but also in his interpretation of what he thought he saw.

2) The interview techniques used during the research may, on reflection, be described as being primitive. However, prior to the research it was not entirely known what all of the conditions would be that could be encountered. Nevertheless, it would pay off in future research of this nature to spend some time developing better interview techniques, possibly along the lines of an in-depth number of questions which can be answered by the operator with a simple 'yes' or 'no'. In addition a more sophisticated follow-on questionnaire which could be put to the operators at a later time, then used to form a comparison with their earlier results.

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APPENDIX A

Stop/Fault Identification List

A complete listing of all possible Stop/Fault conditions of the Material Science Double Rack

EXP./ ELEM.	STOP/FAULT IDENT-NR	IDENTIFICATION/ COMMENT	CREW ACTION
VGS 1	STOP 0-01	SWITCH 2,4 NOT SET /*PWR SWITCHES NOT SET	RESTART
VGS 1	STOP 0-02	SWITCH S1,S2 NOT SET /*VGS SWITCHES AT CCO NOT SET	RESTART
VGS 1	STOP 0-03	T1 > 1.1V OR T1 < 0.9V /*SEL. POINT FOR T1 MALFUNCTION	START VGS SET-DOWN
VGS 1	STOP 0-04	PRESSURE > 10EE-2 MBAR /*SEL. DATA FOR T1 MALFUNCTION	
VGS 1,3	STOP 0-05	VP10 NOT SET /*NO RESPONSE TO 'OPEN V10'	
VGS 1,3	STOP 0-06	VP8 NOT SET /*NO RESPONSE TO 'OPEN V8'	
VGS 1	STOP 0-07	EVENT 'TMP RUN-UP' NOT SET	
VGS 1,5	STOP 0-10	EVENT 'TMP WORKING' NOT SET	
VGS 1	STOP 0-11	I1 > 1.1V OR I1 < 0.9V /*SEL. POINT FOR I1 MALFUNCTION	
VGS 1	STOP 0-12	PRESSURE > 10EE-5 MBAR /*SEL. DATA FOR I1 MALFUNCTION	
VGS 1	STOP 0-13	P8,P9 < 12 BAR /*HE/AR PRESSURE INSUFFICIENT	
VGS 3	STOP 0-14	VP8 SET /*NO RESPONSE TO 'CLOSE V8'	
VGS 3	STOP 0-15	VP1 NOT SET /*NO RESPONSE TO 'OPEN V1'	
VGS 3	STOP 0-16	VP(J) SET /*NO RESPONSE TO 'CLOSE V(J)'	
VGS 3	STOP 0-17	VP1 SET /*NO RESPONSE TO 'CLOSE V1'	
VGS 3	STOP 0-20	VP9 SET /*NO RESPONSE TO 'CLOSE V9'	
VGS 5	STOP 0-21	P8 < 7 BAR AND P1 < 5.5 BAR /*AR PRESSURE INSUFFICIENT	
VGS 3	STOP 0-22	VP10 SET /*NO RESPONSE TO 'CLOSE V10'	
VGS 2	STOP 0-23	EVENT 'TMP RUN-DOWN' NOT SET	SWITCH OFF PUMP

1 SET-UP 3 EVAC REQUEST HANDLING 5 MONITORING
2 SET-DOWN 4 GAS FLOODING REQUEST HANDLING

EXP./ ELEM.	STOP/FAULT IDENT-NR	IDENTIFICATION/ COMMENT	CREW ACTION
VGS 3	FAULT 0-01	VP(J) SET /*NO RESPONSE TO 'CLOSE V(J)'	
VGS 3	FAULT 0-02	VP(J) NOT SET /*NO RESPONSE TO 'OPEN V(J)'	
VGS 3	FAULT 0-03	T(J) > TBD V (J) OR < TBD V (J) /*SEL. POINT FOR T(J) MALFUNCTION [J = 1->6]	
VGS 3	FAULT 0-04	PRESSURE > TBD MBAR (J) AFTER 10 MIN /*TM201 PRESSURE FOR J NOT AT NOM. VALUE	
VGS 2	FAULT 0-05	VP8 SET /*NO RESPONSE TO 'CLOSE V8'	
VGS 1,2	FAULT 0-06	VP7 NOT SET /*NO RESPONSE TO 'OPEN V7'	
VGS 3	FAULT 0-07	I(J) > TBD V (J) OR < TBD V (J) /*SEL. POINT FOR I(J) MALFUNCTION [J = 1->6]	
VGS 3	FAULT 0-10	PRESSURE > TBD MBAR (J) AFTER 10 MIN /*I(J) NOT AT NOMINAL VALUE	
VGS 3	FAULT 0-11	PRESSURE > TBD MBAR (J) /*IM10 PRESSURE MONITORING INCAPABILITY	
VGS 2	FAULT 0-12	VP1 SET /*NO RESPONSE TO 'CLOSE V1'	
VGS 2	FAULT 0-13	VP10 SET /*NO RESPONSE TO 'CLOSE V10'	
VGS 3	FAULT 0-14	VP7 SET /*NO RESPONSE TO 'CLOSE V7'	
VGS 4	FAULT 0-15	P(J) < TBD BAR AFTER 30 SEC /*GAS MONITORING INCAPABILITY	
VGS 5	FAULT 0-16	PRESSURE > 10 EE-2 MBAR /*VENTLINE PRESSURE MALFUNCTION	
VGS 5	FAULT 0-20	HE HIGH PRESSURE P9 < 1.3 BAR	
VGS 5	FAULT 0-21	HE LOW PRESSURE P7 < 1.07 BAR OR > 1.15 BAR	
VGS 5	FAULT 0-22	AR HIGH PRESSURE P8 < 7 BAR	

J = 2 : MHF J = 3 : IHF1 J = 4 : IHF2
J = 5 : GHF J = 6 : HTT

EXP./ ELEM.	STOP/FAULT IDENT-NR	IDENTIFICATION/ COMMENT	CREW ACTION
VGS 5	FAULT 0-23	AR LOW PRESSURE F6 < 1.05 BAR OR > 1.15 BAR	
VGS 5	FAULT 0-24	CONTROL AR P1 < 5.5 BAR	
VGS 3	FAULT 0-25	VP9 NOT SET /*NO RESPONSE TO OPEN V9	
VGS 4	FAULT 0-26	MALFUNCTION FOR PURGING OF GAS-LINE	
ICS 5	FAULT 7-01	EVENTS 'BUS SEL. STATUS' AND 'PUMP SEL. STATUS' NOT SET STILL AFTER 10 SEC	
ICS 5	FAULT 7-02	P2 > P2max (3.2 BAR) STILL AFTER 10 SEC	
ICS 5	FAULT 7-03	P2 < P2min (1.3 BAR) STILL AFTER 10 SEC	
ICS 5	FAULT 7-04	P1 > P1max (2.9 BAR) STILL AFTER 10 SEC	
ICS 5	FAULT 7-05	P1 < P1min (1.0 BAR) STILL AFTER 10 SEC	
ICS 5	FAULT 7-06	TEMPERATURE 2 > T2max (60°C)	
ICS 5	FAULT 7-07	TEMPERATURE 1 > T1max (30°C)	
PWR 5	FAULT 7-10	U5	
PWR 5	FAULT 7-11	U1	
PWR 5	FAULT 7-12	U7 OUT-OF-TOLERANCE	
PWR 5	FAULT 7-13	U6 (4 %)	
PWR 5	FAULT 7-14	U9	
PWR 5	FAULT 7-15	U8	
PWR 5	FAULT 7-16	TEMPERATURE 2 > 60°C	
PWR 5	FAULT 7-17	TEMPERATURE 1 > 30°C	
PWR 5	FAULT 7-20	TEMPERATURE 3 > 60°C	

1 SET-UP 3 EVAC REQUEST HANDLING 5 MONITORING
2 SET-DOWN 4 GAS FLOODING REQUEST HANDLING

EXP./ ELEM.	STOP/FAULT IDENT-NR	IDENTIFICATION/ COMMENT	CREW ACTION
IHF	STOP 1-01	IHF-GO REJECTED /*TIMELINING INHIBITS IHF OPS	RESTART
	STOP 1-02	SWITCH 2,4,5,6 NOT SET /*PWR SWITCHES NOT SET	RESTART
	STOP 1-03	SWITCH S3 NOT SET /*IHF SWITCH AT CCO NOT SET	RESTART
	STOP 1-04	FURNACE TEMP. > TBD C OR MOTOR RATE > TBD V /*M.E. MALFUNCTION	*
	STOP 1-05	NO REAR END CONTACT AFTER 1 MIN	*
	STOP 1-06	NO REVERSER END CONTACT AFTER 1 MIN	*
	STOP 1-07	NO FRONT END CONTACT 1,2 AFTER 1 MIN	*
	STOP 1-10	SAMPLE TEMP. > 45 C AFTER 6 MIN	*
	STOP 1-11	COOLANT TEMP. DIFF. > 100 C	*
	STOP 1-30	ABORT IHF OPS /*ICS DEMANDS IHF ABORT	*
	STOP 1-35	HE-FLOODING NOT COMPLETED	*
	STOP 1-36	EVACUATION NOT COMPLETED	*
	STOP 1-37	ABORT IHF OPS /*VGS DEMANDS IHF ABORT	*
IHF	FAULT 1-01	EVENT 'FURNACE DOOR OPEN' SET /*DOOR OPEN AFTER INPUT 'RESUME'	
	FAULT 1-02	SAMPLE NR. OUT OF RANGE	
	FAULT 1-03	COOLANT TEMP. DIFF. > 80 C (-> MONITORING)	
	FAULT 1-12	SAMPLE TEMP. > 450 C AFTER 15 MIN	
	FAULT 1-13	SAMPLE TEMP. > T_{pc} C AFTER 60 MIN /*TIME FOR PRE-COOLING EXCEEDED	
	FAULT 1-14	SAMPLE TEMP. > T_{p2e} C AFTER 60 MIN /*TEMP. FOR 2nd EVAC NOT REACHED	
	FAULT 1-15	SAMPLE TEMP. > T_{p2f} C AFTER 60 MIN /*TEMP. FOR 2nd FLOODING NOT REACHED	

