Ergonomic keyboard

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ABSTRACT

The problem considered is to apply industrial design methodology to the design of an ergonomically sound computer keyboard.

The procedure followed includes an analysis of ergonomic papers relevant to keyboard design, a study of patent and other documents on previously designed keyboards, and analysis of data on computer operation. The results are used to formulate a design brief which is then used as the basis for design development.

The results indicate commercially available keyboards do not, in the main, attempt to solve fundamental ergonomic problems. They have evolved out of the typewriters of the last century and still conform to that basic layout. In Australia and other countries standards are either nonexistent or tend to follow those created by the larger manufacturers. The ergonomic requirements of keyboard design are well documented and many attempts have been made to apply them. Most of these have failed to have any significant effect on the main stream of keyboard design.

Conclusion; a product entering into this intransigent market, has to offer features which generate a perceived need in the prospective purchaser. This has been done by including features not available on other products, the final design allows lap top operation of a personal computer.
without cables or other impediments to movement. This opens up the possibility of a whole new approach to office layout and posture.

"I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person nor material which to a substantial extent has been accepted for the award of any other degree or diploma of a university or other institute of higher learning, except where due acknowledgement is made in the text."
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A. WORK STATION ERGONOMIC PAPER

IV
The purpose of this project is "to improve the man machine interface" for computers. It is debatable as to whether or not the computer industry has failed to come to terms with user problems at the man machine interface. However there are a significant number of documents criticising the products of this industry and proposing better ergonomic solutions, this is an indicator that there are major problems. There are two areas that have shown some significant improvement in the past 20 years, these are, the quality of the display, and the reduction of keyboard height. In other areas, there has been little progress.

Countering these improvements are the increase in the number of keys on the keyboard and the trend towards putting more and more hardware into or under the display unit.

Currently solving the problems of interfacing these products with the operator, is left to the furniture designer. A whole industry has developed in Australia, dedicated to servicing the need to match inappropriately designed computers, with an anthropologically variable user population. The products of this industry are generally typical of any embryonic industry, groping for form and direction in an uncertain marketplace.

Aggravating the situation is the ever increasing problem of managing the cables feeding to and from the computer.
When taken as a group, the problem of accommodating the operator, the computer, the display, the keyboard and all of the associated cabling is insurmountable, without a new approach, and is only currently being overcome by excessive compromise. The evidence for this can be found in many Australian offices where computer equipment is used, even the best systems furniture needs some tailoring to fit the needs of specific users, and once installed is difficult to reconfigure. Ref. Fig.1.1.

The first step to solving the problem could be to break the _ide'e fixe_ of desks as a computer support. The two are incompatible in many respects, particularly depth of the work surface and working height Ref.appendix A. For clerical work a minimum depth of 600mm and a maximum of 800mm is suitable, a computer on the other hand requires a minimum depth of 900mm and at the extreme can only be accommodated on a 1200mm deep work surface.

When laying out an office, if the computer size dictates the selection of desk depth, a significant amount of floor space is wasted. Typically on an 'L' shaped work station measuring 1800 x 1800mm a strip 100mm x 3700mm would be wasted or 0.37sq m per work station by increasing the work station to 1900 x 1900mm to achieve the same level of
FIGURE 1.1 REAR VIEW OF A COMPUTER WORK STATION MANUFACTURED BY A LEADING GERMAN MANUFACTURER.
accommodation. An alternative to this is to fix the position that the computer occupies in the corner of the 'L' shaped configuration, this gives adequate depth for the computer at the same time as allowing the clerical area to be optimised for the task. The keyboard can also be accommodated on an independently adjustable platen, housed in the corner.

The disadvantages of this solution are that it takes away the freedom to place the computer in any other position, it splits the work area in two and it thereby reduces flexibility in interior design.

By redesigning the keyboard it will be shown to be possible to provide an improved ergonomic solution and at the same time provide:

1) Greater freedom in workplace layout
2) Reduced complexity in furniture design
3) Reduced floor space for each workplace
The primary objective of the project is to improve the man machine interface for computer operation, exploring the use of chair mounted controls as a core feature.

Secondary objectives are to improve the options available for positioning hardware. To allow more elegant solutions to the general office furnishing by reducing the ergonomic constraints imposed by conventional computer controls.

The source material will be drawn from ergonomic studies on keyboard design, data management techniques and office design studies.

Chair mounted controls allow new postural possibilities to be explored, these are to be checked against ergonomic studies and possible work place designs.

The problems to be solved is defined in terms of the modern office and the problem of accommodating a personal computer and its peripherals.

The initial design study should include the following:

1) The relationship between operator and display
2) Methods of communication
3) Storage devices
4) Output devices
5) Relationship between operators
6) General operating environment
7) Compatibility with future offices
8) Typical task design scenarios
9) Competitive products – present and future

Reference Data

1) Ergonomic Studies from Human Factors etc.
2) Patent Documents, Australian and Foreign
3) Trade Literature, relevant product brochures
4) Experimental rigs and models
5) The Preliminary Design Exercise

From the above reference data, a design brief is to be prepared. This will serve as a starting point for the design process, the first stage of which is the preparation of conceptual sketches.

From the conceptual sketches, a design is to be selected and this will serve as a basis for the final design. Working drawings are to be prepared and a model constructed.

The final report will also discuss the features of the product, its target market, possible alternative approaches and suggestions for future research.
ERGONOMIC KEYBOARD METHODOLOGY

This project was commenced in 1987, prior to this a considerable amount of data had been collected. Consolidating these data yielded leads on other relevant documents which were acquired.

A literature search was conducted to collect data on keyboards, office environment and human interaction with computers. This search was conducted in the university library. Ergonomic papers on keyboards yielded the most specific information. It is a popular subject for ergonomists and much has been written on the subject. All titles containing the word keyboard were manually checked and sorted, other keywords used in the search were office and environment. Other searches included Design magazine (UK) 1970 to 1988, Machine Design (USA) 1985 to 1988, Design World 1985 to 1988.

The writers work over the past 10 years has involved the design of furniture for computer operators, this experience provides a considerable amount of undocumented and anecdotal information which has been drawn on.

Whilst Kroemers paper [1] forms a keystone for this project. Its significance is more apparent in retrospect. Many of the conclusions reached in this paper may seem obvious to the keyboard designer, only after construction and testing of
the arm rest keyboard prototype, did the key advantages and disadvantages of the design philosophies in this work become apparent.

The research/design approach used in this project is one in which there is an ongoing interaction between the design and research activities. Research data is explored through design studies and the product is progressively moulded to its final form, this helps in avoiding mind sets at the conceptual stage but still allows the project to be drawn to an informed conclusion.
4.1 ERGONOMIC PAPERS

It would not be unreasonable to state that tradition, fashion and manufacturing convenience have all had far more influence on keyboard design than ergonomics. The numerous papers written on the subject and the hours of research work carried out, have generally, had no effect. This is not to say that this will always be so and with the huge ground swell of ergonomic opinion behind it, the first ergonomic keyboard that also has substantial fashion appeal, could possibly win a substantial market share.

4.1.1 KROEMER : HUMAN ENGINEERING THE KEYBOARD [1]

This paper documents the state the art (for split keyboards) up to 1972. The paper was published one year after Intel patented the first micro processor, one could have hoped the former would have had greater influence on the products developed out of the latter, but this was not to be.

Kroemer summarises, in English, work previously only available in German and relates the results to studies by Kreamer & Trumbo and Webb & Coburn, he further states his intention "to point out some musculophysiological (biomechanical) aspects that may have considerable bearing on postural deficiencies and ailments found with keyboard operators" and "to draw attention to hitherto neglected
human factors problems connected with keyboard design and key operation".

Kroemer discusses Klockenbergs work on typist fatigue and notes with interest "the suggestion to tilt the keyboard sections allotted to each hand concurrently to the left and right sides, respectively,". The obviousness of this conclusion is well illustrated in Fig. 4 of Ferguson & Duncan (Paper on Keyboard Design and Operating Posture [2]), where a male operator is shown trying to cope with a keyboard on a teleprinter. It is significant that a female operator, in the same situation, would have fewer problems, being on average narrower in the shoulders and less muscular.

Kroemer goes on to discuss the static muscle loads involved in maintaining the pronated hand over a conventional keyboard and the consequences of lifting the elbows to try and compensate. He further states "in fact, some muscles are involved in both static holding and dynamic moving. Hence, muscular strain can occur easily in the standard typing position".

The solution to this, he believes, lies in changing the spacial orientation of the keyfields. It would be difficult to argue with this, particularly if we compare Figure 4 in Kroemer's paper [1] with Figure 4 in Ferguson & Duncan's paper [2]. The improvement in the arm and hand orientation, as
well as general posture, is obvious. Kroemer cites the work of Webb & Coburn (1959) and notes their use of hand curved rows and five (5) straight columns of keys. This provides a particularly simple layout, with a lot of user appeal. This concept was supported in Kroemer's paper.

In his analysis of Creamer & Trumbos' (1960) work, Kroemer noted that the highest error rates in their experiments were with the horizontal keyboard, with forty four or sixty six degrees of declination being the preferred solution.

Kroemer conducted an experiment to establish the "preferred posture of forearms and hands" and he compares the results with figures extrapolated from Klockenberg's work. Kroemer makes no comment about the result he has obtained from this experiment. The differential movement that results in the palm angle rotating relatively, only forty five degrees, when the upper arm moves through an angle of ninety degrees, requires further explanation.

Kroemer goes on to describe the construction and testing of a keyboard based on his findings and those of others. He produces a convincing argument for the curved row and straight column key configuration, adjustable height keyboards and declinated keyboard halves. Another significant point was the "separation of the key sets"
allotted to each hand seems to facilitate tactile locating of the correct key”.

4.1.2 ALDEN ET AL: KEYBOARD DESIGN AND OPERATION [3]

This paper "reviews much of the applied research on the operator keyboard interface".

Some of the information in this paper is of particular interest to the keyboard designer. They cite Dvorak et al (1936) on tapping rate (capability) declining from index finger to little finger and Haaland (1962) confirming this and adding that "the thumb is the most resistant to fatigue". Haaland also found that "lateral force resulting in more rapid fatigue than downward force". They also state "extreme ranges of the thumb's motion are to be avoided in keyboard design".