*) SET-DOWN BY SOFTWARE

EXP./ ELEM.	STOP/FAULT IDENT-NR	IDENTIFICATION/ COMMENT	CREW ACTION
IHF	FAULT 1-16	SAMPLE TEMP. > Tsol AFTER TBD(I) MIN /*TIME FOR SOLIDIFICATION EXCEEDED	
	FAULT 1-17	FURNACE TEMP. > 120°C AFTER 15 MIN	
	FAULT 1-35	HE-FLOODING NOT COMPLETED	
	FAULT 1-36	EVACUATION NOT COMPLETED	
CRY	STOP 2-02	SWITCH 2 NOT SET /*PWR SWITCH NOT SET	RESTART
	STOP 2-03	SWITCH S5 NOT SET /*CRY SWITCH AT CCO NOT SET	RESTART
	STOP 2-04	COOLANT TEMPERATURE > 35°C	HALT/ RESUME
	STOP 2-30	ABORT CRY OPS /*ICS DEMANDS CRY ABORT	*
CRY	FAULT 2-01	SLIDE NOT IN INITIAL/OPERATIONAL POSITION (-> MONITORING)	
	FAULT 2-02	COOLANT TEMPERATURE > 35°C	
	FAULT 2-03	FREEZER ABS[dTEMP] > 3°C	
	FAULT 2-04	STABILIZER ABS[dTEMP] > 3°C	

*) SET-DOWN BY SOFTWARE

EXP./ ELEM.	STOP/FAULT IDENT-NR	IDENTIFICATION/ COMMENT	CREW ACTION
MHF	STOP 3-01	MHF-GO REJECTED /*TIMELINING INHIBITS MHF OPS	RESTART
	STOP 3-02	SWITCH 2,4,5(NOT),6 SET /*PWR SWITCHES NOT SET	RESTART
	STOP 3-03	SWITCH S4 NOT SET /*MHF SWITCH AT CCO NOT SET	RESTART
	STOP 3-04	FURNACE NOT IN RETURN POS. AFTER 22 MIN	*
	STOP 3-05	EVENT 'ZCD LIMIT SWITCH 2' NOT SET AFTER 22 MIN /*FURNACE NOT IN LOAD. POS. AFTER 22 MIN	*
	STOP 3-06	EVENT 'SRD 2 LIMIT SWITCH 3' NOT SET AFTER 2 MIN /*FURNACE NOT TURNED COMPLETELY	*
	STOP 3-07	FURNACE NOT IN SAMPLE END POS. AFTER 22 MIN	*
	STOP 3-10	FURNACE NOT SAMPLE START POS. AFTER 22 MIN	*
	STOP 3-11	PHOTO AMPL. SIGNAL < NOM. VALUE AFTER 2 MIN	*
	STOP 3-12	ABS[dU(ph)] > PHOTO AMPL. DEVIATION THRESHOLD AFTER 5 MIN	*
	STOP 3-20	TEMP.1 > 45°C AND TIME FOR MALFUNCT. > 1 MIN /*FRONT LAMP TEMP. TOO HIGH STILL AFTER 1 MIN (-> MONITORING)	*
	STOP 3-21	TEMP.4-TEMP.3 > 25°C /*TEMP. DIFF. FOR MHF OUTLET/INLET TOO HIGH (-> MONITORING)	*
	STOP 3-30	ABORT MHF OPS /*ICS DEMANDS MHF ABORT	*
	STOP 3-31	ABORT MHF OPS /*OPERATOR INPUT 'HALT'	*
	STOP 3-34	AR-FLOODING NOT COMPLETED	*
	STOP 3-35	HE-FLOODING NOT COMPLETED	*
	STOP 3-36	EVACUATION NOT COMPLETED	*
	STOP 3-37	ABORT MHF OPS /*VGS DEMANDS MHF ABORT	*

*) SET-DOWN BY SOFTWARE

EXP./ ELEM.	STOP/FAULT IDENT-NR	IDENTIFICATION/ COMMENT	CREW ACTION
MHF	FAULT 3-01	EVENT 'DOOR OPEN' SET /*DOOR OPEN AFTER INPUT 'RESUME'	
	FAULT 3-02	EXPERIMENT-NR. OUT OF RANGE (>5)	
	FAULT 3-03	EVENT 'ZCD LIMIT SWITCH 3' SET /*FURNACE NOT IN RETURN POSITION	
	FAULT 3-04	EVENT 'ZCD LIMIT SWITCH 3' SET /*FURNACE NOT IN SAMPLE END POSITION	
	FAULT 3-05	$U(lamp) > U(lamp)_m$ DURING LAMP POWER ADJUSTMENT	
	FAULT 3-06	FURNACE NOT IN SAMPLE START POSITION AFTER 22 MIN	
	FAULT 3-07	EVENT 'ZCD LIMIT SWITCH 1' NOT SET AFTER 22 MIN /*FURNACE NOT IN LOCKING POSITION	
	FAULT 3-34	AR FLOODING NOT COMPLETED (FOR SAMPLE LOADING)	

EXP./ ELEM.	STOP/FAULT IDENT-NR	IDENTIFICATION/ COMMENT	CREW ACTION
HTT	STOP 4-01	HTT-GO REJECTED /*TIMELINING INHIBITS HTT OPS	RESTART
	STOP 4-02	SWITCH 2,3 NOT SET /*PWR SWITCHES NOT SET	RESTART
	STOP 4-03	SWITCH S6 NOT SET /*HTT SWITCH AT CCO NOT SET	RESTART
	STOP 4-04	SWITCHING MALFUNCTION (OFFSET OF AMPLIFIERS)	*
	STOP 4-05	SWITCHING MALFUNCTION (MAIN PWR RESISTANCE)	*
	STOP 4-06	TH < -0.1V /*FAILURE IN PWR SUPPLY OR SHORT CIRCUIT AT THERMISTOR	*
	STOP 4-07	TH > THmax /*THERMISTOR TEMP. ABOVE LIMIT	*
	STOP 4-10	TH < -9.5V /*BROKEN HEATER	*
	STOP 4-11	BOTH HEATERS DEFECT	*
	STOP 4-12	SWITCHING MALFUNCTION (TEMPERATURE CHECK)	*
	STOP 4-30	ABORT HTT OPS /*ICS DEMANDS HTT ABORT	*
	STOP 4-31	ABORT HTT OPS /*OPERATOR INPUT 'HALT'	
	STOP 4-36	EVACUATION NOT COMPLETED	*
	STOP 4-37	ABORT HTT OPS /*VGS DEMANDS HTT ABORT	*
HTT	FAULT 4-02	TEMP. > TSK°C AFTER TBD MIN /*TIME FOR COOLING IN HE EXCEEDED	
	FAULT 4-03	TEMP. > TEND°C AFTER TBD MIN /*TIME FOR COOLING WITH ADD. HEATING EXCEEDED	
	FAULT 4-04	ALL THERMOCOUPLES BROKEN OR AMPLIFIERS DEFECT	
	FAULT 4-35	HE-FLOODING NOT COMPLETED	

*) SET-DOWN BY SOFTWARE

EXP./ ELEM.	STOP/FAULT IDENT-NR	IDENTIFICATION/ COMMENT	CREW ACTION
UHV	STOP 5-01	UHV-GO REJECTED /*TIMELINING INHIBITS UHV OPS	RESTART
	STOP 5-02	SWITCH 2 NOT SET /*PWR SWITCH NOT SET	RESTART
	STOP 5-03	SWITCH S3 NOT SET /*UHV SWITCH AT CCO NOT SET	RESTART
	STOP 5-04	UHV STATUS WORD, BIT 1 NOT SET /*UHV POWER BIT NOT SET	RESUME
	STOP 5-05	NO DATA TRANSFER REQUEST AFTER 5 MIN	HALT/ RESUME

EXP./ ELEM.	STOP/FAULT IDENT-NR	IDENTIFICATION/ COMMENT	CREW ACTION
GHF	STOP 6-01	GHF-GO REJECTED /*TIMELINING INHIBITS GHF OPS	RESTART
	STOP 6-02	PPT-BIT NOT SET AFTER 8 HOURS	*
	STOP 6-03	APT-BIT NOT SET AFTER 6 HOURS	*
	STOP 6-30	ABORT GHF OPS /*ICS DEMANDS GHF ABORT	*
	STOP 6-31	ABORT GHF OPS /*OPERATOR INPUT 'HALT'	*
	STOP 6-35	HE-FLOODING NOT COMPLETED	*/HALT/ RESUME
	STOP 6-36	EVACUATION NOT COMPLETED	*/HALT/ RESUME
	STOP 6-37	ABORT GHF OPS /*VGS DEMANDS GHF ABORT	*
GHF	FAULT 6-01	ULE-BIT NOT SET /*FURNACE NOT READY FOR LOADING	
	FAULT 6-02	ESR-BIT NOT SET /*GHF CANNOT RECEIVE CMD 'HEATER ON (HON)'	
	FAULT 6-03	RUN-BIT NOT SET /*GHF EXP. NOT IN OPERATION	
	FAULT 6-04	RUN-BIT STILL SET (AFTER 10 HOURS)	
	FAULT 6-05	GHF FAULT-BIT SET /*GHF FAULT RELAY ON	
	FAULT 6-07	PORT OPEN	
	FAULT 6-35	HE FLOODING NOT COMPLETED (DURING FIRST COOLING AT SET-DOWN)	
FPM	STOP 7-01	FPM-GO REJECTED /*TIMELINING INHIBITS FPM OPS	RESTART
	STOP 7-02	SWITCH 2 NOT SET /*PWR SWITCH NOT SET	RESTART
	STOP 7-03	SWITCH S7 NOT SET /*FPM SWITCH AT CCO NOT SET	RESTART

*) SET-DOWN BY SOFTWARE

APPENDIX B

An evaluation of the observed and recorded attention data for the research study

Attention - Integration & Test Engineer (Immediate)

Out of 255 trials the Integration and Test Engineer's attention was captured 149 times by the signal stimuli presented, which gives the probability of this attention to such signals as 149 ÷ 255 = 0.585.