Also worthy of note, is the statement, regarding short term memory breakdown and its relationship to errors that result from random letter placement in keyboard layout. One may assume that a more orderly keyboard layout may reduce the error rate when typing.

The paper also contains much discussion on aptitude testing of potential typists. This is something that may have been relevant in 1972, when the paper was published, however today the situation is quite different and specialist...
typists could well end up the minority of keyboard users, with almost every occupation now requiring some level of keyboard literacy. For this reason it is even more desirable to make the machine fit the person.

Under the section dealing with key pressing skills, the paper cites Shaffer & Hardwick (1969) as having substantiated that a student should have complete sight of the keyboard, "this maximises the acquisition of keyboard character location and good stroking technique". This supports the clear layout concept, for keyboard design. The seemingly random placement of keys on the conventional keyboard is difficult to visualise as any sort of related order.

The paper also discussed feedback, West (1967) is cited and the statement "performance with kinesthetic feedback alone was always poorer than with all-senses feedback". This is most important when testing a prototype keyboard, it is essential that full feedback is provided rather than, for example a keyboard with dummy keys, which, produces misleading results.

In dealing with "individual key characteristics" the absence of consistent standards and expert opinion is attributed to the fact that "keyboard manufacturers have generally selected their own design criteria for individual keys".
When discussing key parameters, Alden et al cite the work of Deininger (1960) regarding "button top size" who found that increasing the size of a square button top from 9.5mm to 17.4mm "reduced keying times" by over 8% whilst reducing errors from 7.3% to 1.3%. It is not stated whether the pitch of the keys was greater than the key top size. The format for the test was a ten (10) key numeric pad. Deininger also found that varying the key force from 0.97N to 3.92N had an insignificant effect on performance as did varying the displacement from 0.8mm to 4.8mm. However Alden et al cite Kinkead & Gonzalez (1969) who "found that throughput was best when both force and displacement were at relatively low levels. They recommend as optimal operating point key forces of between" 0.25N and 1.47N and "total key displacements between" 1.3mm and 6.4mm.

Key groupings are also addressed in their paper and an analysis of various work undertaken to compare QWERTY, DVORAK and alphabetical keyboards leaves the QWERTY arrangement in a reasonably strong position.

There is also considerable discussion on cordal type keyboards, where each letter has a code either the same as or of the ASCII type. The statement "cording is the principle which underlies the Stenowriter stenotype machine (Galli, 1960) and the Word-Writing machine (Ayres, 1965). Performance claims of 200-300wpm have been made for these
machines. Using this technique could lead to a product of radical and compact design, however the marketing aspects may rule such a product out.

Alden et al also analysed the available literature on keyboard slope, tilt and size. The final paragraph from this paper is "The general conclusion which may be drawn from the above is that key-pressing performance by experienced typists appears to remarkably stable over a wide range of key-board slopes, tilts, sizes and shapes". This leaves the designer with considerable latitude, however the various relevant standards and anthropometric data would also help determine the final values for these parameters.

Finally Alden et al sound a note of caution in taking evidence from users of keyboards, in their statement "therefore, one may conclude that preference rating must be interpreted very cautiously and should seldom, if ever, be the sole basis for design recommendations." this statement was however based on anecdotal evidence.

4.1.3 FERGUSON AND DUNCAN: KEYBOARD DESIGN AND OPERATING POSTURE [2]

This paper principally deals the postural problems associated with a poorly designed workstation used by telegraphists. The authors also extend the study into the
general keyboard design area.

A substantial part of the paper is devoted to an analysis of the load on individual fingers. The authors took a sample of text from a number of sources totalling 7000 characters and analysed them with regard to finger load on the various keyboards examined.

For comparison table [4.1] has been prepared, this is based on part of the text from an earlier draft of Chapter 5 of this thesis. A total of 9529 characters plus non print characters, shift, space etc. were counted. Figure [4.2] was also extrapolated from these quantities. Ferguson & Duncan cite Dvorak as having found 57% to 43% left hand to right hand loading respectively and 32% loading on the middle row of keys to 52% on the back row of keys, in an analysis of the QWERTY keyboard. These figures are very close to those in Figure [4.2] which may be coincidence. What is certain is that the percentages of key usage will vary with many factors, such as, the type of industry, geographical location, time and the vocabulary of those that create the text.

Ferguson & Duncan found different figures to those above, these are shown in Figure [4.2], however these are minor differences and do not invalidate the opinion of many ergonomists that the QWERTY keyboard is not well suited to typing English text.
Ferguson & Duncan state "figures 8 and 9, being derived from a restricted analysis of copy, can be regarded only as a basis for development". This implies that to re-design the keyboard would require a larger sample. However the parameters used for gathering this would need to be carefully defined, to take a representative example of all the text typed in Australia alone, would not suffice. This is because a great deal of typing is carried out in controlled vocabulary environments, government departments etc. Analysing data gathered would need to be carried out against a control based on less transitory text, perhaps gathered from sources such as newspapers, journals of various types etc. There is also the international scene to be considered.

The authors also produced a suggested typewriter keyboard layout. This shows a keyboard that falls part way between the traditional layout and that of Klockenberg, with Ferguson & Duncan's suggested key allocations.

To summarise, the authors attribute shoulder flexion, shoulder abduction, wrist extension and ulnar deviation to this workplace design, all of which are undesirable. Their keyboard design used in conjunction with proper seating and appropriate height settings would be a substantial improvement.
### TABLE [4.1] (Sourced from a draft of chapter 5)

<table>
<thead>
<tr>
<th>LETTER</th>
<th>QTY</th>
<th>%</th>
<th>LETTER</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>720</td>
<td>7.55</td>
<td>E</td>
<td>12.6</td>
</tr>
<tr>
<td>B</td>
<td>213</td>
<td>2.23</td>
<td>T</td>
<td>9.86</td>
</tr>
<tr>
<td>C</td>
<td>275</td>
<td>2.88</td>
<td>O</td>
<td>7.76</td>
</tr>
<tr>
<td>D</td>
<td>380</td>
<td>3.99</td>
<td>A</td>
<td>7.55</td>
</tr>
<tr>
<td>E</td>
<td>1200</td>
<td>12.6</td>
<td>N</td>
<td>6.5</td>
</tr>
<tr>
<td>F</td>
<td>220</td>
<td>2.3</td>
<td>I</td>
<td>6.5</td>
</tr>
<tr>
<td>G</td>
<td>153</td>
<td>1.6</td>
<td>R</td>
<td>5.98</td>
</tr>
<tr>
<td>H</td>
<td>442</td>
<td>4.64</td>
<td>S</td>
<td>5.88</td>
</tr>
<tr>
<td>I</td>
<td>620</td>
<td>6.5</td>
<td>H</td>
<td>4.64</td>
</tr>
<tr>
<td>J</td>
<td>17</td>
<td>0.18</td>
<td>D</td>
<td>3.99</td>
</tr>
<tr>
<td>K</td>
<td>150</td>
<td>1.57</td>
<td>L</td>
<td>3.51</td>
</tr>
<tr>
<td>L</td>
<td>335</td>
<td>3.51</td>
<td>C</td>
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<td>M</td>
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<td>M</td>
<td>2.57</td>
</tr>
<tr>
<td>O</td>
<td>740</td>
<td>7.76</td>
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<td>2.3</td>
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<tr>
<td>P</td>
<td>262</td>
<td>2.75</td>
<td>U</td>
<td>2.23</td>
</tr>
<tr>
<td>Q</td>
<td>6</td>
<td>0.06</td>
<td>B</td>
<td>2.23</td>
</tr>
<tr>
<td>R</td>
<td>570</td>
<td>5.98</td>
<td>Y</td>
<td>2.13</td>
</tr>
<tr>
<td>S</td>
<td>560</td>
<td>5.88</td>
<td>G</td>
<td>1.6</td>
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<td>1.46</td>
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<td>112</td>
<td>1.17</td>
<td>V</td>
<td>1.17</td>
</tr>
<tr>
<td>W</td>
<td>139</td>
<td>1.46</td>
<td>.</td>
<td>1.11</td>
</tr>
<tr>
<td>X</td>
<td>14</td>
<td>0.14</td>
<td>,</td>
<td>0.73</td>
</tr>
<tr>
<td>Y</td>
<td>203</td>
<td>2.13</td>
<td>J</td>
<td>0.18</td>
</tr>
<tr>
<td>Z</td>
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<td>0.14</td>
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<td></td>
<td>106</td>
<td>1.11</td>
<td>Q</td>
<td>0.06</td>
</tr>
<tr>
<td></td>
<td>70</td>
<td>0.73</td>
<td>Z</td>
<td>0.04</td>
</tr>
</tbody>
</table>

**NOTE:** Total characters 9529 + non print characters.
70% of the occurrences of 'H' are preceded by 'T'

**NON PRINT CHARACTERS EXPRESSED AS A % OF THE TOTAL ABOVE:**

- RETURN = 8.81
- SHIFT = 1.11
- SPACE = 16.6
### Table 4.2

#### Finger and Hand Loading

<table>
<thead>
<tr>
<th></th>
<th>Left Hand</th>
<th>Right Hand</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>57.74%</td>
<td>42.18%</td>
</tr>
<tr>
<td>Q</td>
<td>7.65%</td>
<td>18.25%</td>
</tr>
<tr>
<td>W</td>
<td>7.48%</td>
<td>8.8%</td>
</tr>
<tr>
<td>E</td>
<td>19.67%</td>
<td>12.38%</td>
</tr>
<tr>
<td>R</td>
<td>23.14%</td>
<td>2.75%</td>
</tr>
<tr>
<td>T</td>
<td></td>
<td></td>
</tr>
<tr>
<td>A</td>
<td></td>
<td></td>
</tr>
<tr>
<td>S</td>
<td></td>
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<td>D</td>
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<tr>
<td>V</td>
<td></td>
<td></td>
</tr>
<tr>
<td>B</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*TABLE 4.2: FINGER AND HANDLOADING*
for the operators. They have avoided making the radical step to the Kockenberg type keyboard but are supportive of the concept and cite Kroemers work in their paper. They further state that row hopping produced by typing English on a QWERTY keyboard is undesirable.

4.1.4 MARTIN: A NEW KEYBOARD LAYOUT [4]

Martin advocated in this paper the use of a modified "Dvorak Simplified Keyboard (DSK)" which he calls the "Alpha-Metric Keyboard (AMK)". It is essentially a modified DSK keyboard taking into account metricalization. The document is largely irrelevant today as the author did not foresee the flexibility that word processing software would provide for special character generation.

The author does provide useful information in the paper, in the form of an historic explanation for the QWERTY keyboard and draws our attention to "touch typists, whose training is longer than it need be and whose subsequent performance is limited in terms of speed, error rate and fatigue", a condition which more than half a century after the DSK was proposed, still exists.

Martin also has something to say on the subject of optical and aural input devices, he states "such developments are inevitable, but are hardly likely to replace telex operators and typists in the world outside the laboratories". The
likely course that technology takes is sometimes difficult to predict, for example, the common practice of typing a message on a word processor and sending it via a facsimile machine to its destination, which is rapidly superseding direct typing into a telex machine is clearly wasteful in light of available technology but is likely to be with us for some time.

Martin credits Dvorak with having produced a layout that is based on the "frequency of letter patterns and sequences". He also states that "faster operation is possible by tapping with fingers on alternate hand". Table [4.1] shows that 70% of the occurrences of the letter H are preceded by the letter T, both of which Dvorak has placed on the right hand key field. The 'TH' sequence is common enough to make it significant in general typing.

However, Martin presents no shortage of evidence in support of the DSK layout, which many people would agree has to be an improvement over the QWERTY layout.

One last item of interest in the paper is Martins reference to incentives to gain acceptance of the DSK layout by typists, which he suggests could be overcome by introducing it with an upgrade in equipment. There is no doubt a significant problem here. The keyboard operator invests a great deal of time and effort in learning the layout of a
keyboard, this knowledge, he or she, would expect to use in future employment, probably on different equipment, therefore a special layout would tend to limit his or her options.

4.1.5 ZIP ET AL: KEYBOARD DESIGN THROUGH PHYSIOLOGICAL STRAIN MEASUREMENT [5]

The study was carried out using electromyography (EMG) on a small group of subjects, 2 males and 1 female. The size of the sample is small, but it does provide useful data, the authors introduction states "this paper reports the results of electromyographic investigations into the optimal pronation of the forearm and ulnar abduction of the hand and the implications for keyboard design".

This introduction to the paper first substantiates the existence of medical disorders resulting from keyboard operation and quantifies the level of ulnar abduction "20 degrees - 26 degrees and occasionally up to 40 degrees" in using them.

The authors have accepted the work of Kroemer and intended to quantify the "subjective" elements in that work using EMG.

Ref. Figure 3, 4 and 7 from this paper, Figure 3 shows clearly that as the angle of pronation increases the EMG
activity increases with a sharp rise after 60 degrees (in the M.Pronator quadratus). The hatched area is stated to be the normal position for typewriting and "is clearly beyond the optimal range". This verifies Kroemers findings but seems to suggest anything beyond 40 degrees (equivalent to 50 degrees declination) is a compromise. The authors suggest 60 degrees declination as being optimal for the keyboard halves, however they then involve themselves in a discussion about labelling of the key tops and compromise their recommendation for the keyboard declination design parameter of 10 to 20 degrees. Figures 7 and 8 in their paper show the relationship between visual angle and correct identification of various alphanumeric symbols.

Figure 4 in their paper shows the EMG activity of the main abductor muscle as a function of hand abduction. Again the optimal angle is 0 degrees, but anything up to 15 degrees is a substantial improvement over existing keyboards.

The authors look on thumb operated keys as a viable option and clearly come out in favour of the split keyboard concept after the Klockenberg model. The figures they quote for the final design parameters are excessively compromised by the idée fixe of viewing key tops at an angle and these figures should viewed taking this into consideration.
This paper establishes by observation the way people actually work with visual display terminals (VDT). The authors established that the posture adopted by most users is not as recommended in the text books. This is a statement of the obvious, however, when designing a keyboard some of the factors quantified in this document are important. These are the viewing distance, eye to screen, is much greater than that recommended, the authors found a figure of 75% of the subjects observed preferred a visual distance of between 710 and 930mm. This compare with Cakir et al [7] 450 to 500mm recommended viewing distance and Humanscale which puts the upper limit at 710mm. It is also possible that in the right environment operators may opt for the higher limit observed, as, in the past, a viewing distance of 930mm was not a possibility due to the lack of depth on standard desks. Another important factor is the seat back rest angle, the authors found that only 10% of the subjects preferred an upright posture, the majority preferring a trunk angle of between 100 and 110 degrees. This posture, the classic computer operators slouch, effects the approach angles to the keyboard and should be borne in mind when designing a keyboard.

Table 7 from this document should be viewed with caution if only for the reason, that the chair used in this experiment
has a back rest that is so wide that it will inhibit arm movement in normal typing and would therefore in itself effect user decisions regarding posture.
4.2 SPACIAL DATA MANAGEMENT SYSTEM (SDMS).

Spacial data management is a technique for organizing and retrieving information by positioning it in a spacial framework. Herot et al describe the system in their paper [8] and the experiments conducted using it. Similar systems are now available commercially for manipulating catalogue type data. The techniques used are likely to influence the mainstream of computer system design and therefore cannot be ignored when designing any new computer hardware. The method of accessing hierachical layers of information by graphic selection is intended to be more suitable for the computer naive than systems such as keyboard entry which require more precise knowledge of the data base structure to gain access to and manipulate data.

SDMS requires the use of a visual display unit and two control functions, pan and zoom, these allow a data field to be scanned and specific data to be zoomed in on to reveal progressivly more information.

The items of hardware involved in SDMS functions are the joystick and the keyboard. Alternatives to the joystick are touch screens, roller tracker devices and the mouse. At this point in time the mouse is the dominant primary graphic input device.

In their research into SDMS Herot et.al. used armrest mounted joysticks to pan and zoom through data whilst
sitting some distance from the projected graphic information. The illustrated posture adopted by the operator is not discussed in their paper, however it should be noted that the operator is in a relaxed position such as may be adopted by a person watching television.

The use of a joystick to manage the graphic data as opposed to the mouse was to be expected as this type of set up has no surface to place the mouse on. Joystick controls are more difficult to use than the mouse, therefore if a solution could be found that had the portability of the joystick and the controlability of the mouse a significant marketing advantage would be held.

SDMS has a place in the multi-purpose multi-tasking computer environment. As graphic capability becomes more commonplace and large data bases need to be searched for graphic information, this technique could come into common usage, therefore any new computer input device should be able to cope with the technique.
The source of these documents is a computer search conducted by Sydney patent attorneys Shelston Waters in 1984, Arthur S. Cave & Co between 1984 and 1989 and documents in the authors library acquired between 1980 and 1989. The patents in foreign languages are interpreted from the drawings only except where some doubt existed as to the purpose of the product, in these cases help was sought from friends who have the relevant language as a first language.

1. L.M ERICSSON/KENNETH WILLIAM RYAN
   Tangentbord For Terminals
   Skrivmaskiner och Liknande 1983
This patent attempts to solve the mismatch of the keyboard to hand geometry by providing adjustable key groups on the keyboard.

   A number of configurations are shown, all based on a conventional row and column arrangement for the keys, but with the left and right hand keyfields separated to enable various degrees of elevation to be achieved, similar to that suggested by Klockenberg in 1926.

   One of the more interesting aspects of this patent, is a device which bows the key rows to provide an appropriate angle to the hand, at the same time as curving the key field in a convex way to follow the natural curvature formed by
the relaxed finger tips.

With this patent the inventors acknowledge the ergonomic problem associated with conventional keyboards and demonstrate a possible solution, the general direction in which the inventors have gone is not inconsistent with the majority of ergonomic data discussed in chapter 4.
2. WILLIAM C. McCALL

Data Input System Using a Split Keyboard 1983

This design is intended to solve the problems some disabled people have using a keyboard.

The general form of the product is a split keyboard mounted on a rail that allows the keyboard halves to be adjusted in distance apart. It also provides for an arm support in front of each keyboard half.

It makes no provision for lateral declination of the key fields, nor does it include a hand configured column or row layout, (ref. chapter 4.1.1). Both of these features could improve the design.

3. THOMAS CARIC

Zerlegbare Schreibtastur (Split Keyboard) 1984

This design deals principally with the key layout on a split keyboard.

The layout is similar to that of a conventional QWERTY keyboard with the usual German special characters added. The key fields are divided in a conventional manner i.e. with QWERT, ASDFG etc., assigned to the left hand and ZVIOP, HKJL
etc., assigned to the right hand. Note that Z and Y have been transposed.

The features described in this patent document give support to the split keyboard concept. However, the design does not appear to be very inventive when compared with other patents and ergonomic documents listed in this thesis which predate it.

4. JEAN PATRICK BART

Tastatur For Schreibmaschine (Typewriter Keyboard) 1984

This design describes two keyboard layouts, one of which is particularly novel in its approach to overcoming operator fatigue.

The keyboard unit has a pair of armrests, in the form of channels, these are designed to enable the operators arms to be supported, thus allowing his or her hands to hang free in reach of the keys, these are mounted beneath the unit in two scolloped areas.

5. ROY J. LAHR

Splitable Keyboard for Word Processing, Typing and Other Information Input Systems 1984

This patent document describes a splitable keyboard, that allows an operator to progressively adapt from a
conventional keyboard to a split and angled keyboard, after
the style of Kroemers prototype. The document further
describes a layout where a VDU is placed between the
keyboard halves, to facilitate visual accommodation.

The document contains a long discourse on the problems
associated with finding the home row of keys and the way an
operator remembers the layout of the key field.

The inventor considers the home row location to be so
important that he has provided for rapid correction if the
typist types from a misplaced home row position and he
further describes a tactile feedback system to allow blind
location of the home row keys.