Case 1A

During the period of research, there were usually at least 4 engineers present during test of the machine system model elements, therefore, if the requirement was that all 4 engineers (uniquely) should have their attention captured by the warning system-signal stimulus, then the probability of success that this will occur is given by the following formulae:

$$\frac{P}{(4,4)} = {}^{n}\Sigma_{r}{}^{n}C_{r}p^{r}q^{n-r} =$$

$$P = {}^{4}C_{4}\ p^{4}q^{0} =$$

$$P = \frac{n!}{(n-r)!r!} \times p^{4}q^{0} =$$

$$P = 1 \times 0.584^{4}(1) = \underline{0.11631}$$

Case 2A

If on the other hand the requirement was that only 3 of the 4 (uniquely) need to have their attention captured by the warning system-signal stimulus, then the probability of success that this will occur can be re-stated as follows:

$$\frac{P}{(4,3)} = {}^{n}\Sigma_{r}{}^{n}C_{r}p^{r}q^{n-r} =$$

$$P = {}^{4}C_{3}p^{3}q^{1} + {}^{4}C_{4}p^{4}q^{0} =$$

$$P = \frac{n!}{(n-r)!r!} \times p^{3}q^{1} + \frac{n!}{(n-r)!r!} \times p^{4}q^{0} =$$

$$P = 4 \times 0.584^{3}(1-p) + 0.11631 =$$

$$P = 4 \times 0.584^{3}(0.416)^{1} + 0.11631 =$$

$$P = 0.33143 + 0.11631 = \underline{0.44774}$$

Case 3A

Alternatively, if the requirement was that only 2 of the 4 engineers (uniquely) need to have their attention captured by the warning system-signal stimulus, then the probabilities of success that this will occur can be stated as follows:

$$\frac{P}{(4,2)} = {}^{n}\Sigma_{r}{}^{n}C_{r}p^{r}q^{n-r} =$$

$$P = {}^{4}C_{2}p^{2}q^{2} + {}^{4}C_{3}p^{3}q^{1} + {}^{4}C_{4}p^{4}q^{0} =$$

$$P = \frac{n!}{(n-r)!r!} \times p^{2}q^{2} + \frac{n!}{(n-r)!r!} \times p^{3}q^{1} +$$

$$\frac{n!}{(n-r)!r!} \times p^{4}q^{0} =$$

$$P = 6 \times 0.584^{2}(1-0.584)^{2} + 0.33143 + 0.11631 =$$

$$P = 0.35413 + 0.33143 + 0.11631 = \underline{0.80187}$$

Case 4A

Finally, if the requirement was that only 1 of the 4 engineers (uniquely) needs to have his attention captured by the warning system-signal stimulus, then the probabilities of success that this will occur can be stated as follows:

$$\frac{P}{(4,1)} = {}^{n}\Sigma_{r}{}^{n}C_{r}p^{r}q^{n-r} =$$

$$P = {}^{4}C_{1}p^{1}q^{3} + {}^{4}C_{2}p^{2}q^{2} + {}^{4}C_{3}p^{3}q^{1} + {}^{4}C_{4}p^{4}q^{0} =$$

$$P = \frac{n!}{(n-r)!r!} \times p^{1}q^{3} + \frac{n!}{(n-r)!r!} \times p^{2}q^{2} +$$

$$\frac{n!}{(n-r)!r!} \times p^{3}q^{1} + \frac{n!}{(n-r)!r!} \times p^{4}q^{0} =$$

$$P = 4 \times 0.584^{1}(1-0.584)^{3} + 0.35413 + 0.33143 + 0.11631 =$$

$$P = 0.16817 + 0.35413 + 0.33143 + 0.11631 = \underline{0.97004}$$

Case General

For the case where no engineers are required to have their attention captured by the warning system-signal stimuli presented, then the probability can be simply stated:

$$\frac{P}{(4,0)} = 1$$

Attention - Integration & Test Engineer (Delayed)

As stated earlier, delayed attention may have a significant impact particularly, in complex man-machine systems, therefore, observed obvious delays were recorded.

During the period of research 69 delays in attention were made by the Integration and Test Engineer, however, these delays occurred in those trials, where there was no immediate attention, i.e. 255 - 149 = 106 trials, therefore the probability of delayed attention is 69 ÷ 106 = 0.650.
By using the same rationales and formulae as given by cases 1 to 4 above, then the probabilities of success can be stated:

Case 5A

$$\frac{P}{(4,4)} = {}^{n}\Sigma_{r}{}^{n}C_{r}p^{r}q^{n-r} =$$

$$P = {}^{4}C_{4}p^{4}q^{0} =$$

$$P = \frac{n!}{(n-r)!r!} \times p^{4}q^{0} =$$

$$P = 1 \times 0.650^{4}(1) = \underline{0.17850}$$

Case 6A

$$\frac{P}{(4,3)} = {}^{n}\Sigma_{r}{}^{n}C_{r}p^{r}q^{n-r} =$$

$$P = {}^{4}C_{3}p^{3}q^{1} + {}^{4}C_{4}p^{4}q^{0} =$$

$$P = \frac{n!}{(n-r)!r!} \times p^{3}q^{1} + \frac{n!}{(n-r)!r!} \times p^{4}q^{0} =$$

$$P = 4 \times 0.650^{3}(1-0.650) + 0.17850 =$$

$$P = 0.38447 + 0.17850 = \underline{0.56297}$$

Case 7A

$$\frac{P}{(4,2)} = {}^{n}\Sigma_{r}{}^{n}C_{r}p^{r}q^{n-r} =$$

$$P = {}^{4}C_{2}p^{2}q^{2} + {}^{4}C_{3}p^{3}q^{1} + {}^{4}C_{4}p^{4}q^{0} =$$

$$P = \frac{n!}{(n-r)!r!} \times p^{2}q^{2} + \frac{n!}{(n-r)!r!} \times p^{3}q^{1} +$$

$$\frac{n!}{(n-r)!r!} \times p^{4}q^{0} =$$

$P = 6 \times 0.650^2(1-0.650)^2 + 0.38447 + 0.17850 =$

$P = 0.31053 + 0.38447 + 0.17850 = \underline{0.873507}$

Case 8A

$\frac{P}{(4,1)} = {}^n\Sigma_r {}^nC_r p^r q^{n-r} =$

$P = {}^4C_1 p^1 q^3 + {}^4C_2 p^2 q^2 + {}^4C_3 p^3 q^1 + {}^4C_4 p^4 q^0 =$

$P = \frac{n!}{(n-r)!r!} \times p^1 q^3 + \frac{n!}{(n-r)!r!} \times p^2 q^2 +$

$\frac{n!}{(n-r)!r!} \times p^3 q^1 + \frac{n!}{(n-r)!r!} \times p^4 q^0 =$

$P = 4 \times 0.650^1(1-0.650)^3 + 0.31053 + 0.38447 + 0.17850 =$

$P = 0.11147 + 0.31053 + 0.38447 + 0.17850 = \underline{0.98498}$

Attention - Software Engineer (Immediate)

Out of 251 trials the Software Engineer's attention was captured 132 times by the warning system-signal stimuli presented, which gives the probability of attention to such signals as 132 ÷ 251 = 0.525.

Therefore, by using the same formulae defined earlier, it is possible to show the Software Engineer's probabilities of attention.

Case 1B

$\frac{P}{(4,4)} = {}^n\Sigma_r {}^nC_r p^r q^{n-r} =$

$P = {}^4C_4 p^4 q^0 =$

$P = \frac{n!}{(n-r)!r!} \times p^4 q^0 =$

$P = 1 \times 0.525^4(1) = \underline{0.075969}$

Case 2B

$$P_{(4,3)} = {}^{n}\Sigma_{r}\, {}^{n}C_{r} p^{r} q^{n-r} =$$

$$P = {}^{4}C_{3} p^{3} q^{1} + {}^{4}C_{4} p^{4} q^{0} =$$

$$P = \frac{n!}{(n-r)!r!} \times p^{3} q^{1} + \frac{n!}{(n-r)!r!} \times p^{4} q^{0} =$$

$$P = 4 \times 0.525^{3}(1-0.525)^{1} + 0.075969 =$$

$$P = 0.274935 + 0.075969 = \underline{0.350904}$$

Case 3B

$$P_{(4,2)} = {}^{n}\Sigma_{r}\, {}^{n}C_{r} p^{r} q^{n-r} =$$

$$P = {}^{4}C_{2} p^{2} q^{2} + {}^{4}C_{3} p^{3} q^{1} + {}^{4}C_{4} p^{4} q^{0} =$$

$$P = \frac{n!}{(n-r)!r!} \times p^{2} q^{2} + \frac{n!}{(n-r)!r!} \times p^{3} q^{1} +$$

$$\frac{n!}{(n-r)!r!} \times p^{4} q^{0} =$$

$$P = 6 \times 0.525^{2}(1-0.525)^{2} + 0.274935 + 0.075969 =$$

$$P = 0.373127 + 0.274935 + 0.075960 = \underline{0.724031}$$

Case 4B

$$P_{(4,1)} = {}^{n}\Sigma_{r}\, {}^{n}C_{r} p^{r} q^{n-r} =$$

$$P = {}^{4}C_{1} p^{1} q^{3} + {}^{4}C_{2} p^{2} q^{2} + {}^{4}C_{3} p^{3} q^{1} + {}^{4}C_{4} p^{4} q^{0} =$$

$$P = \frac{n!}{(n-r)!r!} \times p^{1} q^{3} + \frac{n!}{(n-r)!r!} \times p^{2} q^{2} +$$

$$\frac{n!}{(n-r)!r!} \times p^{3} q^{1} + \frac{n!}{(n-r)!r!} \times p^{4} q^{0} =$$

$$P = 4 \times 0.525^{1}(1-0.525)^{3} + 0.373127 + 0.274935 + 0.075969 =$$

$$P = 0.225060 + 0.373127 + 0.274935 + 0.075969 = \underline{0.949091}$$

Attention - Software Engineer (Delayed)

There were 57 delays in attention made by the Software Engineer, therefore, the probability of such delays occurring may be expressed as 57 ÷ 119 = 0.478.