The statement in the document "it has been learned that the
keyboard operators function utilising a mental
representation of keyboard layout, in effect, the keyboard
map" is unsupported, the document further states "... the
operator adapts to the technique of operating a split
keyboard, in effect, creating a gapped mind map of
previously learned relationships of keys ... " this
reinforces the first statement and is the basis for a
substantial part of the invention.

The experiments outlined in chapter 9, gave no indication of
a relationship between the distance the keyboard halves were
separated by, within reasonable limits. The motor memory
which allows the fingers to locate the correct key, appears
to be more closely related to the finger movement than the
spacial position of the key.

The document describes the mounting of the keyboard halves
to a desk, with lateral and longitudinal declination
adjustment. As described the combination of these two
movements orients the keys at an angle impossible to use.
Ref. fig. 2A the K keyboard (Kroemer after Klockenberg) this
slopes the keyboard halves down and away from the operator
at the relaxed angle of the hand.

In summary the patent embodies the essential elements of a
workable system, but shows no evidence of research, possibly
it was written without building a reasonably realistic
prototype.

The position selected for the visual display unit is too
close to the operators eye, the keyboard orientation would
dictate an eye to screen distance of approximately 300mm,
which is 150mm under the minimum limit recommended by Cakir
et al (ref. appendix A). The keyboard cannot be oriented at
the appropriate angle to the hand. Passing an electric
current, no matter how small, through the operators fingers
would be unacceptable to many users. The mechanical angle
adjustment could not work without modification.
Not withstanding the above, the authors attempts to solve the problem of providing a suitable split keyboard with adjustment and a suitable position for display and copy, if one accepts Kroemers arguments, this design has some merit.

6. GUNTER SCHULTZE

Elektrische Schreibmaschine mit Geteiltem Tastenfeld
(Electric Typewriter with Split Keyboard) 1984.

This patent appears to attempt to monopolise the concept of splitting the keyboard of a typewriter (and presumably any other keyboard driven device) and remotely locating the two halves.

The keyboard halves can be located for the convenience for the operator, although no method is shown as to how this could be achieved other than by a cable which is shown connecting the keyboard boxes to a device.

This concept is also shown in the patent below and in US patent 3,990,565 filed in 1974.

7. WARREN FELTON AND GEORGE SPECTOR

Remote Controlled Bifurcated Typewriter Keyboard 1974

This design is similar to a conventional typewriter but the keyboard is split in two and mounted on telescopic arms via
an articulated joint.

This system enables the operator to position the keyboard as suggested in Kroemers "Human Engineering the Keyboard".

Having the keyboard on arms and adjustable is also shown in IBM US patent 3,830,352 filed 1972, however this device does not have a split keyboard.

SUMMARY OF PATENTS
Of the 35 patent documents found in the patent search, the seven (7) above have been selected on the basis of inclusion of some form of split keyboard.

The documents have been briefly analysed with reference to Kroemers "Human Engineering the Keyboard". This document is dated February 1972, it predates all of the above patents and is cited in many authoritative papers on keyboard design.

Kroemers work analysis the work of Klockenberg 1926, Webb & Coburn 1959 and others. In any litigation involving any of the above patents Kroemers work would almost certainly be cited as prior art, on the basic principles involved in split keyboard input devices as well as the mechanical layout, leaving the patents with essentially no substance.
Patents are intended to protect the method of manufacture. Many of the above patents however, attempt to gain a monopoly with products which are sketchy in design and behind the times when compared with published scientific literature. Patent inspecting officers do not normally cite scientific information when objecting to the content of a patent, confining their search to previously lodged patents. Applicants are however required to submit any prior art they are aware of with the patent application or during the application process. For these reasons it is possible that the above patents have been granted.

In broad terms these patents attempt to monopolise the following solutions:

1) Method of splitting the keyboard
2) Method of communicating with a device
3) Method of providing adjustability
4) Method of mounting
5) Method of accommodating ancillary equipment
6) Method of supporting arms of user

None of the patents changed the column and row configuration of the conventional typewriter, this may indicate a lack of research, failure to prototype on the part of the inventors, or a desire to maintain as much of the conventional keyboard layout as possible.
Of necessity, the search for data for this project has been international. To keep the volume of data within sensible limits the search path has been restricted to those manufacturers and journals that are known to the writer to be a source for relevant data, these are listed in chapter 3. It has been assumed that the patent and ergonomic searches would provide adequate leads on any relevant products that may otherwise have been missed.

5.2 REVIEW OF TRADE LITERATURE

Only three (3) relevant products could be found, the Maltron Keyboard, the Console from the Datasaab Alfaskop - System 41 and the Cherry KXN3-8451.

1. The Maltron Keyboard

This was the only alphanumeric split keyboard examined that is commercially available. It does not fall directly in line with the theories expounded by Kroemer but it does have many interesting features.

The two (2) keyfields have a space between them of approximately 150mm. The keyfields are concave and this curvature is sloping down from the centreline of the keyboard slightly. The keys in each field are positioned in plan in straight rows and columns. Two (2) other keyfields
are provided at 45 deg. to the primary keyfields for operation by the thumbs. Function keys etc., are grouped in the centre of the keyboard, the whole unit being designed to be interchangeable with an IBM PC keyboard.

Two (2) concave keyfields are designed with a curve intended to follow the arc of the moving fingers thus eliminating hiper extension when moving from key to key. This layout minimises movement in the arms. Whether this last feature is beneficial, is open to question. No scientific evidence is provided in the literature to support the theories of the designer.

2. THE DATASAAB ALFASKOP SYSTEM 41

This unit has a numeric keypad split off from the main keyboard, the keyboard and numeric keypad both feature a long sloping surface below the bottom row of keys, this is designed to prevent bending (dorsiflexion) of the wrists.

This design is not a split keyboard in the sense that Klockenberg envisaged, but it does illustrate one major manufacturer's attempt to come to terms with the pressure to improve ergonomic standards in keyboard design.
3. THE CHERRY KXN3-9451

This unit is an infrared wireless keyboard specifically designed for use with the IBM PC.

The unit is a conventional keyboard in all respects other than the infrared coupling to the computer, it therefore stands as an example of the minimum standard that should be achieved in a new keyboard project.

Table [5.1] shows the result of a test the writer conducted on this unit to establish basic design data for an alternative design.

TABLE [5.1]

<table>
<thead>
<tr>
<th>OPERATING RANGE</th>
<th>MAXIMUM</th>
</tr>
</thead>
<tbody>
<tr>
<td>HIGH SETTING IN LINE</td>
<td>7M</td>
</tr>
<tr>
<td>LOW SETTING IN LINE</td>
<td>1M</td>
</tr>
<tr>
<td>HIGH SETTING AT 45DEG</td>
<td>1.5M</td>
</tr>
<tr>
<td>LOW SETTING AT 20DEG</td>
<td>0.7M</td>
</tr>
</tbody>
</table>

ALL READINGS TAKEN IN LINE IN THE VERTICAL PLANE
SUMMARY OF TRADE LITERATURE

There is very little variety available to the purchaser of keyboards for a new computer system. The situation is reminiscent of the days when keyboards were attached to the visual display screen, with no manufacturer wishing to take the risk of deviating from the traditional path, in spite of the evidence indicating that a change was long overdue.

From the marketing point of view, a split keyboard which has the keyfields positioned as shown in Kroemers prototype, is a radical step. Such a product would almost certainly fail in the market place, without some substantial benefits other than ergonomics.

Such a benefit could be the elimination of height adjustable desks for computer use, by incorporating features in the keyboard. One way of doing this was proposed in the IBM typewriter patent, 3,830,352 of 1972 which never saw production in the main stream of IBM typewriters. With the benefit of hindsight, failure to market this concept, was probably instrumental, in allowing computers to develop with a low standard of keyboard design.

5.3 MAGAZINE ARTICLES

Design World No. 8 1985 ran an article on ergonomic
keyboards, most of the information covered in this article is described elsewhere in this thesis, however one item of interest is a feature on a split field keyboard designed by Michael Rose of Melbourne. This features a key arrangement that requires the thumbs to be used curling in towards the palm, as opposed to lateral movement which is less desirable (Ref. Chapter 4.1.2).

A news item in the American journal Machine Design [9], shows a split field keyboard with two separate elements, these support the palms of the hands, finger holes each equipped with five switches appropriately located. These switches are activated by lateral, longitudinal and vertical movement of the fingers, which, as discussed elsewhere is undesirable. However the product does eliminate the mouse as this facility is built into the base of each unit. This general principle, could work well with a design, incorporating the cording concept of data entry.

In an article in the architectural journal 26 September, 1969, Frank Duffy & Roger Pye analyse the future office. The authors saw the type of office which currently dominates commercial office development in Australia, as being the antithesis of that required for the office of the future. They saw the future office as being more in line with that of the small consultancies, who work from home or small offices of various types, but generally of high quality.
Duffy & Pye also saw the proliferation of micro computers as being a feature of office development as well as the networking of these for communication.
6.1 KEY SWITCHES

A number of quality keyboards from major manufacturers were inspected. The following is an outline of the method of construction used together with some comments on keyboard construction and some keyswitch options available.

The most common method of construction is to use discrete key switches, laid out in a matrix on a printed circuit board. The switches gain additional mechanical support from a perforated steel plate.

The keys are all mechanically identical in any one keyboard, however the key caps vary in design both in graphic information displayed on the key cap and the physical size and shape, these both vary dependent on their position on the keyboard. The key caps are sized so as to produce a generally concave shape, front to back across the key field.

The fundamental mechanical construction of all switches examined, was a spring loaded telescoping construction. Electrically two systems are used, mechanical contact and hall effect (magnetic proximity switch).

When planning a keyboard design, it would be reasonable to assume that proprietary key switches could be used. There are a large number of suppliers of these devices, offering
the product designer a reasonable freedom of choice when selecting.

Proprietary key caps however, do not offer the same freedom of choice. They are designed for an assumed conventional format and as key caps are also visually very important to the keyboard design, it would be too restrictive to use them.

Key caps are very expensive to make tools for, as they are normally two shot injection molded, this is to enable durable graphics to be incorporated in the cap design. Therefore any new keyboard design must be targeted for either high volume or high unit cost, unless a new approach is found to this problem.

Two other options available are purpose designed switches or alternatively membrane switches. The latter is not suitable for rapid light touch operation, but may be suitable for limited use switches, such as function keys.
6.2 GRAPHIC INPUT DEVICE

Graphic input device, usually called a mouse, two types were examined, both were based on interruption of a light beam to generate an electronic pulse.

The first type uses an external light beam on the base of the mouse, which is moved over a reflective grid to generate pulses. This has the disadvantage of being restricted to use on a special surface.

The second type uses a ball mounted in the base of the unit, this drives two shafts mounted at 90 degrees to each other. Movement of the mouse rotates the ball in the corresponding direction and the two shafts are rotated differentially. Each shaft has a perforated disc mounted on it and each disc has two optical detectors mounted across it. The phase shift between these two detectors and the pulse rate generated, shift the cursor on the VDU screen at the corresponding speed, in the corresponding direction. This system can also be used as a roller ball control, perhaps mounted on the keyboard.

The mouse has two or more press switches on it, these are used in conjunction with the cursor control, to enter selections into the computer. The mouse is usually connected either directly to the computer, or plugged into the
keyboard by a small diameter cable and miniature plug.

The mouse is arguably the best solution we have to date for graphic input, but it still has significant problems, such as the amount of space required, distance required between the keyboard and the operating surface etc. These may in some situations make the roller ball, mounted directly in the keyboard, a better solution, in spite of the difficulty in controlling these devices. If a better solution than these could be found, it would be a significant marketing advantage.

It should also be noted, that well designed software makes the changeover from mouse to keyboard and vice versa, transparent to the operator. Changing the cursor design on the screen from, for example, a flashing block to a solid arrow when movement of the mouse is detected, can also be helpful. This feature is included in some word processing packages.

6.3 ELECTRONICS

The total area used for electronic components in the Cherry infrared keyboard, is 90 square centimetres. All of the components used in this device are off the shelf units readily available to any designer. It would therefore seem reasonable that no greater area would be needed for a new
product. Also substantial space saving could be achieved, by using surface mounted technology components, instead of the more traditional pin mounted components, as used in the Cherry product.

Infrared (using light emitting diodes) communications would be the most likely means of linking the keyboard to the computer. This of course would be of no use unless the keyboard was battery operated, therefore provision must be made for batteries (Cherry use 4 by AA cells).

The Cherry unit uses an 80C35 microprocessor as its principal active electronic component, supported by 27C16 EPROM and a number of 74 series CMOS logic elements, all of these components have very low quiescent current drain, as well as a low operating current. No manual off switch is provided for, on this unit, a transistor switch minimises current drain when not in use.

One alternative approach to the technique used by Cherry, could be to use the Motorola MC145026 remote control encoder/decoder series of integrated circuits. A circuit could be designed around these units, using 74 series CMOS integrated circuit modules, for the key switch decoding and latching functions. The MC145026 units are 9 bit trinary data devices, enabling 19,683 different codes to be transmitted and are therefore more than adequate for a
keyboard. The maximum quiescent current at 5V for the encoder is 0.1 micro amps helping to make the unit suitable for battery operation.

6.4 MECHANICAL CONSTRUCTION

It is most likely that injection molded plastic, is the most suitable solution for the case construction, it provides good dimensional repeatability, low unit cost and good tactile qualities, all of which are desirable for this type of product.

One disadvantage with an injection molded case is its low weight. A keyboard needs weight to stabilise it in operation, therefore some solution to this problem needs to be found.
7.1 INTRODUCTION

As can be seen from previous chapters, the QWERTY keyboard is almost unassailable. Therefore any new product has to offer a great deal to gain acceptance. As time passes the entrenchment of the traditional keyboard becomes greater.

This entrenchment of the QWERTY keyboard is so great, that standards such as the German DIN standard, and the British BSI ergonomic standard, accept it, and suggest ways of overcoming its short comings by workplace design. The draft Australian standard SF/38/1/87-204 offers the choice of either a flat keyboard or those defined by more appropriate ergonomic criteria.

It is clear, that the ergonomic keyboard would need to be aimed initially, at that small sector of the market that looks for the new innovative product.

7.2 MARKET SECTOR

Whilst the ultimate market for an ergonomic keyboard could be the entire user population, the unusual nature of the product requires specific targeting to gain initial acceptance. The objective being to tackle a specific market sector in order to finance initial tooling and product development.

Possible target groups are:
1) Domestic
2) Data entry
3) Word processing
4) Accounting
5) Engineering/scientific
6) Desktop publications
7) CAD

The domestic users have over the short history of the home computer, bought a great variety of computer types and styles. These include units with membrane switch type keyboards, keyboards with miniature keys and keyboards with alphabetical layouts. There are also greater problems in accommodating a computer in a home than in an office, principally because of space requirements and the absence of desks and office chairs.

When checking the shelves of suburban computer stores, catering for the domestic user, it was found that the vast majority of software was for computer games. These games in the main are graphic oriented and rely on interaction from the mouse, joystick or a limited number of keys.

These factors indicate opportunities for the keyboard designer. The sketch shown in Fig. 9.18 illustrates a keyboard that would solve many of the problems encountered
in the domestic computer environment. The ability to use the keyboard on the lap, free of cabling and seated on normal domestic furniture are significant sales advantages. These advantages and the feature of a built in graphic input device, could be sufficient to influence a potential purchaser.
The new product has to conform to current ergonomic thinking and provide a realistic alternative to the conventional keyboard.

In its narrowest form, the product is to be an alpha numeric keyboard for use with, for example, an IBM PC.

In its broadest form, the product could be a self contained computer with full voice and electronic communications.

The product should conform to the following:

1) The key field should be split into right and left hand halves and angled with a declination of 45 degrees or alternatively be adjustable in angle.

2) The key fields should be hand configured, with five straight columns and four curved rows as the basic format, other keys can be accommodated around this basic format.

3) The key pitch should be between 18 and 20mm.

4) The key contact area should not be less than 12mm in diameter.

5) The key depression force should be between 0.25N and 1.5N.

6) The key travel should be between 1.5mm and 6mm.

7) The arrangement of the keys should preferably conform to the QWERTY layout but consideration should be given to the Dvorak alternative.
8) The keyboard should be linked to the computer via infrared or other wireless communications.

9) The key labelling should be clearly legible to the user.

10) A new solution for the graphic input device should be designed.

11) The product should accommodate the fifth percentile female, to the ninety fifth percentile male.

12) The product should allow greater freedom in positioning supporting equipment (VDU etc.), than current units.

13) Consideration should be given to the following:
   a) Separating keyboard from the desk
   b) Location of copy holder
   c) Voice communications

14) Provision should be made for at least 90 square centimetres for electronic components (PCB mounted).

15) Power should be supplied by not more than four AA cells.
EARLY EXPLORATORY DESIGN STUDIES

THE ARM-REST KEYBOARD (EARLY 1985)

This solution grew from trying to ignore all the paraphernalia that surrounds a modern computer and ask some fundamental layout questions. Computer manufacturers are often blamed for many of the problems involved in computer work station design and therefore tackling the entire problem, as opposed to one or other element, gives the designer greater freedom and an interesting challenge.

The method selected for this was to firstly take a high quality office chair and place it in the centre of a room. An assumption was made that the potential operator wished to communicate with a device by touching, or pushing keys and receive feedback via some sort of visual display. The chair was adjusted to the appropriate height to enable an erect and comfortable posture to be adopted.

The question was posed, where should the keys be placed and where should the visual display be placed? and then role playing in different postures Fig. 9.1A. This role playing quickly lead to the conclusion that the keys should be placed where the relaxed hand falls. This position for the subject, is, when the upper arm is relaxed, between the bottom of the elbow and the seat, in the vertical plane and in the horizontal plane an area bounded by the centre line
of the thigh and a few centimetres outside of the shoulder. If one assumes that the upper arm is relaxed, the zone that the hand falls in is therefore determined by the length of the hand and forearm and the horizontal and vertical limits described above.

This thigh zone is quite small and departs substantially from the zone used on commercial keyboard units, that is, the desk top in front of and on the centre line of the operators body. The solution to this problem, with a conventional keyboard, is to place the keyboard on ones lap. None of the ergonomic papers found in the search, identify the thigh zone as a possible location for the keyboard, possibly because of lack of a precedent.

On many occasions in the past, the writer had discussed the split keyboard philosophy with various ergonomists and the idea of sloping the key fields latterally. The role playing, with relaxed hands, confirmed that the palm of the subjects hand, lies at approximately 45° to the horizontal and that this is not compatible with a horizontal keyboard.

Compiling the data in appendix A for another project, gave support to the theories above and work was started on the first prototype.

The office chair selected for the prototype, was fully
adjustable and fitted with electronic digital read-out for each element's position setting.

The adjustable elements were as follows:

1. armrest height
2. armrest distance apart
3. seat height
4. seat angle
5. backrest height
6. backrest angle

A full set of keys were acquired for an alpha-numeric keyboard. The keys selected were suitable for wiring individually, this feature allowed the keys to be repositioned more easily.

The supporting frame for the keys was designed after taking the layout of a conventional keyboard and observing a typist's hands moved across the key field. The relative angle of the hand to keyboard was noted and the same angle was used when the keyboard was first split in two and the halves moved to the thigh zone and rotated down and round to match the palm angle and the axis of the hand/forearm. The result of this is shown in Fig.9.1B.

The frame for the keys was constructed from aluminium flat bar, held together with threaded rod, the flat bar was held
apart by tubular spacers, these were sized to allow some frictional grip on the sides of the keys without crushing them.

In the process of developing this design, some compensation was made for the curvature of the finger tips. The frame design allowed for repositioning of the key, either fractionally by loosening the threaded rod and sliding individual keys or groups of keys, the keys could also be rearranged totally, by loosening the threaded rod to the point where the keys were removable.

The keys selected were of the mechanical momentary contact type. This allowed them to be wired directly into the main printed circuit board of a miniature computer, in this case a Sinclair ZX81, at this time the VHF modulator was bypassed to allow the unit to be connected to a conventional green monitor, instead of a television set which produces an inferior display.