Therefore, these delays in the Software Engineers - Attention probabilities, may be stated as follows:

Case 5B

$$\frac{P}{(4,4)} = {}^{n}\Sigma_{r}{}^{n}C_{r}p^{r}q^{n-r} =$$

$$P = {}^{4}C_{4}p^{4}q^{0} =$$

$$P = \frac{n!}{(n-r)!r!} \times p^{4}q^{0} =$$

$$P = 1 \times 0.478^{4}(1) = \underline{0.0522049}$$

Case 6B

$$\frac{P}{(4,3)} = {}^{n}\Sigma_{r}{}^{n}C_{r}p^{r}q^{n-r} =$$

$$P = {}^{4}C_{3}p^{3}q^{1} + {}^{4}C_{4}p^{4}q^{0} =$$

$$P = \frac{n!}{(n-r)!r!} \times p^{3}q^{1} + \frac{n!}{(n-r)!r!} \times p^{4}q^{0} =$$

$$P = 4 \times 0.478^{3}(1-0.478)^{1} + 0.0522049 =$$

$$P = 0.2280416 + 0.0522049 = \underline{0.2802465}$$

Case 7B

$$\frac{P}{(4,2)} = {}^{n}\Sigma_{r}{}^{n}C_{r}p^{r}q^{n-r} =$$

$$P = {}^{4}C_{2}p^{2}q^{2} + {}^{4}C_{3}p^{3}q^{1} + {}^{4}C_{4}p^{4}q^{0} =$$

$$P = \frac{n!}{(n-r)!r!} \times p^{2}q^{2} + \frac{n!}{(n-r)!r!} \times p^{3}q^{1} +$$

$$\frac{n!}{(n-r)!r!} \times p^{4}q^{0} =$$

$$P = 6 \times 0.478^{2}(1-0.478)^{2} + 0.2280416 + 0.0522049 =$$

$$P = 0.3735494 + 0.2280416 + 0.0522049 = \underline{0.6537959}$$

Case 8B

$\frac{P}{(4,1)} = {}^{n}\Sigma_{r}{}^{n}C_{r}p^{r}q^{n-r} =$

$P = {}^{4}C_{1}p^{1}q^{3} + {}^{4}C_{2}p^{2}q^{2} + {}^{4}C_{3}p^{3}q^{1} + {}^{4}C_{4}p^{4}q^{0} =$

$P = \frac{n!}{(n-r)!r!} \times p^{1}q^{3} + \frac{n!}{(n-r)!r!} \times p^{2}q^{2} +$

$\frac{n!}{(n-r)!r!} \times p^{3}q^{1} + \frac{n!}{(n-r)!r!} \times p^{4}q^{0} =$

$P = 4 \times 0.478^{1}(1-0.478)^{3} + 0.3735494 + 0.2280416 + 0.0522049 =$

$P = 0.2719564 + 0.3735494 + 0.2280416 + 0.0522049 = \underline{0.9257523}$

Attention - Systems Engineer (Immediate)

From 220 trials the System Engineers attention was captured 106 times by the warning system-signal stimuli presented, which gives a probability of this attention to such signals as 106 ÷ 220 = 0.481.

The formula given throughout is used to show the probabilities for System Engineer attention:

Case 1C

$\frac{P}{(4,4)} = {}^{n}\Sigma_{r}{}^{n}C_{r}p^{r}q^{n-r} =$

$P = {}^{4}C_{4}p^{4}q^{0} =$

$P = \frac{n!}{(n-r)!r!} \times p^{4}q^{0} =$

$P = 1 \times 0.481^{4}(1) = \underline{0.0535279}$

Case 2C

$$\frac{P}{(4,3)} = {}^{n}\Sigma_{r}\,{}^{n}C_{r}p^{r}q^{n-r} =$$

$$P = {}^{4}C_{3}p^{3}q^{1} + {}^{4}C_{4}p^{4}q^{0} =$$

$$P = \frac{n!}{(n-r)!r!} \times p^{3}q^{1} + \frac{n!}{(n-r)!r!} \times p^{4}q^{0} =$$

$$P = 4 \times 0.481^{3}(1-0.481)^{1} + 0.0535279 =$$

$$P = 0.2310269 + 0.0535279 = \underline{0.2845548}$$

Case 3C

$$\frac{P}{(4,2)} = {}^{n}\Sigma_{r}\,{}^{n}C_{r}p^{r}q^{n-r} =$$

$$P = {}^{4}C_{2}p^{2}q^{2} + {}^{4}C_{3}p^{3}q^{1} + {}^{4}C_{4}p^{4}q^{0} =$$

$$P = \frac{n!}{(n-r)!r!} \times p^{2}q^{2} + \frac{n!}{(n-r)!r!} \times p^{3}q^{1} +$$

$$\frac{n!}{(n-r)!r!} \times p^{4}q^{0} =$$

$$P = 6 \times 0.481^{2}(1-0.481)^{2} + 0.2310269 + 0.0535279 =$$

$$P = 0.3739177 + 0.2310269 + 0.0535279 = \underline{0.6584725}$$

Case 4C

$$\frac{P}{(4,1)} = {}^{n}\Sigma_{r}\,{}^{n}C_{r}p^{r}q^{n-r} =$$

$$P = {}^{4}C_{1}p^{1}q^{3} + {}^{4}C_{2}p^{2}q^{2} + {}^{4}C_{3}p^{3}q^{1} + {}^{4}C_{4}p^{4}q^{0} =$$

$$P = \frac{n!}{(n-r)!r!} \times p^{1}q^{3} + \frac{n!}{(n-r)!r!} \times p^{2}q^{2} +$$

$$\frac{n!}{(n-r)!r!} \times p^{3}q^{1} + \frac{n!}{(n-r)!r!} \times p^{4}q^{0} =$$

$$P = 4 \times 0.481^{1}(1-0.481)^{3} + 0.3739177 + 0.2310269 + 0.0535279 =$$

$$P = 0.268972 + 0.3739177 + 0.2310269 + 0.0535279 = \underline{0.9274445}$$

Attention - System Engineer (Delayed)

Delayed attention to system-signal stimuli by the Systems Engineer totalled 55, the probability of such delays occurring may be expressed as 55 ÷ 114 = 0.482.

Such delays in the System Engineers - Attention probabilities may be stated as follows:

Case 5C

$$\frac{P}{(4,4)} = {}^{n}\Sigma_{r}{}^{n}C_{r}p^{r}q^{n-r} =$$

$$P = {}^{4}C_{4}p^{4}q^{0} =$$

$$P = \frac{n!}{(n-r)!r!} \times p^{4}q^{0} =$$

$$P = 1 \times 0.482^{4}(1) = \underline{0.0538744}$$

Case 6C

$$\frac{P}{(4,3)} = {}^{n}\Sigma_{r}{}^{n}C_{r}p^{r}q^{n-r} =$$

$$P = {}^{4}C_{3}p^{3}q^{1} + {}^{4}C_{4}p^{4}q^{0} =$$

$$P = \frac{n!}{(n-r)!r!} \times p^{3}q^{1} + \frac{n!}{(n-r)!r!} \times p^{4}q^{0} =$$

$$P = 4 \times 0.482^{3}(1-0.482)^{1} + 0.0539744 =$$

$$P = 0.2320229 + 0.0539744 = \underline{0.2859973}$$

Case 7C

$$\frac{P}{(4,2)} = {}^{n}\Sigma_{r}{}^{n}C_{r}p^{r}q^{n-r} =$$

$$P = {}^{4}C_{2}p^{2}q^{2} + {}^{4}C_{3}p^{3}q^{1} + {}^{4}C_{4}p^{4}q^{0} =$$

$$P = \frac{n!}{(n-r)!r!} \times p^{2}q^{2} + \frac{n!}{(n-r)!r!} \times p^{3}q^{1} +$$

$$\frac{n!}{(n-r)!r!} \times p^{4}q^{0} =$$

$$P = 6 \times 0.482^{2}(1-0.482)^{2} + 0.2320299 + 0.0539744 =$$

$$P = 0.3740286 + 0.2320299 + 0.0539744 = \underline{0.660329}$$

Case 8C

$$\frac{P}{(4,1)} = {}^{n}\Sigma_{r}\,{}^{n}C_{r}p^{r}q^{n-r} =$$

$$P = {}^{4}C_{1}p^{1}q^{3} + {}^{4}C_{2}p^{2}q^{2} + {}^{4}C_{3}p^{3}q^{1} + {}^{4}C_{4}p^{4}q^{0} =$$

$$P = \frac{n!}{(n-r)!r!} \times p^{1}q^{3} + \frac{n!}{(n-r)!r!} \times p^{2}q^{2} +$$

$$\frac{n!}{(n-r)!r!} \times p^{3}q^{1} + \frac{n!}{(n-r)!r!} \times p^{4}q^{0} =$$

$$P = 4 \times 0.482^{1}(1-0.482)^{3} + 0.3740286 + 0.2320299 + 0.0539744 =$$

$$P = 0.2679762 + 0.3740286 + 0.2320299 + 0.0539744 = \underline{0.9280091}$$

Attention - Customer Engineers (Immediate)

Customer Engineers were only present for 122 of the total number of trials and even though they came to the trials in groups of two or more, it was not practical to observe all of their actions/reactions, except in the obvious cases, therefore, in general only one customer engineer was observed.

The customer engineer success rate out of 122 trials was 59 immediate attention responses to the warning system-signal stimuli presented which gives a probability of success figure of $59 \div 122 = 0.483$.

The formula given throughout is used to show the probabilities of Customer Engineer attention.

Case 1D

$$\frac{P}{(4,4)} = {}^{n}\Sigma_{r}\,{}^{n}C_{r}p^{r}q^{n-r} =$$

$$P = {}^{4}C_{4}p^{4}q^{0} =$$

$$P = \frac{n!}{(n-r)!r!} \times p^{4}q^{0} =$$

$$P = 1 \times 0.483^{4}(1) = \underline{0.0544237}$$

Case 2D

$$\frac{P}{(4,3)} = {}^{n}\Sigma_{r}{}^{n}C_{r}p^{r}q^{n-r} =$$

$$P = {}^{4}C_{3}p^{3}q^{1} + {}^{4}C_{4}p^{4}q^{0} =$$

$$P = \frac{n!}{(n-r)!r!} \times p^{3}q^{1} + \frac{n!}{(n-r)!r!} \times p^{4}q^{0} =$$

$$P = 4 \times 0.483^{3}(1-0.483)^{1} + 0.0544237 =$$

$$P = 0.2330193 + 0.0544237 = \underline{0.287443}$$

Case 3D

$$\frac{P}{(4,2)} = {}^{n}\Sigma_{r}{}^{n}C_{r}p^{r}q^{n-r} =$$

$$P = {}^{4}C_{2}p^{2}q^{2} + {}^{4}C_{3}p^{3}q^{1} + {}^{4}C_{4}p^{4}q^{0} =$$

$$P = \frac{n!}{(n-r)!r!} \times p^{2}q^{2} + \frac{n!}{(n-r)!r!} \times p^{3}q^{1} +$$

$$\frac{n!}{(n-r)!r!} \times p^{4}q^{0} =$$

$$P = 6 \times 0.483^{2}(1-0.483)^{2} + 0.2330193 + 0.0544237 =$$

$$P = 0.3741335 + 0.2330193 + 0.0544237 = \underline{0.6615765}$$

Case 4D

$$\frac{P}{(4,1)} = {}^{n}\Sigma_{r}{}^{n}C_{r}p^{r}q^{n-r} =$$

$$P = {}^{4}C_{1}p^{1}q^{3} + {}^{4}C_{2}p^{2}q^{2} + {}^{4}C_{3}p^{3}q^{1} + {}^{4}C_{4}p^{4}q^{0} =$$

$$P = \frac{n!}{(n-r)!r!} \times p^{1}q^{3} + \frac{n!}{(n-r)!r!} \times p^{2}q^{2} +$$

$$\frac{n!}{(n-r)!r!} \times p^{3}q^{1} + \frac{n!}{(n-r)!r!} \times p^{4}q^{0} =$$

$$P = 4 \times 0.483^{1}(1-0.483)^{3} + 0.3741335 + 0.2331093 + 0.0544337 =$$

$$P = 0.26698 + 0.3741335 + 0.2330193 + 0.0544237 = \underline{0.9285565}$$

Attention - Customer Engineers (Delayed)

Out of the remaining 63 trials the customer engineers attention to the warning system-signal stimuli was delayed on 25 occasions, which gives a probability of such delays, as 25 ÷ 63 = 0.396.