The computer board and the two keyboard frames, complete with keys were mounted on the armrests of the chair. A simple Basic programme was written, to enable pages of text to be typed onto the VDU screen.

Experimenting with this layout produced encouraging results. However, adjusting the key layout Fig.9.1C and D, clearly
indicated that a more desirable layout for the keys was to arrange them in 5 columns and 4 curved rows similar to that produced by Webb & Coburn 1959 [10]. This layout also eliminated the need to angle the square keys to the axis of the operators arm. As a result of this, a new mounting frame was constructed.

The new frame was far more simple in construction than the old and it allowed the key columns to be moved to allow for various finger tip curvatures Fig.9.2.

Throughout these experiments, the QWERTY layout was maintained. This was to enable the rate of adaption of QWERTY trained operators, to the new key field position, to be observed (at this time the possibility of rapid adaption was purely a theory).

An informal trial of the arm rest keyboard was conducted, using three operators. Each operator was a trained touch typist, conversant with QWERTY typewriter keyboards, with no word processing training. All three were able to touch type proficiently on the armrest keyboard without training and with a few seconds adaption time. An exception to this rapid adaption was the inability to find the letter "B" with ease. No prolonged testing was carried out, each operator was only tested for a few minutes to assess the rate of adaption only. No formal results were compiled from this ad hoc
testing, as this was too early in the development process to make the results meaningful.

Further non typist subjects were tested to assess some of the anthropological variables likely to be encountered.

CONCLUSIONS TO THIS EXPERIMENT

Areas of work worthy of greater exploration are:-

1. Armrest mounted keyboards as a concept
2. All of the adjustments shown in appendix B are probably necessary with the exception of those that position the key field angle.
3. The row and column layout as per the mark III prototype was easy and convenient to use and is worthy of greater research.
4. The keyboard could be mounted in line with the axis of the arm rest, thus simplifying design.
5. A sliding arm support could be an advantage to prevent friction between arm and supporting pad.
6. Infrared or other wireless communications are desirable.
7. The QWERTY format works well with this design.
8. All rows and columns of keys can stay in the same plane.
9. More testing with a more advanced prototype would generate useful data for the final design.

In using the armrest keyboard, the writer found that typing was easier than on a standard keyboard. This is possibly due to the key field format being ordered and the ability to maintain the hands in the typing posture, as this is also the relaxed posture.

Whilst the results of this experiment and the layout of the prototype, are not the same as that produced by Kroemer, they are not inconsistent. The relative angle of the hands to the keyboard, remains similar, even though the spacial co-ordinates of the elements are different. Kroemers work was based on that of Klockenberg who had possibly assumed that a simple mechanical link was necessary, between keyboard and print head and would therefore place the keyfields as close together as possible.

One last modification was carried out on the prototype prior to discontinuing the experiment. That was to include a sliding mechanism in each arm rest. This had some disadvantage, in that the operator uses an arm rest to stabilise his or her body, the sliding element gave a feeling of instability, even though the total movement was
only 80mm and the unit was spring loaded about a slightly off centre position.

An unexpected result of testing these sliding armrests, was the relationship between extending the finger to strike the upper keys and the movement of the relaxed arm. This movement is involuntary and difficult to suppress. The involuntary movement is not so evident when the forearm is supported by the upper arm in normal typing, possibly because the static muscle load, on the upper arm inhibits movement. The benefit to the operator of this effect, is that it effectively reduces the distance the fingers extend to reach the keys.

A product designed around this experiment, could be an office chair incorporating a computer keyboard in the armrests, with wireless communications, integral telephone and a modem.

Figures 9.3 to 9.8 show some possible developments of this concept. Fig. 9.3 shows a pair of conventional, free standing visual display units being used with two chairs, fitted with armrest keyboards and voice communication. A table is provided for occasional use and copy holders have been mounted off this. Fig. 9.4 shows a work station module, featuring visual display units, mounted in the screens to provide a concealed installation in an arrangement suitable
for paperless tasks. This layout also provides privacy in an open plan office, the visual display units could be height adjustable, perhaps behind the screen glazing. Fig. 9.5 shows a solution suitable for a managers office. Fig. 9.6 shows a single arm rest keyboard chair used with three displays, control is achieved by pointing the chair and therefore the operators gaze and the infrared link at the required display. This solution could be useful for process control, air traffic control and security systems etc. Fig. 9.7 shows a pair of arm rest keyboard chairs, used with a large scale wall display, a window manager is used with the display to provide either individual or joint access to windows. As display technology develops, the discrete one user screen may not always be with us, it is possible that full wall displays, may become common with sections of the screen being used by different people, or many people working on a single image collectively. In such an environment, the arm rest keyboard would be an interesting option. Fig. 9.8 shows various options for mounting an arm rest type keyboard.

Chairs designed around these principles, would be free of the office desk for all electronic communications and would allow great freedom in office design. However, in the commercial world, such a product presents a very difficult marketing problem. It actually requires a new look at the way tasks are approached in almost any office and would need
to be installed, taking into consideration such things as task design, office layout and work habits. Examples of these are: Whether or not the task requires a desk. How the telephone is used.

The ICL OPD, (One Per Desk), unit marketed in Australia by Telecom, is designed to integrate communications and computing on the desk top, it is an example of what is possible, when used to its full potential the unit can carry out the work of such devices as, facsimile machines, telephone answering machines, remote computer communications and the general purpose personal computer.

These solutions can only be of use when used by a large number of people, with their work organised to suit the technology available.

Such a project removes the product from the general market place, as it could only be undertaken by large organisations, such as government departments.
FIGURE 9.1 ARM REST KEYBOARD MKI AND MKII TEST RIGS
FIGURE 9.2 ARM REST KEYBOARD MKIII TEST RIG
FIGURE 9.3 ARMREST KEYBOARDS USED WITH FREESTANDING VDU AND COPY HOLDER
FIGURE 9.4 ARMREST KEYBOARD UNITS USED WITH WORK STATION CLUSTER
FIGURE 9.5 ARMREST KEYBOARD FOR USE IN MANAGERS OFFICE
FIGURE 9.6 ARMREST KEYBOARD USED WITH MULTIPLE DISPLAY
FIGURE 9.7 ARMREST KEYBOARDS USING SHARED WALL DISPLAY
FIGURE 9.8 ARMREST KEYBOARD POSTURE OPTIONS

With or without knee pad.

Sit/Stand

Sit/kneel

Sit Upright

Sit Reclined

Recline
ALTERNATIVES

Another approach would be to incorporate the ergonomic advantages of the prototype into a more compact product, which could be more readily assimilated into a conventional office environment.

Having recognised the marketing difficulties associated with the arm rest keyboard, sketches were prepared to explore the possible solutions.

Fig. 9.9 shows these sketches:—

A) Has the keyfields positioned on a tablet similar to those used in lecture theatres, the product is still integrated with the chair. B) Shows the keyfields mounted in the leading edge of a chair seat. C) Is a floor mounted keyboard that a chair could move inside, this has the advantage of allowing almost any keyboard configuration to be achieved. D) Shows the keyfields mounted on the edge of a desk. E) is an integrated copyboard display and keyboard. F) Is an inside out version of C). G) Is the chaise longue variation of B). H) Is a split version of A). I) Is a conventional keyboard on adjustable column. J) Is an armrest mounted keyboard, mounted close to the seat edge.
FIGURE 9.9 EXPLORING THE POSSIBLE SOLUTIONS

A

B

C

D

E

Copy

DISPLAY

Copy
FIGURE 9.10 EXPLORING THE POSSIBLE SOLUTIONS II
### Figure 9.11 Mounting Options Various Keyboard Types

<table>
<thead>
<tr>
<th>Mounting Options</th>
<th>Conventional</th>
<th>Semi-split (Flat)</th>
<th>Full Split</th>
<th>Globe</th>
<th>Slope Face Semi-split</th>
</tr>
</thead>
<tbody>
<tr>
<td>Desk</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✗</td>
<td>✔</td>
</tr>
<tr>
<td>Platform</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
</tr>
<tr>
<td>Lap</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✗</td>
<td>✔</td>
</tr>
<tr>
<td>Armrest</td>
<td>✗</td>
<td>✗</td>
<td>✔</td>
<td>✗</td>
<td>✗</td>
</tr>
<tr>
<td>Seat Edge</td>
<td>✗</td>
<td>✗</td>
<td>✔</td>
<td>✗</td>
<td>✗</td>
</tr>
</tbody>
</table>
Fig. 9.11 was also prepared to help with assessing the flexibility of each of five variations in basic keyboard design. As can be seen the fully split keyboard has the most position possibilities, however it always needs some form of fixing, Fig. 9.9E was selected as the most promising design for further development and various configurations were tried in sketch form.

The sketches Fig. 9.12, 9.13, 9.14 and 9.15 show a fold down computer. The intention being to produce a keyboard, copyholder, display/cursor and computer in one fold down unit. This could be used as a portable computer or coupled to a large display and perhaps a larger central computer and memory bank for more serious work. The display is mounted in the copyholder cursor using a liquid crystal or similar technology display. The cursor could be electrically driven, facilitating visual accommodation when transferring one's gaze from the display to the copy. The whole unit was intended to be mounted on the desk edge with an adjustable clamp for height control.

A cardboard model was constructed and it was found that the triangular key fields could not be folded to an angle suitable for typing. This model was modified to produce the rectangular key field shown in Fig. 9.16 and 9.17. A new model was started in medium density fibreboard (MDF), as
Figure 9.12 Fold Down Computer - Stand Alone
FIGURE 9.13 FOLD DOWN COMPUTER - WITH LARGE DISPLAY
FIGURE 9.14 FOLD DOWN COMPUTER - DESK TOP MOUNTED
FIGURE 9.15 FOLD DOWN COMPUTER - PEDESTAL MOUNTED
FIGURE 9.16 FOLD DOWN COMPUTER - WITH REVISED KEYBOARD

This layout conforms to the data compiled by Kroemer HF Feb. 72.
FIGURE 9.17 FOLD DOWN COMPUTER - SCALE DRAWING
this model progressed, it was prudent to review the ergonomic data and the notes relating to the arm rest keyboard design. At this point, more thought was given to the role playing conducted in 1985, posing the question again, what is the ideal position for the keyfields? The same conclusion was reached, that is, the most desirable position for the keyfields is the thigh zone, described above and that the current best solution for this position, is to place the keyboard on the lap. The difference between this thigh zone and the position used in Kroemers experiments was reassessed and whilst the design shown in Fig.9.16 is more consistent with Kroemers work, the the constraints of it being tied to a mounting device (desk or similar), made this solution less attractive than the possibilities offered by devices mounted at the thigh zone.

The sketch Fig.9.18K shows a lap mountable keyboard, designed to place the primary key fields in the thigh zone. This design provided a large flat area, on which to place function keys and little used symbol keys, as well as providing ample area for some form of graphic input device. An adjustment was allowed for in the centre of the keyboard unit to accomodate various widths of thighs. This design offered enough advantages over the previous designs to warrant a model being constructed,
therefore work on the E model was stopped and work commenced on the K model.

DEVELOPING THE FORM

The precise reasons why a designer arrives at a particular form, are often difficult to establish. A lot of influence comes from instantaneous response, when data and experimentation reveal progressively more about the problem. As this project has developed from armrest mount, to desk mount, to lap mount, its form has been changed from anonymous integration, to sharp flamboyance, to a rounded tactile form, each has an appropriateness for its use, for example the last design, as it is used in contact with the operator, has a rounded tactile form, this is countered by clearly defined planes, which relate to the function of the product.

Clearly, if the user is to be in contact with the product, it must not have sharp edges, in practice even radiused edges can cause discomfort, if the radii are too small. Heat drain (from the operators limbs) is also a problem and rules out metal construction, at least for the external surfaces. The key shape is intended to create the effect of buttons on a plane, rather than forming a plane themselves, as in a conventional keyboard.

Contrasting textures are used, defining the difference
between tactile elements and the supporting structure. Bright colours have been used on the tactile elements, to give clear definition of the functional groups, these are red for printing keys, green for non printing keys and yellow for the graphic input device.

The primary key fields are arranged in the layout described earlier, the QWERTY format has been maintained as an example only.
FIGURE 9.18 LAP MOUNTED KEYBOARD - PRELIMINARY SKETCH

5th percentile fem.
+ 95% male

fold?

Thigh

150
Only the frequently used keys have been given the size, displacement and load rating recommended in the design brief. Infrequently used keys have been made smaller, this enables little used characters to have individual keys, rather than being used in conjunction with the shift control. This last feature, enables one touch operation, making it suitable for the hunt and peck technique, used for these characters.

The graphic input device is unconventional. It attempts to solve the problems inherent in various other graphic input devices, by providing the operator with a scribble pad, designed for a finger painting technique. This pad would cover different screen areas under control of software, typically it would cover one quarter of the screen, complete screen coverage being achieved by multiple stroking of the pad, in a similar way to using a mouse in a confined area.

Two buttons have been provided to enable the select functions as on a conventional mouse.
Unit fitted with copy holder/display and wrist support options.
Sweeping form with key fields closer together.
Fig. 9.19 shows the preliminary layout from which the model was constructed. The form has been kept as simple as possible, while at the same time satisfying the spatial requirements of the various elements. All changes in direction of the surface have been blended, in an effort to minimise the complexity of the basic form. As described earlier, the keys break through this form, leaving the observer with a clear understanding of the structure and the relationship the functional elements have to the product.

The fashion aspects of the design, have been treated conservatively in what is otherwise a radical design. Fig. 9.21 shows an alternative approach, which would bring the product in line with products of the late 1980's. The sweeping form, coupled with a more subtle use of colour, would produce a product with greater fashion appeal, but possibly would be taken less seriously by the prospective purchaser.

Fig. 9.20 shows the product fitted with accessories. A copy holder with cursor/display has been fitted, as well as two wrist supports, designed to eliminate possible dorsiflexion of the wrists.
The final design, consists of an injection moulded plastic case, which envelopes the electronic components. The controls pass through the case and these are also made of injection moulded plastic.

1.1 THE CASE

The choice of material for the case, has been determined on the basis of durability and aesthetics. Two materials readily available that could be used are ABS (acrylonitrile butadiene styrene) and high impact styrene. There are good reasons for using ABS, for example ease of cleaning, high impact strength and good electrical characteristics. However, high impact styrene has been selected because of its superior moulding characteristics. The design of the product, requires large flat areas to be moulded to satisfy aesthetic requirements. The use of ABS would put these requirements at risk, because it is less predictable in regard to sink marks and general distortion.

There are a total of four major mouldings used to form the keyboard case. Drawings KBD02 to 5 show these. The design of the mouldings allows for two piece die construction. The part line for the die runs along the moulding half joint lines. No sliding cores would be required, therefore minimising cost. The case halves are fixed together, using six self tapping cross recess head screws on each half, refer Drawing KBD11.
1.2 KEYS

There are six basic key designs shown on Drawing KBD06, variations to these basic designs are produced by changing colour and graphic information on the key top.

Designs A and B are used for the function keys and low use keys. The design shows two pins, which are part of the moulding. These pins, pass through holes in the printed circuit board and together with the hole in the case upper half, form a complete guide for the key. The contactor for this type of key, consists of a single triangular stamping. This stamping is dished to allow it to be mounted, making contact via the points on the triangular shape. When mounted on the circuit board, the centre of the contactor is out of contact with the track. Under pressure from the key cap the contactor engages the track with a toggle action. This snap action provides tactile feedback. The use of this design provides a cost effective switch.

Key caps C, D, E and F are designed to mount on Cherry MX series switches. Flanges have been provided on all caps to prevent removal from outside of the case and also to reduce the possibility of dust or liquids contaminating the printed circuitry.
1.3 GRAPHIC INPUT DEVICE

The graphic input device consists of a membrane switch, an example design is shown on Drawing KBD07.

The switching network consists of six independent tracks, three on the upper keyboard key pad half and three on the lower. The tracks on the upper and lower halves are at 90deg. to each other. The comb and zig zag track design has been laid out to produce a one two three, one two three sequence. The dotted track is to be electrically masked.

The mouse function only requires a series of pulses and sufficient data to be able to determine direction. No circuit design has been proposed for this element as it is beyond the scope of this thesis, however decoding products are readily available using CMOS building blocks.

The membrane switch has a self adhesive back, which allows it to be mounted in the pocket on the keyboard. The connector on the switch, passes through the 50mm slot on the keyboard upper half (ref Drawing KBD03), to allow connection to the print circuit board.

1.4 WIDTH ADJUSTING MECHANISM

This consists of a rod and tube sliding arrangement, mounted on a pair of brackets. Ref. Drawing KBD09, this mechanism is
shrouded by a rubber bellows ref. KBD08 and KBD11.

Adjustment is achieved by pushing the keyboard halves together, or pulling them apart. Detent V grooves and spring clips hold the set position and the shape of the final groove, prevents the mechanism over extending.

The right angle brackets at each end of the mechanism, are bolted to the case lower halves, via threaded inserts and bolts.

The full percentile range of the user population (ref. chapter 8), is not catered for in this adjustment mechanism alone, as this would lead to an excessively large mechanism. The principle means of compensating for the rise in thigh diameter, is made by the angled ends on the keyboard, this allows the keyboard to rise, thereby accommodating the larger thigh diameters.

1.5 PRINTED CIRCUIT BOARD (PCB) MOUNTING

A total of five printed circuit boards have been allowed for. That is, one for each key field and two for the control electronics. One of these last two, is mounted below the graphic input device and the other below the function keys printed circuit board. The battery pack measuring 37mm x 120mm x 18mm, is mounted beneath the graphic input device,
leaving a total of 160 square centimetres available for electronic components.

The circuit boards can be connected by either, insulation displacement type ribbon cable connectors, or flexible printed circuits joined between the rigid boards.
FIGURE 10.1B THE FINAL MODEL
FIGURE 10.2 PRINCIPLE FEATURES

- Primary Keyfield (Left Hand)
- Primary Keyfield (Right Hand)
- Secondary Keyfield
- Expansion Bellows
- Graphic Input Device
- Infra Red Transmitter
FIGURE 10.3 USING THE GRAPHIC INPUT DEVICE
FIGURE 10.5 USING THE KEYBOARD - DOMESTIC ENVIRONMENT
SEE KBD02 FOR DIMENSIONS

HATCH PATTERNS ON FRAGMENT 15
HATCH 11=M1. 30 (1.5, 1.5)

3RD ANGLE
PROJECTION

ERGONOMIC KEYBOARD
CASING
LOWER HALF - LEFT

DATE: 07-05-1989

DRAWN: CUFFE
FINISH: < >
SCALE: 1:1

THE UNIVERSITY OF NEW SOUTH WALES

KBD04 SHEET 1 OF 1
1 THE REASONS BEHIND THE FINAL DESIGN DECISIONS

1.1 PRODUCT FEATURES

The decision to make the keyboard a lap mounted unit, is a reconciliation of the conflict between, the angled split field keyboard and traditional desk mounting. After desk mounting, lap mounting is the next most common location for the keyboard, making the choice logical.

The decision to make the form saddle bag like, is to stabilise the keyboard in use. This form allows the legs to be moved without giving a feeling of instability, as the keyboard is not balanced or perched on the legs.

The angled planes that the controls are mounted on, reflect the physiological ergonomic requirements of the product, but, also allow the grouping of the keys in a logical fashion.

Key shapes and colours have been designed to reduce the search path for any particular key, as well as accommodating the ergonomic requirements, specified in the design brief.

The graphic input device (GID) has been designed to overcome the major problems associated with other currently available devices. The movement required to move the hand from the primary key field, to the GID is minimal and lies within the...
natural arc of the forearm. This technique offers significant user advantages, it always maintains the same relative position to the right hand key field, thereby eliminating the hunt for the mouse, whilst maintaining the functional advantages of that device.
2.0 EXTENDING THE PRODUCT

The design example shows the product as a peripheral to existing computers. In this role the product could be extended by adding devices such as the copy holder and wrist support shown in chapter 9.