Therefore, the probabilities of delays by the customer engineers may be stated by using the standard formula:

Case 5D

$$\frac{P}{(4,4)} = {}^{n}\Sigma_{r}{}^{n}C_{r}p^{r}q^{n-r} =$$

$$P = {}^{4}C_{4}p^{4}q^{0} =$$

$$P = \frac{n!}{(n-r)!r!} \times p^{4}q^{0} =$$

$$P = 1 \times 0.396^{4}(1) = \underline{0.0245912}$$

Case 6D

$$\frac{P}{(4,3)} = {}^{n}\Sigma_{r}{}^{n}C_{r}p^{r}q^{n-r} =$$

$$P = {}^{4}C_{3}p^{3}q^{1} + {}^{4}C_{4}p^{4}q^{0} =$$

$$P = \frac{n!}{(n-r)!r!} \times p^{3}q^{1} + \frac{n!}{(n-r)!r!} \times p^{4}q^{0} =$$

$$P = 4 \times 0.396^{3}(1-0.396)^{1} + 0.0245912 =$$

$$P = 0.1500315 + 0.0245912 = \underline{0.1746227}$$

Case 7D

$$\frac{P}{(4,2)} = {}^{n}\Sigma_{r}\,{}^{n}C_{r}p^{r}q^{n-r} =$$

$$P = {}^{4}C_{2}p^{2}q^{2} + {}^{4}C_{3}p^{3}q^{1} + {}^{4}C_{4}p^{4}q^{0} =$$

$$P = \frac{n!}{(n-r)!r!} \times p^{2}q^{2} + \frac{n!}{(n-r)!r!} \times p^{3}q^{1} +$$

$$\frac{n!}{(n-r)!r!} \times p^{4}q^{0} =$$

$$P = 6 \times 0.396^{2}(1-0.396)^{2} + 0.1500315 + 0.0245912 =$$

$$P = 0.3432539 + 0.1500315 + 0.0245912 = \underline{0.5178766}$$

Case 8D

$$\frac{P}{(4,1)} = {}^{n}\Sigma_{r}\,{}^{n}C_{r}p^{r}q^{n-r} =$$

$$P = {}^{4}C_{1}p^{1}q^{3} + {}^{4}C_{2}p^{2}q^{2} + {}^{4}C_{3}p^{3}q^{1} + {}^{4}C_{4}p^{4}q^{0} =$$

$$P = \frac{n!}{(n-r)!r!} \times p^{1}q^{3} + \frac{n!}{(n-r)!r!} \times p^{2}q^{2} +$$

$$\frac{n!}{(n-r)!r!} \times p^{3}q^{1} + \frac{n!}{(n-r)!r!} \times p^{4}q^{0} =$$

$$P = 4 \times 0.396^{1}(1-0.396)^{3} + 0.3432539 + 0.1500315 + 0.0245912 =$$

$$P = 0.3490325 + 0.3432539 + 0.1500315 + 0.0245912 = \underline{0.8669091}$$

Attention - Integration & Test Manager (Immediate)

The Integration and Test Manager was only present for 82 of the 255 trials, out of which his immediate attention response to the warning system-signal stimuli presented was 59, which gives a probability of 59 ÷ 82 = 0.719.

The probabilities of immediate attention by the integration and test manager may be stated using the standard formula:

Case 1E

$$\frac{P}{(4,4)} = {}^{n}\Sigma_{r}{}^{n}C_{r}p^{r}q^{n-r} =$$

$$P = {}^{4}C_{4}p^{4}q^{0} =$$

$$P = \frac{n!}{(n-r)!r!} \times p^{4}q^{0} =$$

$$P = 1 \times 0.719^{4}(1) = \underline{0.2672486}$$

Case 2E

$$\frac{P}{(4,3)} = {}^{n}\Sigma_{r}{}^{n}C_{r}p^{r}q^{n-r} =$$

$$P = {}^{4}C_{3}p^{3}q^{1} + {}^{4}C_{4}p^{4}q^{0} =$$

$$P = \frac{n!}{(n-r)!r!} \times p^{3}q^{1} + \frac{n!}{(n-r)!r!} \times p^{4}q^{0} =$$

$$P = 4 \times 0.719^{3}(1-0.719)^{1} + 0.2672486 =$$

$$P = 0.4177851 + 0.2672486 = \underline{0.6850337}$$

Case 3E

$$\frac{P}{(4,2)} = {}^{n}\Sigma_{r}{}^{n}C_{r}p^{r}q^{n-r} =$$

$$P = {}^{4}C_{2}p^{2}q^{2} + {}^{4}C_{3}p^{3}q^{1} + {}^{4}C_{4}p^{4}q^{0} =$$

$$P = \frac{n!}{(n-r)!r!} \times p^{2}q^{2} + \frac{n!}{(n-r)!r!} \times p^{3}q^{1} +$$

$$\frac{n!}{(n-r)!r!} \times p^{4}q^{0} =$$

$$P = 6 \times 0.719^{2}(1-0.719)^{2} + 0.4177851 + 0.2672486 =$$

$$P = 0.2449185 + 0.4177851 + 0.2672486 = \underline{0.9299522}$$

Case 4E

$$\frac{P}{(4,1)} = {}^{n}\Sigma_{r}\,{}^{n}C_{r}p^{r}q^{n-r} =$$

$$P = {}^{4}C_{1}p^{1}q^{3} + {}^{4}C_{2}p^{2}q^{2} + {}^{4}C_{3}p^{3}q^{1} + {}^{4}C_{4}p^{4}q^{0} =$$

$$P = \frac{n!}{(n-r)!r!} \times p^{1}q^{3} + \frac{n!}{(n-r)!r!} \times p^{2}q^{2} +$$

$$\frac{n!}{(n-r)!r!} \times p^{3}q^{1} + \frac{n!}{(n-r)!r!} \times p^{4}q^{0} =$$

$$P = 4 \times 0.719^{1}(1-0.719)^{3} + 0.2449185 + 0.4177851 + 0.2672486 =$$

$$P = 0.0638128 + 0.2449185 + 0.4177851 + 0.2672486 = \underline{0.993765}$$

Attention - Integration & Test Manager (Delayed)

The Integration and Test Manager's delayed attention to warning system-signal stimuli occurred 13 times out of the remaining 23 trials, which gives a probability figure of 13 ÷ 23 = 0.565.

By using the standard formula the Integration and Test Manager's probabilities may be stated as follows:

Case 5E

$$\frac{P}{(4,4)} = {}^{n}\Sigma_{r}\,{}^{n}C_{r}p^{r}q^{n-r} =$$

$$P = {}^{4}C_{4}p^{4}q^{0} =$$

$$P = \frac{n!}{(n-r)!r!} \times p^{4}q^{0} =$$

$$P = 1 \times 0.565^{4}(1) = \underline{0.1019046}$$

Case 6E

$$\frac{P}{(4,3)} = {}^{n}\Sigma_{r}{}^{n}C_{r}p^{r}q^{n-r} =$$

$$P = {}^{4}C_{3}p^{3}q^{1} + {}^{4}C_{4}p^{4}q^{0} =$$

$$P = \frac{n!}{(n-r)!r!} \times p^{3}q^{1} + \frac{n!}{(n-r)!r!} \times p^{4}q^{0} =$$

$$P = 4 \times 0.565^{3}(1-0.565)^{1} + 0.1019046 =$$

$$P = 0.3138301 + 0.1019046 = \underline{0.4157347}$$

Case 7E

$$\frac{P}{(4,2)} = {}^{n}\Sigma_{r}{}^{n}C_{r}p^{r}q^{n-r} =$$

$$P = {}^{4}C_{2}p^{2}q^{2} + {}^{4}C_{3}p^{3}q^{1} + {}^{4}C_{4}p^{4}q^{0} =$$

$$P = \frac{n!}{(n-r)!r!} \times p^{2}q^{2} + \frac{n!}{(n-r)!r!} \times p^{3}q^{1} +$$

$$\frac{n!}{(n-r)!r!} \times p^{4}q^{0} =$$

$$P = 6 \times 0.565^{2}(1-0.565)^{2} + 0.3138301 + 0.1019046 =$$

$$P = 0.3624321 + 0.3138301 + 0.1019046 = \underline{0.7781668}$$

Case 8E

$$\frac{P}{(4,1)} = {}^{n}\Sigma_{r}{}^{n}C_{r}p^{r}q^{n-r} =$$

$$P = {}^{4}C_{1}p^{1}q^{3} + {}^{4}C_{2}p^{2}q^{2} + {}^{4}C_{3}p^{3}q^{1} + {}^{4}C_{4}p^{4}q^{0} =$$

$$P = \frac{n!}{(n-r)!r!} \times p^{1}q^{3} + \frac{n!}{(n-r)!r!} \times p^{2}q^{2} +$$

$$\frac{n!}{(n-r)!r!} \times p^{3}q^{1} + \frac{n!}{(n-r)!r!} \times p^{4}q^{0} =$$

$$P = 4 \times 0.565^{1}(1-0.565)^{3} + 0.3624321 + 0.3138301 + 0.1019046 =$$

$$P = 0.186027 + 0.3624321 + 0.3138301 + 0.1019046 = \underline{0.9641938}$$

The results of these statistical evaluations are discussed in the main part of the thesis.

APPENDIX C

Identification Table

The collated observed and recorded indentification data

IDENTIFICATION (WITH FAULT/STOP IDENTIFICATION LIST)

Data Sheet No.	Date	I/TE	S/WE	SE	CE	I/TM	Remarks
1	03.04.80	Y	N	-	-	-	
2	23.07.80	Y	N	N	-	-	
3	23.07.80	N	N	Y	-	-	
4	23.07.80	X	X	X	-	-	Y = Yes by list
5	23.07.80	N	Y	N	-	-	N = No list referenced
6	09.10.80	Y	N	N	-	-	X = Not possible
7	09.10.80	N	Y	-	-	-	NN = Not Necessary
8	09.10.80	Y	N	N	-	-	(P)= Partial Identification
9	09.10.80	N	Y	Y	-	-	(C)= Identification Check
10	09.10.80	NN	NN	NN	-	-	
11a	09.10.80	Y	Y	N	-	-	
11b	09.10.80	N	Y	N	-	-	
12	10.10.80	NN	NN	-	-	-	
13a	10.10.80	NN	NN	-	-	-	
13b	10.10.80	Y	N	-	-	-	
14a	10.10.80	N	N	Y	-	-	
14b	10.10.80	N	Y	N	-	-	
15	11.10.80	Y	N	N	-	-	
16	13.10.80	Y	Y	N	-	-	
17	13.10.80	X	-	-	-	-	MA evaluation
18	13.10.80	N	-	-	-	-	MA identification
19	04.11.80	N	Y	N	-	-	
20	12.11.80	N	N	Y	-	-	
21	12.01.81	N	Y	-	-	-	
22	13.01.81	N	Y	-	-	-	
23	13.01.81	Y	Y	-	-	-	
24	13.01.81	N	Y	-	-	-	
25	15.01.81	N	Y	-	-	-	
26	15.01.81	X	X	-	-	-	
27	15.01.81	N	Y	-	-	-	
28	15.01.81	Y	Y	-	-	-	
29	15.01.81	N	Y	-	-	-	
30	15.01.81	N	Y	-	-	-	
31	16.01.81	NN	NN	-	-	-	
32	16.01.81		Y	-	-	-	
33	16.01.81	Y	Y(P)	-	-	-	
34a	16.01.81	NN	NN	-	-	-	
34b	16.01.81	X	X	-	-	-	
35	16.01.81	Y(C)	N	-	-	-	
36	16.01.81	N	Y(C)	-	-	-	
37a	16.01.81	NN	NN	-	-	-	
37b	16.01.81	Y	N	-	-	-	
38a	16.01.81	N	Y	-	-	-	
38b	16.01.81	NN	NN	-	-	-	
39	16.01.81	NN	NN	-	-	-	
40	17.01.81	Y	N	N	-	-	
41	20.02.81	NN	NN	-	-	-	
42	20.02.81	NN	NN	-	-	-	
43	20.02.81	Y	N	-	-	-	
44	20.02.81	Y	Y	-	-	-	

IDENTIFICATION (WITH FAULT/STOP IDENTIFICATION LIST)

Data Sheet No.	Date	I/TE	S/WE	SE	CE	I/TM	Remarks
45	20.02.81	NN	NN	-	-	-	
46	20.02.81	NN	NN	-	-	-	
47	27.04.81	N	Y	N	-	-	
48a	30.04.81	Y	N	N	-	-	
48b	30.04.81	Y	Y	N	-	-	
49	30.04.81	Y	Y	N	-	-	
50a	30.04.81	Y	N	N	-	-	
50b	30.04.81	Y	Y	N	-	-	
51	30.04.81	NN	NN	NN	-	-	
52a	04.05.81	N	N	Y	-	-	
52b	04.05.81	X	X	X	-	-	
53a	04.05.81	Y	Y	N	-	-	
53b	04.05.81	N	Y	Y	-	-	
54a	04.05.81	NN	NN	NN	-	-	
54b	04.05.81	X	X	X	-	-	
55a	05.05.81	Y	Y	N	-	-	
55b	05.05.81	Y	N	N	-	-	
56	05.05.81	Y	Y	N	-	-	
57	05.05.81	Y	Y	N	-	-	
58	05.05.81	N	Y	Y	-	-	
59a	05.05.81	Y	N	Y	-	-	
59b	05.05.81	Y	N	Y	-	-	
60	06.05.81	Y	Y	N	-	-	
61	06.05.81	N	Y	N	-	-	
62	06.05.81	N	Y	Y	-	-	
63	06.05.81	Y	Y	N	-	-	
64	06.05.81	N	N	Y	-	-	
65	06.05.81	N	Y	N	-	-	
66	07.05.81	NN	NN	NN	-	-	
67	07.05.81	NN	NN	NN	-	-	
68	07.05.81	NN	NN	NN	-	-	
69	07.05.81	N	Y	Y	-	-	
70	07.05.81	Y	Y	N	-	-	
71	07.05.81	N	Y*	N	N(2)	-	* Without list
72	07.05.81	NN	NN	NN	NN	-	
73	07.05.81	NN	NN	NN	NN	-	
74	07.05.81	Y*	N	N	N	-	* As above
75	07.05.81	NN	NN	NN	NN	-	
76	07.05.81	NN	NN	NN	NN	-	
77	07.05.81	NN	NN	NN	NN	-	
78	07.05.81	Y	Y	N	N	-	
79	07.05.81	Y	N	Y*	N	-	* As above
80	07.05.81	NN	NN	NN	NN	-	
81	07.05.81	Y	Y	N	N	-	
82	07.05.81	N	Y	Y	N	-	
83	07.05.81	Y	N	N	N	-	
84	07.05.81	N	Y	N	Y(1)	-	
85	07.05.81	N	N	Y	N	-	
86	07.05.81	Y	Y	N	N	-	Fault signal
87	07.05.81	N	N	Y	Y(1)	-	

IDENTIFICATION (WITH FAULT/STOP IDENTIFICATION LIST)

Data Sheet No.	Date	I/TE	S/WE	SE	CE	I/TM	Remarks
88	07.05.81	X	X	X	X	-	
89	07.05.81	N	Y	N	N	-	
90	07.05.81	N	Y	Y(C)	N	-	
91	07.05.81	NN	NN	NN	NN	-	
92	07.05.81	Y	Y	N	N	-	Fault signal
93	08.05.81	NN	NN	NN	NN	-	Fault signal
94	08.05.81	N	N	Y	N	-	
95	08.05.81	NN	NN	NN	NN	-	
96	08.05.81	Y	Y	N	N	-	
97	08.05.81	N	Y	N	N	-	
98	08.05.81	NN	NN	NN	NN	-	
99	08.05.81	Y	N	Y	N	-	
100	08.05.81	NN	NN	NN	NN	-	
101	08.05.81	Y	N	N	N	-	
102	08.05.81	NN	NN	NN	NN	-	
103	08.05.81	NN	NN	NN	NN	-	
104	09.05.81	Y	Y	N	-	-	
105	09.05.81	N	Y	N	-	-	
106	09.05.81	Y	Y	N	-	-	VGS signal
107	09.05.81	Y	Y	N	-	-	Stop signal
108	09.05.81	Y	Y	N	-	-	
109	09.05.81	NN	NN	NN	-	-	
110	09.05.81	Y	N	N	-	-	
111	09.05.81	Y	N	N	-	-	Fault signal
112	09.05.81	NN	NN	NN	-	NN	
113	09.05.81	NN	NN	NN	-	NN	
114	09.05.81	NN	NN	NN	-	NN	
115	09.05.81	N	Y	Y	-	N	Fault signal
116	09.05.81	Y	Y	N	-	-	
117	09.05.81	Y	Y	N	-	-	
118	09.05.81	NN	NN	NN	-	-	
119	09.05.81	Y	Y	N	-	-	
120	09.05.81	Y	Y	N	-	-	
121	09.05.81	NN	NN	NN	-	-	
122	09.05.81	NN	NN	NN	-	-	
123	09.05.81	NN	NN	NN	-	-	
124	09.05.81	NN	NN	NN	-	-	
125	09.05.81	NN	NN	NN	-	-	
126	09.05.81	NN	NN	NN	-	-	
127	09.05.81	NN	NN	NN	-	-	
128	09.05.81	NN	NN	NN	-	-	
129	09.05.81	NN	NN	NN	-	-	
130	09.05.81	Y	Y	N	-	-	
131	15.05.81	Y	N	N	-	-	
132	15.05.81	Y	Y	N	-	-	
133	15.05.81	Y	Y	N	-	-	
134	15.05.81	Y	N	Y	-	-	
135	15.05.81	N	Y	N	-	-	
136	15.05.81	NN	NN	NN	-	-	

IDENTIFICATION (WITH FAULT/STOP IDENTIFICATION LIST)