To extend the product range further, could require a change in function to that of a self contained computer. The current development of computers in large companies seems to indicate the need for a device that provides facilities for individual use, connection to main frames and major software and peripherals, as well as portability. If this product was developed to provide these functions, it could meet this need.

3.0 OTHER SOLUTIONS

There are a very large number of possible solutions to the problem of designing an ergonomic keyboard and as discussed earlier these could lie outside of the alpha numeric pushbutton solution altogether.

The research content in this thesis, was contained within defined limits and therefore the outcome of the findings was, to some extent predictable. A product that was created outside of these constraints, could well have a greater market potential. However, such a product presents far less
a threat than does a conventional keyboard, which with its entrenched position, has resisted change to date.

4.0 FEATURES OF THE DESIGN

1. CABLE FREE OPERATION
2. REMOVES THE NEED FOR A DESK
3. GIVES FULL FREEDOM IN SELECTING EYE TO SCREEN DISTANCE
4. PROVIDES GREATER POSTURAL POSSIBILITIES FOR THE OPERATOR
5. SUITABLE FOR DOMESTIC AS WELL AS COMMERCIAL USE
6. GREATER POTENTIAL TO HOUSE EQUIPMENT WITHOUT INTERFERING WITH ERGONOMIC REQUIREMENTS
7. EASY TO LEARN KEY LAYOUT
8. EASY TO FIND LITTLE USED KEYS
9. LOW COST MANUFACTURING POSSIBILITIES
10. INTEGRATED GRAPHIC INPUT DEVICE
11. FORWARD LOOKING DESIGN
12. SOLVES MAJOR ERGONOMIC PROBLEMS

USER CONSTRAINTS

1. NO MARKET TRACK RECORD
2. PRIMARY KEY FIELDS NOT AS SUITABLE FOR HUNT AND PECK TYPISTS
3. LONG TERM ERGONOMIC SOLUTION UNPROVEN
4. LOOKS UNCOMFORTABLE IN A CONVENTIONAL OFFICE LAYOUT
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1. INTRODUCTION

The purpose of this paper is to quantify the dimensions at the 'man (person) machine interface' between operator and Visual Display Unit (VDU) and provide raw data for work station design.

Much has been written on this subject, many of these writings contain material based on available anthropometric data and the authors knowledge of the 'state of the art' in the relevant technologies. Consequently, the latter results in the information becoming obsolescent due to the rapid rate of change in the computer industry. However, the anthropometric data changes much more slowly and would provide a sound basis for the preparation of this document. In Australia the absence of any suitable major study on the population anthropometry removes this basis and leaves the researcher with having to select data from a comparable population, for this paper Humanscale by Diffrient et al of the U.S.A. [1] will be used. State of the art furniture and VDU's
ERGONOMIC KEYBOARD
WORKSTATION PARAMETERS

(as the author sees it) are used as examples.
2. THE PERSON

With the rapid growth of VDU usage, almost all sections of the community can expect to operate these machines, for this reason the 2.5 percentile female for the minimum and the 97.5 percentile male for maximum dimensions have been selected. Only the adult population is used, as the child population would require special consideration and impose unnecessary restrictions on work stations, designed for the adult population.

3. THE MACHINE

The pieces of equipment catered for are Display, Keyboard, Copy, Mouse, Desk and Chair.

The various components have been reduced to simple shapes, this avoids compromising the design, with the boxes, VDU manufacturers, package the functional elements of their products in. The keyboard complies with DIN standard where applicable. The copy holder accommodates A3 landscape 420mm wide x 297mm high. The mouse area has been included as this type of device is becoming more common with the introduction of multi tasking and graphics in general purpose.
ERGONOMIC KEYBOARD
WORKSTATION PARAMETERS

VDU's, its zone has plan dimensions of 300 x 300mm. The desk is assumed to provide a stable plane for mounting the VDU on, with the minimum number of split surfaces and the minimum of knee well obstructions. Height adjustment is also assumed. The chair is assumed to be multi adjustable but is not covered in this paper.

4. ANTHROPOMETRIC DATA

(i) The seated operator in the sagittal plane.

Fig 1 shows an anthropomorph seated at a desk operating a VDU. The dimensions shown are as follows:-

Compressed seat height for a 2.5 percentile female, (standing height 1491) is 363, add to this 25mm for shoes = 388. For 97.5 percentile male, (standing height 1880) is 470, add to this 40mm for shoes = 510mm. These dimensions assume the shank to be vertical in both cases i.e. from the workstation design point of view, best case for 2.5 percentile female, worst case for 97.5 percentile male.

Eye height, this uses shoe heights as above, the viewing angle 20o (After Cakir, Hart and Stewart)
Fig. 2 shows the relationship between VDU distance from the eye and the resultant height from the work surface, for both the 2.5 percentile female and the 97.5 percentile male.

Desk height when calculating desk height for keyboard operation two principle conflicting requirements are found, these are thigh clearance under the work surface and the need to keep the fore-arm to upper arm angle $\geq 90$ deg. (Cakir, Hart and Stewart [21] Table 1 shows the requirement for thigh clearance. A work surface thickness of 25mm has been selected, this being the minimum consistent with stability and good vibration absorbing characteristics. The clearance between work surface and thigh for the 2.5 percentile female and the 97.5 percentile male are 28mm and 9mm respectively. This makes no allowance for cloths, or upper percentiles in thigh thickness.

Work surface Depth, the principle factor determining this dimension is the eye to screen distance. For a maximum viewing distance of 700mm $D=700\cos$, therefore the distance from the eye to the centre of the screen in the horizontal plane $=658mm$, from this subtract the distance from the
eye to edge of the work surface and add the depth of the VDU behind the screen. The distance from the eye to the abdomen is 48mm for the 97.5 percentile male, allowing 50mm for clearance and clothing, the desk depth = 658-98mm plus the depth of the VDU screen, typically 350mm therefore the work surface depth = 910mm.

The above figures give a distance of 280mm from edge of work surface to the home row on the keyboard.
TABLE 1

Lowest point for work surface in contact with thigh

<table>
<thead>
<tr>
<th>Dimension</th>
<th>2.5 Percentile</th>
<th>97.5 Percentile</th>
</tr>
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<tr>
<td>Compressed seat</td>
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<tr>
<td>height</td>
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<td>470</td>
</tr>
<tr>
<td>Shoe</td>
<td>25 to 80</td>
<td>25 to 40</td>
</tr>
<tr>
<td></td>
<td>515</td>
<td>715</td>
</tr>
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</table>

Highest point for keyboard

<table>
<thead>
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<th>Dimension</th>
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<td></td>
<td>543</td>
<td>724</td>
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ERGONOMIC KEYBOARD
WORKSTATION PARAMETERS

Fig. 1

(A) Cakir, Hart and Stewart [2] quote 450 to 500 for this dimension. Humanscale puts the upper limit at 710mm.

(B) ±10° allows personal preference for the operator.

(C) 20° optimum viewing angle after Cakir, Hart and Stewart [2].

(D) 38° relaxed sight line, after Lehmann and Stier [3].

(E) 257—469 ref. Fig. 2.

(F) 1069—1363 seated eye line 2.5 percentile female to 97.5 percentile male.

(G) 388—510 compressed seat height 2.5 percentile female to 97.5 percentile male.

(H) 543—724 ref. Table 1.

(I) 104 modesty panel height for 97.5 percentile male.

(J) 554 knee well depth 97.5 percentile male.

(K) 910 desk depth.
4. ANTHROPOMETRIC DATA (Continued)

Knee well depth, the above figures give a distance from the edge of the work surface, to the front of the 97.5 percentile knee of 350, if the operator sits forward to be in contact with the edge of the work surface, this dimension will be increased to 400. Swinging the leg forward from this point 20°, where 'a' = shank length, this is assuming the foot is still below the modesty panel, ref. Fig. 1, the total depth would therefore be 450 Sin 20° = 154mm + 400 = 554mm.

The vertical clearance for the modesty panel is ankle pivot point plus shoe heel height for the 97.5 male, 94mm + 40mm + 50mm clearance = 184 minimum.

VDU screen pivot of = ± of 10° has been included to allow for personal preference.

ii) The seated operator in the median plane.

Fig. 3 shows an anthropomorph seated at a desk operating a VDU. The dimensions are as follows:

The principle component positions have been fixed
in the sagittal plane above, the two items remaining are the mouse area and the copy. Thus far in this description the copy has been considered as the secondary visual target and the VDU screen the primary target, these components would need to be repositioned if the copy in a particular task was the primary target.

Copy, once the VDU screen position has been fixed in the primary visual target area, the copy can only reasonably be placed either to one side of the VDU screen or between the screen and the keyboard. In both cases the copy should be placed at the same distance as the screen to optimise visual accommodation. in the case of the copy being placed to the side of the screen, the copy will be outside of the normal working (reach) distance for 2.5 percentile female, 378mm from the shoulder pivots. For this reason the preferred position for copy is between VDU screen and the keyboard, at 90° to the line of sight. Another advantage of this layout, is the removal of the need to turn the head from side to side, to alternately view copy and screen. A disadvantage with this layout is the difficulty in illuminating the copy, at the same level as the screen, without interfering with the screen.
ERGONOMIC KEYBOARD
WORKSTATION PARAMETERS

Fig. 2

VIEWING DISTANCE @ 20°

212mm REQUIRED ADJUSTMENT RANGE

HEIGHT AT CENTRE OF SCREEN FROM WORK SURFACE

HORIZONTAL ADJUSTMENT 423 to 658 FROM EYE
4. ANTHROPOMETRIC DATA (Continued)

The mouse area, Bouisset and Monod [4] found by measuring oxygen consumption, that the most efficient angle for moving an object, in the working field, was at 60° to the operator. For each degree greater than 60°, the increase in oxygen consumption is approximately half that for each degree smaller than 60° therefore, the mouse area should be placed in a zone between 45° and 85° to the operator and within the normal working distance of the 2.5 percentile female. Ref. Fig 3. A return at 45° to desk edge, allows the mouse area to be positioned within the required field and also allows clearance for the elbows. The position of the VDU and mouse area would need to be reversed for left-hand operators.
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APPENDIX A