Data Sheet No.	Date	I/TE	S/WE	SE	CE	I/TM	Remarks
137	15.05.81	NN	NN	NN	-	-	
138	15.05.81	X	X	X	-	-	
139	15.05.81	N	N	Y	Y(2=	-	
140	15.05.81	NN	NN	NN	NN	-	
141	15.05.81	NN	NN	NN	NN	-	
142	15.05.81	NN	NN	NN	NN	-	
143	15.05.81	N	NN	NN	NN	-	
144	15.05.81	Y	Y	N	N	-	
145	15.05.81	Y	Y	N	N	-	
146	15.05.81	X	X	X	X	-	
147	15.05.81	N	N	Y	N	-	
148	15.05.81	NN	NN	NN	NN	-	
149	15.05.81	X	X	X	X	-	
150	15.05.81	Y	Y	N	N	-	
151	15.05.81	NN	NN	NN	-	-	
152	15.05.81	NN	NN	NN	-	-	
153	15.05.81	NN	NN	NN	-	-	
154	15.05.81	NN	NN	NN	-	-	
155	15.05.81	NN	NN	NN	-	-	
156	15.05.81	NN	NN	NN	-	-	
157	15.05.81	NN	NN	NN	-	-	
158	15.05.81	NN	NN	NN	-	-	
159	15.05.81	NN	NN	NN	-	-	
160	15.05.81	N	Y	Y	-	-	
161	15.05.81	Y	Y	N	-	-	
162	15.05.81	Y	Y	Y	-	-	
163	15.05.81	Y	Y	N	-	-	
164	15.05.81	-	-	-	-	-	Simulated Signal
165	15.05.81	NN	NN	NN	-	-	
166	16.05.81	N2	N2	N4	N2	Y1	+ MA Team = 12
167	16.05.81	N	Y	N	N	Y	
168	16.05.81	N*	N	N	N	N	* Checked by MA with list
169	16.05.81	N	N	Y	N	Y	
170	16.05.81	N*	N	N	N	Y	* As above
171	16.05.81	Y	Y	N	N	Y	
172	16.05.81	Y	Y	Y	Y	Y	
173	16.05.81	Y	Y	Y	Y	Y	
174	19.05.81	Y	N	N	N	N	
175	21.05.81	Y	Y	Y	Y	Y	
176	21.05.81	NN	NN	NN	NN	NN	
177a	21.05.81	N	N	N	N	Y	
177b	21.05.81	N	N	N	N	Y	
178a	21.05.81	N	N	N	N	Y	
178b	21.05.81	Y	N	N	N	Y	
179	21.05.81	N	Y	N	N	N	
180	21.05.81	Y	N	N	N	N	
181	22.05.81	Y	N	N	-	N	
182a	22.05.81	NN	NN	NN	-	NN	
182b	22.05.81	X	X	X	-	X	
183	22.05.81	N	Y	N	-	N	

IDENTIFICATION (WITH FAULT/STOP IDENTIFICATION LIST)

Data Sheet No.	Date	I/TE	S/WE	SE	CE	I/TM	Remarks
184a	22.05.81	N	N	N	-	Y	
184b	22.05.81	N	N	Y	-	N	
185	22.05.81	NN	NN	NN	-	NN	
186	22.05.81	NN	NN	NN	-	NN	
187	22.05.81	Y	N	N	-	Y	
188	22.05.81	N	N	N	-	Y	
189	22.05.81	N	Y	N	-	Y	
190	22.05.81	Y	Y	N	-	Y	
191	22.05.81	NN	NN	NN	-	NN	
192	22.05.81	NN	NN	NN	-	NN	
193	22.05.81	Y	Y	N	-	N	
194	12.06.81	N	Y	N	-	N	
195	12.06.81	N	Y	N	-	N	
196a	12.06.81	N	N	N	-	N	
196b	12.06.81	N	N	N	-	Y	
197	12.06.81	N	Y	N	-	N	
198	26.06.81	Y	N	N	-	N	
199a	24.07.81	N	N	N	-	Y	
199b	24.07.81	N	Y	N	-	N	
200a	24.07.81	N	Y	N	-	N	
200b	24.07.81	NN	NN	NN	-	NN	
201	24.07.81	Y	N	N	-	N	
202	27.07.81	N	Y	N	-	N	
203	27.07.81	N	Y	N	-	Y	
204	27.07.81	Y	N	Y	-	N	
205	27.07.81	X	X	X	-	X	
206	27.07.81	X	X	X	-	X	
207	29.07.81	N	Y	N	-	Y	
208	29.07.81	NN	NN	NN	-	NN	
209	04.08.81	N	N	Y	-	N	
210	04.08.81	N	Y	N	-	N	
211	23.09.81	N	Y	N	AE (6)	N	AE = Acceptance Engineers
212	23.09.81	N	Y	N	N	N	
213a	24.09.81	N	Y	N	N	N	
213b	24.09.81	NN	NN	NN	NN	NN	
214	24.09.81	NN	NN	NN	NN	NN	
215	24.09.81	NN	NN	NN	NN	NN	
216	24.09.81	-	-	-	-	-	No list available
217	25.09.81	N	Y	N	N	N	
218	25.09.81	N	Y	N	N	Y	
219	25.09.81	N	N	N	Y(1)	N	
220	25.09.81	NN	NN	NN	NN	NN	
221	25.09.81	NN	NN	NN	NN	NN	
222a	25.09.81	N	Y	N	N	Y	
222b	25.09.81	NN	NN	NN	NN	NN	
223	25.09.81	N	Y	N	N	Y	
224	25.09.81	NN	NN	NN	NN	NN	
225a	25.09.81	NN	NN	NN	NN	NN	

IDENTIFICATION (WITH FAULT/STOP IDENTIFICATION LIST) Sheet 6

Data Sheet No.	Date	I/TE	S/WE	SE	CE	I/TM	Remarks
225b	25.09.81	N	Y	N	N	Y	
225c	25.09.81	N	Y	N	N	Y	
226	25.09.81	Y	N	Y	Y	N	
227	25.09.81	Y	Y	Y	Y	Y	
228	25.09.81	NN	NN	NN	NN	NN	
229	25.09.81	Y	Y	Y	Y	Y	
230	25.09.81	NN	NN	NN	NN	NN	
231	25.09.81	N	Y	N	N	N	

APPENDIX D

Signal Stimuli-Causal Factors Table

The collated observed and recorded data for human error, normal fluctuations of the parameters and the hardware/software problem areas evaluated

SIGNAL STIMULI - CAUSAL FACTORS

Data Sheet No.	Date	Eva-luated	Problem	NFP	Human Error	Remarks
1	03.04.80	Y	H	Y	N	Y = Yes
2	23.07.80	Y	H	N	Y	N = No
3	23.07.80	Y	S	N	N	H = Hardware
4	23.07.80	Y	H	N	Y	S = Software
5	23.07.80	Y	H	N	N	
6	09.10.80	Y	H	Y	N	
7	09.10.80	Y	H	N	N	
8	09.10.80	Y	H	Y	N	
9	09.10.80	N	H	Y	N	
10	09.10.80	N	H	Y	N	
11a	09.10.80	Y	S	Y	N	
11b	09.10.80	Y	H	N	N	
12	10.10.80	Y	H	N	N	
13a	10.10.80	Y	H	N	N	
13b	10.10.80	Y	S	Y	N	
14a	10.10.80	Y	S	Y	N	
14b	10.10.80	Y	S	Y	N	
15	11.10.80	Y	H/S	Y	N	
16	13.10.80	Y	H	Y	N	
17	13.10.80	Y	H	N	N	
18	13.10.80	Y	H	N	Y	
19	04.11.80	Y	H	N	N	
20	12.11.80	Y	H	N	N	
21	12.01.81	Y	S	N	N	
22	13.01.81	Y	S	N	Y	
23	13.01.81	Y	H	Y	N	
24	13.01.81	Y	H/S	Y	N	
25	15.01.81	Y	H	N	N	
26	15.01.81	Y	H/S	Y	N	
27	15.01.81	Y	N	Y	N	
28	15.01.81	Y	H	Y	N	
29	15.01.81	Y	H	Y	N	
30	15.01.81	N	Y	N	N	
31	16.01.81	Y	H	N	Y	
32	16.01.81	Y	H	N	N	
33	16.01.81	Y	H	Y	N	
34a	16.01.81	Y	S	Y	N	
34b	16.01.81	Y	H/S	N	N	
35	16.01.81	Y	H	N	N	
36	16.01.81	Y	S	N	N	
37a	16.01.81	Y	S	Y	N	
37b	16.01.81	Y	H	Y	N	
38a	16.01.81	Y	S	N	Y	
38b	16.01.81	N	H	N	N	
39	16.01.81	Y	S	Y	N	
40	17.01.81	Y	H	N	N	
41	20.02.81	Y	H	N	N	
42	20.02.81	N	H	N	N	
43	20.02.81	Y	H	N	N	
44	20.02.81	Y	S	N	N	

SIGNAL STIMULI - CAUSAL FACTORS

Data Sheet No.	Date	Evaluated	Problem	NFP	Human Error	Remarks
45	20.02.81	N	S	N	N	
46	20.02.81	N	H	N	N	
47	27.04.81	Y	H	N	N	
48a	30.04.81	Y	S	N	Y	
48b	30.04.81	Y	H	Y	N	
49	30.04.81	Y	H	N	N	
50a	30.04.81	Y	H	Y	N	
50b	30.04.81	Y	H	N	N	
51	30.04.81	N	H	N	N	
52a	04.05.81	N	H	N	N	
52b	04.05.81	Y	S	N	Y	
53a	04.05.81	Y	H	Y	N	
53b	04.05.81	Y	H	N	N	
54a	04.05.81	N	H	N	N	
54b	04.05.81	N	S	N	Y	
55a	05.05.81	Y	H	N	N	
55b	05.05.81	Y	S	N	Y	
56	05.05.81	Y	H	Y	N	
57	05.05.81	Y	H	Y	N	
58	05.05.81	Y	H	Y	N	
59a	05.05.81	Y	S	N	Y	
59b	05.05.81	Y	H	N	N	
60	06.05.81	Y	H	N	N	
61	06.05.81	Y	S	N	Y	
62	06.05.81	Y	H	N	Y	
63	06.05.81	Y	H/S	Y	Y	
64	06.05.81	Y	H	Y	N	
65	06.05.81	Y	H	N	N	
66	07.05.81	Y	H	N	Y	
67	07.05.81	Y	H	N	N	
68	07.05.81	Y	H	N	Y	
69	07.05.81	Y	S	N	Y	
70	07.05.81	Y	H	N	N	
71	07.05.81	Y	H/S	N	N	
72	07.05.81	Y	H/S	N	N	
73	07.05.81	Y	S	N	N	
74	07.05.81	Y	H	N	N	
75	07.05.81	N	S	N	N	
76	07.05.81	N	S	N	N	
77	07.05.81	N	S	N	N	
78	07.05.81	Y	H	N	N	
79	07.05.81	Y	H	N	N	
80	07.05.81	Y	H	N	N	
81	07.05.81	Y	H	Y	N	
82	07.05.81	Y	H	N	N	
83	07.05.81	Y	H	Y	N	
84	07.05.81	Y	H/S	N	Y	
85	07.05.81	Y	H	Y	N	
86	07.05.81	Y	H	N	Y	
87	07.05.81	Y	H	Y	N	

SIGNAL STIMULI - CAUSAL FACTORS

Data Sheet No.	Date	Evaluated	Problem	NFP	Human Error	Remarks
88	07.05.81	Y	H/S	Y	N	
89	07.05.81	Y	H/S	Y	N	
90	07.05.81	Y	H	Y	N	
91	07.05.81	N	H	Y	N	
92	07.05.81	Y	H	N	Y	
93	08.05.81	Y	H	Y	N	
94	08.05.81	Y	H	N	N	
95	08.05.81	Y	H	N	N	
96	08.05.81	Y	H	Y	N	
97	08.05.81	Y	H	Y	N	
98	08.05.81	Y	H/S	N	N	
99	08.05.81	Y	H	Y	N	
100	08.05.81	Y	H	Y	N	
101	08.05.81	Y	H	Y	N	
102	08.05.81	Y	H	N	N	
103	08.05.81	N	H	N	N	
104	09.05.81	N	H	N	N	
105	09.05.81	Y	H	N	Y	
106	09.05.81	Y	H	N	Y	
107	09.05.81	Y	H	Y	N	NFP = Stop signal
108	09.05.81	Y	H	Y	N	
109	09.05.81	Y	H	Y	N	
110	09.05.81	Y	H	N	N	
111	09.05.81	Y	H	N	N	
112	09.05.81	N	H	N	N	
113	09.05.81	N	H	N	N	
114	09.05.81	N	H	Y	N	
115	09.05.81	N	H	N	N	
116	09.05.81	Y	H	Y	N	
117	09.05.81	Y	H	Y	Y	NFP = Fault Signal-Human Error = S
118	09.05.81	N	H	Y	N	
119	09.05.81	N	H	Y	N	
120	09.05.81	N	H	Y	N	
121	09.05.81	Y	H	Y	N	
122	09.05.81	N	H	N	N	
123	09.05.81	N	H	Y	N	
124	09.05.81	N	H	N	N	
125	09.05.81	N	H	Y	N	
126	09.05.81	N	H	Y	N	
127	09.05.81	N	H	Y	N	
128	09.05.81	N	H	Y	N	
129	09.05.81	N	H	N	N	
130	09.05.81	Y	H	N	N	
131	15.05.81	Y	H	N	N	
132	15.05.81	Y	H	N	N	
133	15.05.81	Y	H/S	N	N	
134	15.05.81	Y	H	N	Y	
135	15.05.81	Y	S	N	Y	
136	15.05.81	Y	H	N	N	

SIGNAL STIMULI - CAUSAL FACTORS

Data Sheet No.	Date	Eva-luated	Problem	NFP	Human Error	Remarks
137	15.05.81	Y	H/S	N	Y(P)	
138	15.05.81	Y	S	N	Y	
139	15.05.81	N	H/S	N	N	
140	15.05.81	N	S	N	Y	
141	15.05.81	N	H/S	N	N	
142	15.05.81	N	H	N	N	
143	15.05.81	N	H/S	N	N	
144	15.05.81	Y	S	N	Y	
145	15.05.81	Y	S	N	Y	
146	15.05.81	Y	H	Y	N	
147	15.05.81	N	H	N	N	
148	15.05.81	N	H/S	N	N	
149	15.05.81	N	H	Y	N	
150	15.05.81	Y	S	N	Y	
151	15.05.81	Y	H/S	N	N	
152	15.05.81	Y	H/S	N	N	
153	15.05.81	N	H/S	N	N	
154	15.05.81	Y	H	N	N	
155	15.05.81	N	H/S	N	N	
156	15.05.81	N	H	N	N	
157	15.05.81	N	H/S	N	N	
158	15.05.81	N	H	N	N	
159	15.05.81	N	H/S	N	N	
160	15.05.81	Y	H	N	N	
161	15.05.81	Y	S	N	N	
162	15.05.81	Y	H	Y	N	
163	15.05.81	Y	S	N	N	
164	15.05.81	-	-	-	-	Simulated signal
165	15.05.81	N	S	N	N	
166	16.05.81	Y	H	Y	N	
167	16.05.81	Y	H	Y	N	
168	16.05.81	Y	S(MHF)	Y(VGS)	N	
169	16.05.81	N	H	N	N	
170	16.05.81	Y	H	N	N	
171	16.05.81	Y	H	N	N	
172	16.05.81	Y	H	N	N	
173	16.05.81	Y	H	N	Y	
174	19.05.81	Y	-	N	Y	
175	21.05.81	Y	S	Y	N	
176	21.05.81	N	H	N	N	
177a	21.05.81	Y	H	N	N	
177b	21.05.81	Y	S	Y	N	
178a	21.05.81	Y	S	N	N	
178b	21.05.81	Y	H	Y	N	
179	21.05.81	Y	H	N	N	
180	21.05.81	Y	S	N	N	
181	22.05.81	Y	H/S	N	N	
182a	22.05.81	N	H/S	N	N	
182b	22.05.81	Y	S	Y	N	

SIGNAL STIMULI - CAUSAL FACTORS

Data Sheet No.	Date	Eva-luated	Problem	NFP	Human Error	Remarks
184a	22.05.81	Y	S	N	N	
184b	22.05.81	Y	H	N	Y	
185	22.05.81	Y	H	N	Y	
186	22.05.81	Y	H	N	N	
187	22.05.81	Y	H	N	N	
188	22.05.81	Y	S	N	N	
189	22.05.81	Y	S	N	N	
190	22.05.81	Y	S	N	N	
191	22.05.81	Y	H	Y	N	
192	22.05.81	Y	H	Y	N	
193	22.05.81	Y	H/S	N	N	
194	12.06.81	Y	H	N	Y	
195	12.06.81	Y	H	N	N	
196a	12.06.81	Y	H	Y	N	
196b	12.06.81	Y	H	Y	N	
197	12.06.81	Y	H	Y	N	
198	26.06.81	Y	S	N	N	
199a	24.07.81	Y	H	Y	N	
199b	24.07.81	Y	H	Y	N	
200a	24.07.81	Y	H	-	-	
200b	24.07.81	Y	H	Y	N	
201	24.07.81	Y	S	N	N	
202	27.07.81	Y	S	N	N	
203	27.07.81	Y	H	N	N	
204	27.07.81	Y	H	N	Y	
205	27.07.81	N	-	N	N	
206	27.07.81	-	-	-	-	
207	29.07.81	Y	H	N	N	
208	29.07.81	Y	S	N	N	
209	04.08.81	Y	H	N	Y	
210	04.08.81	N	S	N	N	
211	23.09.81	Y	H	Y	N	
212	23.09.81	Y	H	N	N	
213a	24.09.81	Y	H	Y	N	
213b	24.09.81	Y	H	N	N	
214	24.09.81	Y	H	Y	N	
215	24.09.81	N	H	N	N	
216	24.09.81	Y	H	Y	N	
217	25.09.81	Y	H	N	Y	
218	25.09.81	Y	H	Y	N	
219	25.09.81	Y	S	N	N	
220	25.09.81	Y	H	N	N	
221	25.09.81	Y	H	Y	N	
222a	25.09.81	Y	S	N	N	
222b	25.09.81	Y	H	Y	N	
223	25.09.81	Y	H	Y	N	
224	25.09.81	N	H	Y	N	
225a	25.09.81	Y	H	N	N	

SIGNAL STIMULI - CAUSAL FACTORS

Data Sheet No.	Date	Eva-luated	Problem	NFP	Human Error	Remarks
225b	25.09.81	Y	H	N	N	
225c	25.09.81	Y	H	N	N	
226	25.09.81	Y	H	Y	N	
227	25.09.81	Y	S	N	Y	
228	25.09.81	Y	H	Y	N	
229	25.09.81	Y	H	Y	N	
230	25.09.81	N	H	Y	N	
231	25.09.81	Y	S	N	N	

APPENDIX E

Research Data Collection Format - Description

A brief description of the format used during the period of research plus the rationales for the inclusion of specific items pertinent to the research

Research Data Collection Format

The research data recording proforma, Figure 8.1, loc cit., (ch.: 8.0.), starts with the basic essentials i.e., date and time the observations were made.

This is followed by "Personnel Present" and was viewed as essential if comparisons were to be made possible between the various team members in terms of their perception, information processing and response performance to the signal-stimuli generated by the machine system, out-of-tolerance condition.

Experiment and Support Elements are well documented, loc cit., (ch.: 3.0., para: 3.2.), and are included on the format to enable identification of the interface effects between them, and the subsequent signal stimuli which may be generated by them in an adverse system condition.

Related to these elements described above is the type of test function being performed when a signal stimuli is generated, as the test itself either via the software or the hardware may be the cause of the out-of-tolerance condition shown by the warning system-signal stimuli.

The space for "Observations" was provided to enable those anomalies that do not fit into the normal pattern of events to be evaluated and the results tabulated, because they may shed light with other anomalies evaluated as to their probable cause.

As shown by the format Figure 8.1, the boxes for Recognition, Evaluation, NFP (Normal Fluctuation of the Parameters), and Human Error only require a simple 'Yes' (Y) or 'No' (N) to satisfy the requirement. On the other hand 'attention' has been divided into two positive parts 'Immediate' (I) and 'Delayed' (D) so that both responses could be observed and recorded. The rationale for the inclusion of delayed attention, is because it was felt to be a factor which should be given due consideration, for example, there are many instances where we may have thought that our attention was immediate, when in reality there has been a pause-a-delay-seemingly so small and insignificant that it can be ignored. However, such hesitancy on the part of an operator, no matter how slight, could be of extreme concern in complex man-machine systems, and could be due to some causal factor which has not been noted in prior research.

A space has also been included on the format to enable the recording of those instances where the operators either collectively or individually failed to recognise the intent of the signal-stimulus presented, and needed recourse to the "Stop/Fault Identification Number List", to achieve total recognition. Even though the "Stop/Fault Identification Number List", identifies those causal factors for the stop or fault signal stimulus generated, it is still essential during the development and test phases of the "Material

Science Double Rack", for the operators to evaluate and verify that the underlying cause of the machine condition displayed is either the one which is listed, or if not, establish if the cause is due to some 'hardware' or 'software' malfunction or failure.

As the machine system model will be undergoing a certain amount of development testing, it provides a unique opportunity to observe and record those normal fluctuations of the machine system parameters which occur, and to evaluate these occurrences in terms of their possible consequences on operator performance.

Likewise, human error also needs to be recorded and evaluated, primarily to try and understand the mechanism, or failure of the mechanism, which allows them to occur, and the secondary effect of possibly creating the potential for a machine system hazard.